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ORIGINAL ARTICLE

A novel concept of a wearable information appliance using context-based human–computer interaction

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Abstract In healthcare environment, different kinds of automatic solutions have been created to monitor and track patients, for example near-field imaging and low-frequency RFID. The problem has been how to use the context-based data these systems produce and how to show the related information to the nursing staff. This paper shows how hospital data can be automatically transmitted to people using location information. The information is transmitted to a name tag that has wireless connectivity and touch screen with electric paper. This concept is piloted with a test application.

Keywords RFID · Context-based information · Multifunctional name tag

1 Introduction

1.1 Background

In many health and security services, such as hospitals and those which care for the elderly, individuals are monitored. Monitored issues may include the location or health status, for example heart rate [1, 2], breathing [3] or the movements [2] of a person. According to the results of the monitoring, alarms are produced to attract the care personnel's attention in situations when actions are required. The situation may be as simple as helping the patient to the bathroom or more serious, for example assisting in an accident such as a fall.

Often the main task of the staff is not to respond to alarms. This is why the alarm management and forwarding should be as ergonomic and non-intrusive as possible. The staff should be informed promptly, get the contextual information of the situation and be able to decide how to react. An efficient alarm management system benefits from context-based information, such as the location of the incident, patient data and locations of the personnel.

Several methods of alarm forwarding have been introduced, ranging from nurse call systems in hospitals to alarm bracelets for independently living seniors. The user interface may be a wall display, PDA, mobile phone, beeper or pager [22]. Often the user interface exploits devices and services which are not designed for that purpose, for example a mobile phone using SMS messages. The use of commercially available user interfaces, however, has some constraints and limitations in applications, usability and ergonomics [4].

1.2 Previous work

Our previous work focused on a location and identification system that can locate people with an accuracy of about 30 cm using passive near-field imaging (NFI) and active radio frequency identification (RFID) [5]. The system can, for example, detect fallen persons [6, 7], receive and acknowledge different alarms and automatically detect a nurse coming into the room [8]. The system is also able to locate different objects like ward equipment or wheelchairs [5]. The preliminary tag (Fig. 1) fulfills the basic

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requirements for the context-based services. It has a display and two buttons for communication. From this basis, a further study of wearable user interface for alarm management was carried out.

The NFI system can locate people using an electric field that is generated with a sensor matrix placed under the floor surface [9]. NFI sensor plates are surrounded with antenna loops that can be used to track RFID tags. With the RFID system, people can be both located and identified [10]. However, the RFID tracking is not as accurate as the NFI localization [39].

The NFI system creates location cells from observations. The cells are software objects, and thus, they can have many different parameters in addition to the location data, for example the cell's lifetime. Our previous work showed that the RFID identification information can also be added to an NFI cell data [5]. When the NFI system observes someone in the room, it starts an RFID scan using a nearest cell localization (NCL). After the scan, the system receives a location and identification from the tag and adds the identification data to the related cell by comparing the location data from both systems [5].

The NFI system creates a map from its service area. With the help of the software, smaller areas can be outlined to act and send messages to the system when someone arrives there (Fig. 2). These active areas (AAs) can be used, for example, to sound an alarm if a patient gets up from the bed when he or she should not or if a patient tries to leave the room. Similarly, if the person has been identified, AAs can be used, for example, to manipulate the user interface of his/her tag.

This paper introduces a novel concept whereby a name tag can be automatically used to display different information. In this concept, the tag also has new purposes, for example to open security doors, etc. The tag can also receive alarms and be used to respond to them with a touch screen. A concept system was built for testing and to find out the requirements of the real context-based applications.

