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Experiences from interaction design for NFC applications

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Abstract. Linking things in the physical world with related digital resources and content in the virtual world is one of the visions of ubiquitous computing. Radio frequency identification tags, more specifically NFC tags, attached to the things and places in the physical world and using personal mobile devices equipped with readers to access the services and information associated to the tags, is studied in this paper. Eight trials representing different applications are described and the results of user experiments are reported. The main design findings are as follows: the standard size of the tag may be too limiting, we should allow tags of different visual appearance, form and size; the spatial positioning of tags in the physical interaction space gives a designer a lot of freedom but may also pose the risk of inconsistent and haphazard designs; complexity of the interaction task may be divided between using menus and keys of the personal device or using multiple tags; consistent and prompt feedback is important, feedback should use suitable modalities, including haptic feedback; the service or information provided should exploit location information, i.e. the place of the specific tag, and finally fallback plans for unoperational or broken tags should exist.

Keywords: Human Computer Interaction, RFID, NFC, physical browsing, mobile phone

1. Introduction

Visions of ubiquitous computing imply that computing resources are embedded into our everyday environment. Linking the objects in the physical world with the digital resources and content is essential for realising this vision. This link can be seen as the bridge between the physical and digital worlds, making the digital (virtual) world aware of the real world and providing access to the information and services of the digital world [14,18,29]. We refer to a user paradigm which links physical objects to digital devices and services by natural interaction, such as touching and pointing, by the name *physical browsing* [3,5,28].

This paper discusses a set of applications relying on a touch-based user interface paradigm, which combines explicit intentions of the user expressed by the touching of a 'tag' and the information or services available in that location where the tag resides. The applications that were implemented as research constructs have been evaluated in realistic field settings with trial users. As a result of studying user experiences within the trials, a synthesis of findings related to interaction design for touch-based interaction paradigm is presented.

This paper is organised as follows. The concept of physical browsing is presented and discussed and then Near Field Communication (NFC) technology, which is widely used in our set of application trials, is introduced in Section 2. The research methods are described in Section 3, and the application trials which constitute the field studies of this research are presented in Section 4. Design findings from the trial cases are given in Section 5, while Section 6 identifies the limitations and generalisability of the results. Finally, we conclude the paper by discussing the potential and limits of touch-based user interaction in Sections 7 and 8. Analyses of business logic and tag capabilities are left for future work.

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2. Physical browsing and NFC

In this section, we first discuss physical browsing in relation to similar concept of physical mobile interaction [7,26], examine possible technologies for physical browsing, and then describe Near Field Communication, i.e. NFC technology, used in the application trials of this research.

The concept of physical selection and physical browsing were coined in [3,28]. Physical selection was described as extending the selection (usually done by a pointing device on a display) to the real world by means of a pointing action and "by initiating a service by real-world selection action continued by interaction using mobile terminal" [28]. The concept was refined in [4,5] where it was defined as "a sequence of actions taken by the user to select an object with a mobile terminal within the physical environment". The potential of NFC technology for implementing the physical browsing paradigm was studied in [4]. Physical selection includes three usage paradigms: pointing, touching and scanning, which can be best implemented with various technologies, i.e. optical, RFID and radio technology. A mobile personal device – in practice a mobile phone – is seen as a crucial enabler for physical selection.

The concept of physical mobile interaction [7,26,30] was defined [27] to describe such interaction styles in which the user interacts with a mobile device and the mobile device interacts with smart objects in the real world. A smart object can be a real world object, a person or even a location. The usage of physical mobile interactions simplifies the discovery and use of mobile services, enables new kinds of object-, person- or location-based applications, and removes several limitations of mobile devices. The most important and widespread physical mobile interaction techniques are identified as touching, pointing, scanning and user-mediated object interaction.

The concepts of physical selection/browsing and physical mobile interaction are similar in three main aspects – namely, both emphasize interaction between user and the real world as opposed to interaction between the user and digital device; both recognize touching, pointing and scanning paradigms; and both see mobile personal devices, i.e. mobile phones, as the means for interaction between the user and the real world. Physical mobile interaction is a wider concept than physical selection/browsing.

2.1. Physical browsing vs. context recognition based automatic decision making

Context awareness can be seen as a way to automatically make some of the decisions users are accustomed to do themselves. Developing context aware intelligent systems is seen as crucial for the realisation of Ambient Intelligence vision [2]. Yet, current context recognition approaches have been identified to have drawbacks and errors in recognizing the context correctly. Furthermore, probabilistic assumptions about the user's intentions and needs have been considered problematic when trying to correctly recognize users' context [10]. So, instead of pursuing artificial intelligence such as automatic operation, we should aim at providing the user with easy and intuitive ways for accessing information and services while at the same time maintaining the feeling of being in control. The need for easy and natural interaction with technology is especially crucial in mobile and ubiquitous computing settings where the user must divide her attention.

Explicit touch-based interaction is a promising approach, since it leaves the decision of selection and use of a service within a context to the user. Thus, in the case of physical browsing, the reasoning and decisions are made by the user, based on the cues provided by the place and context where the tag is located. They should provide all necessary information the user needs in order to understand which services the tag offers and what action is initiated by touching the tag. The physical browsing paradigm allows connecting the physical world with the digital world via tags. Tags can be used for direct access to the services and information without the need for browsing menus, typing addresses or using search engines.

