User Acceptance of the Intelligent Fridge: Empirical Results from a Simulation

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Abstract. The smart fridge has often been considered a prototypical example of applications of the Internet of Things for the home. However, very little research has been conducted on functions desired by prospective users, and how users will eventually use the fridge. A simulation of a smart fridge was developed and tested within a controlled laboratory between-subjects experiment with 105 participants. Four different assistance functions were tested. It was found that generally a smart fridge is evaluated as moderately useful, easy to use and people would tend to buy it, if it was already available. Emotional responses differed between the assistance functions. Displaying information on durability of products, as well as giving feedback on nutrition health and economics are the most appreciated applications. Structurally, overall usefulness ratings of the device are the strongest predictors for the intention to use a smart fridge, but the emotional response to the product was also an important explanatory variable. Results are not influenced by technical competence, gender, or sense of presence in the simulation. Regression models confirmed that the simulation-based results explained 20% more variance in product acceptance than written scenarios. An outlook is given on future questions to be answered using the simulation.

1 Introduction

When speaking of Ubiquitous Computing (UbiComp), or, the Internet of Things, it is often regarded a central point that information and communication technology leaves the workplace and enters the home [1]. In fact, nowadays, every household in industrial countries is packed with a number of devices that contain all kinds of information technology [2].

Ethnographic studies have found that a large part of the social life of people takes place in the kitchen [3]. This place is normally not only used for food preparation but also serves important communication and social bonding purposes [4]. Research on UbiComp applications in the kitchen in the past years has focussed on nutrition and dietary support [5], cooking, recipe planning [6] and communications [7]. The bulk of research, however, are prototype applications that are rarely tested empirically with users. Within the kitchen the fridge is considered especially important because of its ubiquity and format. Every

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household in the western sphere owns a fridge, and almost everyone has contact with it daily. Furthermore, the fridge offers large, flat surfaces that can be used for user interfaces. So it is only natural to give the fridge a prime position when it comes to digitally augmenting kitchen activities. In fact, the intelligent fridge has become a prototypical example for UbiComp applications in the home of the future. Multimedia fridges are already on the market today, but offer no product-based services [8]. Equipped with RFID and sensor technology it will soon be capable to correctly identify all products that are stored in a household [9]. Fridges that are aware of their contents are still a future scenario, albeit a highly desirable one from the retailer's point of view [10].

In this paper we assume that in the not so distant future all technical barriers to the introduction of a smart fridge will have been overcome. Taking a functionalist perspective we envision the smart fridge as a bundle of assistance functions. We concentrate on user-supporting assistance functions [11], as opposed to, say increased monitoring capabilities for a retailer. Furthermore we assume that the most basic function of the smart fridge, namely sensing its content, is hardly of any value to a prospective customer. Therefore, the underlying question of this research is, which intelligent functions will be appreciated, whether people differ in their acceptance of product-based assistance functions, and how its perceived attributes will influence the acceptance of the device.

1.1 Affective Factors in Household Technology Acceptance

Throughout the past years there has been an upsurge of empirical and theoretical works that emphasize the importance of affective appeal of a product for its acceptance [12]. It has also been proposed as a user interface [13,14] or product design aspect [15]. This view, however is in stark contrast to traditional technology acceptance models (TAM) that focus on the workplace [16]. In this tradition a product's usefulness (along with its ease of use) has repeatedly been identified as the core explanatory variable for its acceptance. Some integrations of the disparate traditions have been tried [17,18]. The consensus of the integrating approaches, however, is that the relative weight of affective vs. utilitarian factors in product acceptance is context dependent. It stands to reason that products for private use underlie different acceptance dynamics than products for office use. [19] found that the fun of using a PC for home use positively influenced the participant's intention to use it. [20] classified world wide web users as either work- or entertainment-oriented, and confirmed that usefulness has a greater impact on acceptance in work-oriented web usage, a point that is also mentioned by [21] in the discussion of their results concerning work related world wide web surfing. [22] confirmed the diminished importance of usefulness in favor of ease of use and enjoyment when it comes to hedonic as opposed to utilitarian information systems. [18] recently included work- vs. leisure context as a moderating variable in their unified technology acceptance model. Whether this is true for smart home technology such as the smart fridge as well, remains an open question. Research on the acceptance of smart home technology is rather scarce, owing to the fact that only very few of these products are yet developed. A recent position paper pointed out one of the major questions for the future: "How can we learn about users' experiences in hybrid contexts of everyday life when technology is not yet mature enough to enter users' real everyday life environments?" ([23], p.51). In principle, there are three ways to achieve this: scenarios, simulation, and prototypes. Given that in the case of the smart fridge, a prototype is not yet available, the researcher has to choose between scenario and simulation based research. The following section contrasts these approaches. Conceptually, however, scenario and simulation are not exclusive but hierarchical in that the interactive simulation is based on a scenario of use as described in section 2.2.

1.2 Scenario vs. Simulation

While written scenarios of future technologies are a feasible methodology from an economic standpoint, they have their drawbacks. The main problem with scenarios is their limited external validity. It has been shown that attitudes formed on the basis of direct experience have a stronger influence on the intention to behave toward the attitude object [24]. Therefore one can expect the attitudes formed after direct exposure to a smart fridge to be more valid as predictors of eventual intention to use such a system. Furthermore, several studies showed that people make incorrect predictions when asked about their future feelings in hypothetical situations [25,26]. Therefore, asking people how they would feel interacting with a smart fridge only after a scenario description also bears the risk of limited validity. The simulation approach partly remedies these problems by providing a realistic experience from which people can judge their attitudes. Simulation studies can combine the advantages of a controlled laboratory setting with added realism of a real world experience [27]. Most likely it is the quality of simulations that will determine how valid people's evaluations are in the end.

In the field of workplace technology acceptance, Davis et al. [28] challenged the view that scenario-based predictions can suffer limited predictive validity. They argued that usefulness and intention to use as opposed to ease-of-use predictions are accurate even without hands-on experience with a mainframe computer system and empirically tested this view. Their model, as depicted in a simplified form in Figure 1 was empirically supported allowing for the interpretation that acceptance ratings can validly be obtained already after reading a scenario without the need of further prototype testing. We argue that in the context of radically innovative household products predictions are less valid on the basis of simple scenarios, because it could be difficult for people to imagine the usefulness and emotional factors in interaction with such a system. Therefore the Venkatesh et. al. model will be replicated in this study.

2 The Smart Fridge Simulation

2.1 The Program

The smart fridge simulation is a PHP-based database system with access to a MySQL-database. The database stores characteristics of 350 groceries. These

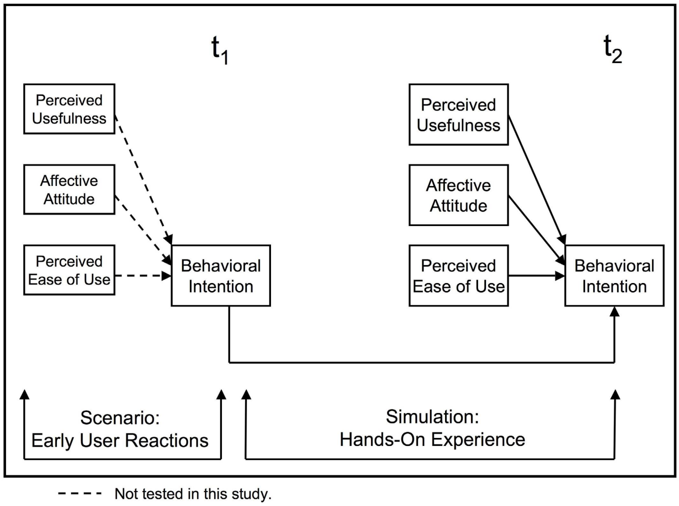

Fig. 1. Research Model, simplified and modified after [28]

groceries can be added to a person's household and subsequently be consumed. The simulation proceeds in rapid motion. A user indicates for each meal the groceries that she wants to eat. Having assembled the respective amounts of food, the consumption is analyzed, feedback is given and the next meal follows. Participants specify their meals for two consecutive weeks in the simulation, which takes about one hour real-time. Every Monday and Thursday participants go shopping in a virtual supermarket, which is designed as a typical online shopping site. After the purchase of an article the respective amount of food is integrated into the household and can be subsequently consumed. The simulation is described in more detail in [44].

2.2 Assistance Functions

The assistance functions offered in the simulation have been derived from a taxonomy in [11]. Wandke deduces these categories from the phases of human action: motivation and activation, perception, information integration, decision making, action execution, and feedback of results. These assistance function categories were mapped to the example of the smart fridge in order to derive meaningful potential assistance functions. Furthermore, the mapping of assistance functions to feasible designs considered the existing literature on smart fridge prototype applications [29,30,31] in order to maximize realism of the assistance functions. The results of the mapping are displayed in Table 1.

From this list of potential assistance functions, four were selected and underwent empirical testing: Best-before dates were displayed in a separate column when participants selected groceries for consumption, feedback about health and economy of the actual consumption were displayed on a separate screen

Table 1. Assistance Functions

Action stage	Assistance Function	Used in Simulation
Motivation, Activation	Recipe Planer	Group 2
Perception	Display of best-before dates	Group 3
Information integration	Categorization and Summation of Items	Group 4
Decision making	Selection of Auto-Replenishment Items	No
Action Execution	Auto-Replenishment	all Groups
Feedback of Results	Nutrition Health and Economy Information	Group 5

after each consumption. The recipe planer was available at shopping trips and on weekends in order to select meals to prepare. For further information on the implementation of the assistance functions, see [44].

3 Study

3.1 Study Design / Procedure

In order to test the perception and evaluation of the various assistance functions, a five-group between-subjects design was chosen. Participants were randomly assigned to one of these groups. The groups differed in terms of the assistance function offered. Every group was introduced to only one assistance function, the mapping of the groups to assistance functions is displayed in Table 1. Group 1 interacted with a simulation that had no assistance function included in order to serve as a baseline model against which to evaluate all other models. For the study, participants arrived at the Institute of Psychology at Humboldt University Berlin. Before interacting with the simulation they filled in questionnaires about their technical proficiency and general attitudes about technology. After that, participants read a scenario about the smart fridge and answered all evaluative questions (t_1). The scenarios and questionnaire items are provided in the appendix. Afterwards they were introduced to the simulation. An introduction explained in detail how to use the simulation. Then, participants interacted with the simulation until the simulated two-week period was over. Subsequently all attitude measures as presented in 3.3 were answered again (t_2). The participants returned for a second interaction session, those results are not included in this report.

3.2 Participants

Participants were recruited via courses and mailing lists at Humboldt University Berlin, as well as via smalladvertisements on the Internet. 105 subjects participated in the study. The age of the participants was restricted to be between 20 and 30 years, a gender distribution of 50 % female and 50 % male was established in every group. Participants were highly educated (90 per cent having obtained A-levels and higher), had low to medium incomes (88 % had less than 1000 €/month net income), lived mostly in shared flats (50 %) or alone (28 %), and were single or in unmarried partnership (95 %).

3.3 Measures

Participants were surveyed in a number of measures concerning their evaluation of the smart fridge at two times during the course of the experiment. Most of the measures were taken from the literature on technology acceptance. All items are given in the appendix.

Usefulness and Ease of Use. The perceived usefulness and ease of use of the technologies were measured using adapted items from the original TAM research studies [16]. Both constructs were measured by three 5-point Likert-scale items respectively.

Intention to use. Intention to use the system was measured using a set of three self-developed items, each on a 5-point Likert-scale. The items were based on the results of a qualitative investigation of people's coping with new technologies [32]. The items were formulated directly encompassing the perceived intention to actively use vs. reject the respective technology. They have been shown to be reliable in former studies [45].

Affective Attitude. Affective attitude toward the technology was measured using three 9-point semantic differential scales adapted from [33], representing the pleasure scale in their model of reactions to environments.

Covariates General technical competence (tech) was tested using the KUT questionnaire [34]. The scale consists of 8 items on five point Likert scales. Participants' sense of presence in interaction with the simulation was tested using the IPQ [35], a questionnaire measuring the presence components spatial presence(SP), involvement(INV), and realness(REAL) on separate scales. A slightly shortened version was used comprising 10 items.

4 Results

All measures of a given construct were tested on their internal consistency using the Cronbach alpha coefficient [36]. As shown in Table 2, all constructs exhibit satisfying levels of internal consistency. The alpha values of the Intention to Use scales are diminished but according to [37] satisfying for exploratory research.

4.1 Absolute Evaluations of Assistance Functions

The evaluations of the smart fridge simulation as well as results of Analyses of Variance with the factor "experimental group" are given in Tables 3 and 4. Generally all groups are neutral to positive about the smart fridge. They regard the system as useful, easy to use, and would slightly tend to use it, if already on the market. As can be seen in Table 4 the evaluations of the different smart fridge models do not differ in terms of usefulness, ease of use, and intention to use but they differ significantly between groups in terms of affective attitude. The group "best-before dates" and "nutrition feedback" felt positive interacting with

Table 2. Cronbach alpha coefficients of constructs

Measure	t1 (after scenario)	t2 (after simulation)
Usefulness	.7979	.8465
Ease of Use	.8841	.9067
Affective Attitude	.7618	.8601
Intention to Use	.6136	.6125
KUT	.8995	

the fridge. Though statistically not significant, group 2 (recipe planer) tended to evaluate the simulation worse than group 1 (baseline) in the intention to use, which means that integrating the recipe planer has a negative effect on overall product appreciation.

Table 3. Evaluations of the Smart Fridge after the Scenario (t1)

Group	1		2		3		4		5		ANOVA	
	M	SD	M	SD	M	SD	M	SD	M	SD	F	Sig.
Usefulness	4.02	0.84	3.88	0.84	4.14	0.68	4.10	0.88	4.17	0.54	.486	.746
Ease of Use	4.03	0.82	3.92	0.64	3.89	0.65	4.17	0.84	4.10	0.63	.568	.687
Affective Attitude	6.18	1.35	6.27	1.13	6.67	0.71	6.73	1.47	6.70	1.09	1.02	.401
Intention to Use	3.67	0.75	3.21	0.80	3.93	0.61	3.33	0.76	3.61	0.71	3.24	.015

Note: df for all analyses of variance = 4

Table 4. Evaluations of the Smart Fridge after the Interaction (t2)

Group	1		2		3		4		5		ANOVA	
	M	SD	M	SD	M	SD	M	SD	M	SD	F	Sig.
Usefulness	3.67	0.86	3.58	0.95	3.42	1.09	3.70	1.20	3.92	0.85	.676	.610
Ease of Use	4.10	0.81	3.95	0.88	4.17	0.52	4.29	0.75	4.30	0.80	.748	.561
Affective Attitude	5.14	1.08	5.29	1.42	6.26	1.52	5.81	1.53	6.13	1.55	2.56	.043
Intention to Use	3.62	0.66	3.20	0.83	3.74	0.71	3.38	0.79	3.49	0.65	1.76	.142

Note: df for all analyses of variance = 4

4.2 Scenario vs. Simulation

Comparing Tables 3 and 4 shows that evaluations of the smart fridge dropped after the interaction. People judge the fridge less useful ($t = 5.38, df = 105, p = .00$) and especially their affective reactions turn out to be worse than expected beforehand ($t = 5.97, df = 103, p = .00$). On the other hand, the evaluations concerning ease of use increase, which hints to the fact that most people imagine the smart fridge more difficult to use than it actually is. This difference, however, is very small and consequently not significant. The intention to use the smart fridge is not significantly affected by interacting with the simulation.

4.3 Structural Relationships

To test whether the evaluations of the smart fridge after the scenario are related to their counterparts after interaction with the simulation a multiple regression analysis was computed including the factors from Figure 1. The results are displayed in the leftmost section of Table 5 (Model 1). Predictors included were the intention to use the system as specified after having read the scenario and the usefulness, ease of use, and affective attitude ratings that were made after interaction with the simulation. The most important factor explaining the intention to use the smart fridge is the intention to use it at t_1. Unlike [28], however, the evaluative statements obtained after the simulation are also predictive of the intention to use. The most important of these variables is perceived usefulness. At the same time, the pleasure a person feels while interacting with the simulation is also a significant predictor of the intention to use. Ease of use of the system, however does not influence the intention to use. Without these three variables the regression model accounted for 40.7% variance in the intention to use, including usefulness, pleasure, and ease of use results in 58.8% variance explained, an increase of 19.2%.

Table 5. Multiple Regression Analysis

	B	SE B	β		B	SE B	β
Model 1				Model 2			
Constant	.178	.344		Constant	-.123	.387	
IntUse (t1)	.469	.070	.469**	IntUse (t1)	.441	.072	.442**
Usefulness	.209	.064	.288**	Usefulness	.221	.066	.304**
Pleasure	.092	.043	.187*	Pleasure	.072	.046	.148
Ease of Use	.082	.072	.081	Ease of Use	.070	.086	.069
				Gender	.071	.104	.049
				Tech	.001	.078	.001
				SP	.045	.059	.063
				INV	.064	.053	.087
				REAL	.052	.073	.056

Note: $R^2 = .588$; $\Delta R^2 = .025$; $^*p < .05$; $^{**}p < .01$

4.4 Covariates

Gender, general technical competence, and sense of presence in using the simulation were tested for their moderating effects on the evaluations of the smart fridge after the simulation. T-Tests for independent samples tested whether there are significant gender differences in any of the variables. None of variables showed significant differences between female and male users of the smart fridge. Furthermore we tested for general technical competence in order to find out, whether this has an effect on the appreciation of the smart fridge. Technical competence was higher for men ($M = 4.14, SD = .63$) than for women ($M = 3.49, SD = .80; t = -4.59, df = 104, p < .01$). Finally, sense of presence was tested for its effect on the evaluation of the smart fridge after interaction with the simulation. Factor analysis of the items resulted in three factors, see the appendix for factor loadings. The items pertaining to each factor were tested for their internal consistency to form a scale ($\alpha_1 = .8367, \alpha_2 = .8617, \alpha_3 = .7528$) and subsequently averaged to preserve original scale metrics. The three resulting factors were named "spatial presence"(SP), "involvement"(INV) and "realness"(REAL), following [35]. They were moderately correlated ($r_{1/2} = .40, r_{1/3} = .49, r_{2/3} = .24$). An analysis of variance with the five-level factor "experimental group" (see Table 6) confirmed that there were significant differences between the groups concerning the factor "involvement"(INV). The factor "realness"(REAL) showed almost significant differences between groups and the factor "spatial presence"(SP) approached significance.

Table 6. Sense of Presence by Experimental Group

Group	1		2		3		4		5		ANOVA	
	M	SD	M	SD	M	SD	M	SD	M	SD	F	Sig.
Factor												
SP	2.79	1.14	2.29	0.82	3.02	0.98	2.35	1.02	2.65	1.01	2.03	.09
INV	2.80	1.10	2.32	0.88	3.20	0.99	2.59	0.83	2.72	0.93	2.46	.05
REAL	2.07	0.76	1.95	0.72	2.52	0.95	1.86	0.73	2.12	0.54	2.40	.06

Note: df for all analyses of variance = 4

In order to find out whether the covariates affect the intention to use, the multiple regression reported in section 4.3 was repeated with gender, technological competence, and sense of presence as additional predictors as shown in the rightmost part of Table 5. The R^2-change was non-significant, confirming that the inclusion of the covariates indeed did not increase the explanatory power of the regression model. Consequently, none of the adjusted beta-coefficients in the regression equation is statistically significant.

5 Discussion

This study investigated people's evaluations of a smart fridge offering different assistance functions to them. Generally, participants were neutral to positive about the smart fridge. They regarded the system as useful, easy to use, and would slightly tend to use it, if already on the market. Participants estimated their likely reactions to a smart fridge, both, before and after interacting with a simulation of it. Results have shown that despite the fact that the intention to use such a system remains stable after interacting with the simulation, usefulness and

Table 7. Presence Items with Factor Loadings

	Item	Factor Loadings INV	SP	REAL
SP1	Somehow I felt that the virtual world surrounded me.		.797	
SP2*	I did not feel present in the virtual space.		.851	
SP3	I felt present in the virtual space.		.775	
INV1*	How aware were you of the real world surrounding while navigating in the virtual world? (i.e. sounds, room temperature, other people, etc.)?	.823		
INV2	I was not aware of my real environment.	.855		
INV3*	I still paid attention to the real environment.	.859		
INV4	I was completely captivated by the virtual world.	.734		
REAL1*	How much did your experience in the virtual environment seem consistent with your real world experience ?			.817
REAL2*	How real did the virtual world seem to you?			.838
REAL3	The virtual world seemed more realistic than the real world.			.701

Note: varimax-rotated PCA, factor loadings < .4 are not displayed, from [35]

affective reactions are negatively affected by interacting with it. This reaction can be interpreted as the participants' disappointment about the apparent dullness of the smart fridge. Because they were confronted with only one assistance function, their expectations might not have been fulfilled. It can be hoped that with a model including *all* the functions under focus the appreciation would increase. Of course, interaction effects could come into play then, resulting in a diminished overall appreciation, because the product is overwhelmingly complex.

The question has been investigated, whether the information contained in a scenario suffices to explain intention to use after interaction with the simulation. This is not the case. Participants' experiences in the simulation contribute nearly 20 % to the explanation of the behavioral intention. This stands in contrast to [28]. We suspect that this difference is due to the fact that the smart fridge, as most other smart home technologies is a "really new product" that can only be insufficiently judged before direct contact. Furthermore, it is a product for voluntary use outside the workplace that also has to be purchased prior to usage. All these differences render it unlikely that users' acceptance can be validly forecasted by help of scenario methodology. Rijsdijk and Hultink [38] see the same limitation in their scenario based evaluation of smart home devices.

Turning to structural relationships, the present study showed on the one hand that usefulness remains the most important predictive variable for the acceptance of the smart fridge, as in traditional workplace technology acceptance literature [16]. On the other hand, however, we learned that pleasure felt during interaction with the simulation is also a valuable predictor, underlining the importance of emotion in the acceptance of household technology. Furthermore it was found that ease of use's impact vanishes completely, even after interaction with the simulation. This probably is due to the characteristics of the so called "calm computing" [39], the acting of technology in the background.

Interestingly, people's evaluations differed between the groups, confirming the hypothesis that smart fridge functions are differently appreciated. Nutrition and healthy lifestyle feedback are evaluated most positively, whereas the recipe planer flops. An anecdotic finding can be added here: in preparation of the smart fridge simulation extensive interviews were lead with households of various family and age compositions. Especially older participants were impressed by a feature offering them easy monitoring of their medically prescribed diets (e.g. diabetic). This feature was valued so highly that it completely outweighed older interviewee's reservations concerning another "high-tech" device in their home.

Integrating the recipe planer resulted in a more negatively evaluated smart fridge model than the baseline model. In the baseline model, the amounts of groceries appeared unordered, without best-before dates and nutrition information on the screen. However, this model was still rated better than the one offering recipe planing functions. This surprising result might have occurred out of two reasons: firstly because of the limited flexibility of the recipe planer. The system included relatively few, namely 274 recipes. Furthermore, recipes were only provided if the exact ingredients required for preparation were available in the household, but individual ingredients, e.g. a certain type of vegetable could not be substituted by, say, similar vegetables. This could be a reason for the comparatively negative evaluation of this feature. Secondly it could be that participants saw this model as one that offers a superfluous extra function, whilst leaving out the basic functions that would be really necessary. Clearly, this is a point for further investigation. Furthermore it has to be kept in mind that this result only approaches statistical significance ($t = 1.84, df = 41, p = .07$) and could therefore be due to random variation between the groups.

Presence was included as a covariate in the regression analyses, because it was expected that the feeling of being immersed into the simulation could play a role in evaluating the fridge. This proved not to be the case. Even though there was some variation between the experimental groups in the different aspects of sense of presence, this variation did not impact the evaluation of the simulation. This is a promising result in evaluating the external validity of experimentally simulating the smart fridge. The presence ratings ranged from low to medium. From our point of view, this result is satisfying given the fact that the system simulated only the logistic aspects of daily food consumption and shopping, but not the processes of food preparation and eating. [40] measured sense of presence as a moderator of the impression of self-motion in a photorealistic environment. Their presence scores, ranging from 2.5 to 4 are somewhat higher than in our study. On the other hand, however, their virtual reality environment was not interactive and had no function rather than displaying a photographic scene. It is acknowledged that the present approach remains an artificial procedure compared to field tests of prototypes. The strongest argument for field testing such a device may be long-term effects of adaptation between user and device - in both directions - that cannot be captured by the present methodology. From the author's point of view, however, the gain in reliability of the findings by using a controlled, laboratory procedure and testing more than 100 prospective users outweighs this drawback.

A limitation of the present research is its exclusive reliance on a highly educated, homogeneous sample. Thereby the results of this study may not be generalized to the entire population. However, it is very likely that with the present course of development, this group of persons will be the ones that will have the opportunity to buy a smart fridge in their 30s or 40s, when they also have sufficient economic backgrounds. These aspects render the group of 20-30 year old people an attractive target group for smart home acceptance research. It would be very desirable, however, for future studies to intent to replicate the findings of the present study with a sample that is representative of the population.

5.1 Marketing Implications

From a marketing perspective, however, it should be kept in mind that the smart fridge to many people may be a so-called "really new product", a radical innovation from traditional practices. For this class of products [41] proposed to use "information acceleration" strategies, among them product simulation, in order to receive valid product appreciation data from customers. Evaluation of such products has been shown to be facilitated by giving clues to multiple analog categories [42]. In the case of the smart fridge, it would therefore be helpful to present the device as a mixture of fridge, storage management system (like in stock keeping in logistics) and health and lifestyle companion. Generally, results of the present study suggest that the fridge is valued for several different reasons by its prospective users, and this even in a rather homogeneous group of people. This implies that *one prototypical* smart fridge is not a feasible option for development. It would be more promising to develop a variety of models for distinct target groups. It is estimated that in the case of the smart fridge the overlap of functions will be much lower compared to mobile phones for example, which offer similar functions to all user groups.

6 Outlook

A major part of the resources of the present research project was spent on programming the smart fridge simulation. By help of this application it is possible to investigate a much broader spectrum of questions than have been the focus of this study. A few next steps are:

– Investigating the reactions of older people.
– Implementing more than one participant and thereby simulating shared usage of the smart fridge, e.g. in families.
– Including consumption and shopping data into the analysis of acceptance: It could for instance be that people who habitually eat very healthy do appreciate a reinforcing feedback mechanism more than people who live rather unhealthy and are constantly parented by the technology.
– Simulating and testing the acceptance of automatic replenishment.

We hope to acquire valid forecasts of smart home technology and to provide guidelines as to how this class of technologies has to be designed to provide the greatest benefits to its prospective users.

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A Appendix

A.1 Scenario Descriptions

"It is the year 2015... It has become normal that many groceries for daily consumption are not bought in stores anymore, but are delivered to the households. This saves time and effort. It is possible to order all items one would usually buy in the supermarket. For this purpose every fridge contains a smart organizer. The organizer is a small monitor attached by default to every fridge..."

Group 1 "...It recognizes by help of sensors, which groceries are still in stock in my household. The list of groceries in my household is displayed."

Group 2 "...It recognizes by help of sensors, which groceries are still in stock in my household and orders them according to categories. The ordered list of groceries is displayed."

Group 3 "...It recognizes by help of sensors, which groceries are still in stock in my household. Furthermore it recognizes the best-before dates of all groceries. Stock and best-before dates of every item are displayed."

Group 4 "...It recognizes by help of sensors, which groceries are still in stock in my household. Furthermore a recipe planer is included, which can propose recipes to me and include the necessary ingredients in the shopping list. The list of groceries in my household is displayed."

Group 5 "...It recognizes by help of sensors, which groceries are still in stock in my household. Furthermore it analyses with every consumption how healthy and economic my nutrition is and displays the respective informations. The list of groceries in my household is displayed."

A.2 Questionnaire Items

Perceived Usefulness ([16])

1. Using the smart fridge would enable me to accomplish eating and shopping more quickly.
2. Using the smart fridge would make it easier to do manage eating and shopping groceries.
3. I would find the smart fridge useful.

Ease of use ([16])

1. Learning to operate the smart fridge will be easy.
2. It will be easy to interact with the smart fridge.
3. The smart fridge will be easy to use.

Affective Attitude ([33])
"Please indicate how you ... would feel using a smart fridge (t_1) / ... felt interacting with the smart fridge(t_2)."

1. pleased / annoyed
2. happy / unhappy
3. satisfied / unsatisfied

Intention to Use (developed on the basis of [32])

1. I would not want to use such a smart fridge at all.
2. I would naturally adopt the smart fridge.
3. I would thoroughly concern myself with the smart fridge trying to master its operations.

Technical competence ([34], translated into English by [43])

1. Usually, I successfully cope with technical problems.
2. Technical devices are often not transparent and difficult to handle.
3. I really enjoy cracking technical problems.

4. Up to now I managed to solve most of the technical problems, therefore I am not afraid of them in future.
5. I better keep my hands off technical devices because I feel uncomfortable and help- less about them.
6. Even if problems occur, I continue working on technical problems.
7. When I solve a technical problem successfully, it mostly happens by chance.
8. Most technical problems are too complicated to deal with them.

Sensor Applications in the Supply Chain: The Example of Quality-Based Issuing of Perishables

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Abstract. Miniaturization and price decline are increasingly allowing for the use of RFID tags and sensors in inter-organizational supply chain applications. This contribution aims at investigating the potential of sensor-based issuing policies on product quality in the perishables supply chain. We develop a simple simulation model that allows us to study the quality of perishable goods at a retailer under different issuing policies at the distributor. Our results show that policies that rely on automatically collected expiry dates and product quality bear the potential to improve the quality of items in stores with regard to mean quality and standard deviation.

Keywords: RFID, sensors, cool chain, supply chain management, issuing policies, inventory management, retail industry.

1 Introduction

The distribution of perishable goods such as fresh meat and fish, flowers, frozen food of all kinds, etc. poses a major challenge to supply chain management. The complexity of the issue arises from the fact that not only cost efficiency, but also a maximum quality level of products in retail stores is necessary to meet customer expectancies. In reality, however, spoilage because of expired products or interrupted cool chains is a common phenomenon in the industry. On the one hand, fresh products make up about 65% of retail turnover. On the other hand, up to 30% of perishable products are estimated to become subject to spoilage at some point in the supply chain [1]. The resulting financial loss for both retailers and their suppliers is substantial. About 56% of shrinkage in supermarkets is attributed to perishables, which equals several billions of US$ in the United States alone each year [2]. The root cause for many of these problems can be found in the current practices of inventory management, e.g. flawed stock rotation [3,4].