Fig. 1 Representation of the tag that has been developed

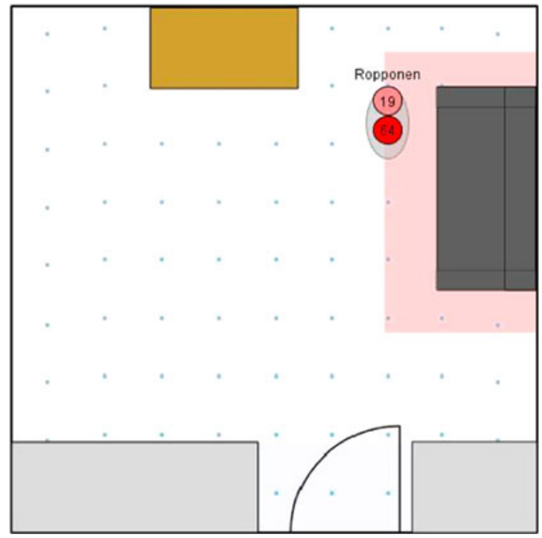


Fig. 2 The AA near the bed is activated when a person comes to the area and the main system is acknowledged

Fig. 3 Tags normally act as a name label

2 Materials and methods

2.1 Requirements

The alarm management user interface should be able to indicate an alarm and forward the user response to it. It should also be able to give the system the location of the employee and display context-based information like patient records or ward directions. The three major strands of data that should be accessed with a PDA in a hospital environment are [11] the following:

- Patient records, laboratory results, etc.

- Location of patients and colleagues
- Location of medical equipment, beds, etc.

The preliminary RFID system could locate patients, nurses and ward equipment [5]. In the new tag, a larger display and a more versatile button arrangement have been introduced.

2.2 Name tag approach

The main idea in the user interface is that the display is manipulated automatically using wireless networks. When the system has identified the tag and located it, the user interface can be changed using the context-based information. Automatic mobile tour guides use similar methods [12, 13]. For example, next to a door the tag changes to an "open" button, and next to a hospital bed the tag changes to show the patient's records. When the system changes the tag's user interface automatically using location information, there is no need for complex tree structures [14, 15]. With mobile phones, many steps have to be made, for example, to create a new SMS (Short Message Service) or to connect to the internet. In hospitals or homes for the elderly, nurses and doctors have no time in emergency situations to push many buttons and follow complex user interface trees to signal alarm and get help.

In hospitals and other healthcare institutions, the doctors and the nurses have enough things to carry. That is why it might be hard to persuade them to carry yet another gadget. The tag that is used to respond to different alarms should also be within easy reach. The solution is to have a multifunctional name tag that hospital staff carry with them at all times. The personal data are displayed by default on the tag screen (Fig. 3), but depending on the context, the user interface can change to display data records, etc.

2.3 User interface of the tag

In mobile device user interface design, there are three major categories that have to be taken into account [16]:

- Interaction mechanisms
- Utilizing screen space
- Design at large (to be explained in Sect. 2.5)

The best interaction mechanism for the tag may be a touch screen. A normal keyboard would need either a great number of buttons or different functions assigned to the same button in different situations, which would make it complex to use. With a touch screen, only the buttons that are needed can be shown and a button can display information about the action that follows (Figs. 4, 5). Because the tag is used in a healthcare environment, it has to be operated by finger. In emergency situations, there is no time to try to find any special pointing equipment. This fact rules out all the touch foils that, for example, require a stylus pen.

