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A LOW-COST INDOOR NAVIGATION SYSTEM FOR VISUALLY IMPAIRED AND BLIND

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Abstract

One of the most important limitations for people with visual impairment is the inability of unassisted navigation and orientation in unfamiliar buildings. An low-cost indoor navigation system, which is based on mobile terminals, supporting technology Near Field Communication (NFC), and Java program access to Radio Frequency Identification (RFID) tags, is developed. The proposed navigation system enables users to imagine the map of the rooms (dimensions, relative position of points of interest). This information is stored in RFID tags in WAP Binary eXtensible Markup Language (WBXML) format. The system allows leaving audio messages that are recorded in RFID tags in Adaptive Multi Rate (AMR) format. Voice enabled navigation, that is familiar to users with visual disabilities, is used.

Keywords

Indoor navigation for blind, NFC-enabled phones.

1. Introduction

The number of people with visual disabilities is around 135 million, of which 45 million are blind (S.a., 2009b). For people with visual disabilities navigating in unfamiliar buildings is more difficult than outdoors, where mainly they rely on guide dogs and white cane. The main difficulties in the indoor navigation and orientation are: missing known landmarks, restrictions to use guide dogs, overcoming obstacles can be risky, not all the blind can read Braille tags, the price of most of the existing systems for indoor navigation (Hesch and Roumeliotis, 2007, pp. 3545-3551) is impossible to afford for most people with visual disabilities.

When creating applications for people with visual disabilities of particular importance is the correct choice of the user interface. The User Centered Design (UCD) must be used in which a selected group of users involved at all stages in the process of application design. It is therefore necessary to learn some basic characteristics of the target group, such as: age, education, employability, level of use of mobile terminals, the preferred method for navigation and orientation, basic navigation problems in unfamiliar environments, and last but not least their income.

One of the major disadvantages of the existing indoor navigation systems for the blind is the high price of hardware part, which in most cases is not consistent with the income of blind people. The indoor navigation system for the blind is proposed, that ensures widespread use thanks to the integration of mobile phones from the low and middle price segments, Java technologies, and passive RFID tags.

The remainder of the paper is organized as follows. Section 2 shows different types of methods used for indoor navigation for the blind. System design (mobile device selection, hardware and software architecture, and navigational data encoding) are presented in Section 3. Section 4 describes experimental results, and Section 5 concludes the paper and gives our future work.

2. Related work

Navigation is a process that consists of two main activities: search road to the specified target point and movement, including the avoidance of obstacles on the road (Montelli, 2005, pp. 257-294). There are two basic methods for navigation (Loomis et al., 2007, pp. 179-202): 1) Navigation based on information from sensors, which determine the position of the blind (piloting methods) and 2) Find the current position of the blind based on information for the previous position and an estimate of velocity and direction of movements (path integration methods or dead reckoning).

Dead reckoning: For the realization of this type of navigation Micro-Electro-Mechanical Sensors (MEMS) are used, which give an estimate of velocity, direction and height (electronic accelerometers, magnetometers and barometers). This type of navigation systems require adjustment of the position after certain time interval. The correction is realized most often through

(D)GPS, A-GPS or Wi-Fi positioning (Ladetto and Merminod, 2002; Beauregard and Haas, 2006, pp. 27-35; Popa et al., 2008, pp. 3063-3068).