In the context of perishables, the performance of inventory management in the supply chain depends to a large extent on the respective issuing policy that is in place at the echelons between the supplier and the store, e.g. at the retailer's distribution center. The purpose of these policies is to determine which products are picked and sent to a specific store when an order arrives. Rules that can typically be found in

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practice are classics such as 'First-In-First-Out (FIFO)', 'Last-In-First-Out (LIFO)', or simply issuing in random order. None of these policies, however, is related to product quality since quality in the sense of perceived optical appearance, microbial safety, etc. cannot be verified effectively for a large number of items or logistical units.

In recent years, however, the ongoing trends of miniaturization and price decline are increasingly allowing for the use of tiny RFID tags and sensors in inter-organizational supply chain applications. These technical artifacts are the foundation for the seamless tracking of containers, pallets, and individual sales units as well as the monitoring of a variety of environmental parameters, e.g. temperature, acceleration, humidity, and so on. These data collection capabilities, again, enable novel issuing policies based on expiry dates and quality-influencing conditions that bear the promise to address the above-mentioned issues [5].

Against this background, this contribution investigates the potential of RFID- and sensor-based issuing policies in the perishables supply chain performance. For this purpose, we develop a simple simulation model that allows us to study the quality of perishable goods at a retailer under different issuing policies at the distributor. The output parameters that we use to measure performance include a) number of unsaleable items and b) the quality of sold units. Furthermore, we consider the impact of the customer's selection criteria when deciding for a specific item.

The remainder of the paper is organized as follows. In the next section, we first provide an overview over sensor technologies in the perishables supply chain. Second, we review the existing body of literature on issuing policies. In section 4, we present our model and numerical results from our simulation experiments including a sensitivity analysis. The paper concludes with a summary and suggestions for further research.

2 Technology Background

The quality of fresh products is affected by a number of factors, including post-harvest treatments (e.g. pre-cooling, heat, ozone), humidity, atmosphere, packaging, etc. The by far most important factor that determines quality, however, is the change in temperature conditions during transport from the manufacturer to the store. From a technical point of view, temperature tracking in supply chains has basically been a well-known issue for many years. A number of different technologies are available on the market that we will shortly present in the following. Furthermore, we discuss the major differences between these classical tools and the possibilities of novel wireless technologies such as RFID and sensor tags.

The traditional means for temperature tracking in logistics is the use of chart recorders as depicted in figure 1. A chart recorder is an electromechanical device that provides a paper printout of the temperature recordings over time. Its main disadvantage – besides cost and size – is in the fact that data is recorded on paper and has to be interpreted manually, which limits its applicability if large amounts of data have to be processed automatically in an information system in real-time.

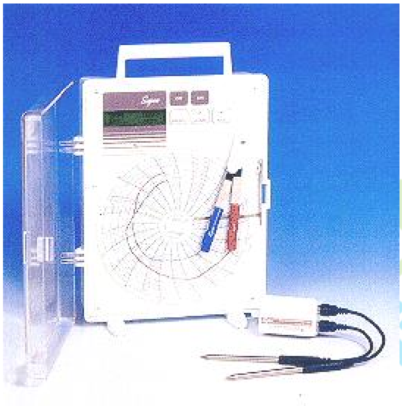

Fig. 1. Chart recorder (source: Linseis)

A second category comprises so-called "data loggers", i.e. digital or analog electronic devices with integrated sensors for measuring and tracking temperature data over time (cf. figure 2). Loggers can easily be started by pressing a key and provide a visual alert upon receiving. In contrast to chart recorders, data is stored digitally in the logger's memory. Unfortunately, data access usually requires a physical connection, e.g. via a serial cable. Accordingly, it is hardly possible to react on unexpected temperature changes in the process without interrupting the workflow. Moreover, data loggers are usually too bulky and expensive to be economically of use in many application settings.

Fig. 2. Temperature logger (source: MadgeTech)

Unlike the above-mentioned technologies, Time-Temperature Indicators (TTI) are based on chemical, physical, or microbiological reactions. TTI are inexpensive labels that show an easily-measurable time- and temperature-dependent change, which cumulatively reflects the time-temperature history of the product (cf. figure 3). The

Fig. 3. TTI on a food package (source: SealedAir)

color shift on the TTI label can easily be read and understood and does not require an additional reader device. These main features, however, are also the technology's main disadvantage since the non-digital information reflects only accumulative effects, requires manual examination, and does not allow for remote monitoring.

Driven by the rise of RFID in general, a fourth technology has evolved in recent years, which combines active RFID transponders with temperature sensors. These integrated sensors continuously record temperature readings and store it in the tag's memory (cf. figure 4). As with other RFID data on the tag, the temperature data can be accessed by an RF reader at any point in the process and forwarded to an organization's information systems. In contrast to other tools, RFID-based sensor tags allow for fully automatic data collection in real-time, which in principle enables the retailer to react on environmental changes before products become unsaleable. In today's retail supply chains, deployments of sensor tags are nevertheless still rare. On the one hand, relatively high tag prices are the consequence of the cost of the energy supply that is needed to power the active sensor. On the other hand, the need to reduce power consumption leads to the implementation of low-power sensors, which do not achieve the same level of accuracy as their traditional counterparts. However, both issues are likely to be resolved in the near future such that the use in the context of logistical units (e.g. pallets and cases) becomes economically feasible along the entire supply chain.

Fig. 4. Temperature sensor integrated with an RFID tag (source: KSW-microtec)

3 Perishables in the Supply Chain

The management of perishables in supply chains has been a research issue since the early 1970s in operations management literature and beyond. The background of these contributions is not only in the food supply chain, but also in entirely different application domains such as blood banks. In the following, we give a short overview of related works in this area that are relevant to our research.

Pierskalla and Roach [10] were among the first to discuss issuing policies such as order-based FIFO and LIFO. The authors study issuing policies for a blood bank, with random supply and demand. They show that FIFO is the better policy for most objective functions, maximizing the utility of the system and minimizing stockouts. Jennings [9] sets his focus on inventory management of blood banks as well. He showed the importance of blood rotation among hospitals. In his analysis, he considers stockouts, spoilage, and costs. Cohen and Pekelman [11] analyzed the evolution over time of the age distribution of an inventory under LIFO issuing, periodic review, and stochastic demand. They concentrate on the analysis of stockouts and spoilage.

Wells and Singh [15] introduce an SRSL policy ('shortest remaining shelf life') and compare it to FIFO and LIFO. They take into account that, because of variations in storage temperature, items have different quality deterioration histories, which motivates their use of SRSL. Their results, however, are a little confusing: in the abstract the authors state that SRSL leads to better performance, but the figures in the paper show that SRSL has a better standard deviation but worse average quality.

Goh et al. [12] study two-stage FIFO inventory policies, where a first stage holds fresher items and the second stage holds older items. Liu and Lian [8] focus on replenishment. They consider the inventory level of an (s, S) continuous review perishables inventory, and calculate and optimize the cost functions for s and S. Chande et al. [6] focus on RFID for perishables inventory management, not issuing policies in themselves. They show that dynamic pricing and optimal order in the perishables inventory can be determined with the help of information – such as the production date – stored on RFID tags.

Huq et al. [13] define an issuing model for perishables based on remaining shelf-life and the expected time to sale. They compare it to FIFO and SIRO with regard to revenue and find a better performance in the majority of cases. Donselaar et al. [7] study the difference between perishables and non-perishables and between different categories of perishables using empirical data available from supermarkets. Ferguson and Ketzenberg [14] quantifiy the value of information shared between the supplier and the retailer on the age of the perishable items. The authors propose heuristic policies for the retailer under both conditions: no information sharing and information sharing with the supplier regarding the age of the products.

In contrast to the previous works, our contribution distinguishes between quality-based and expiry-based policies. For this purpose, we compare a total of seven issuing polices using a simple supply chain model that comprises a manufacturer, a distribution center, and a retail store. We measure performance in the sense of mean quality and standard deviation. Furthermore, we account for unsold items in our analysis. We also consider the impact of different patterns of customer behavior while selecting items.

4 Experimental Results

4.1 The Model

The supply chain we model consists of a manufacturer, a distribution center, and the retailer's store as shown in Figure 5. Customer arrival at the retailer is modeled as a Poisson process. The retailer and the distribution center manage their inventories using a (Q, R) replenishment policy, i.e. when the inventory falls below a value R, a replenishment order of Q items is placed. Lead time from the distribution center to the retailer is deterministic. The lead time from the manufacturer to the distribution center is normally distributed. By varying the initial lead times at the distribution center we are simulating different initial ages for products arriving at the distribution center. This is a plausible assumption because of delays in transportation and because of the retail supply chain where items are always manufactured and stored waiting for the orders, as opposed to build-to-order supply chains. By varying initial ages, we can distinguish between issue policies based on time of arrival (FIFO, LIFO) and those based on age (FEFO, LEFO).

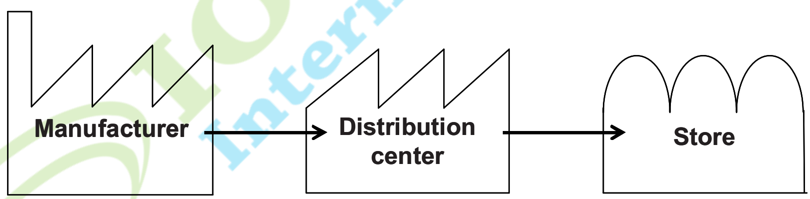

Fig. 5. The supply chain we base our model on

Because of reasons such as deterioration due to cold chain conditions, we also vary the initial product qualities at the manufacturer. We assume that the recording of temperature data by wireless sensors allows for calculating a sufficiently accurate estimate of product quality. Initial qualities are assumed to be normally distributed and then depleted when they arrive to the distribution center based on the initial lead times as discussed above. Production capacity at the manufacturer is unlimited.

We simulate seven different issuing policies at the distribution center. For each issue policy we record the qualities of sold items, calculating at the end their mean and standard deviation. We also record the number of spoiled items. The issue policies we compare are the following:

1. Sequence In Random Order (SIRO). Products in the distribution center are selected randomly and issued to the retailer.
2. First In First Out (FIFO). Products that have been longest in the distribution center are selected first.
3. Last In First Out (LIFO). Products that have been shortest in the distribution center are selected first.
4. First Expiry First Out (FEFO). Products in the distribution center are selected by their age, the items which were manufactured earlier being the first to be issued.

5. Lowest Quality First Out (LQFO). Products are selected by their quality, the items which have the lowest quality being the first to be issued.
6. Latest Expiry First Out (LEFO). Products are selected by their age; the items which were manufactured latest are issued first.
7. Highest Quality First Out (HQFO). Products are selected by their quality; the items which have the highest quality are issued first.

The workflow of the simulation algorithm is shown in figure 6. The simulation comprises a number of runs, each of which simulates all the different issue policies. For each run, we generate a sequence of customer arrivals in advance along with a sequence of initial product qualities and lead times. Thus the different issue policies are compared using the same input. The following main events happen in the supply chain:

- The distribution center and retailer regularly check to see if shipments have arrived in order to replenish their inventories.
- A customer arrives to the retailer and is served an item if the retailer is not out-of-stock
- At the end of the day, the retailer and distribution centers check their inventories and throw any spoiled items.
- When the inventory level at the retailer or distribution center goes below the threshold level, an order is placed.

4.2 Base Case

We implement the model described above in Python and analyze the results in Excel. We consider the following parameters for the base case:

- Demand at the retailer is a Poisson process with $\lambda = 30$ items per day.
- The retailer reorders products with $Q_R = 60$ and $R_R = 40$ items.
- The distribution center reorders products with $Q_{DC} = 120$ and $R_{DC} = 80$ items.
- Lead time from manufacturer to distribution center is normally distributed with mean = 1.5 days and standard deviation = 0.8.
- Lead time from the distribution center to the retailer is 1.5 days.
- The initial quality of products upon leaving the manufacturer is normally distributed with mean 90% and standard deviation = 5%.
- Minimum quality below which products are regarded as spoiled is 50%.
- Products deteriorate according to a linear model with a coefficient of 5% quality per day. This implies that the maximum lifetime of the product is 10 days, which is a plausible assumption for products with short shelf-life, such as strawberries and figs stored at 0°C.
- The retailer performs periodic review of the quality of its products at the end of the day.
- We simulate the supply chain for 1000 days per replication.
- We conduct 50 different replications, and for each we generate a new set of customer arrival times, initial product qualities from the manufacturer, and lead times from manufacturer to distribution center.

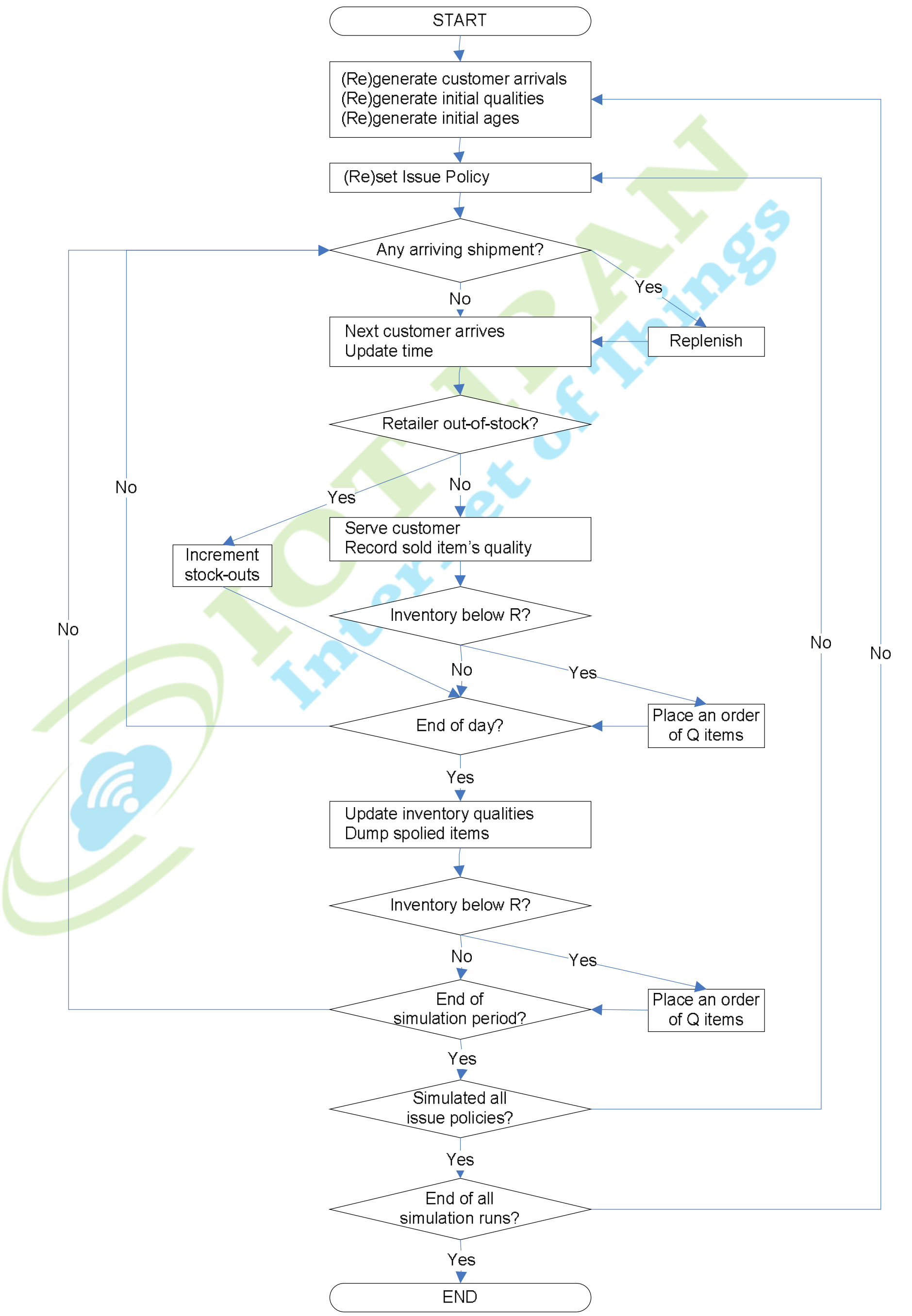

Fig. 6. Flowchart of the simulation algorithm

4.3 Results and Discussion

We first ran the complete simulation assuming that customers select the items randomly from the retailer's store, i.e. the retailer's inventory was modeled as a SIRO inventory. It could be observed that the LEFO and HQFO issue policies had the best average qualities. This was achieved on the expense of having the highest quality deviations and incurring the highest number of spoiled items, which was 25% of all the items. The LIFO issue policy shows slightly better results than LEFO and HQFO. The FIFO, FEFO, and LQFO policies showed the lowest percentage of spoiled items. The quality-based LQFO issue policy showed the least standard deviation of qualities of sold items, which was 4.5%. LQFO also showed the absolute least percentage of spoiled items at 2.6%. Table 1 provides the average qualities of sold items, their standard deviations, the percentage of unsold items due to spoilage, and the percentage of items sold at less than the threshold quality. The quality distribution curves of all issue policies are given in figure 7.

Table 1. Results of the different issue policies for a SIRO retailer inventory

Policy	Average Quality	Std. Dev.	Unsold (%)	Low quality sales (%)
SIRO	67.1	9.6	18.1	3.3
LIFO	70.3	8.6	24.3	**0.6**
FIFO	63.2	8.9	9.5	5.1
FEFO	62.4	7.2	3.4	3.0
LQFO	57.4	**4.5**	**2.6**	4.6
LEFO	71.4	10.0	25.7	1.2
HQFO	**71.9**	10.8	25.6	1.3

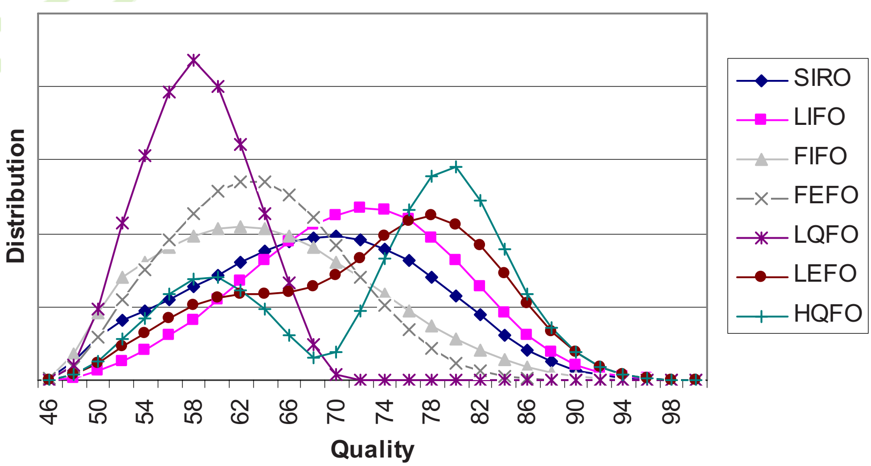

Fig. 7. Quality distribution for the issuing policies for a SIRO retailer inventory

From the results obtained, we conclude that when the primary objective of the retailer is to avoid spoilage and to sell items with qualities that vary as little as possible, the LQFO is the best issue policy. The LIFO, LEFO, and HQFO policies would be considered instead of LQFO if the retailer is willing to incur spoilage given that he can sell more items from the higher quality categories.

We then wanted to see if the results will change if the customers don't select items randomly from the store, but instead pick them based on the basis of age or quality. For this we first ran the simulation assuming that customers select items based on age, basically picking the ones with the latest expiry date first. For simulating this, we model the retailer's inventory as a Latest Expired First Out (LEFO) inventory. The results are shown in table 2 and figure 8 below. The higher standard deviations and percentage of unsold items reveal that all policies perform worse than before despite the higher average qualities of sold items. The LQFO policy is still the one with the least standard deviation of item qualities and with the least percentage of unsold items.

Table 2. Results of the different issue policies for a LEFO retailer inventory

Policy	Average Quality	St. Dev.	Unsold (%)	Low quality sales (%)
SIRO	68.4	10.4	21.7	3.3
LIFO	70.6	9.6	24.9	**1.1**
FIFO	64.2	10.0	13.5	5.7
FEFO	62.7	8.0	5.6	4.1
LQFO	57.6	**5.2**	**4.5**	6.6
LEFO	71.7	10.4	26.3	1.5
HQFO	**72.3**	10.9	26.4	1.8

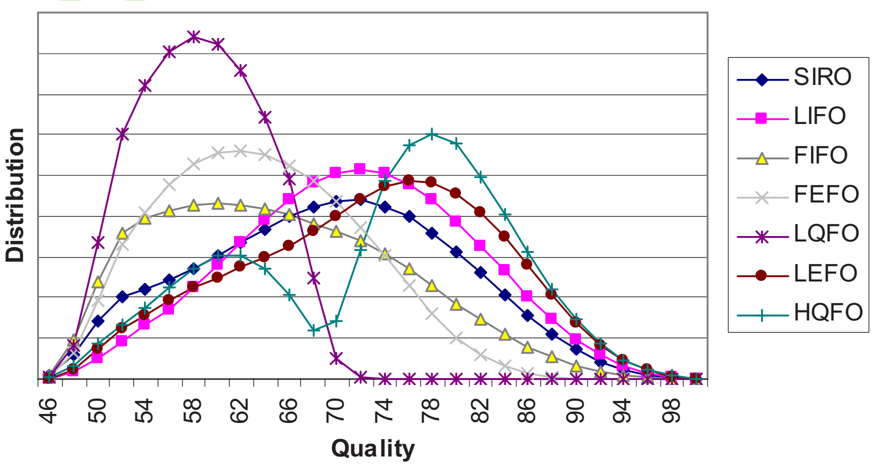

Fig. 8. Quality distribution for the issuing policies for a LEFO retailer inventory

The last customer behavior that we tested was selecting the items based on quality, picking the ones with the highest quality first. For simulating this we model the retailer's inventory as a Highest Quality First Out (HQFO) inventory. The results are shown in table 3 and figure 9. All policies show worse results when compared to the SIRO or LEFO retailer in terms of higher standard deviation, more unsold products, and more products sold that are below the threshold quality. The LQFO issue policy shows again the least standard deviation and unsold items as compared to the other policies.

Table 3. Results of the different issue policies for a HQFO retailer inventory

Policy	Average Quality	St. Dev.	Unsold (%)	Low quality sales (%)
SIRO	68.5	10.7	22.2	3.5
LIFO	70.7	10.1	25.2	**1.3**
FIFO	64.6	10.3	15.3	5.8
FEFO	63.3	8.6	7.8	4.9
LQFO	58	**5.8**	**7.2**	9.4
LEFO	72.0	11.0	27.1	2.0
HQFO	**72.4**	11.3	26.9	2.5

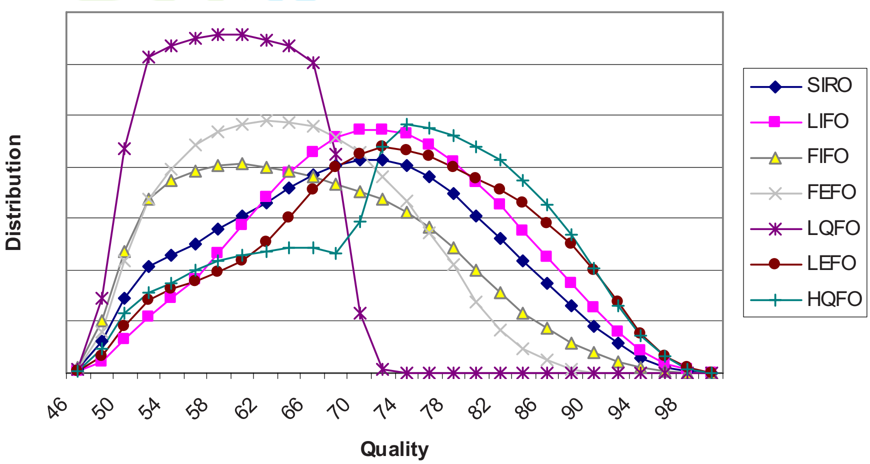

Fig. 9. Quality distribution for the issuing policies for a HQFO retailer inventory

4.4 Sensitivity Analysis

In this section we perform a sensitivity analysis to our simulation study to analyze the effect of varying the initial qualities and the rate of quality deterioration. We conduct all experiments in this section using only a SIRO retailer inventory, not including the HQFO or LEFO customer behaviors.

4.4.1 Varying the Rate of Deterioration

The rate of quality deterioration per day was set to 5% in the base case, which is equivalent to a 10-day lifetime of a product, given that the threshold acceptable quality is 50%. Here we vary the rate of deterioration by ±50%, thus running the simulation with a deterioration rate of 2.5% and 7.5%. We give the results in tables 4 and 5, respectively.

Table 4. Results after decreasing the rate of quality deterioration to 2.5% per day

Policy	Average Quality	St. Dev.	Unsold (%)	Low quality sales (%)
SIRO	76.2	8.4	1.6	0.3
LIFO	79.4	6.2	12.3	0.0
FIFO	73.4	6.2	0.0	0.0
FEFO	73.4	5.5	0.0	0.0
LQFO	73.4	**2.6**	0.0	0.0
LEFO	79.6	6.8	12.4	0.0
HQFO	**80.0**	7.6	13.1	0.0

Table 5. Results after increasing the rate of quality deterioration to 7.5% per day

Policy	Average Quality	St. Dev.	Unsold (%)	Low quality sales (%)
SIRO	62.8	9.9	35.8	9.8
LIFO	62.8	9.3	35.4	7.7
FIFO	59.7	9.3	34.0	14.8
FEFO	56.3	6.7	**28.2**	18.6
LQFO	53.5	**5.0**	30.8	26.2
LEFO	66.3	10	39.1	6.2
HQFO	**68.1**	9.8	41.7	**5.7**

We notice from the results that the LQFO issue policy performs better when the rate of quality deterioration is lower, and as this rate increases, the FEFO policy becomes the better option. When the rate of deterioration is 2.5% (cf. Table 4), the LQFO policy shows a better average quality improvement from the 5% rate (cf. Table 1) compared with the other policies. Having the same average quality as the FIFO and FEFO policies but the least standard deviation makes the LQFO policy the choice for products with low rate of deterioration. But when the rate of deterioration becomes 7.5% (cf. Table 5), the FEFO policy shows a higher average quality and lower percentage of unsold items than LQFO. In addition, the difference between the two policies' standard deviations becomes small, which makes the FEFO policy more suitable for products with high rates of deterioration.

4.4.2 Varying the Standard Deviation of Initial Qualities

The standard deviation of initial product qualities was assumed to be 5% in the base case. We study here the effect of changing this value on the selection of the issuing policy. Thus, we run the simulation twice leaving all the values as in the base case but halving the standard deviation of the initial qualities in one run and doubling it in another. We give the results in tables 6 and 7, respectively.

Table 6. Results after decreasing the initial standard deviation of qualities to 2.5%

Policy	Average Quality	St. Dev.	Unsold (%)	Low quality sales (%)
SIRO	66.9	8.9	17.6	3.2
LIFO	70.3	7.7	24.5	**0.3**
FIFO	62.7	8.5	7.4	5.1
FEFO	58.1	5.1	3.5	4.7
LQFO	57.4	**4.5**	**2.7**	4.6
LEFO	71.2	9.4	25.2	0.6
HQFO	**71.3**	9.6	25.2	0.6

Table 7. Results after increasing the initial standard deviation of qualities to 10%

Policy	Average Quality	St. Dev.	Unsold (%)	Low quality sales (%)
SIRO	67.6	10.7	20.6	4.1
LIFO	70.2	10.3	24.6	**1.9**
FIFO	64.4	9.8	14.5	5.2
FEFO	63.3	8.4	11.1	4.9
LQFO	59.5	**5.5**	**3.1**	3.5
LEFO	71.7	11.3	26.8	2.1
HQFO	**73.0**	12.4	27.2	3.0

Comparing the results shown in tables 6 and 7 with those in table 1 (5% standard deviation) reveals that for low standard deviations of initial product qualities, the FEFO and LQFO issue policies perform very close to each other; however, as the quality deviations increase, the LQFO policy shows significantly better results than FEFO. The advantage of LQFO at higher initial quality variation is due to maintaining its lower quality deviation of sold products and a lower percentage of unsold products as compared to all other policies.

4.4.3 Varying the Mean of Initial Qualities

We specified a mean initial product quality at the manufacturer of 90% for the base case. Here we run two additional simulations, first decreasing this mean to 85% and then increasing it to 95%. We give the results in tables 8 and 9, respectively, and study the changes.

The results show that for higher initial qualities (table 9), LQFO shows the best results both in terms of unsold products and low quality deviation, in addition to a

Table 8. Results after decreasing the initial mean quality to 85%

Policy	Average Quality	St. Dev.	Unsold (%)	Low quality sales (%)
SIRO	63.6	8.7	23.7	5.0
LIFO	65.7	8.2	26.8	**2.2**
FIFO	60.4	8.1	17.9	8.2
FEFO	58.7	6.5	**10.8**	7.5
LQFO	54.3	**3.9**	12.2	13.5
LEFO	67.2	9.4	27.9	3.3
HQFO	**67.9**	10.1	28.3	3.9

Table 9. Results after increasing the initial mean quality to 95%

Policy	Average Quality	St. Dev.	Unsold (%)	Low quality sales (%)
SIRO	70.6	10.3	13.9	2.5
LIFO	74.1	8.4	20.7	0.2
FIFO	66.4	9.5	3.8	2.6
FEFO	63.4	6.5	1.4	1.6
LQFO	61.6	**4.8**	**0.3**	0.4
LEFO	75.6	9.9	23.1	0.2
HQFO	**76.4**	10.5	24.4	**0.1**

reasonable average quality of sold products. For lower initial qualities (table 8), the LQFO policy incurs a higher percentage of unsold products than the FEFO policy but maintains a better standard deviation. In this case, the retailer can adopt either one of these strategies depending on its business priorities.