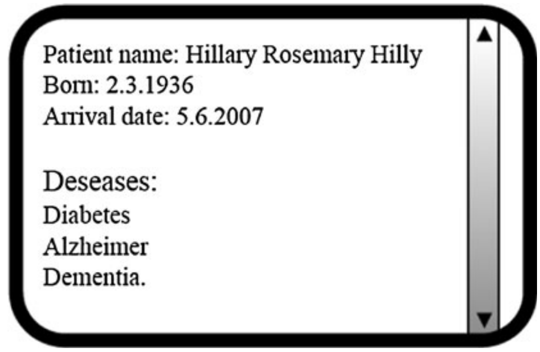


Fig. 4 User interface acts as a patient record

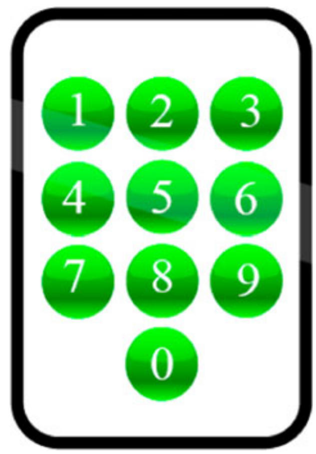


Fig. 5 The tag changes to push button tags

To use the screen space efficiently, each set of data should be adjusted to the size of the display. Any zooming should be avoided. The user is not expected to use the device sitting at a table and might even be moving when using it. In order to keep one hand free, for example to push a hospital bed or open doors, it should be possible to use the device with one hand or with one thumb. As we can see from Fig. 6, all the buttons should be rectangular and almost as wide as the screen to be easily reachable with either thumb. This one-hand approach also imposes restrictions regarding scrolling. For example, scrolling from top left to bottom right for right-handed users, and vice versa, should be avoided [17]. Horizontal scroll bars should be avoided with a mobile device in any case [16]. Using a keyboard, for example to fill patient records, is also a problem because it is difficult and slow to type text with a small touchpad keyboard [18]. A better approach could be to use the device as a dictating machine and later write down the information using a standard computer keyboard.

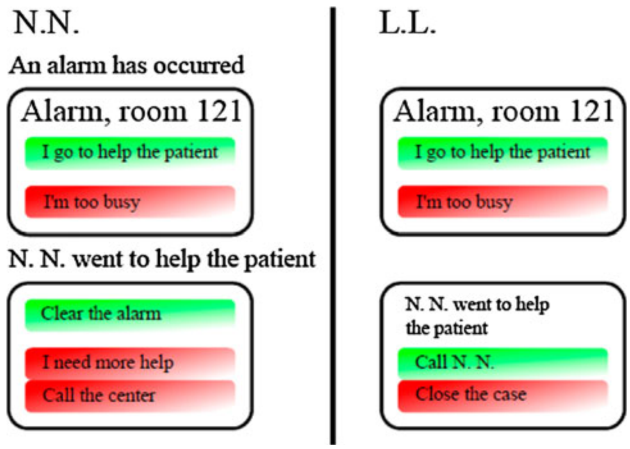


Fig. 6 The tags' operation in alarm situations. On the left is N. N.'s tag. The other tag relates to everyone else (L.L.) within the alarm's context

2.4 Context-based services

Context is any information that can be used to characterize the situation of a person, a place or an object that is considered significant for the interaction between a user and an application. It includes the user and applications themselves [19]. In our case, context would mean the location and identification information of the person holding the tag. The most common service in a hospital environment would be to have patient data and medication lists [20, 21], which appear automatically [22] at the user interface device when the physician arrives at the bed (Fig. 4).

Another beneficial function of the tag would be its use as a key or a security card. When the user goes near a door, it would either open automatically or an open button would appear on the screen. The user would not have to reach for an opening button on the wall. Different security levels can be installed. For example, near a high security door, a number button can appear on the screen for the user to input a security code (Fig. 5). However, a tag will not have access to every room; hence, the tag might not respond by each room.

One of the main purposes of the NFI system is to signal alarm when someone has, for example, fallen on the floor [6]. Because the system knows the location of the nurses, the alarm can be sent selectively to the nearest nurses or the nurses that are responsible for that patient.

When the tag receives an alarm, its state changes and the touch screen buttons can display a specific meaning (Fig. 6). For example, in the case shown in the figures, the tags that fit the context get a similar alarm first. When one of the nurses (N. N.) acknowledges if she/he is going to help the patient, the others, for example L.L., are informed. N. N.'s tag also changes its state, and it can be used to call for more help. If the tag is equipped with a microphone and a speaker, it can be used as a telephone. In this case, it would mean that N. N. can call to get more help or just to consult a colleague. When the system knows the situation of every nurse, the call can be routed automatically to the most appropriate person in this context. Other nurses can also call N. N. to check that everything is all right.