2.2. Alternative methods of physical browsing

Rukzio and coworkers have identified typical situations and scenarios in which various techniques of physical browsing – that is, touching, scanning and pointing – might be useful [26]. They developed and evaluated, within a user study, a low-fidelity and a high-fidelity prototype to assess scanning, pointing and touching interaction techniques within various contexts. The touch-based paradigm as a means of bridging the physical and digital worlds was analysed [5] and an experiment where elderly people used mobile phone-based physical browsing for ordering

their meals was studied [11,12,15]. Riekki and coworkers have studied the use of visual tags in an office setting [25].

2.3. Application categories

We have identified the following application categories for physical browsing.

- Information retrieval [5,18,20,25]. The information retrieval may be location- and situation-independent – such as reading a web address from an advertisement poster – or it can be location or item specific, such as finding the time tables or next arrivals information at a specific bus stop.
- Value transactions [17,23]. This application category consists of two main types: ticketing and payment. Ticketing refers to applications such as mass transit, sport events, concerts and movies, where the value is usually prepaid and usable only for limited and *a priori* known services. Mobile ticketing with augmented posters was experimented in PERCI project [8]. Payments are more general and can be seen substituting both cash-based and debit card-based (small) payments in cafeterias, kiosks, and shops. Mobile payment and ticketing has been considered as the potential "killer application" for NFC technology. Some researchers see potential for great changes in the payment infrastructure in developing countries, where the users can skip the debit and credit card phase as well as bank transfers, and substitute cash directly with NFC and mobile phone-based money transactions.
- Initiating action. Many digital and physical operations can be initiated and even controlled using a physical browsing paradigm. Simple examples include initiating a phone call by touching a business card [20] or a person's photo – both equipped with a computer readable tag – or ordering a taxi to a certain place by touching a special service tag [5]. The uploading of photos from a camera to a home server can be initiated easily by touching the home PC with the camera, if both are NFC-equipped [17]. This is also an example of peer-to-peer application where no commercial partner is – at least directly – involved.
- Creating social networks. We can envisage using physical browsing paradigm for establishing a digital link between persons who have established a similar link in the real world – for example, people meeting in a business meeting or in a bar. The generation of digital links in the real world (by touching) is something between the traditional means of networking (face-to-face) and web-based networking, such as Facebook or LinkedIn.

Herting and Broll [13] suggests categorisation of physical mobile applications according to common functionalities into the presentation of information, physical hyperlinks, tagging, broadcasting, tag emulation and 2-way interaction. Categorisation presented in this paper comes more from end-user perspective or purpose, while Herting and Broll emphasise the functionalities of the applications.

2.4. Alternatives for implementing physical browsing

Physical objects can be linked to digital information or services by augmenting them with some kind of tag and equipping the user with corresponding reader device. The three main options for implementing the linking are visual codes, infrared communication and electromagnetic methods. Wired communication methods are not considered here, since they require clearly more actions from the user than the physical selection a paradigm implies. Mobile devices currently support – at least to some extent – all of these alternatives: cameras in smart phones can be used for reading visual tags; IrDA connectivity is supported by smart phones and PDAs; Bluetooth or wireless local area network (WLAN) are included in high-end smart phones and PDAs. Furthermore, some mobile phones support RFID connectivity in the form of NFC, and it is anticipated that this feature will come into many mobile devices in the near future.

The most interesting methods for implementing the linkage between physical objects and digital information or services are shown in Table 1. The Table shows that the various technologies have highly deviating characteristics in tag cost, power consumption, and flexibility of information contained in the tag and ease of use. Furthermore, the technical maturity and market penetration of the reading devices vary. Depending on the application, various tag and reader technologies may be found most suitable. For example, visual codes are suitable for cases where very low cost and dispensable tags are required and unidirectional fixed tag content is sufficient. A typical case would be advertisements in newspapers with the address of the product's website coded in the vis-

Table 1
Comparison of potential commercial technologies for linking physical and digital. * = with battery (modified from [5])

	Visual code	IrDA	RFID, inductive	RFID, UHF	Bluetooth
Selection concept	Pointing (Touching)	Pointing	Touching	Scanning, (Pointing, Touching)	Scanning
Data transfer type	unidirectional	bidirectional	unidirectional (bidirectional)	unidirectional (bidirectional *)	bidirectional
Data rate	medium	high	medium	low-medium	high
Latency	short	medium	short	short	long
Typical operating range	short-long	medium (long)	short (medium*)	medium-long	long
Data storage type	fixed	dynamic	fixed (dynamic)	fixed (dynamic*)	dynamic
Data storage capacity	limited	not limited	limited (not limited*)	limited (not limited*)	not limited
Data processing	none	yes	no (some)	limited (not limited*)	yes
Unit costs	very low	medium	low	low	medium-high
Power consumption	no	medium	no (low*)	no (low*)	medium-high
Interference hazard	no	medium	low-medium	medium-high	medium-high
Support in PDAs or mobile phones	yes (camera phones)	yes	some (NFC)	no (separate reader device)	yes
Ease of use	poor-medium (needs aiming)	poor-medium (needs aiming)	good	medium	low (needs pairing)

ual tag. When a more robust tag with very easy use is needed, an inductive RFID such as NFC is a good choice.

