Indoor Navigation System for Visually Impaired

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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.*

Key words: *Indoor Navigation Systems for the Blind, RFID-based navigation, NFC-enabled phones.*

INTRODUCTION

The number of people with visual disabilities is around 135 million, of which 45 million are blind [20]. For people with visual disabilities navigation 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, overcoming obstacles can be risky, not all the blind can read Braille tags, the price of the existing systems for indoor navigation does not match the purchasing power of the people with visual disabilities.

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 middle price segments, Java technologies, and passive RFID tags.

RELATED WORK

There are two basic methods for indoor navigation: 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 [1,10,16].

Piloting: This type of navigation is used by systems with infrared, ultrasonic 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 [8]. Better results are obtained when using ultrasonic beckoning. For example, navigation system Drishti [18] have 22cm position accuracy. To calculate the position of blind metric Time Difference of Arrival (TDOA) is used.

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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 [9] or vibration [4]. 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) [2,17]. Accuracy is from 1m to 50m.

There are indoor navigation systems for the blind in which position of the user 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 [19] describe a system that recognizes the Quick Response (QR) markers. There are navigation systems in which information from the video frames is converted to modulated audio signals [13] or to vibrations [3]. Navigation systems based on visual pattern recognition, are still in an experimental stage [5,15].

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. [6,14]. The most of existing RFID-based navigation systems for people with visual disabilities [11,21] 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.

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.

SYSTEM DESIGN

The design of the application takes into account the preferences of the control group of 20 users with visual disabilities. We used an interview to help to 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 [12] 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 with white cane.

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. 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.

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

6212, 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. 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 [7]. This forecast is however too optimistic, because the number of RFID-enable mobile phones is still small.

2. System architecture

The main features of the application are: Speech navigation in Bulgarian and English; Automatic activation of the application when mobile terminal comes close to the 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.

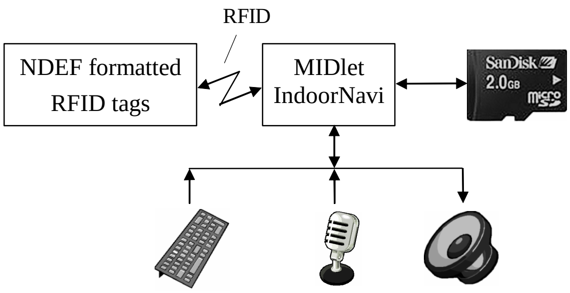

Fig.1. General view of application architecture

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. Navigational data encoding

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), and staircase (S±n, where n is the number of floors). When L and R commands are used direction is changed 90° from the current user orientation and 180° - when command B is used. In the navigation process three metrics can be used: meters (command Um), steps (Us) and number of rooms (Ur). By default, meters are used. For example, 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. Each navi tag contains the following information: Current position of the user (XML tag <pos>); Name of the room (tag <to>); 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

4. Program architecture

Program architecture of the application in Unified Modelling Diagram (UML) format is shown in Fig. 3.

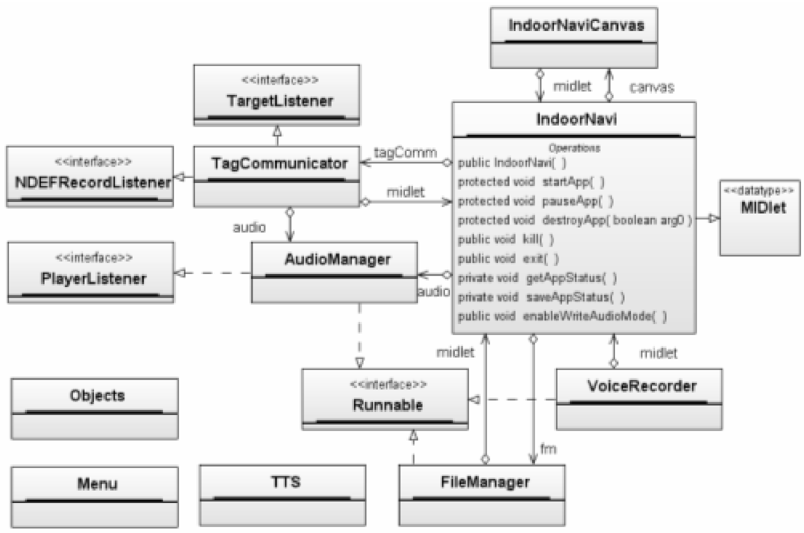

Fig. 3. UML class diagram

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

IndoorNavi base class is used for initialization and registration of the application. It is realized in body of the method startApp. Initially an object of class TagCommunicator is created. Then all other necessary objects, for the functioning of the application, are created.