Some patients need more care and regular checks [23]. For example, if a person needs a regular check three times a day, the system should remind the responsible personnel. The reminder can then be reset by the nurses with the tag. This way an automatic checklist can be created. The next shift nurse will then know which tasks have been done and which have not. Another problem in hospitals is that it takes too long to get a "change of shift" report which includes the tasks that have been done [24]. This way too the checklist can be created automatically.

2.5 Data storage

Design at large (see Sect. 2.3) consists of data base structures and design patterns for user interfaces. All the information in this kind of system which has large amounts of patient data should be stored in a centralized database. For example, the WARD-IN-HAND system uses a centralized database where the patient records can be downloaded [25]. It is much easier to keep one centralized database up to date than to update all the devices constantly with the new information. This approach also keeps the tags simpler because large memories are not needed. Congestion in the network would also be minimized as information will be sent only when it is needed.

There should be at least three centralized units that master the information. The first unit should take care of the location information, regarding identifications and alarms. In this unit, the messages would be short. The unit would include the information of active areas (AA), where the system should manipulate the user interface. This unit would then acknowledge the two others to send the information to the tag. These two other units would be large databases.

The first database would include all the patient data. The second database would include the information about access rights. This database would react in case of security doors that can only be opened with certain tags. Some of the doors could be classified as open access doors, so that they can be opened with every tag. At such points, the location server would open the door without using the passage database.

2.6 Display

If the device is used as a name tag, the display must be extremely power efficient, because it would always be on.

It seems that the best type would be microencapsulated electrophoretic display (EPD) [26]. EPDs, usually referred to as electric paper, are used, for example, in electronic books. The advantage of electric paper is that it consumes power only when the picture on the display changes. If the power is switched off, the picture remains on the screen. Another advantage is that the display is not self-luminous, and so it does not need a backlight and still has a great contrast. This makes EPDs suitable for name tags.

An active-matrix EPD's pictures and graphs can be displayed on the screen. In addition, playing live video, for example ECG (Electrocardiography), can be done with electronic paper, because its ink-switching speed (250 ms) is sufficient to play video [27]. A downside is that at the moment the commercial EPD displays use only gray scales. Colored displays, however, have been developed [28].

The problem implementing the touch screen with the EPD is that the display does not have a backlight. This means that if a touch foil is placed over the screen, it must be almost 100% transparent. This rules out the resistive touch foils because their transparency ratio is normally under 75–85%. For example, with the use of capacitive technology, almost completely transparent touch foils can be produced [29]. Moreover, with surface acoustic waves (SAW), 98% optical transparency can be achieved [30].

One way to avoid the touch foil on the screen is to use the LucidTouch system where the touch element is placed behind the whole device. The touch screen is used from the back of the device, and then, the device is made virtually transparent, so that the fingers appear on the screen [31]. In the name label case, it is impossible to use this kind of approach. The label has to be attached, for example, to the breast pocket, and so there is a clamp behind the device.

2.7 Hygiene

A touch screen also has advantages in hygiene, which is very important in the healthcare environment. It has been shown that 9–25% of mobile communication devices that are used are contaminated with pathogenic bacteria. It is recommended that the devices should be decontaminated [32]. The benefit of a touch screen is that it does not have any mechanical buttons. Mechanical buttons often have narrow gaps that are difficult to clean and disinfect. Also a waterproof touch screen can easily be built. All in all, a personal device that can be used to display a patient's parameters reduces the need for bedside computers that may transmit nosocomial infections [33]. Hygiene reasons also dictate that the tag should be carried on the breast pocket. In a hospital environment, anything held on the wrist should be avoided [34].