Piloting: This type of navigation is used by systems with infrared, ultrasound and radio-frequency (RF) beckoning and systems, based on visual pattern recognition and visual and RFID tags detection. IR based navigation systems require special hardware part, which can receive signals from the IR transmitters witch have a fixed position. The determination of position is based on the ID code of the nearest transmitter (Hancoc, 1998). In the project Talking Sign (Crandall et al., 1995) position is transmitted as a modulated message. Better results are obtained when using ultrasound beckoning. Navigation system Drishti (Ran et al., 2004, pp. 23-30) have 22cm position accuracy. To calculate the position of blind metric Time Difference of Arrival (TDOA) is used. For this purpose, the blind users are equipped with two ultrasound receivers, located on their shoulders. Ultrasound technology, except for determining the position of the blind, can be used and to detect obstacles on the road. Most often detection is based on the conversion of the reflected ultrasound signal to modulated sound (Kay and Chesnokova, 2005) or vibration (Bousbia-Salah and Fezari, 2007, pp. 333-337). The greatest use have RF beckoning techniques. In this case finding the position of the blind is based on analysis of signals from wireless networks, such as: Bluetooth™, Wi-Fi and Ultra Wide Band (UWB) (Youssef et al., 2003, pp.143-150; Ladd et al., 2004, 555-559; Bohonos et al., 2007, pp. 83-88; Rajamaki et al., 2007, pp. 96-101). To determine the user position metrics such as: Time of Arrival (ToA), Time Difference Of Arrival (TDoA) and Receiver Signal Strength (RSS) are used. Accuracy is from 1m to 50m.

There are indoor navigation systems for the blind in which position of the blind is determined by the position of visual markers or objects. In order to reduce the price of the system mobile phones with built-in photo-camera may be used. As example, Rohs (Rohs and Gfeller, 2004, pp. 265-271; Rohs, 2005, pp. 74-89) describe a system that recognizes the Quick Response (QR) markers. For more precise localization of the markers Tjan et al. (Tjan et al., 2005, pp. 30-) suggest markers from IR reflective material to be used. There are navigation systems in which information from the video frames is converted to modulated audio signals (Meijer, 2005) or to vibrations (Bourbakis, 2008, pp. 49-55). Navigation systems based on visual pattern recognition, are still in an experimental stage (Caperna, 2009; Nordin and Alli, 2009, pp. 883-889).

One solution that is cheaper and gives very good position accuracy is the use of passive and active RFID tags. RFID is a technology that has many applications, such as: aviation, building management, logistics, enterprise feedback control, clothing, food safety warranties, health systems, library services, museums, retailing, and etc. (Weinsten, 2005, pp. 27-33; Chan et al., 2008, pp. 507-509; Ngai et al., 2008, pp. 510-520). The number of RFID tags sold has risen to 180% in last six years. This technology allows accurate localization of objects (several centimeters), but has no real tracking capabilities. The most of existing RFID-based navigation systems for people with visual disabilities (Lawrence, 2006; Willis and Helal, 2009) used a grid of tags. Such a solution has the following disadvantages: requires a very large number of RFID tags if in the building has tens or hundreds of rooms; the integration of the tags in the floor or carpets require a lot of money; low speed of movement due to the low speed of RFID tags reading; additional hardware is needed - RFID reader, that can be integrated into the end of the white cane or shoes. Available RFID tags have very short detection ranges (up to 10cm). To make them suitable as indoor electronic beckons, some of techniques for detection range extension are used (Szeto and Sharma, 2007, pp. 6361-6364). The detection range can be expanded up to 10-15m if UHF RFID tags are used (Chumkamon et al., 2008, pp. 765-768).

One of the major limitations in all indoor navigation systems described so far is the high price, which in most cases is not consistent with the financial income of the blind. Part of the existing indoor navigation systems are too complex and work with them requires long training.

3. System design

The design of the application takes into account the preferences of the control group of 20 users with visual disabilities. According to data from the Union of the Blind in Bulgaria (S.a., 2009a), the number of their members is 15116. Of them, 73.6% are with over 90% reduced capacity for work, and the rest – from 71% to 90%. 62.8% of its members are aged over 60 years, 30.8% - from 30 to 60 years, while the remaining 6.4% are less than 30 years. The educational level of the blind in Bulgaria is as follows: 18.1% are with low educational level (below 4th degree), 44.9% have primary education, 29.9% are with secondary education and 7.1% are with college or university degree.