Communication with RFID tags is implemented through class **TagCommunicator**. Its main task is registration of the application in the Push Registry if it has not yet been made. When RFID tag is detected method targetDetected is called. If the mode "audio recording” is enabled, and if tag is Mifare 4K and audio message is available, it content is saved on audio tag.

When NDEF record is recognized method recordDetected is activated. If the tag is navi type its content is read and decoded. This is realized 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 and date and time leaving, and delete message if he/she has necessary rights.

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.

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 and IndoorNavi/cache/navi. 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.

Audio messages are created by the methods of class **VoiceRecorder**. The mobile terminal must support Multi Media API and audio capture mode.

User interface is implemented by class **IndoorNaviCanvas**. It is maximally simplified and intuitive. By Left or Right 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 RFID tags (Tag detected, Record detected).

EXPERIMENTAL RESULTS

The tests are realized 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. For on-line experiments Nokia 6212 mobile phone is used.

In order to evaluate the performance of the application a series of experiments in hospital 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. The doctors can leave messages for their patients in audio tags.

Floor-plan of the building is shown in Fig. 4.

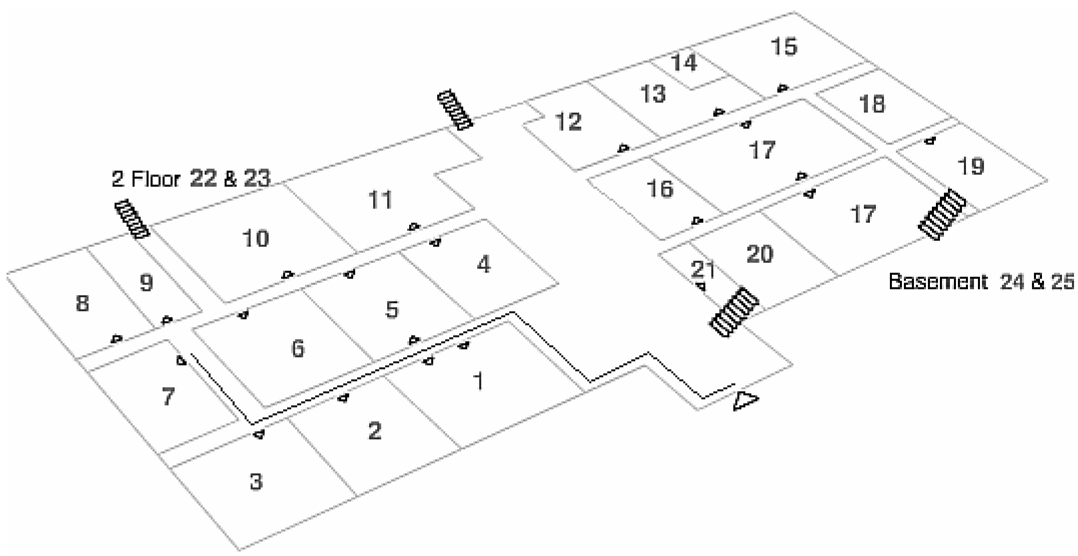

Fig. 4. Floor-plan of the building

Eight blind users participate in the application test (5 men and 3 women from 18 to 61 years). 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 room 7. The selected navigation string 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. For one of them assistance was needed, because she pass a navigational command. The reason for this is pressing <Fire> key (next command) twice instead of once. This problem was solved by blocking <Fire> key for 4 seconds after being pressed. We measured the time required to find room 7. The mean time to complete the task is 136s (1.5km/h). The best time is 106s (1.9km/h), and the worst – 180s (1.1km/h).

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 of people with visual disabilities (from room to room in hospitals, schools, universities, and etc.).

The main advantages of the application are:

- Low cost and widely accessible.
- Simplified and intuitive user interface.
- Automatic activation of the application.
- Local info caching to speed up response.
- Audio-enabled navigation.
- User can leave audio messages.
- Floor-plan of a building and communication with WEB server are not required.

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, will be developed.

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