The tag can be fully waterproof and hence easy to disinfect providing there is no charging plug attached. The plug can be removed if the batteries are charged using inductive coupling. Because the tag uses an LF receiver, it has a ferrite coil antenna. The same antenna can be used to charge the batteries if the data receiving and the charging frequencies are different. With filtering, the receiver can be protected from charging voltages.

3 The concept system

3.1 Test installation

A concept system was built to test the concept where a name label changes to a multifunctional tag. The system comprised three units: A NFI system was used to locate a person and excite the RFID tag; the existing RFID tag [39] was used for location and identification source; and an iPod Touch multimedia player (Apple Inc., California, USA) was used as the multifunctional name label. iPod Touch multimedia player is approximately the same size as a normal name tag, it has a 3.5-inch capacitive touch screen and WLAN (Wireless Local Area Network) radio to communicate with the NFI system [35].

The display of the multifunctional name label was changed according to the location information from the NFI system. The tested case had two AAs in the room where the tag changed the mode. In the first area, the tag changed to a screen with information about a fictitious patient. In the second area near the door to the room, the image on the tag changed to number buttons. In both cases, when the active area was left, the tag changed back to a name label.

The displayed user interface was actually a web page that could be manipulated by a small extension in the NFI system program. This way, a separate user interface program was not needed. Furthermore, web pages are easy to build and modify.

The iPod's web browser opened a CGI-script (Common Gateway Interface) from the server of the NFI system. The script sent back a page that consisted of control and content frames. The control frame decided which content frame appeared on the page. The content frame included the actual information and all the functions (buttons) for the user. In this way, the NFI system could select the content frame that appeared on the iPod's screen and completely different pages could be displayed without changing the actual page address. First, the CGI-script loaded the default frame to the browser (the name tag, Fig. 8) and opened a connection to the NFI system location engine.

When a person came into a room, the NFI system observed him/her and triggered the NCL scan. If a tag was found, the NFI person location cell was identified (Fig. 7). The web page that the iPod opened had a common uniform

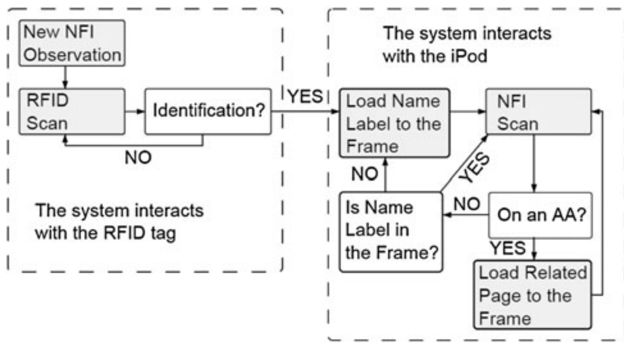


Fig. 7 Principle of operation of the system. First, the cell is identified using the RFID tag. Then, the information regarding the cell's location is used to update the iPod

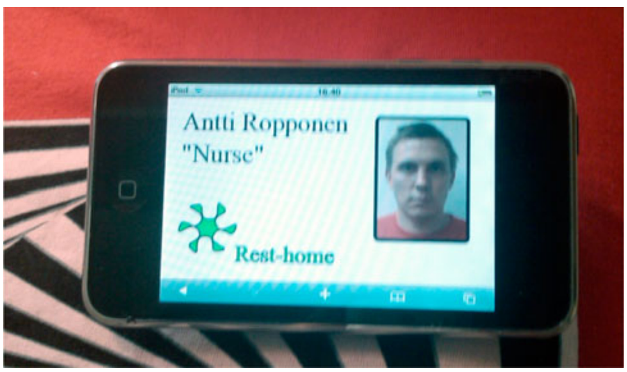


Fig. 8 The name tag is carried attached to the chest

resource locator (URL). However, every iPod opened it with its own identifier, which was the same as in the respective RFID tag. For example, the iPod in Fig. 8 connected to the page "index.html?Ropponen." Hence, when the person location cell has been identified as "Ropponen," the NFI system manipulated only the respective iPod's browser view when the person arrived at an AA.