We used an interview to help identify specific problems of the target user group. The choice of the user interface is very important for people with visual disabilities. Research in this area (Gaunet and Briffault, 2005, pp. 267-314; Loomis et al., 2005, pp. 219-232) indicates that blind and visual impaired prefer to implement navigation with verbal commands. The blind people prefer to walk along the walls than the middle of rooms. The number of changes of direction should be minimized. The route should be constructed by short straight segments with 90° angle between them. The blind users can easily identify doors, walls, and stairs by white cane. After taking into account the preferences of the users of the target group the basic application requirements are defined: Voice navigation in application menu and to reference points; Lowest price of the necessary hardware; Opportunity to obtain additional information through audio messages; Do not use data transfer with WEB server to minimize costs; Easy to use and most simplified user interface; Navigational instructions must be comprehensible and unambiguous. To meet these requirements, it is preferable that the navigation system be based on the use of passive RFID tags and mobile phones of the low and medium price segment (100-180 euro) with built-in RFID reader. The advantages of using RFID-based indoor navigation systems are: Sufficiently high accuracy of localization (few centimeters); Small size and low cost for large quantities of RFID tags (0.3-0.8 euro/tag); Passive tags do not require a power supply; Ability to read information with mobile phones with integrated RFID reader; Very good level of security.

It is proposed to implement the navigation from room to room. For this purpose RFID tags are placed on each door. The system recognizes two types of tags: navi tags that contain navigational information and audio tags that contain voice messages. For easier localization RFID tags are placed above (navi tags) and under (audio tags) the door handle. Therefore, for each door two navi tags are needed - one inside and one outside of the door. This solution has the following advantages: minimum number of required tags; finding RFID tags is easier because it is limited to finding the door handle; each door is a reference point. RFID tag for each reference point contains information about the location of all other reference points within the room. To overcome any obstacles the blind rely on the white cane and messages in audio tags.

3.1. Mobile device selection

There is a psychological barrier associated with the use of technical assistive devices from people with visual disabilities. To access the RFID tags is proposed to use mobile terminals supporting technology Near Field Communication (NFC), for example: Nokia 6131 NFC, Samsung SGH X700

NFC, Samsung D500E, LG 600V contactless, Motorola L7 and Benq T80. The use of such mobile phones is obviously an advantage over use an additional hardware that user must buy and learn to use.

NFC is a short range (up to 10cm) radio frequency technology with data transfer rate between 106Kbps and 424Kbps that evolved from a combination of contactless RFID and interconnection technologies. NFC is standard (ISO 18092) defined by the NFC Forum, founded in 2004. The first fully integrated NFC phone is the Nokia 6131 NFC which is available on market in beginning of 2007. IDTechEx forecast that, the number of RFID-enabled mobile phones sold will rise from 134 million in 2008 to 540 million in 2013 and to 860 million in 2018 (Crotch-Harvey and Harrop, 2009). This forecast is however too optimistic, because the number of RFID-enabled mobile phones is still small. The data exchange between mobile terminals and RFID tags can be realized in the NFC communication read/write mode (Ortiz, 2009). Every NFC Data Exchange Format (NDEF) record contains a payload described by a type, a length, and an optional identifier. We use two type of NDEF records: in navi tags (MIME type text/xml), and in message tags (MIME type audio/amr).

3.2. System architecture

The main features of the application are: Speech navigation in Bulgarian and English; Automatic activation of the application when mobile terminal coming into proximity of RFID tag; Working with two types of tags - navi and audio; Intuitive navigation from the current position of the user. The architecture of the application is shown in Fig.1.