5 Summary and Outlook

The aim of this paper is to investigate the impact of novel sensor-based issuing policies on product quality. For this purpose, we have conducted a simulation study that compares the performance of policies that rely on quality measurements and expiry date information to classical policies that are in place in today's retail supply chains. The main results from our analysis can be summarized as follows:

- SIRO, LIFO, LEFO, and HQFO policies constantly showed high percentages of spoiled products, so the choice of best-policy was usually among FIFO, FEFO, and LQFO.
- LQFO always showed the smallest standard deviation with regard to the quality of sold items and was usually the policy with the lowest percentage of unsold items, making it the policy of choice in general.
- All policies performed worse when the customers selected items based on quality or age, but LQFO was still better than the other policies.
- The sensitivity analysis showed that FEFO's performance relative to LQFO improves under one or a combination of the following conditions:

- High rates of quality deterioration
- Low variation of initial product quality
- Lower initial product qualities

Regarding further research, our contribution may offer opportunities in various directions. On the one hand, more additional simulations might prove useful that also comprise a comparison of more complex supply chain structures, ordering policies, and product types. On the other hand, we see potential in the development of compound policies that integrate available information on quality, expiry dates, demand, etc. Furthermore, empirical works might be necessary to get a better understanding of current technology requirements in cool chains.

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Cost-Benefit Model for Smart Items in the Supply Chain

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Abstract. The Internet of Things aims to connect networked information systems and real-world business processes. Technologies, such as barcodes, radio transponders (RFID) and wireless sensor networks, which are directly attached to physical items and assets transform objects into Smart Items. These Smart Items deliver the data to realize the accurate real-time representation of 'things' within the information systems. In particular for supply chain applications this allows monitoring and control throughout the entire process involving suppliers, customers and shippers. However, the problem remains what Smart Item technology should be favored in a concrete application in order to implement the Internet of Things most suitable. This paper analyzes different types of Smart Item technology within a typical logistics scenario. We develop a quantification cost model for Smart Items in order to evaluate the different views of the supplier, customer and shipper. Finally, we conclude a criterion, which supports decision makers to estimate the benefit of the Smart Items. Our approach is justified using performance numbers from a supply chain case with perishable goods. Further, we investigate the model through a selection of model parameters, e.g. the technology price, fix costs and utility, and illustrate them in a second use case. We also provide guidelines how to estimate parameters for use in our cost formula to ensure practical applicability of the model. The overall results reveal that the model is highly adaptable to various use cases and practical.

1 Introduction

Supply chain scenarios in logistics are an interesting field to apply information and networking technology to objects or things. Here, embedding technology into the application results not only in qualitative improvement - e.g. user satisfaction - but also in quantitative improvement, e.g. process optimization. By

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implementation of quantitative improvements, the technology of things goes beyond general applicability into the business domain.

This paper is largely inspired by the fact that the use of technology, namely in wireless sensor networks, pervasive computing and ubiquitous computing, allows tighter coupling of information about the overall process and the actual process status itself. This is reflected in Figure 1 showing a status of the information world, and a status of the physical world (figure is adopted from Fleisch, Mattern [1]). More complex technology obviously provides closer matching of both

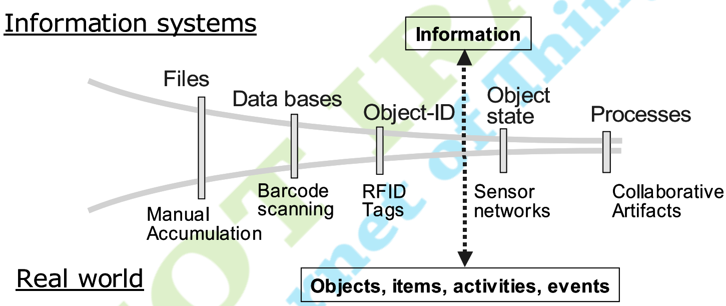

Fig. 1. Bridging the gap between the real world and information systems

worlds, while less complex technology means more fuzzy information. With today's barcode enabled business processes, mostly object-types are collected in databases. Such information offer performance measures for supervision on a process level.

This paper focuses on logistic processes, and the use of information technology in logistic processes. In this business area the use of electronics making objects and processes smart is already a concept used in some settings [2]. The use of RFID-tags for example allows acquiring knowledge about an items location and activities through reading the objects identification. This information is used to accelerate supply chain throughput, thus enabling e.g. lower intermediate inventory stock [3].

A more advanced technology can be attained by the use of sensing technology. A sensing and networking unit is added to each item of a logistic process, e.g. to each container for a chemical good transportation process or to each box of vegetables in a food supply chain process. The electronic device continuously supervises the condition of the item, and reports this information. Reporting can either be carried out continuously or on dedicated synchronization points. The most advanced technology comprises the use of Collaborative Artefacts. Collaborative Artefacts add processing power and smart behaviour to the smart sensor node that is attached to every good or item. They are able to operate independent from an infrastructure and allow spontaneous ad-hoc collaboration with other devices and computer within vicinity. Here, integration of technology allows close collaboration of items and of business processes. One example of such an application is the CoBIs project [4], where items not only deliver information. They also control the business application collaboratively together with business process systems.

1.1 Problem Statement

Such closer control is envisioned to dramatically improve the supply chain process quality. For example, perishable food commodities are prone to post harvest loss in the magnitude of 25% [5], mostly while transport. Sources from the US [6] even report that 40-50% of the products ready for harvest are never consumed - a total sum of several billion dollar per year. Application of smart items into supply chains may therefore be able to save costs in the magnitude of millions or even billions of dollars.

Although such numbers show sheer endless potential for the use of technology in a supply chain process, for any concrete logistic process, benefit has to outweigh cost to be economical feasible. To justify this we require a pre-calculation of cost and benefit. This paper will present a simple, but powerful cost model taking into account overall costs of a logistic process, including the cost for technology, but also the benefit cost when using the technology. The proposed model allows calculating and optimizing the usage of technology in logistic processes for decision makers. The model also enables decision makers to estimate benefits and to justify decisions. E.g., the model can find break-even points at what cost level technology pays-off, and it allows to find the appropriate density of technology usage for a given logistic process.

The paper is driven by applicability, and the model is thus reduced to a set of parameters that are simple to estimate in a technology evaluation process. The paper is focused at supply chain processes and ensures simplicity of use through a black box approach. This allows to only model the most important parameters and views of a supply chain process, and the use of technology therein. The paper will take three different views on the process, which are independently modeled: The supplier, the shipper, and the customer. Each of them may independently optimize it's cost function for the use of smart item technology. The cost formula developed within this paper will enable potential applicants to quantify costs and benefits of use of technology within logistic processes, and especially supply chains. It will also introduce a guideline how to approach the problem of finding parameters for the formula and describe the steps required.

1.2 Paper Overview

The paper first analyses an existing logistic scenario and discusses the use of technology in supply-chains. The scenario is used to develop the parameters used in a cost model for supply chains. In section 3, six cost models are presented, two for each of the major stakeholders in a supply chain: the supplier, the shipper and the customer. The cost model is explained in section 4 using a concrete example. Section 5 provides a short guideline how to estimate and calculate parameters for the cost model in an effective way.

2 Supply-Chain Scenario Analysis

A logistics process in a supply chain consists of planning, implementation and control of a cost efficient transport and storage of goods from a supplier to a customer according to the customer's requirements [7]. The main goal is an increase of the customer's utility while optimizing the performance of the logistics. The basic logistics functions are to transport *the right goods in the right quantity and right quality at the right time to the right place for the right price.* Information systems keep track of the logistics process and implement various techniques to enable the basic functions. Figure 2 associates the functions with the techniques used by information systems. Further it shows different Smart Item technologies and their coverage on the techniques. The information system requires to identify

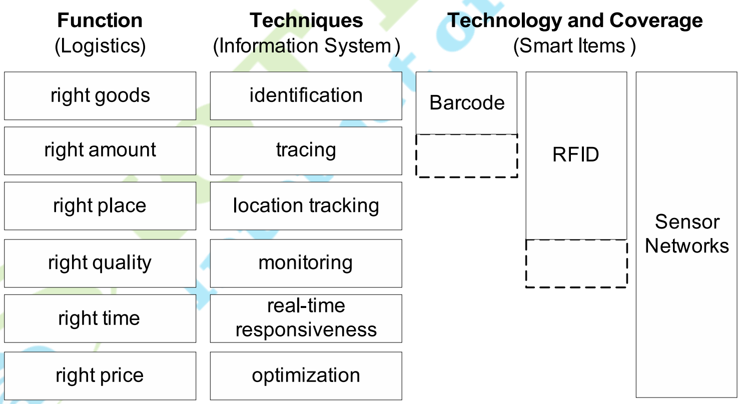

Fig. 2. Techniques of an information system to implement the logistics functions. It also shows how well three Smart Item technologies (barcode, RFID, sensor networks) cover the basic functions. Dashed areas indicate partial coverage.

goods to link electronic processes to the real item. Tracing is necessary to let the system detect when an item gets lost. As a result, it ensures that the right amount of goods is delivered. Location tracking enables the information system to keep track on the transport itself. During the transport the good is not under the control of the supplier. In order to ensure the quality of the delivered goods, an appropriate monitoring of the goods' state is necessary. Having all these data within the information system, the overall logistics process can be observed in very detail. It allows real-time actions to unforeseen events, to determine bottlenecks and it provides the basis for optimization. Finally, this will affect the price accordingly.

Various technologies have been developed for acquiring logistics data electronically directly from the good and process and then delivered to the information system. We refer to this technology as Smart Items. Depending on the technical capabilities (basic to advanced) Smart Items cover different techniques.

Barcodes are a current state-of-the-art technology for electronic identification of goods. A barcode label is attached on the goods and then optically detected by a barcode reader. The reader de-ciphers the printed identification and sends it to the information system, which updates the good's record. Barcodes can support tracing only partly. The line-of-sight requirement makes it impossible to detect single items within a pallet of goods. Solution for in-transit inspections would require a complex infrastructure. As a consequence, barcodes can only be used in loading and unload processes at the ramp at a very coarse-grained scale.

Radio Frequency IDentification (RFID) [8] is a radio-based identification technology. Line-of-sight is not necessary. This allows identification of single items within a box of items. Location tracking and tracing is possible as far as the infrastructure of RFID readers is deployed [9]. A mobile infrastructure, e.g. GSM based readers, allows even a remote identification and tracing while the goods are in transit. Novel RFID transponders acquire sensor information of the goods, e.g. temperature or pressure or shock, during the transport and enable a monitoring of goods' state. However, those sensing capabilities are very limited.

Wireless sensor networks are an upcoming advanced Smart Item technology for logistics processes. Sensor nodes are tiny, embedded sensing and computing systems, which operate collaboratively in a network. In particular, they can be specifically tailored to the requirements of the transported goods. In contrast to previous technology, which delivers data to an information system, sensor networks can executes parts of the processes of an information system in-situ directly on the items. Goods become embedded logistics information systems. For instance, CoBIs [2] presents a sensor network example of storing and in-plant logistics of chemical goods, which covers all identification, tracing, location tracking, monitoring and real-time responsiveness at once.

2.1 A Smart Logistics Example

The following example of the logistics process is derived from previous experiences in [2], [10] and [11]. This example draws a picture of a supply chain process that uses most advanced Smart Item technology. We will first present the example and then analyze the example at the end of the section.

A customer orders chemical substances from a supplier. The supplier subcontracts a shipper for the transport of hazardous chemical substances. The orders and acceptances are recorded in an Enterprise Resource Planning (ERP) system. In this scenario it is important to note that all participants are permanently informed on the state of the transport during the complete process. This is because of legal issues since supplier and shipper are commonly responsible for the safety. This logistics process is very complex because it requires the management of goods in different, potentially unforeseen situations involving different participants. As a consequence, there is a need for smart technology enabling a continuous supervision at any time and place in order to implement this management.

The chemical containers are Smart Items using wireless sensor network technology. The sensor nodes are attached to the containers, identify the containers and constantly monitor their state, e.g. temperature. Further, they establish a network between Smart Items to trace the load of all containers to deliver. The shipper provides a mobile communication infrastructure for the Smart Items with an uplink to a wide area network, e.g. GSM. As a consequence, all participants can query the state and location of their delivery. Figure 3 illustrates the smart logistics process using Smart Items. Following the eSeal approach in [10], the

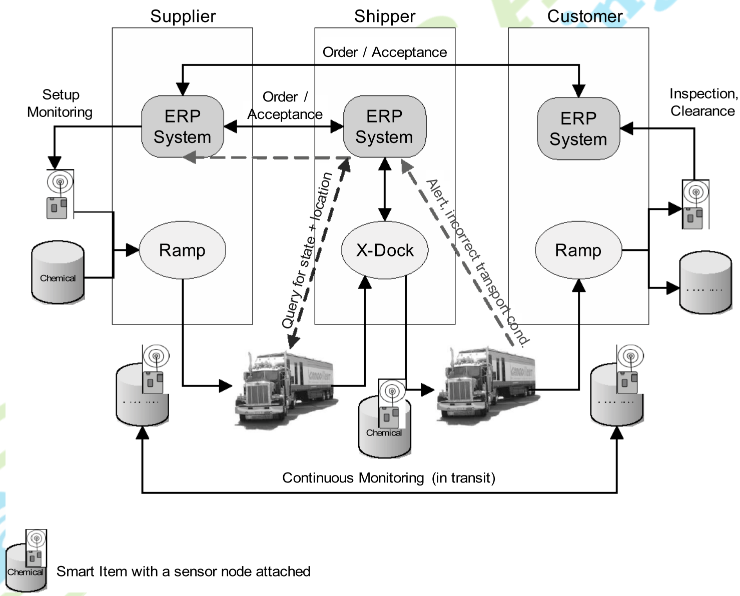

Fig. 3. Smart Items logistics process

supplier first setups and configures all Smart Items with basic transport information. It comprises container identification, destination, transport conditions, size of the delivery, and time to destination.

The shipper plans the routes separately. The different orders are summarized and re-organized in a cross-dock (X-Dock) in order to optimize the utilization of trucks. For instance, loads with the same destination packed into one truck. Other parameters and real-time conditions can also be used for optimising the supply chain. E.g., the supplier and the shipper have to ensure that no hazardous material combination, e.g. flammable and oxidizing substances, is loaded into the truck. Instead of transporting all information to both (supplier and shipper) ERP systems, the Smart Items take care of this by checking the identification of surrounding containers and environment conditions (e.g. temperature). In case of an incompatibility, the items raise an alert.

During transport the Smart Items constantly supervise the transport conditions, e.g. temperature of the chemical containers. Using an uplink to a wide area network the state of Smart Items can directly be queried and checked by the process participants in order to fulfill the safety responsibility. Further, the location can be electronically tracked. Smart Items act proactively and will raise an alert and send out a notification to a participant, if some transport condition does not hold anymore. Appropriate actions can be triggered, e.g. the truck driver is notified immediately to check the load. The Smart Items also trace their packaging. In case that the delivery is accidentally split or a container is left behind, the Smart Items will raise an alert. As a result, Smart Items ensure that the right amount of goods is delivered. All alerts are locally logged for later revision in case that the person in charge is not reached or the alert is ignored.

When the delivery reaches the customer, the Smart Items automatically inform the ERP system on the delivery and the state. Identification and amount are inspected immediately and clearance is given accordingly. If the transport conditions are violated, then a retour process will be initiated and the participant in charge will be determined through the logging data.

Finally, the usage of advanced Smart Items such as wireless sensor networks helped to prevent losses and accidents during the transport. The example shows that Smart Items can accurately supervise the entire smart logistics process.

2.2 Benefits and Deduction of Parameters for a Smart Items Based Supply Chain

We expect major improvements by the usage of Smart Items within the smart logistics process. Based on the benefits we will identify affected parameters for a Smart Items based Supply Chain model:

1. Reduction of critical situations for goods. Smart Items monitor the goods continuously and alert a person in charge when the transport conditions are not appropriate anymore. This leads to a prompt reaction, which prevents further damage or even loss. As a result, we expect a reduced ratio of defective or perished goods and a (positive) change in the
   (a) return costs
   (b) costs for removal of defective goods
   (c) lower transport costs due to lower reshipping rate and higher shipping throughput
2. Clear assignment of responsibilities. If the alert is ignored or the reaction is delayed, the Smart Items will determine and prove the damage or loss of goods. The shipper can accurately be taken into responsibility for the amount of defective goods. This allows for a transparent supply chain process and a clearer separation of costs between supplier and shipper.
3. Since the overall amount of defective and lost goods is known through Smart Items, the supplier is able to accurately conclude on the ratio of defective goods, which is inherent (and previously unknown) in his delivery. This is expected to raise consumer (customer) satisfaction.

As a consequence of the Smart Items usage, each participant in the logistics process can accurately determine its responsibility for the amount of defective goods and transport losses. This enables the potential for process optimization, but involves a complex interplay between the participants and the used technology. In the following section, we break down these relations and we quantify them based on the above analysis of the process.

3 Smart Items Quantification Cost Model

In this section we introduce our model for quantification of Smart Items usage in logistic processes. We describe a cost model of the logistics process and quantify the profit for different technological approaches ranging from simple Smart Items, e.g. barcodes, up to very complex Smart Items, e.g. wireless sensor nodes. In this investigation we adopt three different positions of the three stakeholders: supplier, shipper and customer. For all stakeholders the amount of defective and lost goods determines their profit. Therefore, our approach focuses on how Smart Items relate to lost and defective goods. Important in the model is the complexity of the different technologies from Section 2. We model it by the density ratio ρ. The more complex the technology gets, the larger is the density. Our model describes the shipment scenario in a simplified form and within an ideal environment, e.g. the error free functionality of the Smart Items, the supplier only produces one type of good and the parameters and variables are known or can be determined through a simulation or a field trial. In Table 1 the used variables and parameters are defined and explained.

3.1 Analysis from the Supplier's Point of View

First we define a simplified profit function (Equation 1) for a supplier who uses Smart Items (SI) with limited capabilities, e.g. barcode or passive RFID tags.

$$
\begin{aligned}
\prod\nolimits_{perShipment}^{SimpleSI,supplier} &= ((1-\omega)p_{good} - c_{production}) \cdot q_{sales} && \text{turnover} \\
&- \omega \cdot q_{sales} \cdot c_{retour} && \text{costs for processing defective good} \\
&+ \psi \cdot s \cdot q_{sales} && \text{penalty for shipper for loss} \\
&- C_{fix} && \text{fixed costs}
\end{aligned} \qquad (1)
$$

The profit $\prod$ (Equation 1) results from margins between the price of the good p_{good} and the costs of production $c_{production}$ per unit multiplied with the amount of sold units q_{sales} less the defective goods ω which were delivered to the customer. The defective goods which were delivered to the customer need to be manually addressed with costs c_{retour}. The shipper has to pay a fee s depending on the price of the good p_{good} for the ratio ψ of goods lost or not delivered in time. The fee is a compensation for costs of damage, customer dissatisfaction and loss of reputation. Additionally the fixed costs C_{fix} get deducted. The profit $\prod$ is interpreted as a profit per shipment. To model the profit under usage of advanced Smart Items (e.g. wireless sensor nodes) Equation 1 is extended to Equation 2.

Table 1. Variables and parameters for the Smart Items cost model

p_{good}	price charged for good
$c_{production}$	variable costs of production per good
q_{sales}	amount of sold/distributed goods
c_{retour}	cost of manual processing of returned goods (defective or perished)
C_{fix}	fixed costs
$C_{fix,SI}$	additional fixed costs using Smart Items (infrastructure)
$c_{operation}$	variable operational costs per Smart Item and shipment (e.g. recharge battery, programming)
c_{SI}	acquisition costs of Smart Item
s	penalty depending on cost of goods (shipper $\Rightarrow$ supplier)
$p_{transport}$	price of shipping per good (to be paid by the customer)
$c_{transport}$	variable transportation costs per good (for shipper)
$p_{special}$	additional shipping charge for usage of Smart Item per good
$c_{capacity}$	costs of capacity loss for reshipping
c_{GSM}	costs of message sent over GSM to ERP-System
F	fleet size of shipper
W	non quantifiable advantage through usage of Smart Items (consumer satisfaction, etc.)
$\rho \in (0,1]$	factor of density, ratio of Smart Item quantity to quantity of goods
$\nu \in [0,1]$	factor of maintenance: $\nu = 0$ all Smart Items get shipped back (reusable); $\nu = 1$ no Smart Item is returned
$\omega \in [0,1]$	ratio of defective goods delivered to customer
$\phi \in [0,1]$	ratio of triggered Smart Items, $0 \leq \phi \leq \omega \leq 1$
$\psi \in [0,1]$	ratio of searched (potentially lost) goods during shipping
$\kappa \in [0,1]$	ratio of recovered goods (previously lost)

$$
\begin{aligned}
\prod\nolimits_{perShipment}^{Adv.SI,supplier} = {} & ((1-\omega)p_{good} - c_{production} - \rho \cdot (c_{SI} \cdot \nu + c_{operation})) \cdot q_{sales} \\
& - (\omega - \phi) \cdot q_{sales} \cdot c_{retour} && \text{costs for processing defective goods} \\
& + \phi \cdot q_{sales} \cdot s && \text{penalty for shipper for damage} \\
& + (1-\kappa) \cdot \psi \cdot s \cdot q_{sales} && \text{penalty for shipper for loss} \\
& + W && \text{not quantifiable advantage} \\
& - (C_{fix} + C_{fix,SI}) && \text{fixed costs plus SI invest}
\end{aligned} \tag{2}
$$

An important parameter is the density factor ρ which describes the ratio of goods with Smart Items to the amount of goods without. If every good is equipped with a Smart Item, the density factor will be $\rho = 1$. The density factor is proportionally reduced the higher the number of goods per group which are equipped with a Smart Item. E.g. if there is a pallet with 20 boxes containing each 16 TFTs the resulting density factor would be $\rho = \frac{1}{320}$ if there is only one Smart Item per pallet or $\rho = \frac{1}{20}$ for one Smart Item per box. The assumption is, of course, that the goods are equally grouped and the Smart Items are also equally distributed.

The density factor directly influences the profit, as can be seen in Equation 2. Depending on the density of Smart Items, additional costs for operation, acquisition and maintenance arise. If a Smart Item is not reused, its costs will have to be paid for each shipment, which results in a maintenance factor of $\nu = 1$. In the best case of reuse the maintenance factor is $\nu = 0$, i.e. there is no abrasion or loss. Also new in Equation 2 is the parameter ϕ, which indicates the fraction of Smart Items which trigger at least one alert, i.e. at least one detection of violation of the shipment agreements. So the ratio of defective goods due to improper shipment is expressed through ϕ. The supplier does not adhere for the return costs c_{retour} and gets a penalty s per alerted good paid by the shipper. If only a small amount of goods are equipped with a Smart Item, the penalty for the shipper is high since he needs to cover the whole amount of damaged goods. Through the possibility of locating Smart Items, the ratio of shipment loss is reduced by the parameter κ and accordingly the amount of penalty s. The variable W indicates the not quantifiable advantage resulting of the use of Smart Items, e.g. customer satisfaction, positive reputation as a result of fast deliveries, optimization of the shipment process, etc.

The fixed costs C_{fix} include along the original costs the costs for acquisition of the Smart Items and the equipment for programming and reading them.

3.2 Analysis from the Shipper's Point of View

We model the profit function for the usage of low-performance Smart Items, e.g. barcode and passive RFID-Tags, as follows:

$$\begin{aligned}\prod\nolimits_{perShipment}^{SimpleSI,shipper} = {} & ((1-\phi)p_{transport} - c_{transport} && \text{penalty paid to the producer} \\ & - \psi \cdot (s + c_{capacity})) \cdot q_{sales} && \text{for loss and loss of capacity for reshipment} \\ & - C_{fix} && \text{fixed costs}\end{aligned} \tag{3}$$

The profit $\prod$ per shipment results out of the shipment price $p_{transport}$ the customer has to pay, less the shipment costs $c_{transport}$ and the ratio ψ. Again, the ratio ψ indicates the loss of goods during shipment, which gets multiplied with the penalty s. In addition, the shipper has to do a subsequent delivery of the lost goods, which results in a capacity loss of $c_{capacity}$.

If advanced Smart Items are used, the resulting profit function is modeled as follows:

$$\begin{aligned}\prod\nolimits_{perShipment}^{Adv.SI,shipper} = {} & ((1-\phi)(p_{special} + p_{transport}) - c_{transport}) \cdot q_{sales} && \text{turnover} \\ & - c_{GSM} \cdot (\phi + \psi \cdot 2 \cdot F) \cdot q_{sales} && \text{penalty for loss} \\ & - \phi \cdot q_{sales} \cdot s && \text{penalty for damage} \\ & - (1-\kappa) \cdot \psi \cdot (s + c_{capacity}) \cdot q_{sales} && \text{comm. costs} \\ & + W && \text{not quantifiable adv.} \\ & - (C_{fix} + C_{fix,SI}) && \text{fixed costs including SI investment}\end{aligned} \tag{4}$$

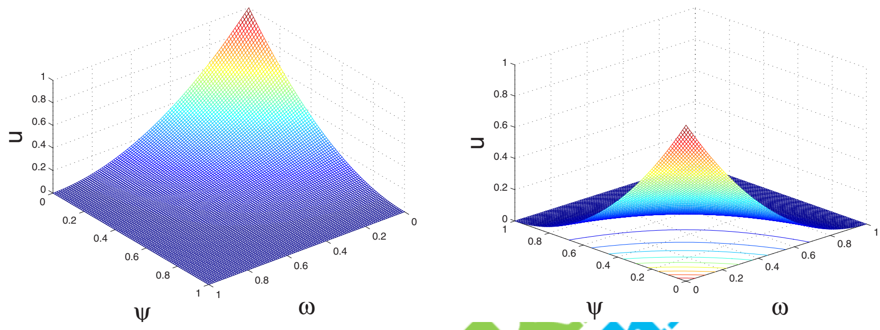

Fig. 4. Gain function $u(\psi, \omega)$ from two perspectives

Because of specialization and higher effort the shipper needs or can demand a higher price $p_{transport} + p_{special}$. The reduction of shipment loss through tracking of lost goods reduces the payments for penalties by a factor of $1-\kappa$. For detected shipment damage ϕ the penalty s needs to be paid to the supplier. Additionally, the costs c_{GSM} arise for transmitting alerts and tracking ψ of goods. Here the worst case costs are denoted, i.e. all alerts arise outside the reach of an access point at the cross dock stations and for tracking the complete fleet needs to be addressed. The fixed costs C_{fix} comprehend the acquisition of the readers, communication infrastructure and the original fixed costs per shipment. The variable W also indicates the not quantifiable advantage, e.g. customer satisfaction.

3.3 Analysis from the Customer's Point of View

The perspective of the customer is modeled as a profit function with two dimensions, quality and completeness of a shipment aggregating the profit level u. Further values influencing the profit level, e.g. speed of delivery, are omitted for reasons of simplicity. For further extension of the profit function several additional factors can easily be included. The highest profit level is reached at the best case, when the delivery is complete and without defective goods reaching the customer. According to the previous modeling this case occurs when $\psi = 0$ and $\omega = 0$. The result is a normalized Cobb-Douglas function [12] (Equation 5) with its saturation defined in point $u(0, 0) = 1$.

$$u(\psi, \omega) = (1 - \psi)^2 \cdot (1 - \omega)^2 \tag{5}$$

The Cobb-Douglas function can be seen from two different perspectives in Figure 4. We assume that the improved amount converges into point $(0, 0)$. Presumably, the assignment of the budget (allocation) utilizing basic Smart Items, e.g. barcode, is (ψ', ω') and the customer pays the price $m' = (p_{good} + p_{transport}) \cdot q_{sales}$. The amount of defective goods ω can be reduced by a ratio ϕ through the use of more complex Smart Items. This relationship is shown in Figure 5. Besides, the shipment loss can be reduced through tracking by

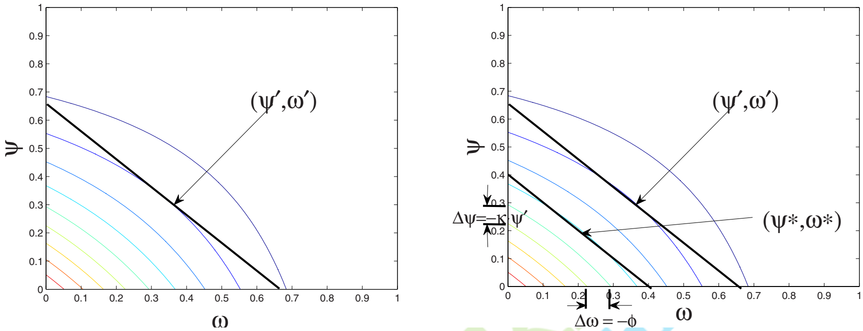

Fig. 5. Indifference curves of $u(\psi, \omega)$

Smart Items in average by $-\kappa \cdot \psi^{'}$, which is also apparent in Figure 5. The allocation is improved from $(\psi^{'}, \omega^{'})$ to (ψ^{*}, ω^{*}). In return, the customer has to pay the increased price $p_{special}$. In sum the costs for the new allocation are $m^{*} = (p_{good} + p_{transport} + p_{special}) \cdot q_{sales}$.

If the gain of profit through improved allocation is bigger than the loss of usefulness through raised prices, then the customer will have a direct advantage of the use of advanced Smart Items. Let $\widetilde{u}$ be the utility function according to the preferences of the customer that maps monetary units onto a scale comparable with u. If the following inequality evaluates to true, the customer considers the use of advanced Smart Items as beneficial compared to a technology like barcode.

$$\widetilde{u}(m^{*} - m^{'}) < u(\psi^{*}, \omega^{*}) - u(\psi^{'}, \omega^{'}) \tag{6}$$

4 Use Case for Our Model

In this section we will present a simple use case to exemplify the usage of our model. A supplier is selling apples to a customer, which are transported by a shipper. The parameters (e.g. costs) from the model are derived from real world data.

One box of apples holds 18 pounds. In July 2007 a box of apples cost an average of $c_{production} = 5.27\$$ [13] and could be sold for an average of $p_{good} = 17.14\$$ [14] in the United States. We will consider one shipment to be $q_{sales} = 400$ boxes of apples, which is the amount a small truck can transport. From all boxes that arrive at the customer, $\omega^{'} = 20\%$ are rotten. The customer does not pay for boxes with rotten apples and further requires the supplier to pay $c_{retour} = 2\$$ for their disposal. Using Equation (1) we can calculate the supplier's profit when using barcodes for each delivery:

$$\prod_{perShipment}^{barcode,supplier} = 5,484.80\$ - 2,108.00\$ - 160\$ - C_{fix} = 3,216.80\$ - C_{fix} \tag{7}$$

Notice that the supplier looses 20% of his income because of rotten apples. It is also not clear at which point they got rotten (during transport or already at the supplier). To cope with this problem, the supplier decides to track the temperature of the apples during delivery using Smart Items. Every fourth box ($\rho = 25\%$) is equipped with an expensive Smart Item which costs $c_{SI} = 50\$$. The Smart Items are reusable ($\nu = 0$), so the supplier only has to buy them once. Maintenance costs for each Smart Item are $c_{operation} = 0.50\$$ per shipment, e.g. for charging batteries and programming.