Figure 2 shows the two active areas in the test room. One was at the "patient's" bed and the other at the door area. In the test, the iPod came to the URL with its own identifier and the corresponding name tag was loaded. When the person arrived in the room, the person's location was connected with the identification. When the NFI system saw the person approach the bed, the patient information appeared on the iPod (Fig. 9). When the person leaved the AA, the name tag appeared on the screen again. The same thing happened again when the person went near the door with the exception that this time the code buttons were loaded.

3.2 Tests

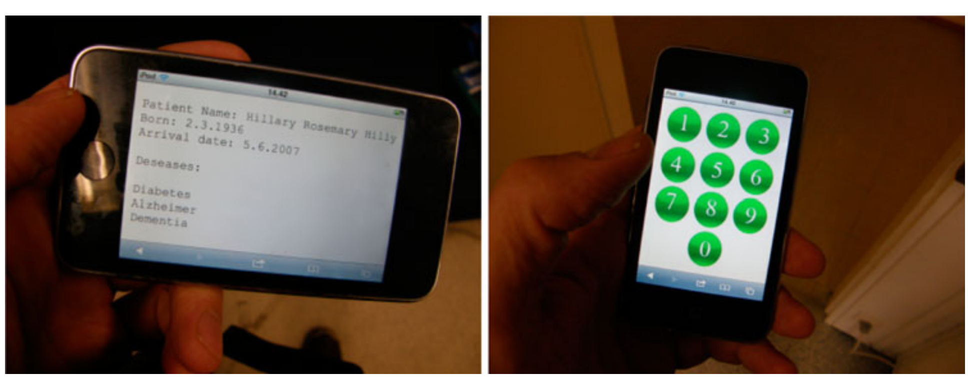
To verify the functioning of the different parts of the test setup, the NFI system and its capability to identify persons together with the RFID system were previously tested in separate locations [5]. In this test, the RFID tag was used for identification and the NFI system was used for localization. When the results of this test suggested that the method can be used for context aware and ubiquitous computing, the tests for the name tag system were commenced.

The name tag system was tested by 10 test persons carrying the iPod-RFID-tag combination. IPod acted as a multifunctional display device. The test persons were instructed to enter the room and go to the center of the room, to the bed and to the door. In some cases, there were other people in the room. Test persons were encouraged to enter the AAs using arbitrary paths. The changes on the display were monitored.

3.3 Results

In the tests, right pages were downloaded on the screen every time when the AAs were accessed and the NFI system perceived the identified user. Also, the display was updated when the identified user left the AA. Hence, it can be said that the web-based interface was robust. However, the identification was not fully robust, when other people were in the room. In some cases, the RFID identification was given to a wrong person (wrong NFI cell). In these cases, iPod's display was not updated or was updated in wrong time. The NFI and the RFID systems still need improvements in the infrastructure to be fully reliable.

Fig. 9 A tag in different modes



Also, the test room had a blind spot where the NFI system could not locate anyone due to broken wirings.

4 Discussion

4.1 General discussion

The concept system worked well even when the user interface device was not ideal. However, the concept system needs also some improvements. The NFI and RFID systems need to be more robust in the identification [5, 36]. Also to ensure the privacy of the patients, it would be better if in the actual system, a patient record does not appear on the screen as soon as the doctor approaches a bed. When the tag is held on the breast pocket, the record is then visible to all the people in the room. A better approach would be that only a button appears on the name tag screen. The button then allows a user to open the record when the tag is hand held and the data are thus kept private. However, the use of the web browser is a very flexible way to handle the user interface. The pages just have to be adjusted for the mobile device to avoid, for example, unnecessary zooming.