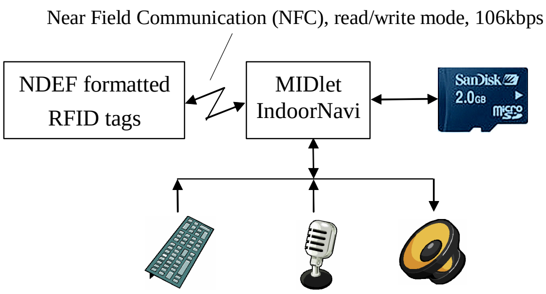

Fig.1. General view of application architecture

Developed application uses the following access to hardware resources: NDEF formatted RFID tags, local FLASH disk of mobile terminal or external FLASH card, keyboard, microphone and speaker. To permit such access is necessary to deploy a signed MIDlet. The applications can be installed on mobile terminals that support: Profile MIDP 2.0/2.1 (JSR-118); File Connection API (JSR-75); Multi Media API (JSR-135) with enabled audio capture mode; Contactless Communication API (JSR-257). We use javax.microedition.contactless.ndef optional package to communicate with NDEF-formatted RFID tags. The NDEF data transfer is selected because automatic activation (startup) of the application by the MIDP Push Registry is possible only for NDEF record types.

3.3. Data encoding on navi tags

To enable description of any reference point in navi tags a self-describing data representation is sought. This implies the use of meta language which can describe any data types. Extensible Markup Language (XML) is most widely used language when platform independent transfer is needed. It allows the description of any type of user data and will therefore be used. The main problem with XML in particular application is the limited size of the memory of RFID tags. XML would not allow compact data representation. To compress XML data WAP Binary XML (WBXML) format is used. The WBXML enables information for approximately 35-40 reference points to be stored in Mifare 4K tag.

Navigation is from current reference point to the target reference point. For this purpose we use the following commands: forward (F), left (L), right (R), backward (B), staircase (S±n): n floor up (+) or down (-) and set navigation metric (Ux): meters (Um), steps (Us) and number of rooms/doors (Ur). By default, meters are used. When L and R commands are used direction is changed 90° from the current user orientation and 180° - when command B is used. For example, encoded navigation string "F5.5 Ur L R5" means: “Go straight ahead for 5.5 meters, turn 90° left, desired room is the fifth in right side of the corridor.” The equivalent voice command is: “1) Go straight 5,5m; 2) Turn left; 3) Right side of corridor; 4) Count 5 doors”.

When navigation string contains many commands most users forget how far they reached and what is the next command. Therefore, navigation is at the level of command after command. Pressing a key the user hears the current command. After its completion the user press a key and hear the next command until the target reference point has been reached.

Each navi tag contains the following information: Current position of the user (XML tag <pos>); Name of the room (tag <to>). If the name is a number, it is assumed that this is the number of office or apartment. The name can be formed by the combination of word and number, such as "floor 6"; Dimensions of the room in meters (tag <dim>); Name of reference points and navigational information to reach it (tags <object>, <name>, <navi>). An example content, stored in the navi tags, is shown in Fig. 2.

```
<?xml version="1.0"?>
<tag>
    <pos>entrance</pos>
    <to>leaving-room</to>
    <dim>5.5x4</dim>

    <object>
      <name>bedroom</name>
      <navi>L1 L3 R0.5</navi>
    </object>

    <object>
      <name>terrace</name>
      <navi>L1 L4.5 L3</navi>
    </object>
</tag>
```

Fig. 2. Example content of navi tag

To record information on navi tags C++ application is written, which communicate with Omnikey CardMan® 5321 USB RFID reader. The structure of data stored in RFID tags is shown in Fig. 3. For each tag identification code is used, which is formed by: date and time of recording (eTag), the tag identification code (tag ID) and record MIME type.

Serial No. and manufacturer data
Record MIME type: text/xml, audio/amr
Record ID, date & time, tag ID
NDEF record (payload data)

Fig. 3. Tags data structure

3.4. Program architecture

Program architecture of the application in Unified Modelling Diagram (UML) format is shown in Fig. 4.