2.5. NFC technology

Near Field Communication (NFC) is a new, short-range wireless connectivity technology that evolved from a combination of existing contact-less identification and interconnection technologies. Products with built-in NFC are considered to simplify the way consumer devices interact with one another. In addition to that, NFC helps people to receive and share information and securely pay with a mobile phone.

NFC is both a “read” and “write” technology. Communication between two NFC-compatible devices occurs when they are brought within four centimetres of one another: a wave or touch can establish an NFC connection. The underlying layers of NFC technology follow universally implemented ISO, ECMA, and ETSI standards. Technically, NFC operates at 13.56 MHz and transfers data at up to 424 Kbits/second.

NFC can be used with a variety of devices, from mobile phones that enable payment or transfer information to digital cameras that send their photos to a TV set by means of touch [21]. Furthermore, it is expected that NFC will make accessing new media and content services more intuitive.

3. Research method and process

The research presented in this paper has been organised to follow the principles of the Research Through Design method [31]. The method proposes three inputs:

- field data: in our cases, all application concepts were defined by and with the end user organizations,
- technology: the starting point for all application concepts was to utilize the possibilities of NFC-technology, i.e. NFC-enabled devices and tags,
- theories and models: other models about user needs and conditions where the concept would be placed.

As the Research Through Design method proposes, the goal was not to construct applications and services that would be commercially viable as such, but to create design knowledge that could be used by practitioners for designing and implementing new NFC based concepts. However, our research process used constructive research by actually implementing

Table 2
Trials of the research

Trial	Number of users/number of respondents (response rate)	Duration	Data gathering method
Access control	9/7 (77.8 %)	Approx. 5 months	E-mail attachment final questionnaire
Bus ticketing	270 (~90 %)	Approx. 6 months	Online questionnaire
KAMO – Mobile guide for the city traveller	Initial questionnaire: 20/20 (100%) Mid-term questionnaire: 20/20 (100%) Final questionnaire: 18/20 (90%)	two months	Paper questionnaires in the beginning of the trial, after one month of use, and after the trial Possibility for mobile feedback
Catering service for the elderly	9/9 (100 %)	Approx. 8 weeks	Semi-structured initial and final interviews / observation / diary
Restaurant	Initial questionnaire: 27/21 (77.8 %) Final questionnaire: 27/23 (85.2 %)	Approx. 5 weeks	Initial questionnaire / final online questionnaire / online feedback page
Public house	19/16 (84.2 %)	Approx. 6 weeks	Final online questionnaire / online feedback page
Theatre	141/101 (71.6 %)	Approx. 1,5 months (8 plays)	Online questionnaire after plays
Parking	Initial questionnaire: 51/41 (80.4 %) drivers Final questionnaire: 51/48 (94,1 %) drivers Initial and final questionnaires: 5/5 traffic wardens (100 %)	Approx. 8 weeks	Initial and final questionnaires (Online and paper-based) / 11 semi-structured interviews with drivers and a face to face feedback meeting with traffic wardens

the service constructions so that they could be evaluated and analyzed in real world settings in field trials. The field trials expose the technology under evaluation to an *in situ* setting, i.e. outside the laboratory and into the "real" world. Of course, the definition of "real" is relative and subjective. In experimental psychology, the goal of "experimental realism" is used for describing a research setup where the research setting is arranged in a way where the experiment has an impact on the participants, it forces the participants to take the matter seriously, and it involves them with the procedures under examination [6]. The evaluation settings described here can be said to aim at achieving high experimental realism.

4. Trials

This section gives an overview about the research trials. More details on the trials can be found in [4, 12, 15]. The general vision of using NFC-based mobile phones is that they provide one-touch connection to a service. Ticketing services [1] and payment solutions [22] have been seen as promising domains for NFC-based solutions. However, there is a large variety of other services that could benefit from the simplicity and controllability of touch as a user interface paradigm. This section explores the issues related to interaction design in a variety of different application domains. The applications and related field trials used as a basis of this research have been described in Table 2. The Table describes briefly the field trials, number of users that participated in a trial, duration of the trial, methods used for collecting experiences and findings on the trial.

The first two examples represent a simple service where the tag is touched once with the NFC reader-equipped mobile phone and some control for the user is provided through the software applications. The amount of control or logic depends on the domain specific needs: in the first trial, a pin code, or in the second one the information for bus ticketing. In the latter trial, the tag is inserted for the environment. The third one the elderly care service trial – shows how the application complexity has been externalized to a physical artifact, a selection table. Also, in restaurant and theatre trials, several tags are placed near each of the physical artifacts, in a menu and poster. These trials also involved characteristics of a ticketing and payment service. In a parking trial, tags are inserted in the city environment. In the street parking application, touch is extended by means of menus

Fig. 1. A card reader.