Smart phones have developed rapidly in the last decade. These devices have touch screens and web browsers, and they can handle multiple wireless communication protocols and hence be used as a multifunctional user interface device. Because smart phones are produced in large volumes, they might be cheaper than a tailored end device. However, ZigBee has not come to the smart phones, and they do not either have a capability to receive LF localization signal. Hence, the devices cannot be located as accurately as the developed RFID device [5]. The RFID infrastructure makes also it possible to develop cost efficient tags to locate different items accurately. Also using smart phones would rule out the name tag approach because of the power hungry LCD display.

4.2 Structure of the future tag

The future tag will be based on a web browser, because the system functioned so well and web platforms give superior opportunities to build different services. However, a new kind of tag should be developed.

In Fig. 10, we can see in summary the hardware that is needed for the tag. Some kind of a microprocessor is needed to govern the whole tag. To build a device that has a graphic web browser, a modern operation system is needed. Nowadays, there are several embedded operating systems that are tailored to be used with a touch screen, for example Meego [37], Android [38] or Ångström [38]. Apple's mobile operating system is designed only for Apple devices. Modern operating systems need a more powerful device than the CC2430 used, for example an ARM processor.

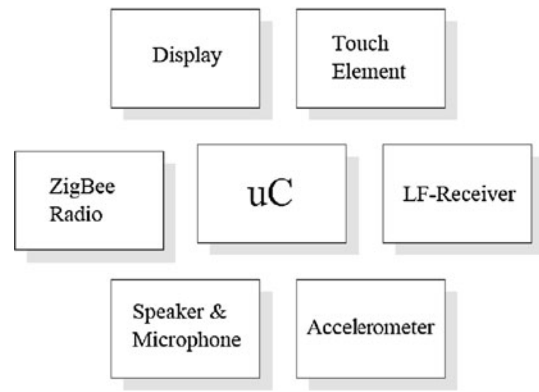


Fig. 10 A tag's functional blocks

Since previous work has shown the advantages of ZigBee over, for example, WLAN [39], all the context-based information can be sent through the ZigBee network. With a Pocket WinView handheld device, it is possible to display vital patient parameters using either WLAN or GPRS (General Packet Radio Service) networks [40]. ZigBee's data rate (250 kbps [41]) is much lower than WLAN's, but it is almost as fast as GPRS's (in the WinView system, 384 kbps). The ZigBee network has been used to obtain simulated ECG data simultaneously from up to 80 "patients" [42]. ZigBee also has enough capacity to stream audio data [43]. ZigBee specification has two security levels that are based on a 128 bit advanced encryption standard (AES): a commercial mode and a residential mode. Even though the commercial mode is quite secure even better protocols have been created [44]. Web-based design is not a problem, because the TCP/IP network can be run over the ZigBee network [45].

As we have demonstrated, previously developed LF and NFI systems can be used to locate and identify people for context-based services. Hence, the LF receiver is needed. An acceleration transducer is needed to automatically change the orientation of the screen.

Because the tag is intended to be used as a name label, the screen size cannot be much bigger than an iPod's. However, for browsing patient data, a larger display would be convenient. One solution could be to use a flexible display, which can be partly rolled under the tag. These kinds of solutions have already been introduced [46].

EPD displays can be made flexible but not sufficiently at the moment to slide half of the screen under the device when the tag acts as a name label [47]. A flexible screen, however, also causes more problems for the touch element. For example, SAW elements are not foils, but stationary emitters and detectors that are placed around the screen [48]. This is why SAW cannot be used with flexible displays if the whole screen is to implement the touch ability. At the moment, most of the EPDs are black and white, but color displays have also been developed [49].

5 Conclusions

The concept system gave valuable information to assist in developing the real one. Except for the color EPD, all the parts necessary to build the tag are widely available. Hence, the first tag will have a normal LCD display. This will be the platform for the creation of context-based services.

The NFI system has been installed to nearly 30 rest homes in Finland; thus, it has been proven to be beneficial and workable. In the near future, the RFID system [5] will also be implemented to some of the location to start the user tests. At the same time, tests with the multifunctional tag in real healthcare environment will begin.

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