Now, the shipper can be held responsible if apples get rotten because of wrong shipping and handling conditions. The tracking with Smart Items further allows the shipper to monitor the apples temperature. Therefore we assume the total amount of rotten apples will fall to $\omega^* = 10\%$. Now, only $\phi = 1\%$ of all apples get rotten because of the shipper, so he has to refund the supplier and pay a penalty making a total of $s = 20\$$ to supplier per rotten apple box.

If we consider the fixed costs to stay unchanged ($C_{fix,SI} = 0$), then Equation (2) will show the supplier's profit when using Smart Items as follows:

$$\prod_{perShipment}^{SI,supplier} = 6,170.40\$ - 2,158.00\$ - 72.00\$ + 80.00\$ - C_{fix} = 4,020.40\$ - C_{fix}. \tag{8}$$

The supplier's profit will increase by 803.60$ per shipping. The one time investment of 5,000$ for buying 100 Smart Items amortizes after 7 shipments. Now let us see how the use of Smart Items influences the shipper's business. The shipper charges the customer $p_{transport} = 4\$$ for each box shipped. His costs are $c_{transport} = 2\$$. Through Equation (3) we get the shipper's profit for each delivery with a simple Smart Items technology, such as barcode:

$$\prod_{perShipment}^{barcode,shipper} = 800\$ - C_{fix} \tag{9}$$

When using advanced Smart Items, the supplier will charge $p_{special} = 0.50\$$ extra since he also has to sustain a Smart Items infrastructure. But he will also have to refund the supplier and pay a penalty making a total of $s = 20\$$ for damaged products. The shipper's profit calculated through Equation (4) is

$$\prod_{perShipment}^{SI,shipper} = 900.00\$ - 80.00\$ - C_{fix} = 820 - C_{fix}. \tag{10}$$

The shipper's profit will increase by 20$. Even though he is responsible for the goods he damages during transportation, he will also be earning more money.

Now let us consider how the use of Smart Items influences the customer. We expect him to profit from the smaller amount of rotten apples, even though he will be paying higher transport costs. When using barcodes, we get $m' = (17.14 + 4.00) * 400 = 8,456.00$ and $u(\psi', \omega') = (1 - 0.20)^2 = 0.64$. And the use of Smart Items results in $m^* = (17.14 + 4.50) * 400 = 8,656.00$ and $u(\psi^*, \omega^*) =$

$(1-0.10)^2 = 0.81$. We assume the following model structure for the customer's utility function: $\widetilde{u}(x) = 1 - e^{-kx}$. This utility denotes the normalized value of an additional (financial) effort x for the customer. The scalar k expresses the slope of the value of the additional effort. In this example, an additional financial effort of $m^* - m^{'} = 200\$$ for more powerful Smart Items leads to 10% less rotten apples. This makes the delivery more valuable for the customer. However, this has to be compared with the value of an additional investment of 200$ per shipment. Inserting the above values into Equation (6) and assuming $k = 0.9‰$ results in the following equation

$$\widetilde{u}(m^* - m^{'}) = 0.16 < u(\psi^*, \omega^*) - u(\psi^{'}, \omega^{'}) = 0.81 - 0.64 = 0.17, \tag{11}$$

The right side of the inequality evaluates to 0.17 and denotes how much more the delivery becomes valuable for the customer. This is due to the reduction of the amount of rotten apples. The customer's additional financial effort has a value of 0.16 according to his utility function. The inequality evaluates to true. The delivery becomes more valuable than the additional effort spent by customer. Hence, the use of more powerful Smart Items pays off.

5 Guidelines for Parameter Estimation

One of the cornerstones of our model is the use of simple abstract parameters that estimate certain values within one type of supply chain. This allows us to compare various types of supply chains, e.g. traditional vs. Smart Items supported supply chains. The major problem for doing so is how to obtain these parameters in a practicable way.

We proposed to estimate the parameters using a black-box approach, as we see it difficult to measure detailed values or to uncover complex interplay within a supply chain. This approach is less sophisticated than a full-blown analysis and may be more error prone. On the other hand, the proposed method is faster and can be carried out at lower costs. Furthermore, it can be applied to supply chains where it is impossible to retrieve a detailed understanding, e.g. because not all participants in the supply chain are willing to participate. The model we present here requires only three stakeholders to work together: The supplier, the customer and the shipper. In the simplest form of the model, we consider only one instance of these stakeholders within the process.

Our proposal for the black-box oriented approach is to estimate parameters based on small trial-runs of the technology. Here, the technology is brought into the supply chain for selected items only, and parameters are continuously measured. In a first run, parameters will not be used for improving the process, but used for quantification of the factors ω and ψ. Additionally, from the calculation model of the supply chains other parameters are derived (p_{good}, $c_{production}$, q_{sales}, c_{retour}, s, C_{fix}, $c_{capacity}$). In a second run, Smart Items technology is used to additionally quantify parameters ν, ω, ϕ and ψ. From the cost calculation for the introduction of the Smart Items technology we finally project the total cost of a full-blown application of technology, and their parameter $C_{fix,SI}$, $c_{operation}$, c_{SI}, c_{GSM}, plus additional known and estimated parameters (F, W).

6 Discussion

The derived cost model is mainly linear. This may be considered as an over-simplification. However, an iterative approach for the parameter estimation could compensate this and reflect a close to the real-world model. If one of the parameters changes, we will initiate a re-investigation of the other parameters according to the method described in section 5. If any two or more parameters depend on each other, this re-investigation will figure out a new parameter set. This accounts for the non-linearity in real-world processes. One has to be aware that this approach increases significantly the effort to work with the Smart Items cost model.

Another point of discussion is the usage of the Cobb-Douglas function introduced in section 3.3. This function structure is neither derived, nor does it have its fundament in a larger theory of logistics processes. However, it has attractive mathematical features and introduces a non-linear behavior which is inherent in real-world processes, but on the other side very hard to model. In our opinion, the non-linearity accounts for the effects that some ranges of parameters have less influence on the overall result than others. In our example a decreasing ratio of loss and defective goods will contribute to the overall utility. The utility gets largest, when approaching zero-loss. However, this is quite hard as the non-linear slope of the Cobb-Douglas function illustrates.

Related to Cobb-Douglas is the customer utility $\widetilde{u}$. It is difficult to determine and may involve many parameters which may require a broader study. The selection of the function and its parametrization may partially depend on psychological factors, e.g. previous experiences in a business domain or personal risk assessment. The utility function is very open to an adaptation according to the specific needs of a concrete domain.

Another point of criticism is the simplifications in the model. We assumed an ideal environment, where the supplier only produces one type of good and Smart Items operate error-free. However, experiences from field trials involving Smart Items, e.g. CoBIs [2], revealed a variety of errors. For logistics applications, the most crucial are RF shielding, i.e. the Smart Items cannot communicate to each other anymore, and the power supply of the electronics. Latter adds significantly to the operation costs.

A deeper investigation on the effects of our design decisions is clearly a task for future work.

7 Related Work

The research on RFID and related technologies for supply chains of specific business and market contexts is well established. In many cases the research is driven by applications or scenarios where technological solutions for specific market segments (e.g. grocery stores) are developed or evaluated [15][16][17]. Examples can be found in various areas, e.g. livestock tracking [18], military [19] and evaluations of pilot projects of retailers such as Gillette [20], Tesco, Wal-Mart [21], Metro AG [22], and Smart Packaging of Hewlett-Packard [23]. The main discussions of RFID driven applications is currently appearing in whitepapers of technology consultants or magazines (e.g. RFID Journal, Information Week or Infoworld.com) and are facing the challenges of poor forecasting accuracy, low effectiveness and responsiveness, high inventory, high returns processing cost and the presence of counterfeit products in their value chain [24].

Many researchers concentrate on technical aspects of RFID applications which are emphasized in several engineering and computer science publications outlining the system architecture and circuit design. The replacement of barcodes to automatically tag and inventory goods in real-time situations, including the whole process chain is just seen as the beginning. The real benefits come from high level uses like theft and loss prevention, reduced turnaround times, avoidance of unnecessary handling and streamlined inventories [25][26]. The main focus of many consulting-oriented and management-related publications is the integration of new technology in ERP systems to provide managerial insights. They offer an in-depth technological overview of state-of-the-art developments and outline different aspects of e-business and supply chain management [27][28][29]. From the general technological and integration approaches analytic models have been derived to show the benefits and costs resulting from the usage of the RFID in supply chains. In [30] item-level RFID usage for decentralized supply chains is discussed by means of two scenarios for one manufacturer and retailer. Within these particular scenarios they capture important benefits reflecting real-world cost considerations in a model based on RFID.

8 Conclusion and Outlook

The proposed cost model for supply chain management is a first step towards estimating the benefits of introducing Smart Items into a logistic process. We presented separate cost models for supplier, shipper and customer. This allows for split benefit calculation, which is often required in supply chain management processes where mixed calculation is not possible or not attractive.

The proposed model can be used to maximize profit according to different types of technologies for Smart Items. It also incorporates different granularities of technology applications. We have shown in this paper, that there are three classes of technology to be distinguished: the use of barcode, the use of RFID-tags and the use of (smart) sensor systems and networks. Each of these options require a set of parameters to calculate their costs. To simplify estimation and calculation of these parameters we introduced guidelines to increase practical applicability of our model.

Our ongoing and future research has two directions. Firstly, we try to evaluate the model on further trial runs and collect experiences regarding the applicability of the guidelines and the cost model. Secondly, we seek to identify parameters that can be used for standard settings, and different technology options. This requires to define standard procedures for various types of supply chain applications, and to perform test runs on the same process using various technology options. Although we have experienced, that this will be very restricted to the specific application case, we envision to commence such parameter and data collection based on our approach on a case by case basis.

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Generalized Handling of User-Specific Data in Networked RFID

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Abstract. As RFID technology has been widely adopted, it has been acknowledged that user-specific data carrying RFID tags can be conveniently used. Since the typical user-specific data is sensor data, some existing studies have proposed new RFID architectures for sensor data handling. However, there are industrial demands to include non-sensor data, such as sales records, repair history, etc., as well as sensor data in the purview of our study. To realize handling of such general user-specific data, we need to satisfy requirements such as the minimum set of data semantics required to access the user-specific data, flexible user-specific data memory schema determination and partial collection of user-specific data. For this purpose, we designed the role of "session manager", which communicates with associate applications and notifies an interrogator what to do upon retrieval of a unique identification number. The session manager with the structured user-specific data can provide flexible collection and processing of user-specific data in the networked RFID. Since the fundamental drawback of the session manager might be the lookup overhead, we examined the overhead with a simulation based on experimental data. It was revealed that the overhead is equivalent to and in some cases even better than that of the existing method, which relies on structural tag memory.

Keywords: RFID middleware, Sensor tag, Battery Assisted Passive tag (BAP), User data handling, User data collection performance, Tag memory schema resolving, Data semantic resolving.

1 Introduction

In past years Radio Frequency Identification (RFID) technology has been designed and realized for asset identification in the supply chain. Recently, however, RFID systems have spread to wider applications. As RFID technology has become more widely adopted, it has been acknowledged that user-specific data in tag memory can be conveniently used in conjunction with globally unique identification numbers such as EPC [1].

An example of user-specific data can be found in life-cycle management of consumer electronics. Major consumer electronics makers have been conducting research on and pilot testing how to manage the whole life cycle of consumer electronics using RFID technology. They recommend storing a variety of data such as the manufacturing-specific code, shipping and sales dates, repair history and other information in a consumer item's tag memory [2].

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Another example of user-specific data can be found in the sensor-integrated RFID system, which records environmental information such as temperature, humidity and/or acceleration information, as well as evidence of tampering, into the existing RFID system. Using sensor devices with high-performance RFID tags (sensor tag) would enable manufacturers to realize value-added asset identification. For example, the smart seal is a typical sensor-integrated RFID system [3] for tamper protection. Sensor-enabled cold-chain management is another exemplary usage. A sensor-integrated RFID system can realize not only traceability but management of the proper temperature for the merchandise, which may justify an additional tariff.

It is, thus, expected that a myriad of user-specific data together with unique IDs will be adopted in industrial RFID systems. A networked RFID system which accommodates user-specific data in a general manner, therefore, needs to be established.

The de facto networked RFID standard, EPCglobal network, essentially handles events which comprise tag IDs and their read times [1]. Sensor-integrated RFID networks have been studied in the literature [4][5][6][7][8][9]. The authors' research group compiled a short review on sensor-integrated RFID and related wireless sensor network technologies [10]. International standardization bodies have been working to associate sensor data in networked RFID systems [11][12]. While sensor data can be structured as in a plug-and-play sensor [13], the life-cycle information in consumer electronics, for example, might not always fit this sensor data structure. Since the emerging technology on battery-assisted passive and active tags may house a large logging memory, 4Mbit for example [14], partial collections of tag data need to be accommodated because of the relatively slow air communication speed [15]. Naruse has proposed a network-based tag memory schema resolver for sensor-integrated networked RFID, which only can apply to a fixed memory length [4]. In this paper we propose a network RFID system which provides flexible association with user-specific data in tag memory. The fundamental idea is a combination of structured tag memory and lookup of a registry in a network, which provides memory schema information to interrogators.

The paper is organized as follows. In Section 2, we investigate the architecture requirements to establish a networked RFID system which can handle a variety of user-specific data efficiently. The qualitative benefit of the proposal is also stated. Section 3 examines the registry lookup overhead of the proposed method compared with those of previous works [11][12]. A conclusion is presented in Section 4.

2 The Proposed Networked RFID System Description

In this section we first consider the networked RFID requirements for generalized handling and processing of a user-specific data collection. Secondly, a networked RFID system that meets those requirements is proposed.

2.1 Requirements

General user-specific data can be accommodated

User-specific data may be sensor data or another type of record such as sales and repair history. Different from sensor data, which may be well structured as in [13], the structure of the sales and repair history likely is diverse. All or a part of the data may also need to be encrypted or may need to be human-readable depending on the usage. As such, general user-specific data can be collected with the minimum set of semantics in the data.

Resolving tag memory schema
An interrogator needs to resolve the tag memory schema, which depends on the type of user-specific data, and also the length of the memory block before collection. The procedure for handling user-specific data may not enforce any change in the procedure to inventory ID tags[1].

Resolving data semantic
In an RFID application layer, user-specific data collected from RFID tags need to be incorporated with data semantics, in order to generate more meaningful events in a business context. For example, the raw temperature data "0" will need to be translated into a physical quantity (e.g. 0 degree Celsius or 0 Kelvin) with calibration.

Collection of dynamically changing data
User-specific data can be classified into static and dynamic types. In this paper, "static" user-specific data means that the data length and data types are consistent throughout the operations. "Dynamic" user-specific data, on the other hand, has variable data length. The typical dynamic data is data logging.

Partial collection of user-specific data
The most rudimentary method for collecting user-specific data is to read all the tag data with every interrogator. This may cause significant reading performance degradation particularly when the target tag is equipped with a number of sensors or has a large memory for data logging. There may be a situation in which the owner of the user-specific data demands to control which part of the data can be read depending on the interrogator. Thus, an interrogator needs to be controlled such that only the group of user-specific data which is requested from applications is collected from a tag.

Minimum collection overhead
User-specific data collection needs to be time-wise efficient.

2.2 Proposal Description

The proposed networked RFID system is shown in Figure 1.

The essential entity in the proposal is the session manager, which communicates with the associate applications and notifies the interrogator of the specific memory address and its range for user-specific data collection.

[1] ID tags denote RF tags which do not have user-specific data or handling capability in this paper.

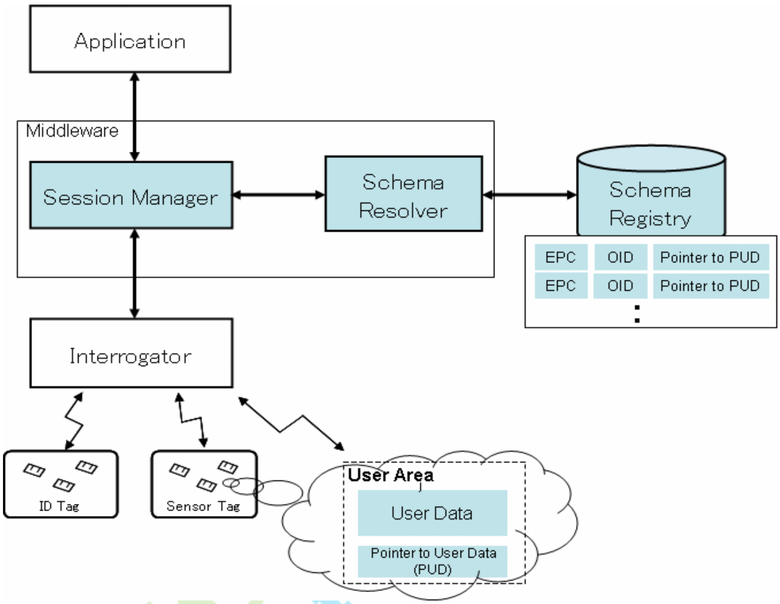

Fig. 1. Principal entities of the proposal

The typical procedure to collect user-specific data is shown in Figure 2.

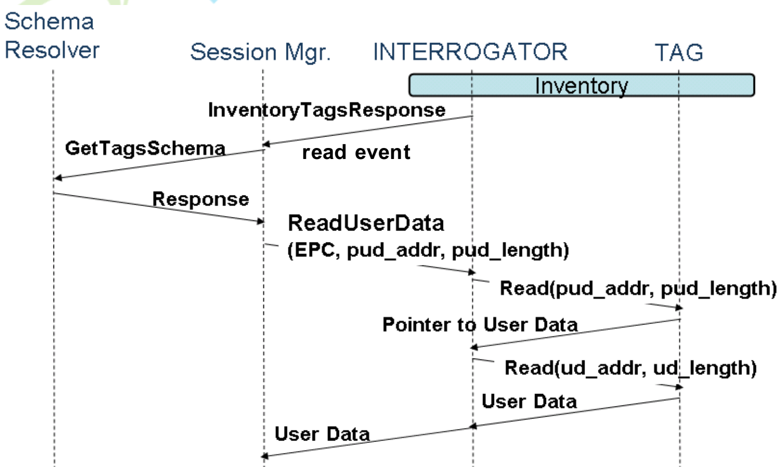

Fig. 2. User-specific data collection

The interrogator collects the user-specific data in the following procedure.

1) The interrogator collects globally unique IDs such as EPC in Tag (UII) by tag inventory.
2) Upon receipt of the unique ID, the interrogator generates a read event to place an inquiry for further action to the associate session manager.

3) The session manager examines the unique ID in the read event and looks up the tag memory schema, which contains OID (Object ID) and Pointer to PUD (Pointer to User Data), via the schema resolver.
4) The interrogator may collect a part of the tag memory (PUD) to determine the memory range to be collected.
5) The interrogator collects the body of user-specific data and delivers it to associate applications through the session manager.

For the purpose of comparison, the user-specific data collection in [11][12] can be summarized as follows.

1) The interrogator collects a globally unique ID in Tag (UII) by tag inventory and identifies the sensor data capability either by user memory indicator (UMI) or XPC (extended PC bit) or XI (extended PC bit indicator).
2) The interrogator accesses a particular bit of area in the Tag (TID) and collects meta-data named PSAM (pointer to Sensor Address Map) by the next tag inventory.
3) Upon receipt of the PSAM, the interrogator collects the NoS (Number of Sensors), which indicates how many sensor devices are attached.
4) The interrogator collects the SAM-Entries (User) that contain sensor record addresses.
5) From NoS and SAM-Entries[2] information, the interrogator collects an SID (Sensor Identifier) (User) and then judges which sensor record needs to be acquired by an associated application.
6) The interrogator collects the body of user-specific data (User) and delivers it to the application.

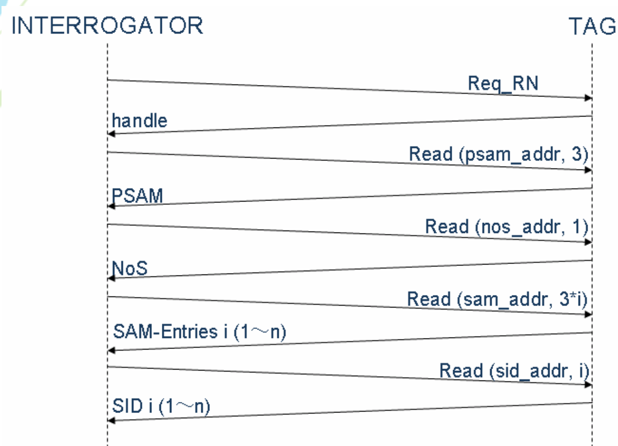

Fig. 3. Transaction for resolving memory schema on tag (fixed pattern)

Figure 4 shows the tag memory map example in [12].

[2] A SAM-Entry and SID are prepared in each sensor device. If a sensor tag contains two sensor devices, it has two SAM-Entries and SIDs in its memory.

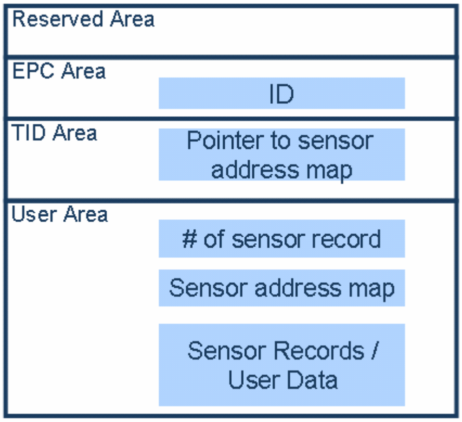

Fig. 4. RFID tag memory map example in ISO 24753

It should be stated that, in the existing method shown in Figure 3, the interrogator needs to collect all the data from the tag unless the interrogator has knowledge of which sensor data needs to be collected. Similarly, in a write operation without an inquiry to the session manager, the interrogator can only write the predefined pattern of data to the tag, or cannot determine whether it is requested to write a datum or collect a datum. In this regard, the proposed method (Figure 2) and the existing method (Figure 3) can be complementary. If we have a network connection, the interrogator may place an inquiry depending on the UIM or XPC to a session manager to find any updated request for user-specific data collection and writing. If there is no updated instruction, the interrogator collects or writes in the predefined pattern, which may be to collect all the data or no data.

A qualitative comparison between the proposed and the existing methods is shown in Table 1.

Table 1. Comparison table with related studies and our proposed model

item	ISO Working Draft	Proposed Model
General user-specific data can be accommodated	Sensor data centric	Combination of registry and structured address map on tag
Resolving tag memory schema	Sensor address map on tag	Combination of registry and structured address map on tag
Resolving data semantic	Canonical spec. sheet data in tag	Combination of registry and structured address map on tag
Collection of dynamically changing data	Sensor address map involves range	Combination of registry and structured address map on tag
Partial collection of user-specific data	Not in the charter	Combination of registry and structured address map on tag

3 Registry Lookup Overhead Estimation

Since the proposed method is a combination of a structured memory map in the tag and the network session manager, it is important to quantitatively evaluate the turn-around time for placing an inquiry to the session manager, which is referred to as the registry lookup overhead in this paper. We have already measured the registry lookup time in [2] in accordance with the number of user-specific data. In that experiment, a data base server which is operating the schema registry is set up in the same network segment as the session manager. But we don't have a reference turnaround time to compare with since we don't have an interrogator that can be instructed to collect user-specific data in accordance with the procedure in Figure 3. For this, we measured the actual user-specific data collection time using a commercial interrogator and a tag assuming we have already resolved the memory schema before data collection. The turnaround time involving both the processing and transmission time between the interrogator and the tag was analyzed in detail and computationally re-assembled to estimate the collection time using the procedure in Figure 3. It should be noted that the collection of a body of user-specific data was out of the scope for this evaluation since it is irrelevant how the memory map is resolved.

3.1 Experiment Setup Description

The experimental setup to measure the turnaround time is shown in Figure 5. A commercial interrogator (R/W) is connected to a battery-assisted passive (BAP) tag [14] by a cable, and user-specific data is collected using an ISO/IEC 18000-6 Type C [15] command. The turnaround time was measured by monitoring the demodulated signal and the backscattering signal at the tag using an oscilloscope (OSC). Figure 6 shows a screen shot of the signals in the oscilloscope when user data (30 words) are retrieved using a commercial interrogator. The configuration of the communication between the interrogator and the tag is summarized in Table 2.

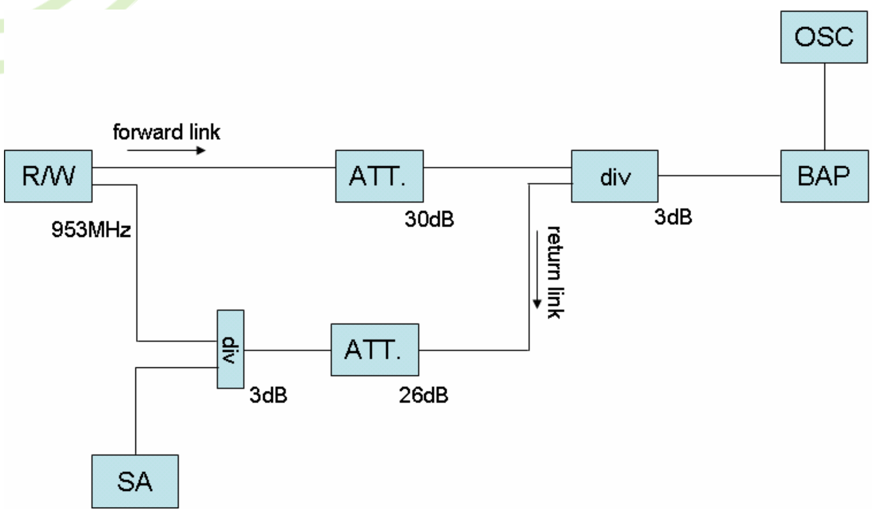

Fig. 5. Experimental setup

Table 2. Experimental configuration

Item	value
Air protocol	ISO18000-6 Type C
communication speed	Forward link: 40kbps Return link: 40kbps
Frequency	953MHz
Band width	200KHz
R/W output PWR	30dBm

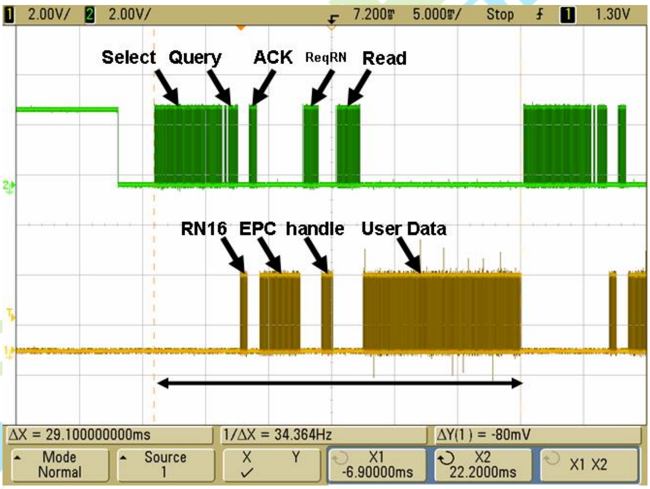

Fig. 6. Screenshot of Oscilloscope

3.2 Estimation Result

With the above experiment environment, we estimated the turnaround time for the protocol shown in Figure 7. The numbers of SAM-Entries and SIDs depend on the number of sensor devices installed in a tag. If a certain tag contains numerous sensor

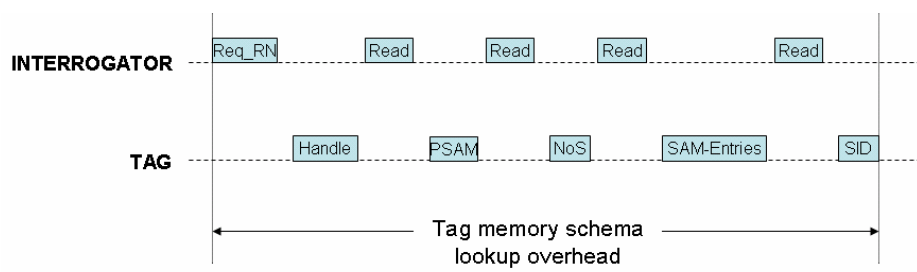

Fig. 7. Air protocol sequence

devices, the length of the data that should be read by the interrogator becomes longer. The data length of one SAM-Entry and one SID are 3 words and 1 word, respectively, for a total of 4 words (1 word = 16 bits).

Figure 8 shows the result of tag memory schema lookup overhead in the two methods. The legends “proposed” and “existing” in Figure 8 represent the procedures in Figure 2 and Figure 3, respectively. The horizontal axis denotes the number of sensor devices installed on one tag and the vertical axis is the time (msec) required to collect that amount of user-specific data. The lookup overhead of the proposal was found to be around several 10 msec, which is almost equivalent to that of the existing method and even shorter when the number of sensor devices installed on a tag is increased. This is because we set up the registry to be network-wise close to the interrogator and the communication protocol is relatively slow, resulting in longer time for plural sensor data collection.