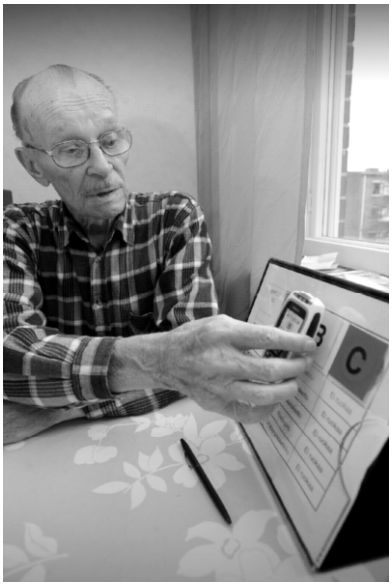

Fig. 2. A meal selection with an NFC-enabled mobile phone.

from a mobile application. In contrast, the use of a parking hall application is based solely on a single touch.

Access control trial. Door-locking is an example of an application which requires only a single 'touch'. Thus, a mobile device is a key to a space, such as an indoor sports hall, gym, etc. The background system of the lock makes all the necessary information exchange and verifies the user as the one allowed to access the space. Figure 1 presents a card reader which can also read an NFC phone.

NFC phone has a software application that holds the key issued by the property owner for the lock. It is possible to use a PIN code for the lock, which would result in further user interaction with the mobile device, i.e. keying the PIN code.

Bus ticketing trial. Bus ticketing is one of the most widely used NFC application examples. The following example is provided by RMV (Rhein-Main Vehrkersverbund). Especially interesting is that the tag is attached to the bus stop instead of reading the mobile phone in the bus.

At the bus stop, in order to purchase a ticket the customer has to touch the ConTag. With this single touch the customer's mobile phone reads travel-related data over short distances automatically out of the chips mounted at the bus stops. The ticketing program then launches automatically on the mobile phone and automatically identifies and displays the departure time and point – so users only have to select the desired type of ticket, choose their destination, and confirm the transaction. Within three clicks, the ticket is purchased.

KAMO – Mobile guide for the city traveller. An application called KAMO, mobile application targeted for city travellers provides online bus stop information [19]. Imagine that you are at the bus stop and you touch a NFC tag to access information as to when the next bus will arrive. KAMO also helps the user in route planning and gives location-specific timetable information on request.

The benefit of the bus stop tag is in that it is fairly inexpensive to attach on the advertisement wall at the bus stop. If the bus stop does not have a large online display, then the benefit is obvious: you get your information at that place at that time.

Elderly care trial. In elderly care, the problems are not in the technology but more in the way how technology presents itself to the subjects who are using it [15]. From the user interface design point of view, elderly people are very demanding. They may not have been using mobile phones at all – and if they have, they have used it for voice communication. Fig. 2 shows how a user interface has been designed for meal ordering. In order to create simplicity, the Table externalizes the choice. Naturally, it also could be created in the mobile phone software. The user has three choices to choose from: A) meal choice 1, B) meal choice 2 and C) no meal.

Fig. 3. A lunch order in a restaurant (Picture copyright: Juha Sarkkinen).

Fig. 4. Fetching information in a pub (Picture copyright: Juha Sarkkinen).

When bringing the phone close to the choice of the day, a software application opens and tells the person in large letters that A, B, or C was selected. If another choice is made later, it overrides the earlier choice. Thus, C can be used to cancel the meal.

Artifact, the menu table used for selection, externalizes part of the software functionality, thus making the selection, in principle, simpler for the user.

Restaurant trial. The restaurant trial comprises two different NFC-based applications, an order application and a payment application. A restaurant menu may look rather simple in the start but when we scrutinize the lunch menu the result may be surprising. A lunch menu turned into an NFC phone compatible restaurant selection table is shown in Fig. 3.

There are 10 tags in this selection table. After touching the table number tag, to identify the table, and launching the application, lunch orders can be collected into an application list in the phone. An order can include, for instance, a starter salad, and any main course choice from the table. The drink choices are soft drink, water, milk, and are selected from the software application menu inside the phone. Also, potato choices are built into the application.

The 'traditional' paper based menu was A5 size, and the 'tagged' menu is two A5s standing on tabletop opposite to each other. After the lunch, the payment occurs at the cash machine using the phone. When bringing the phone near the NFC reader device on the service desk, the reader device reads data from the NFC-enabled mobile phone. After this, the cashier must check that the identification number read corresponds with the meal selections.

Public house trial. In a public house trial [16], users had a possibility to check the presence of other trial users in a pub. A mobile application shows the nicknames of the "buddies" in a buddy list, if s/he has logged in by touching a 'log in' tag in the pub. Users were also asked to touch 'log out' tag when they left the pub, so that the information would be up-to-date. All users were logged out automatically when the pub was closed. Users were also provided with a possibility to check daily offers by touching a 'log in' tag.

Product tag stands, which provided information about various beers, were placed on the tables and on the counter of the pub. Product tag stands were similar to the info tag stands, which were also used in the other trials. The only difference was that product tag stands also provided information about the products (special beers) which were for sale in the pub. A user fetching information by touching a tag is shown in Fig. 4.