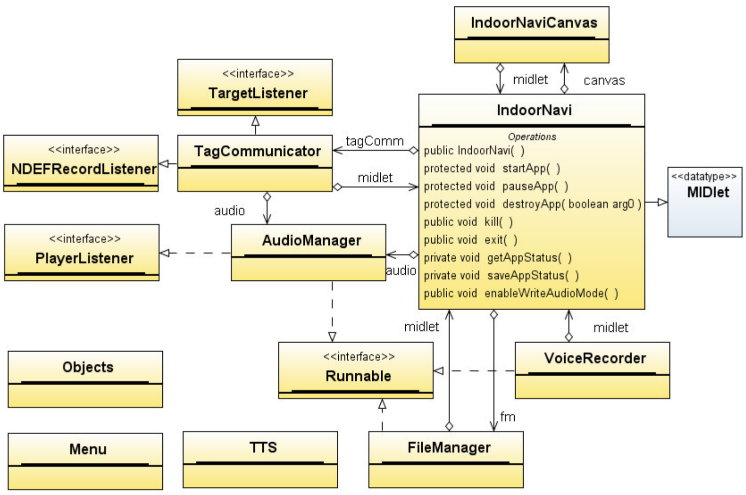

Fig. 4. UML class diagram

The description of the most important classes and interfaces is follows:

IndoorNavi base class is used for initialization of the application. It is realized in body of the method startApp. Initially an object of class TagCommunicator is created. To ensure that the application when launched by Application Management Software (AMS) receives notification related to discovered NDEF record it must register its NDEFRecordListener as soon as it is started. Then all other necessary objects, for the functioning of the application, are created. The values of the parameters needed for the application initialization are kept in the Record Management System (RMS) - ttsFlag, writeEnableHash. Read and write from/to RMS is realized by methods getAppStatus and saveAppStatus. Two ways to exit from application are supported: exit without unsubscribe from Push Registry (method exit) and exit with unsubscribe from Push Registry (method kill).

To speed up the communication with RFID tags, data is cached on the local disk of the mobile terminal. When the application is started for the first time, the following folders are created: IndoorNavi/cache/audio (information from audio tags) and IndoorNavi/cache/navi (information from navi tags). Caching is implemented by the methods of class **FileManager**. When RFID tag with NDEF record is detected, the following information is extracted: the record identification code (RID), the record date and time (eTag) and MIME type. The file specification is based on RID, eTag and MIME type. If in the local cache such file does not exist the content of the tag is read and saved into the cache. Otherwise, the contents of the record is extracted from the cache. Unnecessary records are automatically deleted.

Communication with tags is achieved by class **TagCommunicator**. Its main tasks are: registration of the application in the Push Registry if it has not yet been made, and implementation of interfaces TargetListener and NDEFRecordListener. When RFID tag is detected method **targetDetected** is called. If the mode "audio recording” is enabled (object writeEnableHash exists), and if tag is Mifare 4K and audio message is available, it content is saved on audio tag. When writing to audio tag record ID is formed by two parts: current date and time and value of writeEnableHash. When NDEF record is recognized, method **recordDetected** is activated. If the tag is navi type its content is read and decoded. This is realised through internal class **ParseXML**. Information for all reference points in the room is described by objects of class **Objects** (name of the reference point and navigation to it). If the tag is audio type the user can: hear the voice message, date and time leaving and delete message if he has necessary rights (the value of object writeEnableHash in

RMS and in tag’s ID match). The algorithms that handle event recordDetected, generated by navi or audio tags, are shown in Fig. 5 in the form of pseudo code.

a) Navi tag detected	b) Audio tag detected

if (tag data are in cache)
    read it
else
    read payload data and
    decode to XML format and
    write to cache
end if
parse XML data and create
description object
	if (delete command is selected)
	  delete message from cache
	  and tag
	else
	  if (message is in the cache)
	    read it
	  else
	    read data from the tag and
	    write to cache
	  end if
	play leaving date and time and
	audio message
	end if

Fig. 5. Pseudo code for handle event recordDetected

Audio messages are created by the methods of class **VoiceRecorder**. The mobile terminal must support Multi Media API and audio capture mode. To control the size of AMR file method setRecordSizeLimit is used. This ensures that the audio message will be successfully recorded into the Mifare 4K tag.