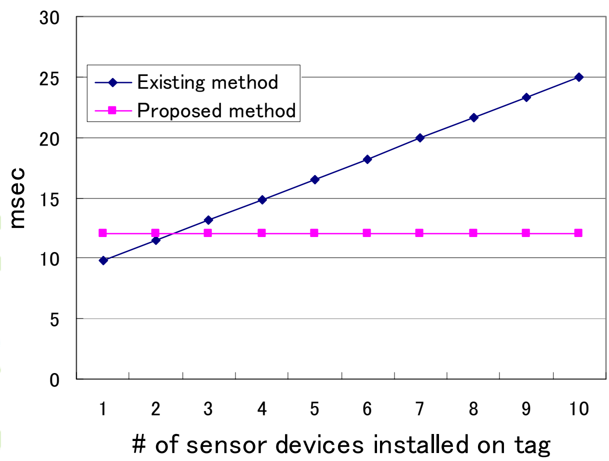

Fig. 8. Tag memory schema look up overhead

4 Conclusion

As the industrial adoption of networked RFID expands, the importance of user-specific data has been widely acknowledged. Typical user-specific data is sensor data, which can be well structured. When we consider also handling non-sensor user-specific data, such as sales records and repair history, a generic method for handling user-specific data is needed. The requirements for general handling of user-specific data in the networked RFID are the identification of a memory schema for user-specific data, accommodation of dynamically changing data length and partial collection of the user-specific data. These requirements can be satisfied when we implement the role of “session manager”, which essentially instructs the interrogator what to do upon retrieval of a unique identification number. The session manager may instruct the tag to retrieve user-specific data in the specified memory range or may instruct a write operation. In order to accomplish such tasks, the session manager needs to connect with associate applications and the tag memory schema resolver to determine the instruction. The session manager role can be complementary to that of structured tag memory, in which all the information required to collect user-specific data is stored in tag memory, tailored to sensor data. Despite the qualitative advantage of having a session manager, the mandated registry lookup by the session manager may degrade the reading performance. Our simulation revealed, however, that the registry lookup is equivalent to or even faster than that of structured tag memory because the interaction between tag and interrogator in the latter is relatively slow and a number of data needs to be exchanged to determine the range of tag memory to be collected.

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A Passive UHF RFID System with Huffman Sequence Spreading Backscatter Signals

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Abstract. At present passive RFID standards, the tag collision problems are solved using time division multiple access technologies, including slotted ALOHA schemes and binary-tree search schemes. In order to accelerate an inventory process, a multiple access scheme that can identify more than one tag simultaneously is necessary. Considering the characteristics of a passive UHF RFID system, a novel passive tag backscatter scheme using Huffman spreading sequences is proposed, which can effectively improve an inventory process. The performances of several studied multiple access schemes are compared. Simulation results validate the performance enhancement of the proposed system.

Keywords: passive RFID, multiple access, Huffman sequences.

1 Introduction

At present passive RFID standards, the tag collision problems are solved using time division multiple access (TDMA) technologies, including slotted ALOHA schemes and binary-tree search schemes [1, 2]. Because only a single tag can be identified at one time slot, the throughput of an inventory process is hence limited. In order to accelerate the inventory process, several multiple access schemes that can identify more than one tag simultaneously have been proposed [3, 4].

In [3], similar to other code division multiple access (CDMA) systems, the proposed scheme utilizes a set of 256-bit length gold sequences to spread the tag backscatter signals, so that the RFID reader can successfully separate the signal of each individual tag. However, due to the non-zero cross-correlation of each spreading sequence, the performance of this method deteriorates when there exists power inequality amount the tag backscatter signals. In general, a passive tag merely returns its response by backscattering the incident continuous wave (CW), which is emitted from a reader. The strength of a received tag backscatter signal is determined by a variety of factors, including the power of the incident CW, the radar cross section (RCS) of the tag, the polarization of the tag antenna, the propagation loss in the tag-to-reader link, and so on. In order to mitigate the near-far problem, a sophisticated power control scheme is required. Unfortunately, the implementation of power control mechanism on each individual tag is impractical due to the limitations of the tag power and cost. Moreover, because a tag singulation must be accomplished within

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1 ms, the protocol complexity is strictly constrained. Another approach is given in [4], which utilizes the orthogonality of sinusoidal functions to singulate individual tag by estimating their signal phases. The paper however does not disclose how the phases of backscatter signal can be estimated. Consequently, it is difficult to evaluate the feasibility of the method.

In this paper, a novel passive tag backscatter scheme using Huffman spreading sequences is proposed. The Huffman sequences are more near-far resistant and can preserve code orthogonality without precise synchronization of received signals. Consequently, it is more suitable for a passive UHF RFID system. Simulation results demonstrate that the proposed scheme can effectively speed up an inventory process than other methods do.

The reminder of this paper is organized as follows: Section 2 briefs the tag-to-reader (T-R) communication, which brings challenges of multiple access technologies in present passive RFID systems; Section 3 introduces Huffman spreading sequences used in this work; Section 4 presents the simulation results; Section 5 draws conclusions. Finally, some measurement results of link timing are presented in Appendix.

2 The Tag-to-Reader Communication of a Passive UHF RFID System

In general, for example in an EPC Gen2 system, a reader broadcasts a reader-to-tag (R-T) command, and listens for individual tag response thereafter. In order to initialize an inventory process, the reader sends a QUERY R-T command with tag clock instruction to all tags within its coverage. After receiving the QUERY command, each tag should reply its modulated backscatter signal (MBS) in its corresponding time slot. The tag-to-reader communication is asynchronous and the powers of received MBS of different tags are usually unequal as explained below.

2.1 Asynchronous T-R Communication

According to the link timing specification [2], the tag backscatter signal should begin after T_1 seconds starting from the last rising edge of R-T command as shown in Fig. 1. In [2] the parameter T_1, as shown in Table 1, is defined in the link timing parameter table with typical value as

$$T_1 = MAX\left(RTcal,\ 10T_{pri}\right), \tag{1}$$

where $RTcal$ denotes reader-to-tag calibration symbol, and T_{pri} denotes link pulse-repetition interval. Some examples of the parameter T_1 with divide ratio (DR) as 8 are given in Table 2. When multiple tags reply the same received R-T command in the same time slot (that is, a tag collision occurs), they may not be synchronized due to the deviation of T_1 parameter in each tag. Moreover, since the variation of T_1 can be nearly a tag backscatter symbol long, the orthogonality of the spread backscatter signals may be impaired if the spreading sequences require precise synchronization to maintain their mutual orthogonality. The Walsh codes, for instance, may hence be unsuitable to such a system.

Experimental measurements of three different type Gen2 tags, presented in Appendix, validate that the T_1 parameter of these tags are indeed different.

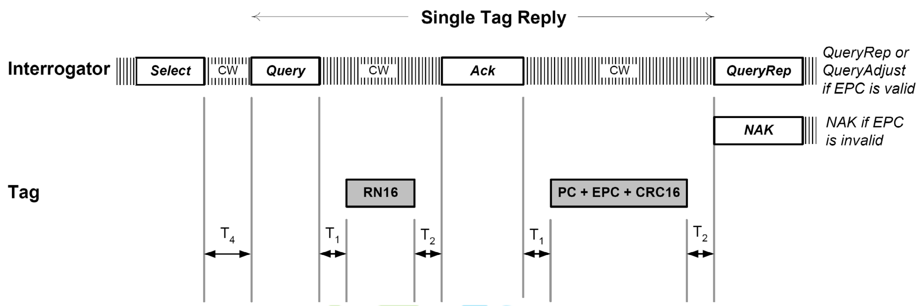

Fig. 1. The tag response time [2]

Table 1. T_1 link timing

Parameter	Minimum	Typical	Maximum
T_1	MAX(RTcal,10T_{pri}) × (1-FT)-2μs	MAX(RTcal,10T_{pri})	MAX(RTcal,10 T_{pri}) × (1-FT)+2μs

Table 2. Some examples of T_1 link timing

DR(Divide Ratio)=8				
LF(Link Frequency, KHz)	Minimum(μs)	Typical(μs)	Maximum(μs)	Max.-Min.(μs)
40	238	250	262	24
160	56.125	62.5	68.88	12.75
320	26.13	31.25	36.38	10.25

2.2 Unequal Received MBS Power

In a free space propagation model without consideration of reader antenna pattern (assuming unit gain, omni-directional), there are two main factors that can affect the strength of received MBS: one is the distance d between the reader and the tag, and the other is the tag antenna gain G_{tag}. According to the well-known Friis free space equation, the received MBS power can be written as

$$P_r(d) = \frac{P_{Back} G_{tag} \lambda^2}{(4\pi)^2 d^2 L}, \tag{2}$$

where P_{Back} denotes the power of tag MBS, λ is the wavelength of the reader operation frequency, and L is the system loss factor not related to propagation. Because P_{Back} is proportional to G_{tag} and reverse proportional to the squares of d, we can rewrite (2) as

$$P_r(d) \propto \frac{G_{tag}^2}{d^4}, \tag{3}$$

where $\propto$ denotes proportional relationship.

There are a variety of tag antennas, in which the half-wavelength dipole antenna is most extensively used. The normalized antenna power gain of a half-wavelength dipole antenna is sensitive to the angle of arrival (AOA) as presented in (4).

$$G_{tag}(\theta) = \frac{\cos^2\left[\dfrac{\pi\cos\theta}{2}\right]}{\sin^2\theta}, \tag{4}$$

where θ denotes the AOA of an incident wave with $\theta = 0$ as the direction of antenna boresight. Therefore, the powers of MBS signals from any two tags can be very different because of the different AOA of impinging CW from the reader; even they are equally separated away from the reader.

Consequently, we can conclude that the received MBS power from each tag is often unequal. This phenomenon results in the inevitable near-far problem in a commonly used direct sequence spread spectrum system. Therefore, the Gold sequences, for example, may not be suitable for the system because they are not sensitive to the near-far effect.

3 Huffman Sequence Backscatter Signals

Unlike a cellular phone, a passive tag is designed as a low cost simple device, whose operation must rely on external limited power source. The tag is incapable to perform a sophisticate power control mechanism as a cellular phone does. Hence, commonly used spreading sequences with low cross-correlation, such as gold sequences used in [3], are not suitable for a passive RFID system due to the severe near-far effect.

On the other hand, the orthogonal spreading sequences like Walsh codes can resist the near-far effect. However, the orthogonal spreading sequences require synchronization to preserve their mutual orthogonality. Unfortunately, multiple tags hardly backscatter their responses simultaneously as described in section 2.1.

In order to apply CDMA technology to the passive UHF RFID system, orthogonal spreading sequences without precise synchronization are hence desired.

Huffman [5] has defined a $N+1$ chip long complex (or real) sequence, whose autocorrelation value is zero for all shift except no shift or N chip shift.

A Huffman sequence $\begin{pmatrix} c_0 & c_1 & \cdots & c_N \end{pmatrix}$ can be represent as

$$\mathbf{c}_0 = \begin{pmatrix} c_0 & c_1 & \cdots & c_N \end{pmatrix}^T, \tag{5}$$

and the i-th shift sequence can be written as

$$\mathbf{c}_i = \begin{pmatrix} c_i & c_{i+1} & \cdots & c_N & c_0 & \cdots & c_{i-1} \end{pmatrix}^T. \tag{6}$$

Equation (6) can be obtained from (5) using

$$\mathbf{c}_i = P^i \mathbf{c}_0, \tag{7}$$

where P is a N+1 by N+1 permutation matrix as

$$\underset{N+1\times N+1}{P} = \begin{bmatrix} 0 & 1 & 0 & \cdots & 0 \\ 0 & 0 & 1 & 0 & \cdots \\ \vdots & \ddots & \ddots & \ddots & \vdots \\ 0 & \cdots & 0 & 0 & 1 \\ 1 & 0 & 0 & \cdots & 0 \end{bmatrix}. \tag{8}$$

The normalized autocorrelation function ρ of a Huffman sequence is presented as

$$\rho_{ij} = \mathbf{c}_i^H \mathbf{c}_j = \begin{cases} 1, & i = j \\ \varepsilon, & i-j = N \\ \varepsilon^*, & i-j = -N \\ 0, & otherwise \end{cases}, \tag{9}$$

where ε^* denotes the complex conjugate of ε, and the magnitude $|\varepsilon|$ can be smaller than $1/(N+1)$.

Recently, a method to generate a real Huffman sequence (also known as a shift-orthogonal sequence) has been proposed [6] and [7]. In this work, a real Huffman sequence, shown in Table 3, is used in our simulation to verify the performance of our proposed scheme.

An MBS can be generated by varying the tag reflection coefficient Γ [8] and [9]. In order to produce a Huffman sequence spreading MBS, both magnitude and phase of the time-variant tag reflection coefficient $\Gamma(t)$ in (10) need to be changed according to the Huffman sequence.

$$\Gamma(t) = \frac{Z_L(t) - Z_A^*}{Z_L(t) + Z_A}, \tag{10}$$

where $Z_L(t)$ denotes the time-variant tag load impedance, Z_A denotes tag antenna impedance, and Z_A^* denotes complex conjugate of Z_A. Note that, a normalized Huffman sequence is used because the magnitude of $\Gamma(t)$ is always less or equal to 1.

Rearranging (10), we have the tag load impedance $Z_L(t)$ at time t as

$$Z_L(t) = \left(\frac{\Gamma(t) Z_A + Z_A^*}{1 - \Gamma(t)} \right). \tag{11}$$

Therefore when the reflection coefficient $\Gamma(t)$, which is equal to the Huffman sequence at time t, is given, the corresponding tag load impedance $Z_L(t)$ can be obtained.

The last digit of 16-bit random number (RN16) [2] in each tag is used to determine its associated Huffman spreading sequence. In this work (N=8), if the last digit of a tag RN16 is 0, the tag uses $\mathbf{c}_0$ to spread its FM0 encoding backscatter signals; otherwise, it uses $\mathbf{c}_5$ to spread its FM0 symbol. Note that, $\mathbf{c}_0$ and $\mathbf{c}_5$ are orthogonal. There is only one Huffman sequence is used, the reader design is hence simpler than other CDMA system because it only use different shift of the same code to separate the received signals.

When two tags reply in the same time slot, a tag collision occurs at present passive RFID system. Depending on the power difference of the two received MBSs, a reader of present RFID system may identify one or none of the tags. However, using Huffman sequence spreading scheme, the reader can have 50% probability to simultaneously identify both tags successfully when their spreading sequences are different. If both tags have the same last RN16 digit, the reader can still indentify both tags if the link timing parameter T_1 of the two tags separate more than 1 chip of the Huffman spreading sequence (providing that both MBSs are still orthogonal).

Table 3. A 9-chip normalized real Huffman sequence used in this work

C_0	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
0.4577	0.5763	0.1160	-0.2660	0.0633	0.2120	-0.3640	0.3440	-0.2733

4 Simulation Results

4.1 Simulation Setting

In this work, a 9-chip (M=9) Huffman spreading sequence is used as depicted in Table 3, and the corresponding waveforms of MBS are illustrated in Fig. 2. In the simulations, we assume that all tags are uniformly distributed within a sphere with radius 2.64 meter. An omni-directional reader with $P_{EIRP} = 1watt$ is located in the center of the sphere. The antenna of each tag is assumed as a half-wavelength dipole antenna. The orientation of each tag is arbitrary, which means that AOA of the incident CW (both azimuthal angle and elevation angle) from the reader are uniformly distributed from 0 to π ; Fig. 3 presents the sketch of simulation environment.

In order to simulate more realistic scenario, the tags are assumed EPCgloble Gen2 compatible [2]; link frequency (LF) of 40KHz and A Type A Reference Interval (Tari) of $25\mu s$ are assumed. The duration of a FM0 symbol in the given condition is also $25\mu s$. The parameter T_1, according to the specification [2], can vary from $238\mu s$ to $262\mu s$ with typical value as $250\mu s$. It is noteworthy that the deviation of T_1 can be as large as $24\mu s$, which is nearly a FM0 symbol duration. The T_1 of each tag is assumed Gaussian distributed with mean of the typical value of T_1, and less than 0.1% probability that the T_1 falls out of the valid duration.

The simulation block diagram is presented in Fig. 4. In the simulation channel we consider free space propagation only. The power of additive white Gaussian noise (AWGN) is normalized by the power of maximum MBS signal from a tag separated 2 meter away from the reader.

In the simulation, an 8-chip normalized Gold code spreading MBS and an 8-chip normalized Walsh code spreading MBS are compared with the proposed scheme. The normalized spreading sequences are listed in Table 4.

In order to optimize the performance of the system throughput, a modified slotted Aloha algorithm is used with the mean number of tags in a time slot as 2. The details of the cross-layer design, however, are beyond the scope of this paper.

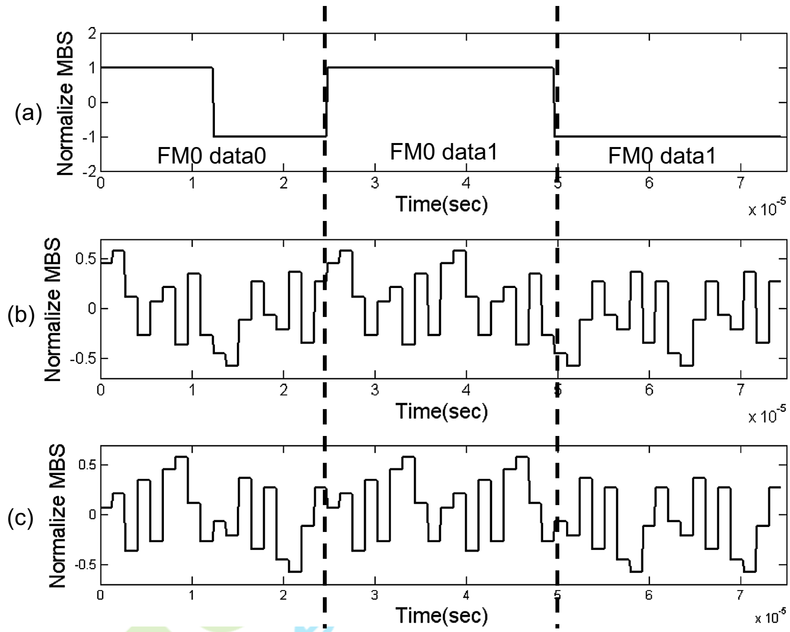

Fig. 2. (a) FM0 backscattering signal. (b) Huffman sequence spreading waveform using $\mathbf{c}_0$. (c) Huffman sequence spreading waveform using $\mathbf{c}_5$.

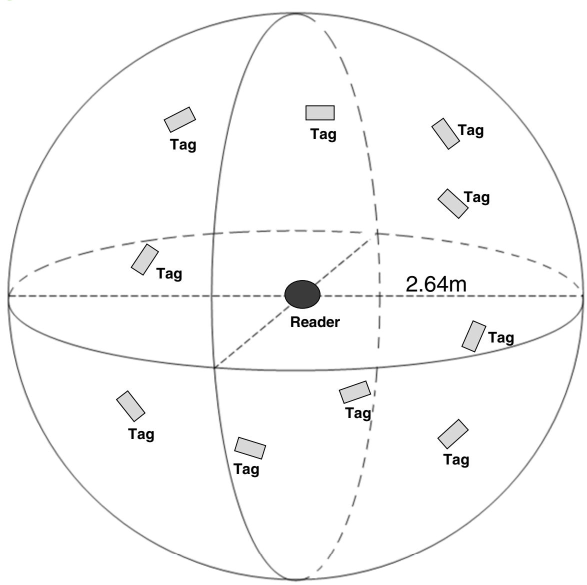

Fig. 3. The sketch of simulation environment

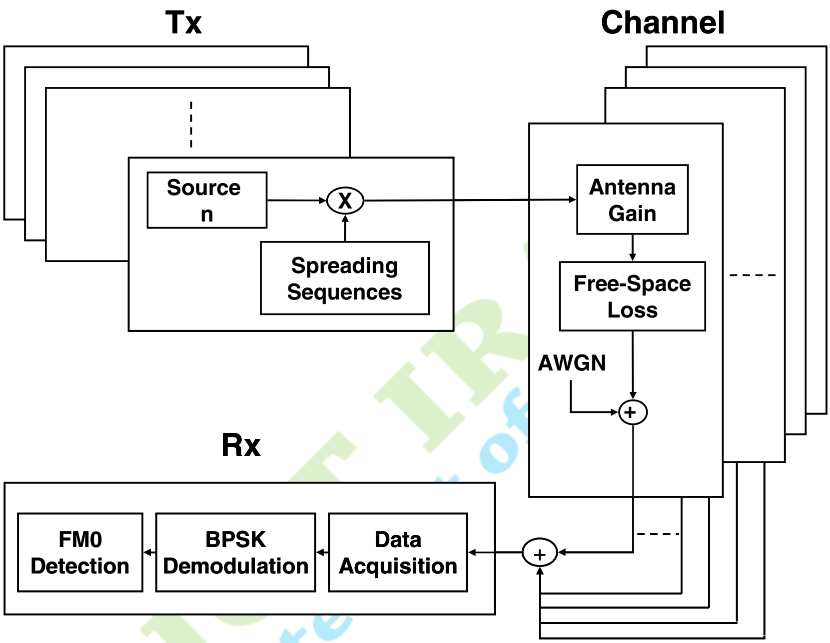

Fig. 4. The simulation system

Table 4. The spreading sequences used in the simulation

	Last bit of RN16	C_0	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
Gold sequences	0	1/8	-1/8	1/8	-1/8	1/8	-1/8	1/8	-1/8	NA
	1	-1/8	1/8	1/8	1/8	1/8	-1/8	-1/8	1/8	NA
Walsh Sequences	0	1/8	-1/8	1/8	-1/8	1/8	-1/8	1/8	-1/8	NA
	1	1/8	1/8	-1/8	-1/8	1/8	1/8	-1/8	-1/8	NA
Huffman sequence	0	0.4577	0.5763	0.1160	-0.2660	0.0633	0.2120	-0.3640	0.3440	-0.2733
	1	0.2120	-0.3640	0.3440	-0.2733	0.4577	0.5763	0.1160	-0.2660	0.0633

4.2 Simulation Results

The throughput of the system is defined as

$$Throughput = \frac{number\ of\ total\ tags}{number\ of\ used\ slots\ in\ an\ inventory\ process}. \quad (12)$$

The performance comparisons for different numbers of tags are listed in Fig. 5 to Fig. 7. Apparently, the proposed scheme outperforms other multiple access methods, especially in high SNR conditions. Walsh code spreading method is the second best choice. All results demonstrates that using TDMA technology only, such as EPC Gen2 slotted Aloha algorithm, results in poor performance in an inventory process.

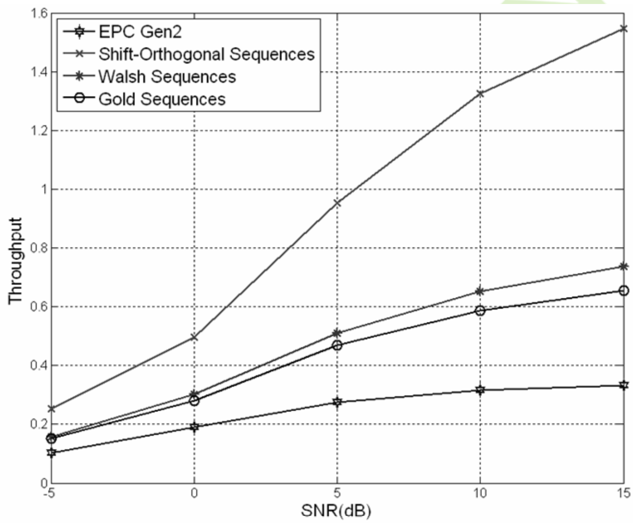

Fig. 5. An inventory of 500 tags. Note that the Shift-Orthogonal sequence denotes the proposed scheme.

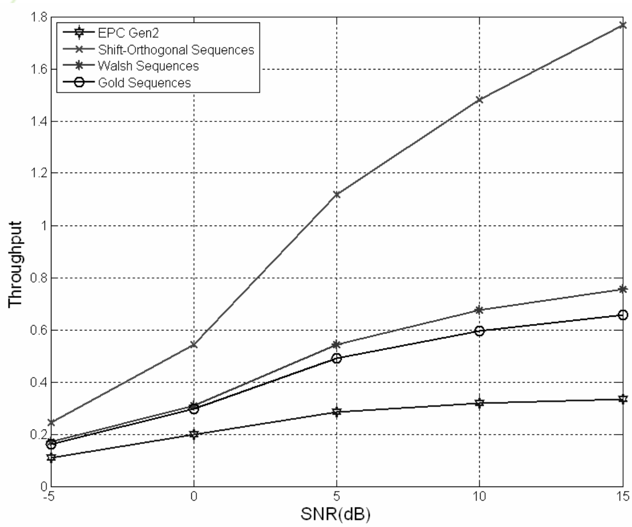

Fig. 6. An inventory of 1000 tags. Note that the Shift-Orthogonal sequence denotes the proposed scheme.

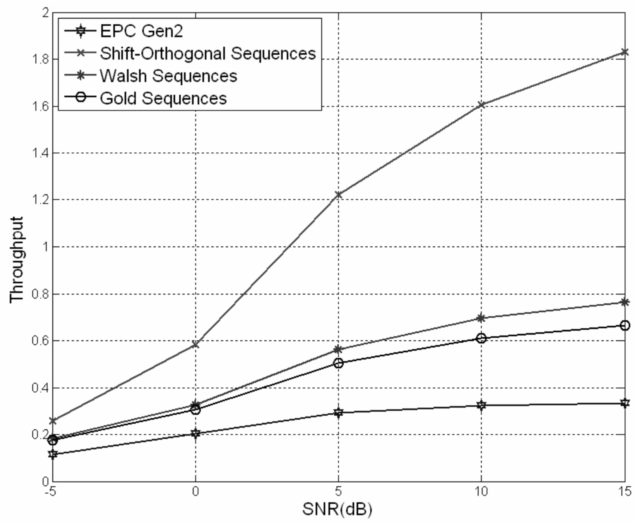

Fig. 7. An inventory of 2000 tags. Note that the Shift-Orthogonal sequence denotes the proposed scheme.

5 Conclusions

A novel passive tag backscatter scheme using Huffman spreading sequences is proposed, which can effectively improve an inventory process. The performance of several studied multiple access schemes are compared. Simulation results validate the performance enhancement of our proposed system. However the system may require a reader with high sensitivity, so that the levels of backscatter signals can be detected correctly. In addition, to implement such a system, further studies of cross-layer technologies combining TDMA (Mac layer) and CDMA (Physical layer) technologies are necessary.

Acknowledgments. This study is partially supported by the National Science Council of Taiwan under grant no. NSC 96-2221-E-011-017.

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Appendix

Some experimental results of T_1 link timing parameter of different tags are presented in this section. Table A presents the statistical results and Fig. A illustrates how the measurement is performed.

Table A. Experimental T_1 measurements using three different type Gen2 tags

Tag	Average T_1 (μs)
Alien GEN2 SQUIGGLE	244.53
Alien GEN2 OMNI-SQUIGGLE	246.09
TI Gen2	248.04

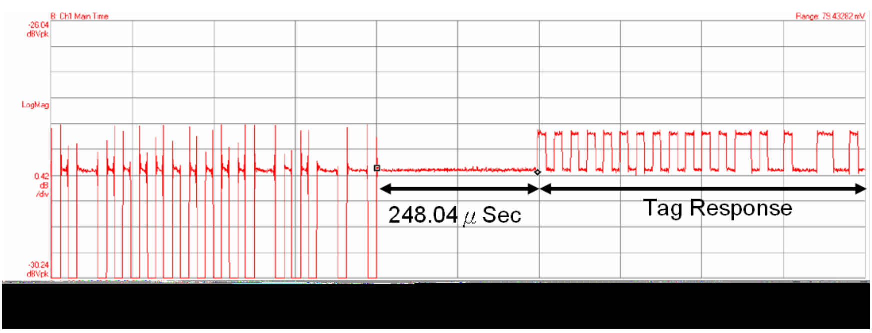

Fig. A. A snapshot of T_1 measurement of a TI Gen2 tag try to open visitors' bags in hope of a free lunch. The park therefore introduced the "Monkey bag", a green bag with an extra clip lock which monkeys cannot open. The bag is obligatory, which is enforced by the receptionists providing the bag at the entrance of the park […] Aside from this security reason for implementing the bag, the department of marketing added a marketing feature to the bag: scanning visitors movements through the park through an active RFID sewn into the bag […] The Monkey Bag RFID has a marketing function: how do visitors move through the park and how can the flow of people be optimized. […]"[8]

"Bag Paradigm". Clearly the "Bag Scenario" complies with traditional information privacy law because no personally identifiable information is involved. "The visitors remain unanimous, are not traced real time and do not suffer any consequences as a result of the data they provide."[9] Moreover, it is evident that such tracing should not be legally prohibited. Nevertheless future RFID law should incorporate a principle of transparency for non-personally identifiable information retrieved by RFID (the "Bag Paradigm" developed here). Consequently the marketing department of the zoo would be forced to inform the visitors about the active RFID. Nevertheless, it is then a matter of consumer choice whether they visit the zoo and a matter of provider choice whether the marketing department also offers bags without RFID. The "Bag Paradigm" poses the question whether "law for one technology" (LOT) – the RFID Law – is needed. In 2007 Germany's Green Party [8] as well as the German Parliament – the Bundestag – asked the German government to check if such a LOT [9][10][11][10] is necessary:

„[…] In particular it has to be granted that the concerned persons are comprehensively informed about the usage, the reason for usage and the content of the RFID tag. It has to be possible to deactivate the tags used on the sale level or to delete the contained data when they are not needed anymore. Furthermore it has to be granted that data contained in RFID tags of different products are only processed in a way that prevents the profiling of secret behavior, usage or movement. The federal government is asked to report to the German parliament about a need for legislative action."[13] [11]

1.3 Law Versus Market

Self-Regulation, Self-Control and Self-Protection in the European Community. Law is the product of legislature, judiciary and administration. In 2007, RFID poses questions to the legislature and not yet to courts or agencies. The law model (legislation) is the opposite of the market model, in which providers choose self-control or self-regulation through Fair Information Practices (FIPs) [15] and customers choose self-protection through Privacy Enhancing Technologies (PETs) [6][15]. A well known [16] example for the market model is the Electronic Product

[8] See [7] p. 21 f.
[9] See [5] p. 16.
[10] Some opinions on RFID and Privacy Law see [12].
[11] See [14] p. 24 favoring ten different RFID fair information practices and self-regulation and privacy enhancing technologies.

Code (EPC) Guidelines by EPCglobal – “a subscriber-driven organization comprised of industry leaders and organizations focused on creating global standards for the EPCglobal Network [17]”. The concept of the EPC-Guidelines is based on components like “Consumer Notice,” “Consumer Education” and “Retention and IT-Security-Policy.”[18] Infringements on the EPC-Guidelines only lead to a discussion of the infringement on an electronic platform. Neither penalties nor the expulsion of the infringer from the network is warranted. Therefore the EPC-Guidelines must be qualified as self-control and not as self-regulation. The EPC-Guidelines are highlighted because they can potentially provide an answer to the Bag Paradigm. Even industry spokespersons interested in global RFID marketing have understood that the customer has to be informed about the existence (“consumer notice” through special labels on tagged products) and the functionality of RFID (“consumer education”). According to the EPC-Guidelines, even RFIDs that do not contain any personally identifiable information have to be “discardable.” With EPCglobal’s self-control strategy, the “Bag Paradigm” could be answered as follows: Those individuals who are interested in a zoo visit have to be informed. Additionally the tags in the provided bags have to be discardable or the customers have to be offered an untagged bag. Still, EPC-Guidelines are an instrument of self-control, a strategy of the so called business ethics[12].