Theatre trial. There were several different NFC-based applications available for users in the theatre case [16]. An intermission refreshment order list in the theatre trial was very similar to the restaurant menu described above. There are four tags in the intermission order list. After touching a certain tag, it is possible to select items to the order by using keypad of a mobile phone. Theatre-goers booked their intermission refreshments before they arrived to the theatre. So, they had their refreshments served at the table at the ready when an intermission started. Tags were inserted in play posters in the theatre. These tags provide access to information about the plays. Data is downloaded from a server to a mobile phone after touch to a tag.

A mobile theatre ticket is checked by touching mobile phones: a ticket inspector and a theatre-goer touch each other's mobile phone before the play.

Fig. 5. A Parking zone selection by touching a zone tag (Picture copyright: Juha Sarkkinen).

After touching, the individual identification number in the theatre-goer's mobile phone is compared with the one in the backend system.

Parking trial. Parking case comprised of three NFC applications, which were street parking, a parking hall and warden applications.

The process for street parking with the NFC-enabled mobile phone was the following:

1. User touches the car tag in his vehicle
2. User selects a parking zone by
   a. using the keypad of a mobile phone and menu or
   b. touching a parking zone tag (shown in Fig. 5)
3. User touches the car tag in order to finish the parking

As described above, the street parking application provided two alternative ways to select parking zone; a conventional way by navigating menus in the phone or touching.

Whereas in the street parking case, the NFC-enabled phone is the reader, in the parking hall case there is a reader nearby the gate (shown in Fig. 6), and the NFC-enabled phone operates as a tag. The parking hall application follows principles of a ticketing system with a single touch. When the NFC reader by the gate is touched with a mobile phone, the system checks from a server whether the driver is allowed to drive to the parking hall or not.

Traffic wardens can use parking controller application to control street parking. In order to check a car, a traffic warden touches the car tag attached to the windscreen. After the touch, the validity of the car parking is checked from a server. The validity of parking is displayed on the screen of the warden's mobile phone.

Fig. 6. A reader in a parking hall.

In addition to primary applications used in trials, users in parking, theatre and restaurant trials had a chance to use "info tags", which provide a possibility to load different information into a mobile phone by touching a tag. Info tags are located in restaurant tables, tables in a theatre and parking meters.

5. Design findings

Moving user interface components from the digital representations into components in the physical world sets special requirements for user interface design. The user interface can extend over the physical boundaries of the technical device into the environment where people interact. In this chapter, a summary of design findings that have emerged in the trials described above is presented.

5.1. Tag size and format

One of the challenges of designing a mixed reality user interface with NFC tags is the fixed and limited size and form of the tag. Currently, tags come in standard sizes and forms. Even though tags are used for implementing a link between the visual object in the physical world with the digital information in the digital realm, tags do not adapt to the visual form and size of the physical object. This can be compared with doing web-design with fixed link size and format, i.e. not being able to have link size adjusted according to the lengths of the word, or according to the size and form of the picture. Fixed link size and format requires that the location and boundaries of the tag must be somehow communicated to the user,

MONDAY	Chicken sauce	Mushroom soup	No meal
TUESDAY	Bolognese	Beef in peppercorn sauce	No meal
WEDNESDAY	Meat soup	Vegetable loaf	No meal
THURSDAY	Beef and potato bake	Salmon bake	No meal
FRIDAY	Game casserole	Ham vegetable soup	No meal

Fig. 7. Column-sized tags (tags are outlined with dashed lines.).

as the tag does not follow the natural form and size of the object of the natural world. Also, it restricts some user interface solutions. For example, the meal menu could not be implemented with having a single tag attached to one column of the menu, as the tag could not cover the area of the entire column (see Fig. 7). Instead, small tags had to be placed on top of the column, not visible in the figure, which made reading the menu table cognitively challenging. Consequently, the user had to select the order above the text referring to the meal. The mobile device provides the day – row as such has only conceptual meaning. Also, a four centimetre diameter tag is relatively small when it is attached into a large poster (see Fig. 8) that is viewed from a distance. Small tags and tag indicators may be difficult to notice from a distance.

5.2. Spatial perception

Embedding user interface components to the physical world also gives designers possibilities for utilizing the spatial behaviour, environmental perception and embodiment. For example, user interface components can be within reach, or can be placed further away; objects within reach invite interaction. They can be located on the right or the left side of the user. Things placed on the right side shelf in supermarkets sell more than on the left shelf. Unlike device-bound user interface, mixed reality interface mingles with the social context – the user experiences and positions herself with the user interface with other people. How people spatially arrange themselves may have profound effects on how reachable and accessible a user interface embedded into the physical structures is for the user. For example, people standing between the user and the tag strongly affect the accessibility of the user interface – even if the actual physical distance between the user and the tag would be convenient. The fore-mentioned circumstance emerged in the pub trial case in practice. In a crowded pub, the trial users were uncomfortable in using touch-based interaction, as reaching tags through the crowd was challenging.