Speech navigation is realized by class **TTS**, which calls the necessary methods of class **AudioManager**. Class TTS provides static methods for word, sentence and digit to speech conversion. To each word, which the application support, corresponds resource AMR audio file. File specifications, corresponding to words, are saved in queue and wait for their processing. It is implemented in a separate thread from class AudioManager.

User interface is implemented by class **IndoorNaviCanvas**. It is maximally simplified. By Left Soft key application’s menu is called. The menu is constructed using static methods of class **Menu**. Menu items is changed adaptively depending on the operation mode and events from tags (see fig. 6)

Detected event	Key commands	Menu commands
No event detected	<*> TTS on/off	TTS on/off Record audio message or Save audio message Play audio message Clear cache Exit Kill
Navi tag detected	<↑> <↓> reference point <←> current position <→> room dimensions <fire> select reference point	Next reference point Current position Room dimensions Navigate
Reference point selected (navigate)	<fire> next command <#> reverse route	Next command Reverse route
Audio tag detected	<fire> play audio message	Play audio message Delete audio message

Fig. 6. Application commands description

4. Experimental results

The tests are realised in the off-line mode by Nokia 6131 NFC SDK and the Nokia 6212 NFC SDK. As an external RFID reader is used Omnikey CardMan® 5321 (see fig. 7).

In order to evaluate the performance of the application a series of experiments in hospital settings is conducted. RFID tags are placed on the doors of all rooms to which visitors have access (doctor's offices, manipulation, registration, toilets), including the entry-exit doors. RFID tags are placed over buttons of the elevators and on electronic information boards. The doctors can leave messages for their patients in audio tags.

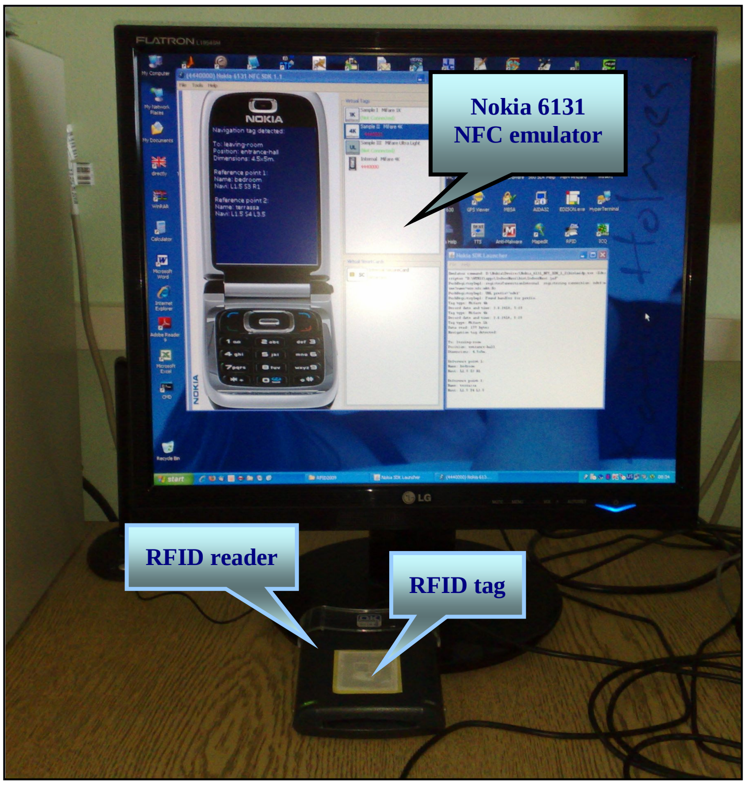

Fig. 7. Off-line experiments

In order to evaluate the performance of the application a series of experiments in hospital settings is conducted. RFID tags are placed on the doors of all rooms to which visitors have access (doctor's offices, manipulation, registration, toilets), including the entry-exit doors. RFID tags are placed over buttons of the elevators and on electronic information boards. The doctors can leave messages for their patients in audio tags.