From the legal perspective of this essay, the EPC-Guidelines’ lack of an enforcement strategy has to be seen as a disadvantage. Naturally it is the creed of a jurisprudent: only law that can be enforced by jurisdiction and administration creates certainty for users of RFID and for persons being confronted with RFID (wearable and implanted RFIDs). Consequently the Commission of the European Communities communicated in March, 2007:

> “It is clear that the application of RFID must be socially and politically acceptable, ethically admissible and legally allowable […].[13] Privacy and security should be built into the RFID information systems before their widespread deployment (security and privacy-by-design), rather than having to deal with it afterwards.[14]”

The Commission did not answer the question: “Does this “security-and-privacy-by-design-concept” include the necessity of RFID legislation?”[23] Nevertheless the Commission asked this question in an online-consultation in 2006[15]. At least 55 % of the 2014 respondents believed that legislation is necessary and did not only want to rely on the market model with “Self Control” and “Fair Information Principles” (which 15 % preferred). From a 2007 perspective it can be summarized as follows: The Commission deals with the usage, the standardization and the interoperability (termed here as “Utilization Legislation”) of RFID.[16] Concerning RFID privacy law, the European Commission only announced the establishment of an informal task force

[12] See [19] p. 28; other aims of business ethics are described in [20].
[13] See [21] p. 5; RFID in European Law see [22] p. 107 ff.
[14] See [21] p. 7.
[15] See [24] p. 18; [25] describing the European RFID initiatives.
[16] Commission Decision (2006/804/EC) of 11/23/2006 on harmonization of the radio spectrum for radio frequency identification devices operating in the ultra high frequency band (Art. 2 No.1).

(so called “Stakeholder Group”[17]). Still the Commission reserved the possibility for a future change of European data protection law.

RFID Legislation in the USA. Surprisingly, the worldwide pioneers of RFID law come from US state level, not from US federal level.[18] The future is forecast in the bills of state senates, houses of representatives and assemblies that are now processed in eighteen states of the USA – compare the attached table that is based on internet research in September 2007.[19] These RFID law initiatives might be the omen for change to privacy paradigms in the USA.[27][20] And this change might bridge the privacy gap between the USA and Europe. RFID in the USA is not only a matter of legislative policies, but is already a matter of law. In two states of the USA – Wisconsin (2006) and North Dakota (2007) – a chaptered referred to here as “Prohibition Legislation” exists:

(1) No Person may require an individual to undergo the implanting of a microchip. (2) Any person who violates subsection 1 may be required to forfeit not more than $ 10 000[…].”[21]

These two states have assumed a positive obligation for a protection against the implantation of RFID chips. Both laws do not provide a concept of informed consent to the implantation of RFID.[30] This omission might be criticized, because embedded RFIDs could be useful in high-security environments (e.g. nuclear plants and military bases) in order to protect people and valuable gears or data.[31][22] Therefore this RFID legislation can really only be the beginning. In summary, the following agenda can be drawn:

1. Do we need law or is the market sufficient?
2. If legislation is postulated: Is traditional law sufficient or do we need new law?
3. If we decide on new law – like it is discussed in the USA right now: When do we need this law?

Technology First or Law First? There are few examples for the pre-existence of law before the technology reached the market. In Germany, such an example is the Law of Electronic Signatures that is older than a decade and that wanted to open the market for electronic signatures. RFID law could also precede the spread of RFID technology in the market – but this is exactly what Governor Arnold Schwarzenegger (California) rejected in 2006 [34][23]. He vetoed a RFID “IT Security Bill” with the words:

[17] See [21] p. 6: “This group will provide an open platform allowing a dialogue between consumer organizations, market actors and national and European authorities, including data protection authorities, to fully understand and take coordinated action […]”
[18] See [26] discussing the various options for RFID Law on state and federal level.
[19] See the attached table at the end of section A.
[20] [28] p. 12 arguing the constitutionality of the tracking of persons with RFID; [29] p. 6 designing principles of fair information practice.
[21] 2005 Wisconsin Act 482 for 146.25 of the statutes (2005 Assembly Bill 290); Chapter 12.1-15 of the North Dakota Century Code (2007 Senate Bill No. 2415).
[22] See [32], p. 4, discussing the VeriChip, an implantable device carrying an unique key that hospitals could use to access medical records in emergency cases; [33] p. 8, describing the information market place for implantable and wearable chips.
[23] Arguing about a legal moratorium [35] p. 13.

> "I am returning Senate Bill 768 without my signature. SB 768, which would impose technology regulations on RFID-enabled ID cards and public documents, is premature. The federal government, under the REAL ID Act, has not yet released new technology standards to improve the security of government ID cards. SB 768 may impose requirements in California that would contradict the federal mandates soon to be issued. In addition, this bill may inhibit various state agencies from procuring technology that could enhance and streamline operations, reduce expenses and improve customer service to the public and may unnecessarily restrict state agencies. In addition, I am concerned that the bills provisions are overbroad and may unduly burden the numerous beneficial new applications of contactless technology."

This veto to RFID "IT-Security-Law" arouses transatlantic interest, because the German and European legislators also deal with the IT security of identification documents at the moment. The European Regulation Law and the German Passport Act[24] is comparatively non-specific regarding security standards.[25]

> "Passports and travel documents shall include a storage medium which shall contain a facial image. Member States shall also include fingerprints in interoperable formats. The data shall be secured and the storage medium shall have sufficient capacity and capability to guarantee the integrity, the authenticity and the confidentiality of the data."[26]

New RFID Legislation – A Systematic Approach. The representation of the developments in the USA, Europe and Germany requires a systematic approach.

(2) The systematization of the challenges RFID places on law is done by coordination along the axes globality, verticality, ubiquity and technicity (Radar Chart, "Question position" of lobbyists and the legislature).
(3) The systematization of facts about RFID using scenarios (beyond the Bag Scenario I.). The scenarios enable legal and jurisprudential discourses on the grounds of identified facts.
(4) The systematization of the legislative initiatives and laws serves to qualitatively classify the answers to the challenges placed on RFID law ("Answer Position").

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[24] New§ 4 Sec. 3 PassG of 07/20/2007 in action since 11/01/2007: „[…] sind der Reisepass […] mit einem elektronischen Speichermedium zu versehen, auf dem das Lichtbild, Fingerabdrücke, die Bezeichnung der erfassten Finger, die Angaben zur Qualität der Abdrücke und die in Absatz 2 Satz 2 genannten Angaben gespeichert werden. Die gespeicherten Daten sind gegen unbefugtes Auslesen, Verändern und Löschen zu sichern. […]".

[25] The „Bundesrat" has passed the Bill on 07/08/2007. Describing the IT-Security measures [36] p. 176 and [37] criticizing the security standards.

[26] Art. 1 Sec. 2 Council Regulation (EC) No 2252/2004 on standards for security features and biometrics in passports and travel documents issued by Member States, Official Journal L 385/1.

Table 1. Pending State-RFID-Legislation in the USA in 2007 (State September 2007)

(SB = Senate Bill; AB = Assembly Bill; HB = House Bill)

<table>
<tr><th>State</th><th>Right-To-Know-Legislation</th><th>Prohibition Legislation</th><th>IT-Security-Legislation</th><th>Utilization-Legislation</th><th>Task-Force-Legislation</th></tr>
<tr><td>Arkansas</td><td>-</td><td>SB 195</td><td>-</td><td>SB 183</td><td>SB 846</td></tr>
<tr><td>California</td><td>SB 388</td><td>SB 29
SB 31
SB 362</td><td>SB 30</td><td>-</td><td>-</td></tr>
<tr><td>Georgia</td><td>-</td><td>HB 276</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Massachusetts</td><td>HB 261
SB 159</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Michigan</td><td>-</td><td>HB 4133
HB 5061
HB 5091</td><td>-</td><td>HR 51</td><td>-</td></tr>
<tr><td>Missouri</td><td>SB 210
SB 13</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>New Hampshire</td><td colspan="2">HB 686</td><td>-</td><td>HB 269</td><td>-</td></tr>
<tr><td>New Jersey</td><td>AB 3996</td><td>SB 1866</td><td>AB 3015</td><td>AB 4061</td><td>-</td></tr>
<tr><td>New York</td><td colspan="4">AB 222
AB 261</td><td>AB 225
SB 165</td></tr>
<tr><td>North Dakota</td><td>-</td><td>SB 2415</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Oregon</td><td>HB 3277</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Pennsylvania</td><td>HB 993</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Rhode Island</td><td>-</td><td>SB 474</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Tennessee</td><td>HB 2190</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Texas</td><td>-</td><td>HB 1925</td><td>SB 2027</td><td>SB 574
HB 1308
HB 2990</td><td>-</td></tr>
<tr><td>Virginia</td><td>HB 2086</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Washington</td><td colspan="3">HB 1031
SB 6020</td><td>HB 1133
SB 5366</td><td>-</td></tr>
<tr><td>Wisconsin</td><td>-</td><td>AB 141
AB 488</td><td>-</td><td>-</td><td>-</td></tr>
</table>

2 RFID Legal Challenges in a Radar Chart

Every RFID lobbyist and legislator must first ask the question, if there should be a homogenous RFID law or if RFID law should be heterogeneous ("Question Position"). The classification of two RFID scenarios in the coordinate system with the four axes "globality, verticality, ubiquity and technicity" proves that RFID law will be differentiated and heterogeneous. The four axes can be defined briefly as follows:

1. Globality: In how many countries should RFIDs be freely produced and marketed?
2. Verticality: How long is the lifespan and/or the length of use of the tag/chip, reader and background device?
3. Ubiquity: To what extent are RFIDs part of our inner (subcutaneous use) or outer (ambient intelligence) present? To what extent are we surrounded by RFIDs – or not?
4. Technicity: Which technical qualities does the system show with respect to the processing of data, as well as the protection against unauthorized access?

Both scenarios – one EPC (Electronic Product Code II.) scenario and one RTAMP (Real-time Authentication and Monitoring of Persons III.) scenario – can be outlined as follows:

– In the EPC scenario II. obviously a huge number of products are supposed to be identified worldwide with a unique identifier number contained in a tag (this goes from clothing to household articles).
– In the RTAMP scenario III. here chosen, a chip is implanted into a person. This chip contains medical information (blood type, allergies or special diseases e.g. diabetes or epilepsy). In emergencies the chip enables doctors to access life saving information.

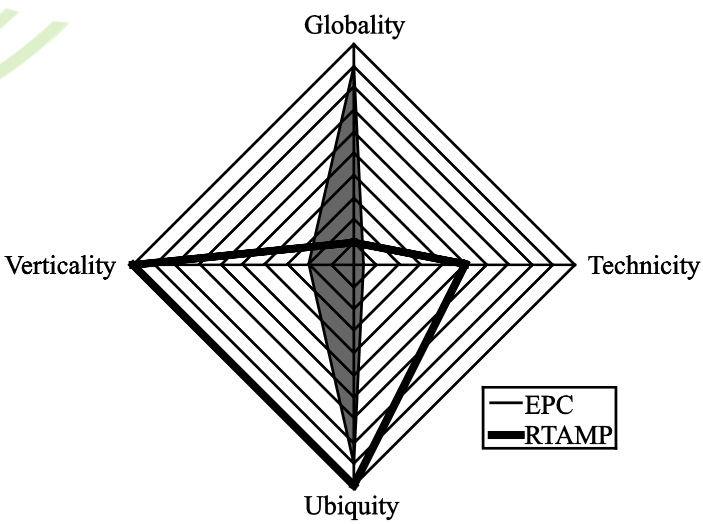

Fig. 1. Legal Challenges in a Radar Chart

2. The validation of the complexity of the background devices – like the reader or other linked media (PC, laptop, cell phone, palm or Blackberry) – depends on how the RFID data are organized – especially if they are aggregated or profiled with other data. Furthermore, the communication between tag/chip and background device has to be protected against spying.[11][41]
3. The principle of transparency demands that the reading range of the RFID system is ascertained. Reading ranges from only a few centimeters (so called near-field-communication, e.g. at the purchase of tickets) [42] to several meters are possible. The principle being that the longer the reading range is, the less transparent is the sending or reading process. The shorter the reading range is, the more transparency exists. If a tag can only be read from 15 centimeters, the wearer will expectantly notice the reading process. If instead the tag can be read from 10 meters, the wearer probably would not notice. The reading/sending distance is – aside from the deactivation challenge – a very important aspect of RFID.[32]

EPC-Scenario II. Overall (1-3) the technicity value of the EPC scenario is low (5 %), because the tag is passive, not rewritable and it does not have sensors or any computing power. It has a small reading range.

RTAMP-Scenario III. The RTAMP scenario with the implanted chip gets a middle value (50 %). Such a tag contains sensitive data (§ 3 Section 9 German Data Protection Act) and therefore needs a more stringent IT-security policy that protects it from unauthorized reading or rewriting.

3 RFID Law Scenarios

Apart from the four challenge axes globality, ubiquity, verticality and technicity, a legal perspective can distinguish between four privacy orientated function scenarios.[43] Privacy – the protection of personal data – is a paradigm of traditional law and requires us to determine whether RFIDs are used to

- monitor products (*Electronic Product Code* scenario = EPC),
- monitor animals (*Real-time authentication and monitoring of animals* scenario = RTAMA)
- monitor persons (*Real-time authentication and monitoring of* persons scenario = RTAMP) or
- collect data for profiling purposes (*Aggregation* scenario = AGG).

The product scenario is called *EPC* scenario, because it characterizes a product just like a barcode.[33] Characteristically, EPC scenarios initially do not show any relation

[32] The online consultation of the European Commission [24] asked what the respondents thought about the maximum reading distance, which could be considered as acceptable for “proximity tags”. It “received answers from 1342 respondents (60 %). About 10 % do not consider the concept of “proximity tags” as a valuable solution to preserve privacy. A variety of arguments are brought forward, e.g., “inappropriate for certain applications”; “useless because of the discrepancies between specified and real reading ranges”; “difficult to enforce”, “consumers should be notified”.

[33] Differing from a barcode scenario an individual product is identified.

to personal data. Still, a person who carries an RFID tagged item gives the entity which uses the RFID system the opportunity to collect their information. This is why the legislative initiative in New York[34] demands that EPC tags must be able to remove or deactivate. The verticality of this scenario is legally limited to the presence of the customer in the retail shop.

RTAMA scenarios – e.g. the tagging of dogs[35] or cattle[36] – do not show any personal relation if the tag contains only a number. In the case of more complex tags, even such RTAMA scenarios can involve personal data (e.g. if the tag contains information about the breeder or owner). From a legal perspective, questions about the sanitary harmlessness of the implantation of tags [44] and the owners' interest in keeping depreciating information uncovered have to be asked.

From a traditional privacy law point of view, *RTAMP* scenarios are the most challenging. Examples for RTAMP are the authentication of persons through identification documents that contain an RFID tag and make personal data remotely readable, as well as the monitoring of pupils, employees or elderly requiring care.

The privacy importance of all three scenarios can be qualified with the *AGG* scenario. An example of this is when the EPC scenario is combined with credit card data. The New York legislature initiative wants to prohibit exactly that:

> "No retail mercantile establishment shall combine or link a consumer's personal information with information gathered by, or contained within, a radio frequency identification tag."[37]

In summary, it can be said that the four challenge axes of the radar chart are coordinates for the actual usage of RFID. Each of the four scenarios reflects a different quality of privacy law. The greater the privacy relation is – as always in RTAMP scenarios – the more significance the "traditional law" has. The less privacy issues are affected by the application of RFIDs – as it is in the EPC scenarios or the "Bag Paradigm" – the greater is the importance of the legislature politics and the more relevant is the question about the need for new law. Also, this new law in action can be further categorized as follows:

4 Categories of Future RFID Legislation

Future RFID legislation might have five different goals:

(1) Right-to-Know-legislation,
(2) Prohibition-legislation,
(3) IT-Security-legislation,
(4) Utilization-legislation and
(5) Task-Force-legislation.

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[34] As in Fn. 29.
[35] E.g. in Hamburg, Germany.
[36] E.g. in Texas, USA.
[37] Section 219 (4 A.) General Business Law as in New York 2007 Assembly Bill 222 (RFID Right to Know "Act").

1. *Right–to-Know-legislation* denotes initiatives demanding that the customer be informed in RFID scenarios. Furthermore, the customers shall be able to deactivate the tags after purchase, so that after leaving the retail shop reading attacks are unsuccessful. In 2004 (108th congress), there was an unsuccessful legislative initiative with the title “Opt Out of ID Chips Act” on the federal level. RFID tagged products were supposed to be labeled.[38] On the state level, such legislative initiatives can be found in: California (2007 Senate Bill 388 “RFID Privacy”), Massachusetts (2007 Senate Bill 159 and House Bill 261 “Consumer Protection and RFID”), Missouri (2007 Senate Bill 13 and 210 “RFID Right To Know Act of 2007”), New Hampshire (2007 House Bill 686 “Regulation of tracking devices”), New Jersey (2007 Assembly Bill 3996), New York (2007 Assembly Bill 261 “Labeling of retail products”; 2007 Assembly Bill 222 “Radio Frequency Right To Know Act”), Oregon (2007 House Bill 3277), Tennessee (2007 House Bill 2190 “Labeling of Retail Products”), Virginia (2007 House Bill 2086 “Labeling”) and Washington (2007 Senate Bill 6020, 2007 House Bill 1031 “Labeling”).
2. *Prohibition-legislation* means initiatives that want to forbid or at least restrict the usage of RFID in certain scenarios. Prohibition-legislation is the opposite of Utilization-legislation. On the federal level, no examples for such legislation can be found. On the state level, several bills have been introduced. In California, the legislation was concerned with RTAMP scenarios (attendance and tracking of location of pupils shall be prevented by prohibiting their tagging, California 2007 SB 29 “Pupil Attendance: Electronic Monitoring”). A legislative initiative in Texas (Texas 2007 House Bill 1925 “Electronic Monitoring of Students”) demands that the identification of students through RFIDs should only be used after prior consent of the guardians. Those who did not give their consent have to be offered an alternative option for identification. In Rhode Island, one initiative wants to prohibit the governmental use of RFIDs for the identification or monitoring of students, employees or contractual partners (Rhode Island 2007 Senate Bill 474 “Restriction of Radio Frequency Identification Devices”). A Michigan initiative plans to forbid the implantation and even the provision of RFIDs to humans without their prior consent (Michigan 2007 House Bill 4133 “Implanting RFID Chips into Individuals”). In the Wisconsin Assembly, an initiative has been introduced that wants to forbid the embedding of RFIDs in documents and bank notes (Wisconsin 2007 Assembly Bill 141 “Prohibition of RFID Tags in Documents”). An Arkansas Senate Bill wants to restrict the reading of RFIDs after the tagged product has been purchased and the item has been removed from the premises of the retail shop (Arkansas 2007 Senate Bill 195 “Limitation on Use of RFID Tags”).
3. *IT-Security-legislation* denotes initiatives that demand certain IT security standards and aims for the protection of RFIDs from unauthorized reading and rewriting. Accordingly, initiatives in California and Washington demand that RFIDs in identification documents have to be provided with IT-security technologies (e.g. encryption, California 2007 Senate Bill 30 “Identity Information Protection Act of 2007”; Washington 2007 House Bill 1289 “RFID Chips in Driver’s Licenses or Identicards”).

[38] H.R. 4637 108th Congress, Sponsors: Klezka and Lewis.

4. *Utilization-legislation* means initiatives that want to use RFID in certain scenarios. On the federal level, RFIDs shall be embedded in identification documents – RTAMP scenario. On the state level – e.g. in Texas – RFIDs are supposed to be used for the identification of animals (Texas 2007 Senate Bill 574, 2007 House Bill 1308 "Deer Identification") – RTAMA scenarios. In California, a bill concerning the use of RFID for the access of visually impaired persons to financial services was introduced, but not further pursued (California 2005 Assembly Bill 1489). Since the touch screens of point-of-sales-systems were not manageable for visually impaired persons, RFID was supposed to grant identification. Another RTAMP scenario can be found in a legislative initiative of Texas. Hereafter inmates, employees and visitors of correctional facilities are supposed to carry a RFID tag with them (Texas 2007 House Bill 2990).
5. *Task-Force-legislation* means initiatives that demand a round table for the research of the legal and technical challenges of RFID. Characteristically Task-Force-legislation encompasses all scenarios (EPC, RTAMP, RTAMA, AGG). In the USA, no such legislation exists on the federal level. According to a hint from the internet, all that seems to exist in this context is an RFID Caucus in the US Senate that only describes an informal political board and does not have any legal accreditation. On the state level, legislative initiatives for RFID task forces exist in Arkansas (2007 Senate Bill 846) and in New York (2007 Senate Bill 165 and 2007 Assembly Bill 225).

5 Outcome and Outlook

This report concentrates on two pioneer states, despite having a global perspective.

5.1 RFID Law Pioneer: USA

The three questions posed by this report can be answered for the RFID Law Pioneer, the USA, in the following manner: the overview of legislative activities in eighteen states shows that the market is most likely insufficient and the fact that the discussion for new laws is both important and controversial (questions 1, 2). If and when (question 3) these laws will be put into action depends on the length and sustainability of these procedures. One cannot exclude the possibility that these legal initiatives "dry up" in the various houses (senate, assembly, house) or that one of the governors passes a veto. However, it should be highlighted that on the federal level a utilization legislature exists with the "Food and Drug Administration Amendments Act of 2007"[39]. Standards should be developed accordingly,

> "to identify and validate effective technologies for the purpose of securing the drug supply chain against counterfeit, diverted, subpotent, substandard, adulterated, misbranded, or expired drugs". …Not later than 30 months after the date of the enactment of the Food and Drug Administration Amendments Act of 2007, the Secretary shall develop a standardized numerical identifier (which, to the extent

[39] Food and Drug Administration Amendments Act of 2007, Pub. L. No. 110-85 [45], Sec. 913 inserting Section 505d "Pharmaceutical Security".

practicable, shall be harmonized with international consensus standards for such an identifier) to be applied to a prescription drug at the point of manufacturing and repackaging (in which case the numerical identifier shall be linked to the numerical identifier applied at the point of manufacturing) at the package or pallet level, sufficient to facilitate the identification, validation, authentication, and tracking and tracing of the prescription drug." The standards developed under this subsection shall address promising technologies, which may include: radio frequency identification technology; nanotechnology; encryption technologies; and other track-and-trace or authentication technologies."

5.2 Data Protection Pioneer: Germany

The three questions posed in this report can be answered for the Data Protection Pioneer, Germany, in the following manner: The honest answer to the first two questions "Do we need law or is the market sufficient (1)" and "If we need law: is traditional law sufficient or do we need new law? (2)" is "It depends.". This answer is as unloved as it is old, and prepares us for the necessity of differentiation.

- An RTAMP Scenario III., in which patients are required to have a chip with medical information implanted, requires a legal foundation and that the IT-security be secured legally. This chip must be protected from both unauthorized access to the information stored on it and unauthorized overwriting of the information. According to German law ("de lege lata")[40], the government must first legally recognize this type of under-the-skin healthcare. In this respect, the answer is: yes, traditional law postulates that we need new law. [41]
- For an EPC Scenario II., which is only used for identification of objects in supply chains and in which no aggregation interest with personal data exists (AGG), in our opinion the market and its traditional market law is sufficient. All members of the chain can reach an agreement about whether or not they support the use of RFID. The answer is: no, we do not need new law. As a "caveat" we must adhere to the following: If EPC data are aggregated with personal data in such a way that localization and performance statements about employees become possible, then the area of application[42] – at least according to existing German law ("de lege late") – has been opened up (yes, there is constitutional and statutory law). The answer for the EPC-AGG scenario is: no, we do not need new law.
- The market is not sufficient for the Bag Scenario I. Laws currently in effect do not encompass this scenario. The creation of new laws ("de lege ferenda") is necessary, that allow the informed public to choose between providers with such profiling strategies and others ("Consumer Information" and "Consumer Choice"). The answer is: yes, we need new[43] law.

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[40] E.g.: Positive obligation resulting from Art. 2 sec. 2 GG (German Constitution): Everyone has the right to life and physical integrity. The liberty of the individual is inviolable. These rights may be encroached upon only pursuant to statute.

[41] For experts: new statutory law.

[42] E.g. § 28 BDSG; § 87 sec. 1 item 6 BetrVG.

[43] E.g.: This scenario requires a new interpretation of constitutional law (Art. 1 sec. 1 GG and Art. 2 sec. 1 GG) and then the remittal of a statutory law.

The answer to the third question: "if we decide on new law – like it is discussed in the USA right now: When do we need this legislation?" is: as soon and qualified as possible. Legislative procedures attract high levels of publicity. In this way they inform the citizens, prevent technophobia and they are the way to weigh differing interests – with all skepticism and criticism – in our legal systems. Prerequisite for a qualified legislative procedure is that the participating antagonists can present their positions in a qualified manner. This requires technology to be defined, the economy to be calculated and law and politics to be interested and involved.

5.3 Ideal RFID Law

We must wait and see what the outcome of the legislative procedures in the USA is. It could be a valuable experience for the still hesitant lawmakers of the European Community and for Germany in particular. Only then will it be decided if this RFID Law will satisfy the ideal of "legal and market compatible" and "technology and market tolerable" law.

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Why Marketing Short Range Devices as Active Radio Frequency Identifiers Might Backfire

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Abstract. This paper analyses why marketing short range devices (SRD) as radio frequency identifiers (RFID) might backfire on the RFID industry. To support this claim it provides a legal use case as basis and gives an overview of selected technical parameters of RFID. Furthermore an analysis of 43 legal articles shows that legal experts perceive the technology of RFID in an undifferentiated way. Finally an analysis of 11 tag providers of so called "active RFID tags" shows that SRD are marketed as active RFID. It concludes that in order to avoid inhibiting legal consequences which might have negative effect on the RFID industry a differentiated approach regarding the functionality of short range transmitters and RFID is necessary.

Keywords: Radio frequency identification (RFID), short range device (SRD), passive tag, active tag, law, industry.

1 Introduction

This paper analyses the legal perception and technical use of so called "active" radio frequency identification (RFID) tags. It is of value not only to the legal community to clarify and differentiate the technology of RFID but also to the RFID industry in that it assumes that marketing short range transmitters as active RFID tags could be counter-productive to the RFID industry after all.

Admittedly, the understanding of RFID technology is not always clear. For instance, there is a narrow and a wide understanding of what an active RFID tag is insofar as short range transmitters are also marketed as RFID. Therefore the question about an accurate and also differentiated understanding of RFID technology in the legal discussion becomes crucial. While the RFID industry includes short range transmitters in the product line of RFID to increase sales, the legal consequences of merging the functionalities of both RFID and short range devices (SRD) might lead to a restrictive legal interpretation and understanding of RFID because the technical features of SRD are broader than those of RFID.

First, a legal use case is presented as basis for the subsequent legal and technical analysis (section 2). Second, an overview of RFID technology with regard to tag functionality, energy supply and coupling is given in section 3 to set the technical ground in the discussion of RFID and SRD. Third, an analysis of 43 journal articles

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shows the legal perception and understanding of RFID technology between 2001 and 2007 (section 4). Fourth, an industry analysis with an empirical sample of 11 providers of so called “active” RFID tags illustrates how the RFID industry is marketing SRD as RFID (section 5).

This paper concludes by suggesting that the industry’s approach of marketing short range transmitters as RFID could backfire on the industry (section 6).

2 Use Case

The use case selected to support the claim of this paper is taken from the empirical sample provided in section 3.1. It illustrates why it makes a difference to discriminate RFID tag functionality.

Dalal [5] examines the use of RFID technology in various contexts and privacy invasions. The use case of this paper focuses especially on the potential use of RFID and the Fourth Amendment of the Constitution of the USA [29] which stipulates that it is “[t]he right of the people to be secure in their persons, houses, papers, and effects against unreasonable searches and seizures […]” [29]. There has been extensive ruling on this topic with the following four landmark cases on telephony, radio transmitter and thermal imaging surveillance:

1. In Olmstead v. United States [22] the plaintiff(s) was (were), among others, convicted of violating the National Prohibition Act [21] for unlawfully possessing, transporting and importing intoxicating liquors. The (divided) U.S. Supreme Court held that evidence collected by wiretapping telephone lines did not violate the Fourth Amendment because “[t]he language of the amendment cannot be extended and expanded to include telephone wires” [22]. The wiretapping had been effectuated without a physical trespass by the government, and was thus legally obtained.

2. In 1967 the U.S. Supreme Court overruled its decision in Olmstead [22]. In Katz v. United States [15] the court argued that evidence overheard by FBI agents who had attached an electronic listening and recording device to the outside of a public telephone booth from which the plaintiff had placed his calls for bets and wagers in violation of the Criminal Law was searched unconstitutionally. Whether a given area was constitutionally protected deflected attention from the problem presented, as the Fourth Amendment protected people, not places: “[…] the Fourth Amendment protects people – and not simply ‘areas' – against unreasonable searches and seizures [… so] it becomes clear that the reach of that Amendment cannot turn upon the presence or absence of a physical intrusion into any given enclosure.” [15]

3. In 1983 the U.S. Supreme Court ruled on a Fourth Amendment Case that monitoring the progress of a car carrying a container with a “beeper” (i.e. a battery operated radio transmitter which emits periodic signals that can be picked up by a radio receiver) did not violate the defendant’s constitutional rights. In United States v. Knotts [30] the court decided that monitoring the beeper signals did not invade any legitimate expectation of the defendant’s privacy because there was a diminished expectation of privacy in an automobile: “One has a lesser expectation of privacy in a motor vehicle because its function is transportation and it seldom serves as one's residence or as the repository of personal effects. A car has little capacity for escaping public scrutiny. It travels public thoroughfares where both its occupants and its contents are in plain view.” [4]

4. Finally, in Kyllo v. Unites States [19], the U.S. Supreme Court ruled in a case of thermal heating surveillance that use of thermal imaging devices to gather information about heat in a house's interior is not removed from scope of Fourth Amendment search merely because the device captures only heat radiating from external surface of a house, and thus involves “off-the-wall” rather than “through-the-wall” observation. In this case agents of the United States Department of the Interior suspected that marijuana was being grown in the petitioner’s home. The court argued that where “the Government uses a device that is not in general public use, to explore details of a private home that would previously have been unknowable without physical intrusion, the surveillance is a Fourth Amendment “search,” [sic!] and is presumptively unreasonable without a warrant.” [19]

To date there have been no Supreme Court rulings on RFID surveillance. However, spinning forth the courts’ present decisions, Dalal [5] argues that among the many factors to be considered in a potential RFID ruling, RFID searches are likely to be found constitutional under the Fourth Amendment because “tracking devices in public places are not considered to violate an objective expectation of privacy”. [5]

After having provided the use case in this section an overview of selected technical parameters necessary for the subsequent analysis is discussed in the next section.