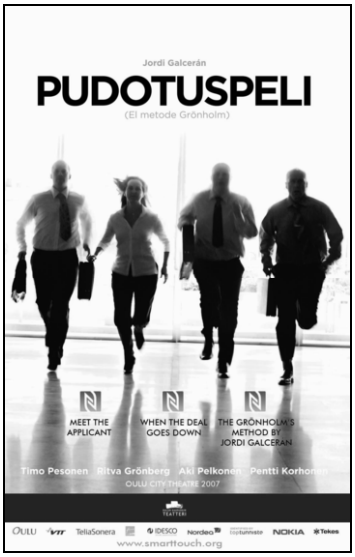

Fig. 8. A poster with three NFC tags in the theatre trial.

The location of tags should also take into account the social interaction naturally taking place in the space. The use of the media services accessible through the smart poster was regarded as socially distracting. The smart posters were placed in an entrance hall of the theatre in a place where people gathered together before theatre plays. Some users felt that consuming media content with a mobile phone was socially disturbing and unacceptable, as it interrupted people who were discussing near by. In addition, one user of the pub trial related that "Some drunken clients in a pub were sometimes annoyed because of a tag reading, and their behaviour could be slightly threatening."

Thus, it can be seen that the use of NFC-based applications may have varying social impacts in various environments, and an important design issue is to consider how the tags are located in certain environments.

5.3. Positioning of tags

A simple rethinking in the NFC tag position can provide new opportunities for a mobile application to succeed. When designing a mobile NFC application, it may not always be reasonable to repeat the pattern of how things have been done in the past.

The KAMO application brings access to the digital data at the location it is needed. However, some location-based services need to be accessed from another location. An NFC tag can provide extra benefits with a different kind of positioning. In the bus stop information example, there are two emerging opportunities for that: home and store as a location. At home, the user can attach a NFC tag at the front door instead of at the bus stop. There is no need to go outside if the weather is poor, and bus delays can be seen immediately inside the house. Furthermore, families can stay inside until the bus comes closer, a benefit which obtains added value in minus 20°C. In the KAMO case, the tag is even very easy to create for the nearest bus stop, since the bus stop IDs can be found from web. The ID can be written to the tag, and then the application accesses the bus schedule information accordingly.

Providing the KAMO NFC tags in stores or shops, people would be able to plan for their trip back home inside the shop instead of wasting time at the bus stop. Apparently, shops would also be able to keep the customers inside for longer, generating more revenue.

5.4. From 'one-touch' action to multiple selection

Even though the touch-based UI paradigm thrives on simple 'one-touch' interaction, our examples show that it can be easily integrated into user interface concepts that require more complex interaction between the user and the device. For example, the lunch order trial required the user to touch tags in sequence, and also to interact directly with the phone UI by pressing phone keys.

Although the application logic of a mobile phone in the lunch order application was more complex to use than, for example, the parking hall application, 17 out of 23 (~74%) users experienced it as very easy to use.

Shifting from the idea that you have one-touch use towards multi-touch requires changes in interaction design thinking. One-touch opens an application or content which is then usable through the mobile device. Interaction design in this case, after touching, focuses on the user interface of the device.

The user interface is designed to follow the "multi-touch" paradigm; the interaction path is not transferred to the device after launch, but continues as environmentally integrated task. The user should be able to navigate through a set of selections or other interaction components that are embedded into the physical environment. For example, there may be an object and location pair to be considered, as in a case where the car is selected first by touching a tag and a parking lot chosen from a tag in a parking meter. Another example is a restaurant where the location is the table and objects are chosen from the menu. Relations of objects and location are presented in Table 3.

Table 3
Relations of objects and locations

Object	Location
car, tag under window	parking lot chosen from parking meter tag
menu items, tags in menu	table chosen from table tag
meal, tags in a table	home known by phone number

In the car parking and lunch ordering examples, the application has dependency; without car information, the parking lot tag selection does not make sense. Designing for object-location requires consideration of the physical distance and affordance for the tags in the environment. Then there will be consideration for the complexity of the artifact providing the object selection: size and layout of the artifact, size and imaging of the choices, artifact material and its positioning in the environment. The graphical user interface of the mobile device can be used to support the interaction; for example, it can reflect the selection of choices.

Multiple selection is also discussed by Broll and coworkers [9]. They broaden the interaction beyond single objects and tags to mobile interaction with multiple objects, tags and associated information. Collect&Drop is introduced as a generic technique for Multi-Tag Interaction that supports the collection, storage and management of information from the real world, as well as its usage with different services.

5.5. Consistency in feedback, touch, visualisation and location

Multimodal feedback is relatively easy to implement into NFC applications. It can also be seen that multimodal feedback makes it easier to interact with NFC-tagged physical objects in the real world. Various forms of feedback – such as haptic, visual and auditory feedback – works differently in a different environment. For example, in a restaurant – where there can be a lot of noise during a rush hour – haptic and visual feedback can be seen as more suitable forms of feedback than auditory feedback. A recent review on haptic interaction indicates the increasing

role of the modality in mainstream human technology interaction [24].

Various forms of feedback were used in NFC applications in NFC trials. An immediate vibrating alert was commonly used in trial applications. This alert indicates when a mobile phone can be moved away from proximity of a tag. Consistency of feedback was identified as an essential feature based on the trials. Particularly, the importance of consistent haptic feedback emerged in the NFC trials.