Floor-plan of the test building is shown in Fig. 8.

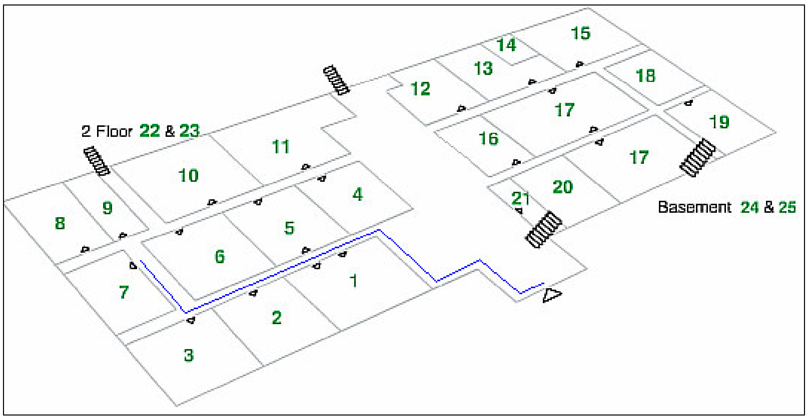

Fig. 8. Floor-plan of the test building

Twenty blind users participate in the application test (15 men and 5 women from 18 to 69 years). All participants in the test are familiar with the mobile application and its functionality. The selected hospital and target reference point are both unfamiliar for users. To avoid any obstacles on the way users use their white canes. The start reference point is hospital entrance door and target reference point is Dermatology (room 7). The selected navigational string for Dermatology is: "L2.5 R4.5 L4.5 R6.5 Ur L L4 R L1". Two metrics for navigation are used: number of rooms for navigation in the corridors of the hospital and meters for navigation in rooms. Because corridors are long, navigation in steps and meters is not appropriate, because of the possibility of large errors. In this case the user counts the number of rooms to be passed before reaching the desired reference point.

All participants in the test reached a target reference point. We measured the time required to find Dermatology. The mean time to complete the task was 140 sec. The best time is 104 sec, and the worst – 191 sec.

5. Conclusions and future work

An cost effective, RFID-based mobile indoor navigation application for the people with visual disabilities, has been developed. Application combines the capabilities of modern mobile phones, allowing the creation of multi-modal interfaces and low cost passive RFID tags. It can be used for indoor navigation (from room to room in hospitals, schools, universities, and etc.) of people with visual disabilities.

The main straights of the application are:

1. Low cost.
2. Using J2ME technology allows the application to be accessible to many users. Mobile phones represent technology that is most familiar for the visually impaired.
3. Room-to-room navigation by verbal commands. The application notifies the users via voice for: current position; name of reached reference point, room dimensions, names of the reference points in the room; navigational information to reach selected reference point; navigation in menu of the application and errors encountered when working with the application.
4. Floor-plan of a building and communication with WEB server are not required.
5. Simplified and event-driven user interface.
6. User can leave audio messages in tags.
7. Local info caching to speed up program response.
8. Automatic activation of application when NDEF-formatted tag is detected.

The main weaknesses of the application are:

1. The application can not be used for buildings with very long corridors and in the presence of numerous obstacles.
2. The number of mobile phones with built-in RFID reader are still small.

Navigational information must be corrected if the user stray from the route between two reference points or get lost. This is easily feasible, if the mobile phone supports program access to an electronic compass and accelerometer. Currently there is no NFC-enabled mobile phone, which has built-in compass and accelerometer. A prospective module "electronic compass and accelerometer" which will communicate with mobile phone via Bluetooth interface is to be developed in the future.

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