3 Technical Parameters

This section covers the technical parameters of RFID technology. An overview of these parameters is important to understand the inaccuracy in legal analyses (section 4) and to better understand the industry approach (section 5).

According to Kern [16], Finkenzeller [11] and Glover [12] the most common classifications for RFID are:

Table 1. Differentiators of RFID according to Kern [16], Finkenzeller [11] and Glover [12] (adapted). Characteristics that are italicized often but not necessarily (or solely) group in the vertical.

Differentiator	**Characteristics**		
Frequency	*Low frequency (30 – 300 kHz)*	*High frequency (3 – 30 MHz)*	*UHF (300 MHz – 3 GHz) and Micro-ware (> 3 GHz)*
Memory and data	1-bit (no chip)	n-bit (chip with ID)	
Energy supply chip	*Passive*	*Semi-active/-passive*	*Active*
Communication	Full Duplex	Half Duplex	Sequential
Coupling	*Capacitive (electrical) coupling*	*Inductive coupling*	*Backscatter coupling*
Read range	*Close proximity): ≈ < 1cm*	*Remote (or vicinity): ≈ 1cm – 1m*	*Long Range: ≈ > 1m*
Antenna	*Coil*	*Ferrite*	*Dipole*

A more detailed explanation follows for the energy supply of RFID tags (section 3.1), and the way they broadcasts to the reader (section 3.2).

3.1 Energy Supply

Three types of transponders vary in energy supply: passive, semi-active/semi-passive, and active RFID tags. It is important to note and it is herein argued that the common division of tags by energy supply – i.e. passive tags without own energy supply and active tags with their own energy supply for the chip in the tag (for example batteries or solar cells) – has nothing to do with the transmission of data from the transponder to the reader. In either case the tag needs the energy of the reader to transmit the data.

Active transponders use their own power source only to supply the chip in the tag with energy and not to transmit the data from the transponder to the reader. The advantage of an own power supply in active tags is that all energy from the reader can be used for data transmission because the chip is already supplied with energy by a separate source (e.g. battery). This dual energy supply has positive effects on the read range because all energy derived from the reader can be used for transmission and no energy is lost for powering the chip. [11] [16] Active RFID tags – herein understood as active RFID tags in the narrow sense according to Finkenzeller [11] – do not have the capability of emitting their own high frequency signal. According to Finkenzeller [11] transponders with the capability of emitting an own frequency signal are not RFID transponders but rather SRDs. These devices emit their own high frequency electro-magnetic field without influencing the field of the reader. [11] Bensky [2] makes the same differentiation:

> "A quite different aspect of the data source is the case for RFIDs. Here the data are not available in the transmitter but are added to the RF signal in an intermediate receptor, called a transducer. […] This transducer may be passive or active, but in any case the originally transmitted radio frequency is modified by the transducer and detected by a receiver that deciphers the data added […] A basic difference between RFID and [transmitter-receiver] is that RFID devices are not communication devices per se but involve interrogated transponders." (Bensky [2])

Glover et al. [12] acknowledge the differentiation of power source for passive and active tags. Traditionally active tags use the internal energy source to power the chip and the reader to power communication. However, these authors opt to use the term semi-passive for tags that only use the internal power supply to feed the chip (or other devices) but not for communication. [12]

A further source of definitions for passive, semi-passive/semi-active and active RFID tags is EPC Global Inc.[1] and RFID Journal[2]. EPC Global and RFID Journal discriminate the following functionalities of the different tag types in Table 2.

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[1] http://www.epcglobalinc.org (last visited December 9, 2007). EPC Global Inc. is a leading organisation for the industry-driven standards of the Electronic Product Code (EPC) to support RFID.

[2] http://www.rfidjournal.com (last visited December 9, 2007)

Table 2. Selected definitions of RFID functionalities

Source	Type	Tag definition and functionality [own emphasis]
EPC Global Inc.	Passive tag	"RFID tag that does not contain a power source. The tag generates a magnetic field when radio waves from a reader reach the antenna. This *magnetic field powers the tag* and enables it to send back information stored on the chip." [43]
	Semi-passive/ semi-active tag	"A class of RFID tags that contain a power source, such as a battery, to power the microchip's circuitry. *Unlike active tags, semi-passive tags do not use the battery to communicate with the reader*. Some semi-passive tags are dormant until activated by a signal from a reader. This conserves battery power and can lengthen the life of the tag." [43]
	Active tag	"A class of RFID tag that contains a power source, such as a battery, to power the microchip's circuitry. Active tags *transmit a signal to a reader* and can be read from 100 feet (35 meters) or more." [43]
RFID Journal	Passive tag	An RFID tag without its own power source and transmitter. When radio waves from the reader reach the chip's antenna, the energy is converted by the antenna into electricity that *can power up the microchip in the tag*. The tag is able to send back information stored on the chip. […]" [44]
	Semi-passive/ semi-active tag	"Semi-*passive* tags are"[s]imilar to active tags, but the *battery is used to run the microchip's circuitry but not to broadcast a signal to the reader*. Some semi-passive tags sleep until they are woken up by a signal from the reader, which conserves battery life. Semi-passive tags can cost a dollar or more. These tags are sometimes called battery-assisted tags." [44]
	Active tag	"An RFID tag that has *a transmitter to send back information, rather than reflecting back a signal from the reader*, as a passive tag does. Most active tags use a battery to transmit a signal to a reader. However, some tags can gather energy from other sources. Active tags can be read from 300 feet (100 meters) or more […]." [44]

EPC Global Inc. and the RFID Journal also define SRD as active RFIDs (Table 2): First, the definitions of semi-active/semi-passive tags by both EPC Global and RFID Journal stipulate that these tags use their battery to power the chip's circuitry. Second, EPC Global states that "[u]nlike active tags, semi-active tags do not use the battery to communicate with the reader". This means e contrario that these active tags use the battery power to broadcast the signal. Furthermore, EPC Global's definition of active tags states that they transmit a signal to the reader. Third, the RFID Journal defines the active RFID tag to include a "transmitter to send back information, rather than reflecting". These definitions of semi-active/semi-passive tags and active tags also clearly show that (i) active tags as understood by Finkenzeller [11] and Kern [16] are referred to as semi-active/semi-passive tags by EPCglobal and RFID Journal (and Glover [12] respectively); and that (ii) active tags as understood by EPCglobal and RFID Journal (and Glover [12] respectively) are referred to as SRDs by Finkenzeller [11] and Bensky [2].

Based on the differentiation between these three different RFID tag types, the next subsection explains how passive and active RFID tags as understood in the narrow sense by Finkenzeller [11] and Kern [16] derive the necessary power for transmission of the data.

3.2 Coupling

The following subsection introduces the technology of coupling. It gives a brief technical overview on how energy is derived from radio waves of a reader to power an RFID tag. This understanding is necessary to differentiate between energy supply and data transfer to the reader as discussed in the industry review (section 5.2).

Coupling is the mechanism by which a transponder circuit and a reader circuit influence one another for energy supply of the transponder as well as for data transfer to the reader. There are three main coupling modes: inductive coupling, capacitive coupling and backscatter coupling.

First, transponders of inductive coupling systems are mostly only used in passive tags. The reader must provide the required energy for both the data signal as well as for the operation of the chip. The inductively coupled transponder usually comprises a chip and an antenna coil. The reader's antenna generates an electromagnetic field. When a tag is within the interrogation zone of a reader the tag's antenna generates voltage by electromagnetic induction which is rectified and serves as power supply for the chip. The data transfer back to the reader works by load modulation: When a resonant transponder is within the range of the electromagnetic field it absorbs and reduces the energy of the reader's magnetic field which can be represented as change of impedance. Switching on and off a load resistor by the transponder can also be detected by the reader. The course of this change allows the interpretation of a signal (data transfer). [11] [16]

Second, capacitive coupling systems use plate capacitors for the transfer of power from the reader to the transponder. The reader comprises an electrode (e.g. metal plate). Through the very precise placement of the transponder on the reader a functional set-up similar to a transformer is generated. If high-frequency voltage is applied to this electrically conductive area of the reader, a high frequency field is generated. Electric voltage is generated between the transponder electrodes if the transponder is placed within the electrical field of the reader. This electrical voltage supplies the transponder with power. Similar to load modulation of inductive coupling, the read range of a reader is dampened when an electrically coupled tag is placed within the resonant circuit. This allows switching on and off of the modulation resistor (data transfer). [11]

Last, long distance backscatter systems are often active (in the narrow sense) or semi-passive (in the wide sense) tags, i.e. they are supported by an additional energy source for the chip within the transponder. The source energy for the transponder emitted by the reader is partly reflected by the transponder and sent back to the reader. Backscatter coupling is based on the principle of radar technique that electromagnetic waves are reflected by objects with dimensions larger than half the length of a wave. Also in this coupling mode a load resistor is switched on and off in time to transmit data from the transponder to the reader, thereby modulating the amplitude of the reflected power (modulated backscatter). [11] [16]

4 Legal Analysis

The two previous sections have introduced the use case and provided the technical background on energy supply and coupling of RFID. This section presents an empirical sample of legal journals and reviews the technical understanding by legal experts. It forms the legal basis of the claim that marketing SRD as RFID might backfire on the RFID industry.

4.1 Research Method and Legal Empirical Sample

The legal articles that form the basis for the empirical sample have been searched and selected in the WestLaw[3] and LexisNexis[4] databases. Both databases are leading providers of comprehensive legal information and business solutions to professionals. Two queries were conducted in each legal database. The parameter set in both databases for retrieval used the following keywords: radio frequency ident* (as group word and truncated using a wild card to allow variances such as ident*ification* or ident*ifiers*) and RFID (the acronym for radio frequency identification). Within Westlaw and LexisNexis the search was conducted in the database for combined journals and law reviews. Apart from searching for articles containing the keywords listed above, a filter was set by searching articles written in English and limited to the regions North America and Europe.

As both legal databases have similar but not identical content some results overlapped. After manually sifting out the duplicates of both databases, 141 legal journal articles, reviews and reports dating from 1997 to several months into 2007 remained (gross sample). Almost 80 per cent of the selected articles date back to the years 2005 and 2006. From the total 141 retrieved articles some 98 articles were excluded because a full text analysis showed neither their main nor side content relates specifically to the technology of RFID. The 98 excluded articles in many cases only mention RFID as an example in one sentence, part of a sentence or footnote. These 98 articles do not have any in-depth relation to RFID, explanation or analysis of RFID technology. A total of 43 articles were selected for this analysis (net sample). These selected articles have either a (sub-) chapter dedicated to RFID technology or comprise RFID as secondary content in either main text or footnotes with technological and/or legal analysis of RFID (as compared to the excluded 98 articles).

The year 2001 has 1, the year 2004 has 3, the years 2005 and 2006 each have 17 and 2007 (not full year) has 5 in-scope articles. Most in-scope articles are found in legal journals, reviews and reports for Information and Communication Technology law (42%). General legal journals and legal policy journals account for another third (30%). The remaining selected articles relating to RFID (28%) are distributed among administrative/public law, finance law, food and drugs reports, human rights law, intellectual property law, lawyer associations, and procurement law.

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[3] http://www.westlaw.com (accessible only with license; last visited May 18, 2007)
[4] http://www.lexisnexis.com (accessible only with license; last visited May 18, 2007)

In summary, the large part of the 43 legal articles researched for this analysis has a similar structure. The articles mostly comprise (i) an introduction, followed by (ii) *a technical description*, (iii) a legal analysis and lastly (iv) a conclusion. Other articles explain the technical advancements of RFID only in footnotes. Within the technical description many authors recall the history of RFID as far back as World War 2, differentiate between passive and active tags, and provide a few examples of RFID implementation.

It is recognised that there are several limitations to the proposed methodology. First, the search is limited to two legal databases. Second, English language articles are relied upon exclusively which introduce a certain bias regarding countries, especially in Europe. Lastly, no quality assessments regarding the type of law journal is made. Despite these possible sources of error, it is suggested that analysing these 43 articles is a reasonable method for conducting the proposed analysis of the technical RFID understanding legal articles.

4.2 Legal Review

This section reviews the technical RFID understanding and perception of legal experts based on the legal empirical sample.

Of the 43 in-scope legal journal articles a little less than 50 per cent differentiate between passive, semi-passive/semi-active tags and active tags: Two articles use the functionality for tags in the narrow sense according to Finkenzeller [11] and Kern [16], thirteen articles refer to the functionality in the wide sense according to Glover [12], and five articles are inexplicit in the definition of the active tag (i.e. narrow or wide sense).

Both Landau [20] and Smith [23] mention the necessity of the active tag first being activated to transmit the data to the reader regardless of whether they have a battery or not. This makes them active according to Finkenzeller [16] or semi-active/semi-passive according to Glover [12]. Unclear remain the technical statements of Brito [3], Thompson [28], Eng [9], Kobelev [17], and Eleftheriou [8]. These five authors mention (active) tags with batteries or tags that are self-powered, but do not explain whether such energy is also used to transmit the data or whether transmission power is generated by the reader.

Stark [25], Delaney [6], Terry [27], Eschet [10], Asamoah [1], Herbert [14], and Smith [24] not only refer to the necessity of a battery (or other power supply) in an active tag, but more importantly consider such power supply essential for the transmittal of the data to the reader. Other authors like Eden [7], Willingham [31], and Stein [26] especially emphasise the lack of need for an active tag to be within activation range of a reader. Such tags continuously transmit their data. The tag range referred to by Eden, Willingham and Stein is only exceeded by tags as mentioned by Handler [13] and Koops [18] with transmitters capable of sending the signal over up to several kilometers. The tags as referred to by these ten authors are active tags by definition of Glover [12] and SRD as understood by Finkenzeller [11] and Bensky [2].

With passive tags there is no doctrinal or industry driven differentiation similar to the one with active and semi-passive/semi-active tags. In principle all reviewed authors agree that passive tags do not have an internal power supply and transform the (electromagnetic) waves of the reader by induction. Many reviewed authors explicitly mention the lack of battery supply and/or the energy powering by the reader. Thompson et al. [28] also refer to the virtually unlimited operational life of a passive tag while Smith [24] inaccurately states that a passive tag cannot be turned off. Indeed the opposite applies: a passive tag is always off and needs external manipulation to be "switched on" by influence from the reader. If at all, it would be more accurate to envision the metaphor of active tags (as defined by Finkenzeller) or semi-passive tags (as defined by Glover) being "woken up".

5 Industry Analysis

This section analyses the RFID industry by first providing an empirical sample of the active tag providers and then by reviewing the active RFID tag providers' marketing strategy.

5.1 Research Method and Industrial Empirical Sample

Similar to the legal analysis an empirical sample is drawn for the industry analysis. The Buyer's Guide 2007 online database[5] of the RFID Journal has been searched for industry suppliers of active RFID tags. The RFID Journal claims to be the only independent media company devoted solely to RFID and its many business applications. Its mission is to help companies use RFID technology to improve the way they do business.

Two queries were conducted for this empirical sample of industry suppliers of active RFID tags. The search parameters were set to search the RFID Journal Buyer's Guide 2007 database by type of technology (e.g. passive or active tag). In addition, a geographical filter was set to limit the search to the U.S. and to Europe respectively.

The database search for the U.S. market provided 104 hits; the database search for the European market provided 72 hits. A manual comparison of these 176 query hits resulted in an overlap of 64 resources (i.e. RFID providers based in both the U.S.A. and in Europe). Subsequently, the product range of these 64 RFID providers was analysed (gross sample). They offer among others tag hard- and software, readers, printers, and services such as consulting and system integrations. To qualify in the empirical sample of this analysis the provider must supply active RFID tags and issue a tag datasheet (PDF or html format) for evaluation and verification of the tag parameters. A total of 16 providers meet these selection criteria: AAiD Security Solutions[6], AeroScout[7], Axcess[8], Deister Electronic[9], Ekahau[10], Identec Solutions[11],

[5] http://www.rfidjournal.com/article/findvendor (last visited December 9, 2007)
[6] http://www.autoaccessid.com (last visited December 9, 2007)
[7] http://www.aeroscout.com (last visited December 9, 2007)
[8] http://www.axcessinc.com (last visited December 9, 2007)

Multispectral Solutions[12], RF Code[13], RFID Inc.[14], RFind[15], Savi[16], Smartcode[17], Synometrix[18], Tagmaster[19], Ubisense[20], and Wherenet[21].

It is also acknowledged in this empirical sample that there are several limitations to the proposed methodology. First, the search is limited to the online database of the Buyer's Guide 2007 offered by the RFID Journal. Second, the search is geographically limited to fit the legal empirical sample (North America and Europe). This excludes providers in other regions of the world like South America, Africa and Asia Pacific. Lastly, only tag providers with a datasheet for evaluation of the technology are included in the sample. Despite these possible biases it is suggested that analysing the RFID tags of these providers is a reasonable method for conducting the proposed analysis of the marketing approach of the RFID industry.

5.2 Industry Review

The selected technical parameters in the previous section 3.1 have shown that technically there is a difference between RFID and SRD. While Finkenzeller [11] and Bensky [2] argue in favour of a strict differentiation of these technologies, Glover et al. [12] concede this distinction as accurate but opt to lump active RFID and SRD together under the term active RFID. These authors leave the traditional path of distinguishing the energy for the chip and energy for broadcasting, and use the term active RFID as synonym for SRD. The industry also seems to follow the wider functionality of active RFID tags.

From the total of 16 active tag providers selected in the empirical sample (footnotes 5 through 20) five are eliminated from the count. Although they meet the selection criteria ("active" RFID tag and online datasheet) it is not clear from the datasheet description whether they broadcast automatically to the reader or not. From the remaining eleven active tag datasheets (net sample) eight refer explicitly to the marketed tag as "active tag" (or similar), while all eleven datasheets include the feature of self-dynamic signal transmission to the reader, i.e. these tags beacon or blink periodically. The RFID tags offered by these providers include the following features as outlined in Table 3. Only one example is presented per tag provider even if its product line includes more than only "active" tag.

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[9] http://www.deister.com (last visited December 9, 2007)
[10] http://www.ekahau.com (last visited December 9, 2007)
[11] http://www.identecsolutions.com (last visited December 9, 2007)
[12] http://www.multispectral.com (last visited December 9, 2007)
[13] http://www.rfcode.com (last visited December 9, 2007)
[14] http://www.rfidinc.com (last visited December 9, 2007)
[15] http://www.rfind.com (last visited December 9, 2007)
[16] http://www.savi.com (last visited December 9, 2007)
[17] http://www.smartcodecorp.com (last visited December 9, 2007)
[18] http://www.synometrix.com (last visited December 9, 2007)
[19] http://www.tagmaster.com (last visited December 9, 2007)
[20] http://www.ubisense.net (last visited December 9, 2007)
[21] http://www.wherenet.com (last visited December 9, 2007)

Table 3. Selected short range transmitters with features [own emphasis]

Tag name	**Tag feature as stated in the online datasheets**
AAiD AA-T800	"The AutoAccess AA-T800 Long Range Tags are designed for high value asset identifcation, real-time loss prevention, inventory management and tracking applications. [It features] low power consumption. Tag life is estimated at 5-7 years when transmitting *at 1.5 second intervals*." [32]
Aeroscout T3 Tag	"The AeroScout T3 Tag is the most advanced Wi-Fi based Active RFID tag on the market, from the market leader in the WI-FI-based Active RFID industry. The T3 Tag is a small, battery-powered wireless device for accurately locating and tracking any asset or person. [The *t]ransmission interval [is] programmable [from] 128 msec to 3.5 hours*." [33]
AXCESS ActiveTag Container Tag	"The AXCESS Container Tag provides a low cost solution for improving cargo container security, efficiency of movement and tracking capabilities while ensuring the integrity of the cargo within shipping containers. It uses the AXCESS ActiveTag™ RFID technology. […] Under normal conditions the container tag *will 'beacon'* to the AXCESS system, letting the system know the tag is still in place." [34]
Multispectral Model Sapphire Vision	"Multispectral Solutions' Sapphire VISION puts this unique technology to work for active RFID applications [with a t]ag battery life in excess of 5 years (*at one update per second*)." [35]
RF Code M100 Active RFID Tag	"RF Code designs and manufactures active Radio Frequency Identification (RFID) monitoring systems that utilize beacon tags that *periodically broadcast* their status using encoded radio transmissions. […] Every tag broadcasts its unique ID and a status message at a periodic rate (that is programmed at the factory). […] Motion activated tags can be programmed to operate at *2 beacon rates*: slow when the tag is stationary, and faster when the motion sensor is activated (to provide immediate notification when objects are moving)." [36]
RFID Inc. EXT1 Personnel Tag	"Our Extend-a-Read product is based on 433 MHz active (battery powered) anti-collision (read many simultaneously) Tags. Tags simply *emit a data signal every 1.8 to 2.2 seconds* which is picked up by the Reader." [37]
RFind active RFID Talon Tag	"The RFind active RFID Talon Tag is a core component of our 3-element 915MHz RTLS architecture. […] Battery Lifetime: 5 years @ *400 communication events per day*." [38]
SaviTag ST-656	"The SaviTag™ ST-656 is an innovative, data rich, active RFID tag for ISO containers, enabling shippers, carriers and logistics service providers to monitor their shipments in real-time as they move through the global supply chain. [One of the key features is the] UHF transmitter to transmit alarms, *beacon* and Savi Reader Interrogation Responses." [39]
SynoTag SMPTK-002	"Read Write Active RFID Tag with LED. [This] tag transmits *signal to reader every 300ms - 500 ms*." [40]

Table3. (*continued*)

Ubisense Compact Tag	"The Compact Tag is a small, rugged device that, when attached to assets and vehicles, allows them to be dynamically located to a precision of 15cm in 3D. [Power supply & battery life last o]ver 5 years at a continuous 5 second *beacon rate*." [41]
WhereTag III	"The WhereTag III is […] a small device that can be attached to assets of many kinds, [and i]t is used to manage those assets by allowing them to be identified and located by the system. The WhereTag III *'blinks' an RF transmission* at pre-programmed rates ranging from 5 seconds to one hour between blinks [with a] User Configurable Blink Rate of 5 sec to 1 hr." [42]

It is here argued that the RFID tags marketed by these suppliers are SRD. While all eleven tags contain a battery equally to the active RFID tags in the narrow sense referred to by Finkenzeller [11], Kern [16] and Bensky [2], the RFID tags by the providers listed in Table 3 continually and indiscriminately broadcast a signal to the environment. They blink at different intervals with beacon rates ranging from a few milliseconds to several hours. They have battery lifetimes of up to several years. To such extent they need neither the energy supply from the reader (section 3.1) nor do they broadcast by coupling (section 3.2). The active tags in the wide sense as listed in Table 3 have an independent energy supply and transmitter for broadcasting.

6 Discussion

Following the technical and legal outlines this section discusses the arguments supporting the claim why marketing SRD as (active) RFID tags might backfire on the RFID industry. It also sheds light why this strategy is unlikely to backfire on the SRD industry.

6.1 Backfire on the RFID Industry

Neither Dalal [5] nor various other legal authors accurately differentiate the types of RFID tags. It is argued in this paper that it will make a difference in the outcome of a court decision and in policy making whether the surveillance is with a passive RFID tag, an active RFID tag, or with a short range transmitter. By the definitions used in this analysis (details especially in section 3.1), the radio transmitting device used in United States v. Knotts [30] is a short range transmitter, not an RFID. To such extent the findings of SRD should not be and as argued herein are not applicable to active RFID in the narrow sense (see section 3).

People carrying RFID tags will generally fall within the protection of the Fourth Amendment as the Fourth Amendment protects people, not places. [15] RFID tags in the narrow sense as understood and advocated in this paper need power from the reader to transmit the information back to the reader. While people in public will generally expect other people to see where they go [30], it must remain a persons right of privacy (not) to disseminate information generally contained in an RFID tag, i.e. information that is not generally accessible by other people. As both passive and active RFID tags in the narrow sense need the energy of a reader to transmit data back to the reader, broadcasting the data is not possible without an antecedent manipulation by the reader. By contrast SRDs continually and indiscriminately transmit information contained in them in intervals to the environment. In the case of a SRD the person (deliberately) carrying the SRD will expect the environment to pick up the transmitted data and "searching" such data will thus not be unconstitutional under the Fourth Amendment.

On the one hand, eleven tag manufacturers and suppliers are marketing their short range transmitters as active RFID tags. The tags of these suppliers do not transduce the radio frequency of the reader. They have their own energy supply for broadcasting and have a transmitter to broadcast a signal in intervals indiscriminately to the environment. On the other hand, the legal community does not differentiate accurately between the different tag functionalities. If at all, it relies on Glover's understanding of functionality for passive, semi-passive/semi-active and active tags. This means that the legal community includes the self-dynamic functionalities of short range transmitters in their understanding and analysis of RFID. The legal analysis should differentiate between the tag functionalities but it does not. It is here argued that legally it makes a difference if the tag needs the reader's radio frequency for energy supply and broadcasting, or not.

In line with this argumentation the claim can be made that if the RFID industry keeps marketing their short range transmitters as RFID, the legal community might continue including such broad and self-dynamic device functionalities in its legal interpretation and analysis of RFID. The inclusion of broad SRD functionalities by the legal community in their interpretation, policy and decision making might lead to restrictive interpretation, use and limited legal acceptance of RFID. Why? Because if monitoring a beeper that broadcasts its signals in public is *not* unconstitutional under the Fourth Amendment and the legal community perceives SRD and RFID to be the same technology due to the marketing endeavours of the industry, then the privacy advocates might join forces to legally stop the implementation and deployment of RFID in order not to run the risk of having constitutional surveillance of RFID tags in the narrow sense without a warrant. Hence, the marketing strategy of riding on the trend wave of RFID might backfire on the RFID industry as the industry will need to follow (more) restrictive law and case decisions. The result might be restrictive implementation and deployment possibilities and therefore limited device and service sales.

6.2 Backfire on the SRD Industry?

Why should the lack of differentiation between RFID and SRD be a problem for the RFID industry and not for the SRD industry? Could the SRD industry not also suffer from the joint marketing of both technologies as RFID? Could marketing SRD as active RFID backfire on the SRD industry?

It has been argued that reading an (active) RFID in the narrow sense is more intrusive as compared to an SRD because it requires an antecedent manipulation by the reader to trigger the data broadcast. Consequently it could be argued that marketing SRD as RFID will have negative effect on the SRD industry (and not the other way around as stated in the previous section) because the more restrictive legal interpretation of RFID in the narrow sense could spill over to SRD and make the surveillance of SRD broadcasts unconstitutional without a warrant.

The following arguments disapprove such assumption: SRD is being marketed as RFID, not vice versa. Section 5.2 lists short range transmitters that are promoted as active RFID. The indiscriminate broadcasting of SRD merges into the RFID technology in the narrow sense, not vice versa. RFID is in focus, SRD is out of perception. What remains is the notion that short range transmitters are active RFID tags.

From a legal perspective the analysis in section 4.2 reveals that the majority of authors in the investigated legal articles use Glover's and not e.g. Finkenzeller's understanding of active RFID tags (in the narrow sense). Hence, they perceive the technology exactly as it has been promoted by the industry. So the legal community transposes the constitutional surveillance of a beeper as ruled in United States v. Knotts [30] into the RFID field and not vice versa.

For these reasons it is not anticipated that marketing SRD as active RFID will backfire on the SRD industry.

7 Conclusion

As has been consistently argued in this paper, marketing SRD as active RFID might backfire on the RFID industry. This leads to the following two conclusions:

1. The industry needs to clarify its terminology for SRD and RFID. The term SRD seems deceptive anyhow since it infers that the range is even shorter than with RFID (whereas in reality it is much longer). Furthermore the current marketing strategy of marketing SRD as active RFID (section 5.2) might need to be reconsidered.
2. The legal community needs to better differentiate both RFID and SRD technology. In order accurately analyse the technical and make distinguished legal recommendations and regulations the legal community must better understand the underlying technology.

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Object Recognition for the Internet of Things

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Abstract. We present a system which allows to request information on physical objects by taking a picture of them. This way, using a mobile phone with integrated camera, users can interact with objects or "things" in a very simple manner. A further advantage is that the objects themselves don't have to be tagged with any kind of markers. At the core of our system lies an object recognition method, which identifies an object from a query image through multiple recognition stages, including local visual features, global geometry, and optionally also metadata such as GPS location. We present two applications for our system, namely a slide tagging application for presentation screens in smart meeting rooms and a cityguide on a mobile phone. Both systems are fully functional, including an application on the mobile phone, which allows simplest point-and-shoot interaction with objects. Experiments evaluate the performance of our approach in both application scenarios and show good recognition results under challenging conditions.

1 Introduction

Extending the Internet to physical objects - the Internet of Things - promises humans to live in a smart, highly networked world, which allows for a wide range of interactions with this environment. One of the most convenient interactions is the request of information about physical objects. For this purpose several methods are currently being discussed. Most of them rely on some kind of unique marker integrated in or attached to the object. Some of these markers can be analyzed using different kinds of wireless near field communication (for instance RFID tags [24] or Bluetooth beacons [11]), others are visual markers and can be analyzed using cameras, for instance standard 1D-barcodes [2] or their modern counterparts, the 2D codes [21].

A second development concerns the input devices for interaction with physical objects. In recent years mobile phones have become sophisticated multimedia computers that can be used as flexible interaction devices with the user's environment. Besides the obvious telephone capabilities, current devices offer integrated cameras and a wide range of additional communication channels such as Bluetooth, WLAN or access to the Internet. People are used to the device they own and usually carry it with them all day. Furthermore, with the phone-number,

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a device is already tied to a specific person. Thus it is only natural to use the mobile phone as a personal input device for the Internet of things.