As mentioned, haptic feedback was commonly used in NFC applications presented in this paper. However, a limitation in implementing the immediate haptic feedback is that the vibrating alert cannot be attached to a reading operation before a mobile application is opened. Exceptions for this in a test phone (Nokia 6131 NFC) used in trials are sending a text message to a certain address, calling to a certain number, connecting to a certain site (bookmark) and sharing a business card. These functionalities are in the phone at the ready without any programming. In contrast, independent Java applications require that an application is opened before it is possible to attach immediate haptic feedback to touch. In this case, the delay of haptic feedback depends on, for example, how large the application is which must be opened. Thus, if haptic feedback is implemented into an independent mobile application, delay of haptic feedback can be clearly longer than in applications integrated in a phone at the ready.

Trial users experienced a vibrating alert as a clear form of feedback, and some users were criticed when they touched a tag and immediate haptic feedback was not given after touching. Thus, haptic feedback was not consistent, which decreased the fluency of interaction. Particularly, it can be seen that if there are several different NFC applications in the same environment, it is reasonable to aim at consistent feedback in these applications. For example, one user was wondering why the log-in tag did not give haptic feedback such as the product and info tags of the pub.

The “sensitivity” of an NFC reader proved to be an essential issue. There were four separate NFC applications in a restaurant trial; an info tag menu, taxi call tag, lunch order tag menu and payment service. The first three worked on a same principle, so that an NFC-enabled mobile phone acts a reader and reads data from NFC tags. The NFC payment application had a separate reader which read information from a mobile phone. Users were familiar with using lunch order tags and info tags, but when they tried to use the payment application, finding a right touch point proved to occasionally be a challenging task for users. A problem concerning interaction resulted from a different touch style, required by a reader of a payment application. Thus, it is essential to take into account the consistency of touch when designing NFC applications used in the same environment, so that the interaction technique is as coherent as possible. This way it is possible to avoid gratuitous touches.

In addition to consistency of feedback and touch, the significance of consistency concerning visualisation of the touch target emerged during the trials. In the parking trial, street parking tags and the touch point of a parking hall reader were visually different, which resulted in unsureness concerning a touch target at a gate of a parking hall. Just as in other interaction-related issues, consistency should also be taken into account when designing the visualisation of touch targets in order to avoid unclear situations in interaction.

The consistent location of tags should be considered carefully in a design. In the restaurant trial, there was menu tag stand, info tag stand and table tag in every table. Thus, tags were always easily and consistently available. In contrast, in the pub trial a location of the product tag stands and the info tag stands were changed frequently. Because of this, trial users had to sometimes search trial stands in the pub. Particularly, the importance of a consistent location of tags was highlighted in the parking trial. Traffic wardens touch a car tag attached on the windscreen of car in order to check parking status. If car tags are located in various places on the windscreens of cars, controlling takes much more time than if car tags are located consistently. Particularly, consistent location of car tags is highlighted during winter, when the windscreen can be covered by snow and ice.

5.6. Location-aware and dynamic content

In the information tag trial, the program of the theatre was rated interesting in subjective ratings. However, many users were disappointed since the content of the theatre program was static, which meant that it contained old information. This observation was repeated in several comments; the users expected digital content to be up-to-date, and they wished that it would be frequently updated.

Also, the users expressed hopes of better utilizing the possibilities of the digital platform by, for example, providing location-aware services. For example, a tag that provided access to a tourism information service provided information about another city as

the default. The users were puzzled as to why they were provided information about events in the city located many hundred kilometers away from their home city. Of course, they could access information about events in their home town by selecting the correct city from a pull-down menu, but the users expected the knowledge about their location to be automatically processed by the service.

The users expect digital content to be up-to-date, dynamic and changing. Even when the basic nature of the application data is static, one should provide some content that dynamically changes, so that the user perceives the information to be up-to-date and the service worth coming back to.

Available information on the location, use situation, social context, etc., should be exploited to the maximum so, that the information the user gets is directly what she wants, without any additional steps of skipping through unwanted data. Extra steps are especially undesirable in a mobile environment where the wait times can be long and unwanted downloads costly.

5.7. Unoperational tags

Some of the tags that the users found were visible and available for touching, but were not operational because they were broken or set up to work only with certain devices for specific users. The users found these situations very annoying. They expected that they would get some response from all the tags that were available for touching, and if that did not happen, they were irritated.

As tags are cheap and easy to attach almost anywhere, there is a danger of "tag litter" that can destroy the user experience of tags in general. As tags are not continuously connected to a network, it is difficult for the service providers to notice when a tag gets broken. As tags can be distributed by virtually anybody, it might not be reasonable to assume all service providers even care to maintain tags after distributing them.

Tags can be programmed to give response only when a special application is installed into the mobile device used for reading the tag. In these cases, tags are unresponsive to the devices that do not have that specific application. If only a fraction of the tags available for the user actually work, the users may not bother to try using them at all. Therefore, it would be important to program all tags to somehow respond to the touch of an odd user, even when they are targeted for specific users only.

6. Limitations and validity

Even though the goal of the field trials was to provide as high experimental reality [6] as possible, there are issues in the trial settings that may have affected the results.