Indeed, some of the technologies mentioned above have already been integrated in mobile phones, for instance barcode readers or RFID readers. The ultimate system, however, would not rely on markers to recognize the object, but rather identify it by its looks, i.e. using visual object recognition from a mobile phone's camera image. Since the large majority of mobile phones contain an integrated camera, a significant user base can be addressed at once. With such a system, snapping a picture of an object would be sufficient to request all the desired information on it. While this vision is far from being reality for arbitrary types of objects, recent advances in the computer vision field have led to methods which allow to recognize certain types of objects very reliably and "hyperlink" them to digital information.

Using object recognition methods to hyperlink physical objects with the digital world brings several advantages. For instance, certain types of objects are not well suited to attach markers. This includes tourist sights, which are often large buildings and a marker might only be attached at one or few locations at the building, an experiment which has been attempted with the Semapedia project [1]. Furthermore, a user might want to request information from a distance, for instance for a church tower which is up to several hundred meters away. But even if the object is close, markers can be impractical. A barcode or RFID attached to the label of an object displayed in the museum would be difficult to access if the room is very crowded. Taking a picture of the item can be done from any position where it is visible. Furthermore, consistent tagging the objects is often difficult to achieve. One example are outdoor advertising posters. If a poster company wanted to "hyperlink" all their poster locations, they would have to install an RFID or bluetooth beacon in each advertising panel or attach a barcode to each of them, which requires a standardized system and results in costs for installation and maintenance. Another field of application are presentation screens in smart meeting rooms or information screens in public areas. The content displayed on the screen is constantly changing and it would be a involved process to add markers to all displayed content.

Using object recognition to interact with these objects requires only a database of images. That being said, object recognition does not come without restrictions, either. For instance, it is currently (and maybe always) impossible to discriminate highly similar objects, such as two slightly different versions of the same product in a store. Furthermore, efficient indexing and searching visual features for millions or billions of items is still a largely unsolved problem.

In this paper we present a method and system enabling the Internet of Things using object recognition for certain types of objects or "things". At the core of our server-side system lies a retrieval engine which indexes objects using scale invariant visual features. Users can take a picture of an object of interest, which is sent to the retrieval engine. The corresponding object is recognized and and an associated action is executed, e.g. a web-site about the object is opened. The

[1] http://www.semapedia.org

Fig. 1. The user "tags" a presented slide using our mobile application by taking a picture (left), which is automatically transmitted to the server and recognized (middle), a response is given in an automatically opened WAP browser (right).

system is completed with a client-side application which can be installed on a mobile handset and allows true point-and-shoot interaction with a single click.

We present two fully functional applications, which demonstrate the flexibility of the suggested approach. The first one is slide tagging in smart meeting rooms. Users have the ability to "click" on slides or sections of slides that are being presented to record them for their notes or add tags. The second application is a cityguide on the mobile phone. Users have the possibility to take a picture of a sight, send it to a recognition service, and receive the corresponding Wikipedia article as an answer. For this application, the search space is limited by integrating location information, namely cell-tower ids or GPS.

Both systems are experimentally evaluated in different dimensions, including different phone models with different camera qualities, for the trade-offs using different kinds of search space restriction (geographic location etc.), and with and without projective geometry verification stage.

The remainder of this paper is organized as follows: we start with an overview over related work in section 2. The main body of the paper is built around the two applications presented, namely hyperlinked slides for interactive meeting rooms in section 3 and hyperlinked buildings for a cityguide in section 4. Each of these sections discusses method and implementation, followed by an experimental evaluation of the respective system. Finally, conclusions and outlook are presented in section 5.

2 Related Work

Our method can be related to other works in several aspects. One aspect covers work related to our smart meeting room application, for instance the use of camera-equipped mobile phones as an interaction device for large screens. Here, Ballagas et al. have suggested a system [4] which allows users to select objects on large displays using the mobile phone. However, their method relies on additional 2D barcodes to determine the position of the camera and is meant to use the mobile phone like a computer mouse in order to drag and drop elements on the screen. Very recently, in [7] a system similar to ours has been proposed for recognizing icons on displays. While the screens are conceptually similar to the ones used in meeting rooms, we are not aware of any other work that has proposed using camera-equipped mobile phones for tagging or retrieval of slides in smart meeting rooms. The most similar works in that respect deal with slide retrieval from stationary devices. For instance, Vinciarelli et al. have proposed a system [23] which applies optical character recognition (OCR) to slides captured from the presentation beamer. Retrieval and browsing is done with the extracted text, i.e. the method cannot deal with illustrations or pictures in the slides. SlideFinder [18] is a system which extracts text and image data from the original slide data. Image retrieval is based on global color histograms and thus limited to recognize graphical elements or to some extent the global layout of the slide. Using only the stored original presentation files instead of using the captured image data does not allow to synchronize the slides to other meeting data such as recorded speech or video. Both systems are only meant for query-by-keyword retrieval and browsing from a desktop PC. While our system could also be used for off-line retrieval with query-by-example, we focus on tagging from mobile phones. This requires the identification of the correct slide reliably from varying viewpoints, which would not be possible with the cited approaches.

Another aspect that relates to our work are guiding applications on mobile devices. Bay et al. have suggested a museum guide on a tablet PC [5]. The system showed good performance in recognizing 3D exhibition objects using scale invariant local features. However, in their system the whole database resisted on the client device, which is generally not possible for smaller devices such as mobile phones and larger databases. A similar system on a mobile phone, but with somewhat simpler object recognition is the one proposed in [12]. The suggested recognition relies on simple color histograms, which turns out not to be very robust to lighting changes in museum environments. Discriminating instances of the objects in our applications, namely slides or outdoor images of touristic sights, is even less reliable with global color histograms.

The work most similar to our city guide application is maybe [20]. Similar to the cityguide application presented in this paper, the authors also suggest a cityguide on a mobile phone using local features. However, their focus is on improving recognition capabilities using informative and compact iSift features instead of SIFT features. Our work differs significantly in several points: we use multiple view geometry to improve recognition, we rely on SURF features (which are also more compact and faster than SIFT features), and we also investigate

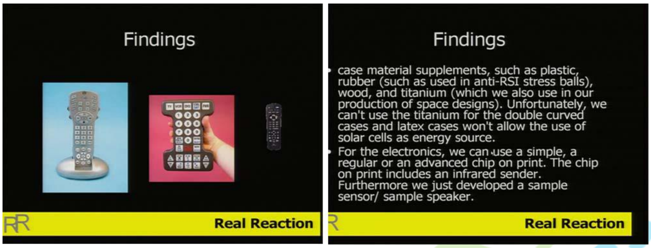

Fig. 2. Typical presentation slides from the AMI corpus [8] database

numerically the effects of restriction by GPS or cell ids on the recognition rate and matching speed. That is, instead of improving the features themselves, we add a global geometry filter as a final verification stage to the recognition system. Finally, the test databases we propose contains images taken from viewpoints with much larger variation than the databases used in [20].

The main contributions of this work are thus: a full object recognition system pipeline, including a server side recognition server and a client side software for single-click interaction with the environment; a complete object recognition pipeline for the Internet of Things, which starts with local feature correspondences, verification with projective geometry, and search space restriction by multimodal constraints, such as GPS location; the implementation evaluation for two sample applications, namely slide tagging and bookmarking in smart meeting rooms, as well as a cityguide application for the mobile phone; last but not least, for both cases the evaluation on challenging test datasets.

3 Hyperlinked Slides: Interactive Meeting Rooms

Today's meeting rooms are being equipped with an increasing number of electronic capturing devices, which allow recording of meetings across modalities [1,3]. They often include audio recording, video recording, whiteboard capturing and, last but not least, framegrabbing from the slide projector. These installations are usually deployed to facilitate two tasks: allowing off-line retrieval and browsing in the recorded meeting corpus and turning the meeting rooms into smart interactive environments. In the work at hand, we focus on the captured presentation slides which are a central part of today's presentations. As shown in figure 2, the slides usually contain the speaker's main statements in written form, accompanied by illustrations and pictures, which facilitate understanding and memorizing the presentation. Indeed, the slides can be seen as the "glue" between all the recorded modalities. Thus, they make a natural entry point to a database of recorded presentations.

A typical usage scenario for our system is as follows: Using the integrated camera of her mobile phone, an attendee to a meeting takes a picture of a slide which is of interest to her. The picture is transmitted to a recognition server over a mobile Internet connection (UMTS, GPRS etc.). On the server, features are extracted from the picture and matched to the database of captured slides. The correct slide is recognized, added to the users personal ”bookmarks”, and she receives a confirmation in a WAP browser on her mobile phone. Note that the messaging from the phone can be done using standard MMS or using a custom client-side application which we programmed in C++ on the Symbian platform. Figure 1 shows screenshots of our mobile application for a typical usage scenario.

Back at her PC, the user has access to all her bookmarked slides at any time, using a web-frontend which allows easy browsing of the slides she bookmarked. From each bookmarked slide she has the possibility to open a meeting browser which plays the other modalities, such as video and audio recordings, starting at the timepoint the slide was displayed. By photographing only a section of a slide, the user has also the possibility to highlight certain elements (both text or figures) - in other words, the mobile phone becomes a digital marker tool.

Please note that one could assume that a very simple slide bookmarking method could be designed, which relies only on timestamping. The client-side would simply transmit the current time, which would be synchronized with the timestamped slides. Our system does not only allow more flexible applications (the beforementioned ”hightlighting” of slide elements) but is robust towards synchronization errors in time. In fact, using a ”soft” time restriction of some minutes up to even several hours, would make our system more scalable and unite the best of both worlds.

The basic functionality of the proposed slide recognition system on the server is as follows: for incoming queries, scale invariant local features are extracted. For each feature a nearest neighbor search in the reference database of slides is executed. The resulting putative matches are verified using projective geometry constraints. The next two subsections describe these steps in more detail.

3.1 Slide Capturing and Feature Extraction

We start from a collection of presentation slides which are stored as images. This output can be easily obtained using a screen capture mechanism connected to the presentation beamer. From the image files, we extract scale invariant features around localized interest points. In recent years significant progress has been made in this field and has led to a diverse set of feature extraction and description methods [16,6,17], which have been successfully applied in domains such as video retrieval [22], object class recognition [15] etc. It turns out that such local features cannot only be used to describe and match objects and scenery, but work also reliably for text such as license plates [9]. Thus, this class of features is a good choice for description of the slide content which contains both text and visual data such as pictures and charts. Furthermore, as opposed to global features proposed in [18,12] they also allow the user to photograph specific sections or elements of a slide as a query to our system. In our implementation we use the publicly available SURF [6] detector and descriptor combination. This choice was motivated by the fast computation times and competitive recognition performance shown in [6]. The output of the SURF detector consists of 64-dimensional feature vector for each detected interest point in an image.

3.2 Slide Recognition System

The slide recognition approach consists of two steps: feature matching and global geometric verification. For the feature matching we compare the feature vectors from the query image to those of the images in the database. More precisely, for each 64-dimensional query vector, we calculate the Euclidean distance to the database vectors. A match is declared if the distance to the nearest neighbor is smaller than 0.7 times the distance to the second nearest neighbor. This matching strategy was successfully applied in [16,6,5,17].

Finding the best result could now be done by just selecting the query-database pair, which receives the highest number of matches. However, without verification of the geometric arrangement of the matched interest points, the wrong query-database pair may be selected. This is particularly true in our case, where we have a high number of matches stemming from letters in text parts of the slides. These matches are all "correct" on the feature level, but only their consistent arrangement to full letters and words is correct on the semantic level.

To solve this problem, we resort to projective geometry. Since the objects (the slides) in the database are planar, we can rely on a 2D homography mapping [13] from the query image to a selected candidate from the database in order to verify the suggested matching. That is, the set of point correspondences between the matched interest points from query image $\mathbf{x}_i^q$ and database image $\mathbf{x}_i^d$ must fulfill

$$H\mathbf{x}_i^q = \mathbf{x}_i^d \; i \in 1 \ldots 4 \tag{1}$$

where H is the $3x3$ homography matrix whose 8 degrees of freedom can be solved with four point correspondences $i \in 1 \ldots 4$. To be robust against the beforementioned outliers we estimate H using RANSAC [10]. The quality of several estimated models is measured by the number of inliers, where an inlier is defined by a threshold on the residual error. The residual error for the model are determined by the distance of the true points from the points generated by the estimated H. The result of such a geometric verification with a homography is shown in Figure 6.

3.3 Experiments

For our experiments we used data from the AMI meeting room corpus [8]. This set contains the images of slides which have been collected over a extended period using a screen-capture card in a PC connected to the beamer in the presentation room. Slides are captured at regular time intervals and stored as JPEG files. To be able to synchronize with the other modalities (e.g. speech and video recordings), each captured slide is timestamped.

To create the ground truth data, we projected the slides obtained from the AMI corpus in our own meeting room setting and took pictures with the integrated camera of two different mobile phone models. Namely, we used a Nokia N70, which is a high-end model with a 2 megapixel camera, and a Nokia 6230, which is an older model with a low quality VGA camera. We took 61 pictures

Fig. 3. Examples of query images, from left to right: with compositions of text and image, taken from varying viewpoints, at different camera zoom levels or may contain clutter, example which select a specific region of a slide, or contain large amounts of text.

with the N70 and 44 images with the Nokia 6230 [2]. Figure 3 shows some examples of query images. The reference database consists of the AMI corpus subset for the IDIAP scenario meetings, which contains 1098 captured slide images.

We extracted SURF features from the reference slides in the database at two resolutions, 800x600 pixels and 640x480 pixels. For the 1098 slides this resulted in $1.02 * 10^6$ and $0.72 * 10^6$ features, respectively. For the SURF feature extraction we used the standard settings of the detector which we downloaded from the author's website.

The resolutions of the query images were left unchanged as received from the mobile phone camera. We ran experiments with and without homography check, and the query images were matched to the database images at both resolutions. A homography was only calculated if at least 10 features matched between two slides. If there were less matches or if no consistent homography model could be found with RANSAC, the pair was declared unmatched. If there were multiple matching slides, only the best was used to evaluate precision. Since the corpus contains some duplicate slides, a true match was declared if at least one of the duplicates was recognized.

Table 1 shows the recognition rates, for the different phone models, different resolutions and with and without homography filter. At 800x600 resolution, the homography filter gives an improvement of about 2% or 4% for each both phone type, respectively. The recognition rate with a modern phone reaches 100%, the lower quality camera in the older 6230 model results in lower recognition rates. The results for the 640x480 database confirm the results of the 800x600 case, but achieve overall lower recognition scores. This is due to the fact, that at lower resolution fewer features are extracted.

4 Hyperlinked Buildings: A Cityguide on a Mobile Phone

The second scenario we present in this paper deals with a very different kind of "things". We "hyperlink" buildings (tourist sights etc.) to digital content. Users

[2] The query images with groundtruth are made available for download under http://www.vision.ee.ethz.ch/datasets/.

Table 1. Summary of recognition rates for slide database

	Prec. with Geometry Filter		Prec. without Geometry Filter	
	800x600	640x480	800x600	640x480
Nokia N70	100%	98,3%	98,3%	96,7%
Nokia 6230	97,7%	93,2%	91%	86,3%

can request information using an application on their mobile phone. The interaction process, the software and user interface are very similar to the meeting room scenario. However, this time the number of objects is nearly unlimited, if the application is to be deployed on a worldwide basis. To overcome the resulting scalability problems, we restrict the search space geographically. That is, we restrict the visual search to objects in the database, which lie in the geographic surroundings of the user's position.

In the following sections we describe this approach in more detail and evaluate its performance.

4.1 Visual Data and Geographic Location

From the user perspective, the interaction process remains the same as in the meeting room scenario: by the click of a button on the mobile phone, a picture is taken and transmitted to the server. However, unlike in the meeting room application, the guide client-side application adds location information to the request. This information consists of the current position read from an integrated or external (bluetooth) GPS device and of the current celltower id the so called CGI (Cell Global Identity).

This combination of a picture and location data forms a perfect query to search for information on static, physical objects. As mentioned before, location information alone would in general not be sufficient to access the relevant information: the object of interest could be several hundred meters away (e.g. a church tower), or there could be a lot of objects of interest in the same area (e.g. the St. Mark's square in Venice is sourrounded by a large number of objects of interest). Furthermore, in urban areas with tall buildings and narrow roads, GPS data is often imprecise. On the other hand, relying on the picture only would not be feasible either: the size of the database would make real-time queries and precise results very difficult to achieve.

After the query has been processed, the user receives the requested information directly on the screen of her mobile phone. In our demo application we open a web browser with the Wikipedia page corresponding to the object. This is illustrated in Figure 4.

4.2 System Design

The cityguide system consists of a server side software and a client-side software on the mobile phone.

Fig. 4. Client software for the cityguide application: the user snaps a picture, waits a few seconds, and is redirected to the corresponding Wikipedia page

The server side elements consist of a relational database for storage of image metadata (GPS locations, cell information etc.) and information about the stored sights. We used mySQL for this purpose. The image recognition is implemented as a server in C++ which can be accessed via HTTP.

Queries from the client-software are transmitted to the server as HTTP POST requests. A middleware written in PHP and Ruby restricts the search by location if needed and passes this pre-processed query to the recognition server. The associated content for the best match is sent back to the client software and displayed in an automatically opened browser, as shown in figure 4.

Client software on the mobile phone was implemented both in Symbian C++ and Java[3]. Note that the feature extraction of the query happens on the server side, i.e. the full query image is transmitted to the server. It is also possible to extract SURF features on the mobile phone and then transmit them as a query to the server. An implementation of this method showed, that SURF feature extraction on the phone is currently too slow: our un-optimized version in Symbian C++ on a Nokia 6630 required about 10 seconds to calculate the query features. In contrast, on a modern PC SURF feature extraction takes a few hundred ms [6]. Since the SURF features are not much more compact than the original image (several hundred 64 dimensional feature vectors per image), the main advantages of feature extraction on the phone would be increased privacy (only features transmitted instead of image) and the possibility to give a user

[3] Unfortunately, only the Symbian version allows access to the celltower ids.

instant feedback if a query image contained too few features, for instance due to blur, lack of texture, or low contrast due to back light.

Alternatively our system can also be accessed using the Multimedia Message Service MMS. A picture is transmitted to the server by sending it as an MMS message to an e-mail address. The response (Wikipedia URL) is returned as an SMS message.

4.3 Object Recognition Method

The data from the client-side application are transmitted to the recognition server, where a visual search restricted by the transmitted location data is initiated. If GPS data is used, all database objects in a preset radius are searched (different radii are evaluated in the experimental section of this paper). If only cell-tower information is used, the search is restricted to the objects annotated with the same CGI string.

The object recognition approach is very similar to the method discussed for the meeting room slides. That is, putative matches between pairs of query and databases images are found by nearest neighbor search for their SURF [6] descriptors. These putative matches are validated with a geometry filter. However, since we deal with 3-dimensional objects in the cityguide application, the precise model is now the $3x3$ Fundamental matrix F instead of the Homography matrix H [13]. The Fundamental matrix maps points in one image to epipolar lines another view. Residual errors for the models are thus determined by the distance of the true points from the epipolar lines generated by the estimated F [13].

From a practitioners point of view, for objects such as buildings which consist basically of multiple planes (facades) one can approximate the results by using a homography nevertheless, which requires less point correspondences. The estimation of the model from putative point correspondences can be done with RANSAC [10] in both cases.

Note that the model is particularly important to filter out false positive recognitions: Especially on structures on buildings, there are a lot of repeated patterns which match between different buildings. Only their correct arrangement in space or the image plane, respectively allow for a robust decision if an object was truly detected. Simply setting a threshold on the number matches is dangerous particularly, since discriminating a false positive recognition (e.g. a query image of an building which is not even in the database) from a query with few matches due to challenging conditions (e.g. image taken from a distance) is infeasible.

4.4 Experiments

To evaluate the proposed method, we collected a database of 147 photos covering 9 touristic sights and their locations. The 147 images cover the 9 objects from multiple sides, at least 3 per object. The database images were taken with a regular point-and shoot camera. To determine their GPS location and CGIs (cell tower ids) we developed a tracker application in Symbian C++ which runs on a mobile phone and stores the current GPS data (as obtained from an external bluetooth GPS device) and CGI cell information at regular time intervals. This log is synchronized by timestamps with the database photos.

We collected another 126 test (query) images, taken with different mobile phones (Nokia N70 and Nokia 6280, both with 2 Megapixel camera) at different days and times of day, by different users and from random viewpoints. Of the 126 query images 91 contain objects in the database and 35 contain images of other buildings or background (also annotated with GPS and cellid). This is an important to test the system with negative queries, an experiment which has been neglected in several other works. Compared to the MPG-20 database [4] we have fewer object but from multiple sides (in total about 30 unique representations), more challenging viewpoints for each side (distance up to 500 meters), full annotation with both GPS data and celltower ids, and more than 4 times as many query images. The database with all annotations (GPS, cellids, objects Wikipedia pages etc.) is available for download under [5]. Both database and query images were re-scaled to 500x375 pixels. (Sample images from the database are visible in Figure 7 and are discussed a few paragraphs below).

Note that the CGI (Cell Global Identity) depends on the network operator, since each operator defines its own set of cell ids. If the operator does not release the locations of the cells (which is common practice in many countries for privacy reasons), we have to find a mapping between the cellids of different operators. We achieved such an experimental mapping by using our tracker application: tracks obtained with SIM cards of different mobile network operators were synchronized by their GPS locations: if GPS points were closer than 50m a correspondence between the respective cell-ids was established. This mapping is far from complete, but it simulates an approach which is currently followed by several initiatives on the Web.

We present experiments for three scenarios: linear search over the whole database without location restriction, restriction by GPS with different search radii, and restriction by cellid. For all cases we compare the trade-off between search time and recognition rate. A pair of images was considered matched, if at least

Table 2. Summary of recognition rates for cityguide

	Prec. with Geometry Filter		Prec. without Geometry Filter	
	Rec. rate	Avg. Matching Time	Rec. rate	Avg. Matching Time
Full database linear	88%	5.43s	67.4%	2.75s
GPS 300m Radius	89.6%	3.15s	76.1%	1.62s
Cell id	74.6%	2.78s	73%	1.34s

20 features matched. From the images which fullfiled this criterion the one with the most matches was returned as a response. Table 2 summarizes the results.

[4] http://dib.joanneum.at/cape/MPG-20/

[5] http://www.vision.ee.ethz.ch/datasets/

For the baseline, linear search over the whole database without geometry filter we achieve 67.4% recognition rate. This value is outperformed by over 20% with the introduction of the geometry filter, resulting in 88% recognition rate. This is due to the removal of false positive matches. However, the improved precision comes at a price in speed.

Restricting search by GPS position with a radius of 300 meters is about 40% faster while increasing precision slightly for the case with geometry filter and more substantially for the case without filter. Restriction by celltower CGI is slightly faster but significantly worse in precision. This seems mostly due to the fact, that our CGI correspondences for different operators might be incomplete. For a real world application where an operator would hopefully contribute the cell-id information or a search radius bound by GPS coordinates we would thus expect better results.

Overall the best results are achieved with GPS and a rather large radius of several hundred meters. In figure 5 we plot the precision versus time for different radii. At 100 meters we retrieve most of the of the objects correctly, but only between 300 and 500 meters we achieve the same recognition rates as for linear search, however at significantly higher speed. In fact, this speed-up over linear search will obviously be even larger, the more items are in the database. The recognition times can be further sped up with a suitable indexing structure such as [14,19]. We have compared several methods, however the results are preliminary and beyond the scope of this paper.

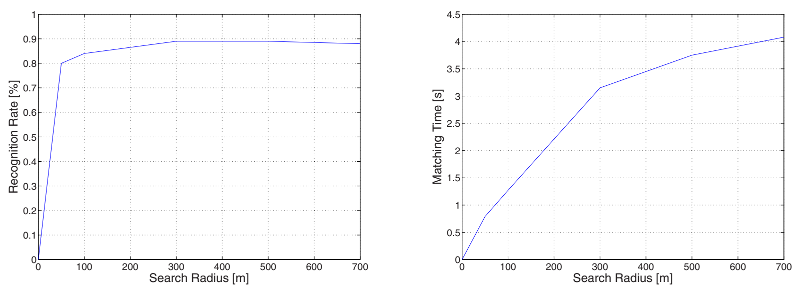

Fig. 5. Recognition rate (left) and matching time (right) depending on radius around query location

Visual results are shown in Figure 7. Section (a) shows query images in the left column and best matching database images for each query in the right column. Note the distance of the query image to the database image in the first row and the zoom and low contrast of the query in the second row. Section (b) contains a query image at the top and the best database match at the bottom. Besides the viewpoint change and occlusion through the lamp and railing, note that query and database image have very different clouds and lighting since they were taken several weeks apart. Section (c) shows an other query database pair, this time for a facade with strong cropping and change of angle. The last image in section (d)

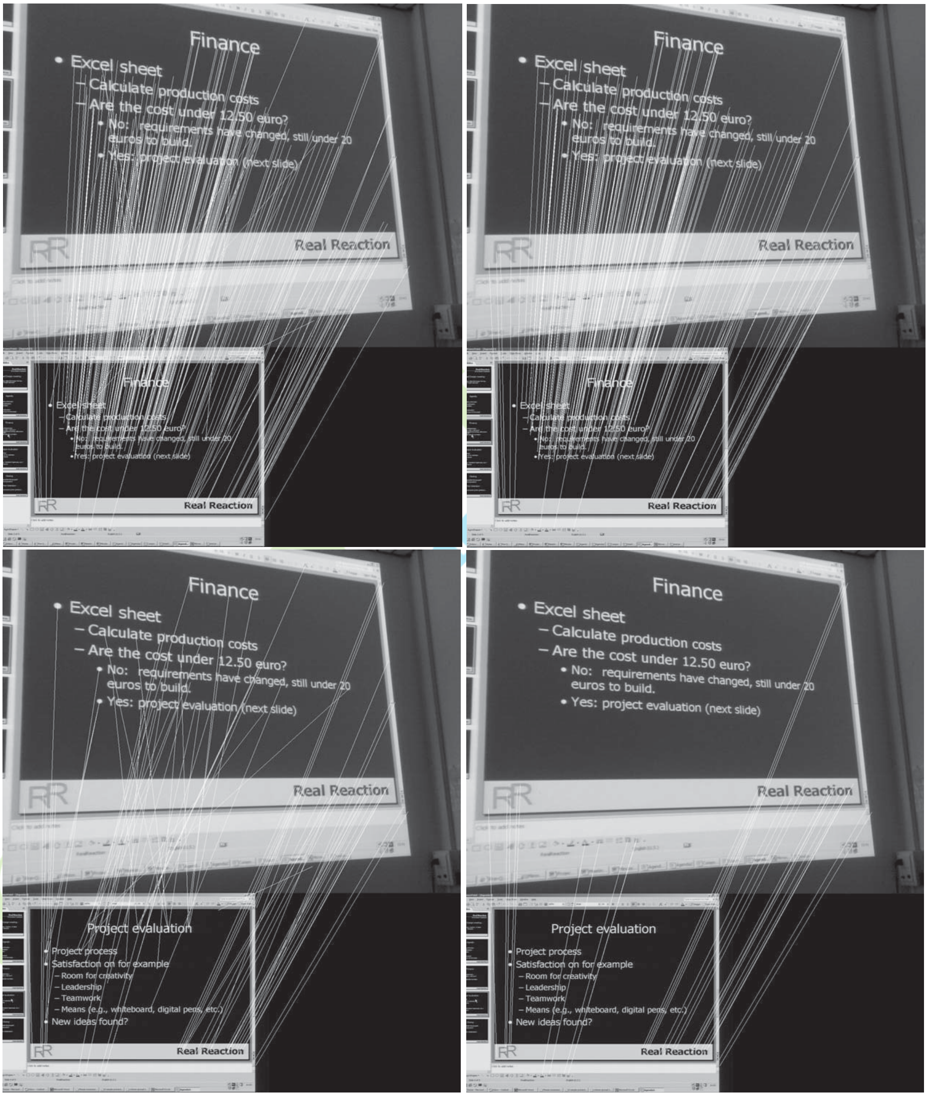

Fig. 6. Geometric verification with a homography. Top rows: matches for a query image with the correct database image. Top left: before homography filter, top right: after homography filter. As the match between the slides is correct most of the putative feature matches survive the homography filter. At the bottom rows we match the same image to a false database image. As can be seen at the bottom left, a lot of false putative matches would arise without geometric verification, in extreme cases their count can be similar to or higher than for the correct image pair. At the bottom right all the false matches are removed, only features from the (correctly) matching frame survive and the discriminance to the correct pair is drastically increased.

Fig. 7. Result images for the city-guide application, see text for details

contains a typical "negative" query image, which should not return any matching object.

The results highlight the qualities of the suggested approach: the geometry filter improves recognition rates drastically. Restricting search to a geographic radius of a few hundred meters increases speed significantly even in our test database and will be essential for large-scale real world applications. At the same time, the results show that relying only on GPS information (objects up to several dozen meters away) would not be suitable for a real-world guiding application. Being able to "select" the objects with their mobile phone brings significant usability benefits to the user.

5 Conclusions and Outlook

We have presented an approach for object recognition for the Internet of Things, which allows users to request information on objects by taking a picture of them. We have implemented and demonstrated a full system and evaluated its capabilities in two challenging scenarios: slide tagging and bookmarking from screens in smart meeting rooms and a cityguide on a mobile phone. For both applications a server side object recognition system executes the following pipeline: local features are extracted from an incoming image. The features are matched to a database, where the search space is optionally restricted by metadata delivered with the request, for instance by geographic location from GPS coordinates or celltower ids. The resulting candidate matches are verified with a global geometry filter. The system is completed with a client-side software, which transmits query image and metadata such as GPS locations to the server with a single click.

We have demonstrated the flexibility of the suggested approach with an experimental evaluation for both sample applications. To that end, the system was evaluated on two very challenging test datasets. Building on local features and boosting the recognition rate with a geometry filter we achieved very high recognition rates. This approach worked well for both matching of slides with large amounts of text and images of tourist sights from strongly varying viewpoints which underlines the flexibility of the proposed approach. For the especially challenging cityguide application we could find a good balance between performance and recognition rate by restricting the search space using GPS location information.

The results showed, that the Internet of Things by object recognition can be realized already today for certain types of objects. In fact, the system can be seen as a visual search engine for the Internet of Things. Relying just on an image sent from a mobile phone, the system can be easily adopted by both end-users and system providers. With the advance of computer vision methods, we expect a wealth of additional possibilities in the coming years.

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