Perhaps the most severe limitation of our research setting was the availability, selection and content of the services and Mobile Internet content accessible through the tags. As the tags were evaluated in a research project, there were no actual goals for business or the public good for providing the users with access to mobile content. Tag placement, design and accessed information content were not rigorously designed to meet any specific goals, such as optimal coverage of a certain user group.

The content provided through tags was selected in a brainstorming session of the researchers, and the selection criteria used were probably very different from those that would be used if the tags were used for commercial, or any other than research purposes. As a result, some tag content was obviously very badly suited for the specific place they were offered in. For example, many users commented that a tag that helps you call a taxi when you are paying your parking fee was pretty useless. However, badly placed tags provided us with useful information for research and design purposes. On the other hand, the tags are cheap, and if in the future they are commonly used and ubiquitously available everywhere, badly chosen and placed tags will probably be rather common. Some tag providers find it faster, cheaper and easier to attach tags randomly than do proper analysis where the optimal locations for tags would be.

Also, as the tags were evaluated in one single research project, the availability, selection and variety of tags was very limited. If tags become popular access points to the Mobile Internet, there will be more variety in selection, and tags will be more numerous and better available.

Another issue that may have an effect on the results is that none of the users were able to use their own mobile phone to access the Mobile Internet through tags, but had to use a special NFC-enabled trial phone. This meant that the users usually carried two mobile phones with them and used their own mobile as a phone, and the trial phone only for the NFC-enabled features. This might have had an effect on the usage frequency, perceived accessibility and ease of use.

The fact that the user experiences were collected in a trial setting probably had an effect on the motiva-

tion of the users. The users were recruited as trial users, so they were committed to try out the provided services. Therefore, the first usage was probably initiated by this commitment, and not purely due to interest or curiosity towards the services provided.

7. Discussion

The applications using touch-based user interfaces have different, at least partly independent characteristics. We have identified the following:

- Purpose, i.e. why does the application exist, what service or function does it offer to the end user?
- Business logic, i.e. what is the business motivation for the party or parties offering the service, which actors are involved in the value network?
- System complexity, ranging from a stand-alone application requiring only the tag and a reader device to a more complex system incorporating specific back-end sub-systems dedicated to serving the request generated by the touch-based UI.
- Locality of the application; is the service or function offered tied to the location or object to which the physical tag is attached or is it independent of this?
- User Interface: What is the complexity level of UI, i.e. is it one touch or several steps? Where does the UI apparently reside – for example, is it relying solely on a touch paradigm, or is it a mixed model / multi modal containing touch and more traditional HCI means, such as messages on device display, key-clicks and radio buttons.
- Tag capabilities, ranging from simple RFID substitutes of barcodes containing only product code or URL to sophisticated microcomputers with sensors, memory and processing capability, using the tag property only as (one) means of communication.
- Visual information of the tag, how much information is conveyed visually from the tag to the user. Are there other special requirements, e.g. because of ambient weather conditions or the need for vandal-proof housings?

Here we have briefly discussed purpose, system complexity, user interface and the design of the user interaction process. Business logic, tag capabilities and visual information conveyed by the tag symbols were left outside this study.

8. Conclusion

Physical browsing, the use of computer-readable identification tags attached to real world objects and places is seen as a natural Human Computer Interaction paradigm useful in the ubiquitous computing world. The alternative technical realisations include visual codes, such as matrix codes, radio frequency identification tags or infra-red beacons. A promising implementation of the proposed HCI paradigm employs RFID tags – more specifically NFC tags, which are readable with personal mobile devices equipped with readers to access the services and information associated with the tags.

Eight trial cases representing various applications were implemented and the results of user experiments were studied. It was found that possibility to extend the UI outside the physical limit of the technical device offers new possibilities for interaction design. It was also found that the standard size of the tag may be too limiting – we should allow tags of different visual appearance, both in form and size. The spatial positioning of tags in the physical interaction space gives a designer considerable freedom but may also pose the risk of inconsistent and haphazard designs. It should also be acknowledged that the user is not alone in the space with the tag-based UI; other people and their location in the space may affect the user experience or even cause using the tag-based UI awkward. The seemingly obvious location of the tag is not necessarily the best one: as an example, think what benefits can be gained if a tag linked to real-time “next bus” info is placed inside a home or a bar instead of the obvious bus stop. Complexity of the interaction task may be divided between using menus and keys of the personal device or by using multiple tags. Furthermore, the practice of designing consistent and prompt feedback for similar interaction situations was supported by our experiments. Feedback should use suitable modality, e.g. haptic feedback is often useful when the reader device is in the hand of the user and its display is not necessarily visible to her/him. Related to the feedback is the issue of sensitivity of the reader device, i.e. from how far does it read a tag. Again, consistency should be favored. Evidence was found that the service or information provided should be location-specific and dynamic whenever possible. Finally, fall-back plans for unoperational or broken tags should exist.

NFC tags and compatible readers embedded in personal devices, such as mobile phones, are a promising means of implementing the concept of physical browsing and thus bridging the physical and digital

worlds. Taking into account the considerations and findings described here when designing NFC-based applications should help in making them more efficient and improving the user experience.

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