RSNAVI: An RFID-Based Context-Aware Indoor Navigation System for the Blind

Rosen Ivanov

Abstract: *Most of the existing indoor navigation systems for the blind do not take into account their specific needs related to orientation and movement in an unfamiliar buildings. This paper presents an indoor blind navigation system called RSNAVI that has the following strengths: First, the system uses 4D modelling of buildings - 3D building and objects geometry and status of all sensors in time. To improve the navigation process we use semantic-rich interior model to describe not only the position and shape of all objects but also their characteristics. Second, the algorithm for route planning uses multi-parametric optimization to obtain the optimal route for the blind users. The system allows automatic re-routing when the blind user deviated from the route or if it detects a change of status of the sensors, for example blocking access to the room due to fire alarm. Finally, only algebraic expressions to calculate optimal route waypoints and to detour obstacles are used.*
Key words: *Indoor Navigation, Visual Impairment, Context-Aware Applications, NFC-Enabled Phones*

INTRODUCTION

According to a British Journal of Ophthalmology [12] in 2010, there are at least 285 million visually impaired people, of whom 39 million are blind. The possibility of independent orientation and navigation of the blind in an unfamiliar environment, both outdoors and indoors, is a key challenge that allows them to participate in the social, economic and cultural life.

In recent years, outdoor navigation for the blind relatively successfully is implemented by applications that use of Global Navigation Satellite Systems (GNSS) such as GPS, GLONASS, Differential GPS (DGPS), Satellite-based Augmentation System (SBAS) and maps with high accuracy and number of landmarks. Blind navigation in an unknown indoor environment is a problem that so far has no practically applicable solution [5]. The reasons for this are complex: (1) The use of GNSS positioning in buildings is not directly applicable at present. In the future, development of GNSS receiver architecture [15] that uses algorithms for digital signal processing to minimize degradation effects (signal attenuation, multi-path and near-far effects) is expected. (2) A large part of indoor navigation systems for the blind are not in accordance with the specific way of orientation and movement of the blind in an unknown environment. (3) Part of the systems requires modification of the infrastructure of the buildings, which in most cases is too expensive. (4) Some systems require continuous training of the blind before they can be used in practice. (5) Other systems [9, 14] integrate electronics in the white cane. This reduces the sensitivity of the blind, due to an increase of the weight of the white cane. (6) The use of stereo signals in some navigation systems can be dangerous for the blind, because they lose the ability to use acoustic cues.

When design navigation systems for the blind, should take into account their preferred way of orientation and movement in an unknown environment. For this purpose, should be used User-Centered Design (UCD). Such systems must be easy to use, reliable, and with a price, which is consistent with the purchasing power of the blind. The Organization for Economic Co-operation and Development (2010) [11] reported that the employment rate was 44% and 75% for people with and without disabilities, respectively. The inactivity rate for disabled is 2.5 times higher.

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Most of the existing indoor navigation systems for the blind use 2D building models and required an additional infrastructure and devices to locate and navigate the blind [1]. User tracking is usually network-based [8]. Techniques such as Time Difference of Arrival (TDOA), Angle Of Arrival (AOA) and Receiver Signal Strength (RSS) are used. For computing optimal route, Dijkstra's and A* algorithms are most widely used. One of blind indoor navigation systems, which do not mention the use of white cane or guide dogs, is Drishti [13]. 2D ultrasound localization for indoor environments is used. The location error is within 22 cm. It is assumed that the obstacles in the rooms are stationary. The major drawback of this navigation system is too high price for the blind users. One of the few systems that do not require modification of the infrastructure (unassisted tracking) is AudioNav [4]. The authors plan to use 3D modelling of buildings and path integration based navigation. The specific way of orientation of the blind in unfamiliar buildings suggests that the navigation system should give detailed information for surrounding objects and their characteristics. However, small number of existing navigation systems [3, 10] considers this. When planning the route, should not be looking for this with the shortest length. The optimal route is one that is safer for the blind. They must feel secure during the whole route and should therefore move mainly along the walls of the rooms and hallways, doors and handrails. In [16] is proposed a route-planning algorithm that takes into account not only the length of the route, but the number of landmarks and clues along the route.

RSNAVI ARCHITECTURE

The architecture of the proposed indoor navigation system for the blind is selected after an interview with a control group of 20 blind individuals. It is divided into three layers (see Fig.1): *Building layer.* It is responsible for blind users and objects tracking, things identification, and monitoring of status of the sensors (smart phones, passive RFID tags, and Control & Monitoring Gateway); *Network layer*. Its main function is to deliver information obtained from the building layer to Internet-located services; *Application Layer*. This layer realizes the functionality of the navigation system by a Java-based WEB services. Where it is not possible to realize a network connection between Control & Monitoring Gateway and Internet-located services, SMS-based communication via GPRS (UMTS) modem is used.

The proposed navigation system uses following technologies: (1) RFID passive tags (Mifare Classic 1K and Mifare Ultralight). They are used for blind user identification and tracking, object localization, and things identification - Internet of Things [2]. (2) Mobile phones with integrated Near Field Communication (NFC) interface, electronic accelerometer and magnetometer (compass). The requirements for the successful installation of the client side Java application are as follows: profile MIDP 2.0/2.1 (JSR-118), configuration CLDC 1.1 (JSR-139), File Connection API (JSR-75), Java APIs for Bluetooth™ (JSR-82), Location API (JSR-179), Wireless Messaging API (JSR-205), Contactless Communication API (JSR-257) and Mobile Sensor API (JSR-256). At this stage of development of client software, an additional C++ application is used to calibrate the compass, as Nokia phones do not allow calibration from the Java level. (3) Voice-based navigation. We use Text-To-Speech (TTS) engine. (4) Beck's SC13 System on Chip (SoC) is used for implementation of the Control & Monitoring Gateway.

The RSNAVI indoor navigation system allows optimal route planning, user tracking and exploration, voice-based navigation along a route, real-time evacuation, and pre-journey learning (ability to explore and learn a route virtually). All modes of the navigation system must be realized in real time when using a mobile platform. For this purpose, we use only algebraic expressions to calculate optimal route waypoints and to detour obstacles.

RSNAVI navigation system operates in two modes:

1. Local mode: this mode does not require access to Internet-located services. All algorithms are realized on the client side (mobile user). The Control & Monitoring Gateway via Bluetooth interface notifies client about the status of the sensors. This mode is suitable for navigation in small homes.

2. Global mode: this mode requires users to have a permanent Internet connection. To reduce the number of requests to the Internet-located services, the information necessary (building floor plan, calculated routes, information about smart objects, etc.) is cached on flash disk of the mobile terminal. If the user can not reach to destination point, for example because of fire in room, route-planning service automatically calculates a new route. In this case, the navigation service sends push message to notify client. We use Simple Object Access Protocol (SOAP) to transfer XML-encoded data between mobile clients and Internet-located services. Global mode is appropriate for navigation in public buildings (hospitals, schools, universities, hotels, government offices, etc.)

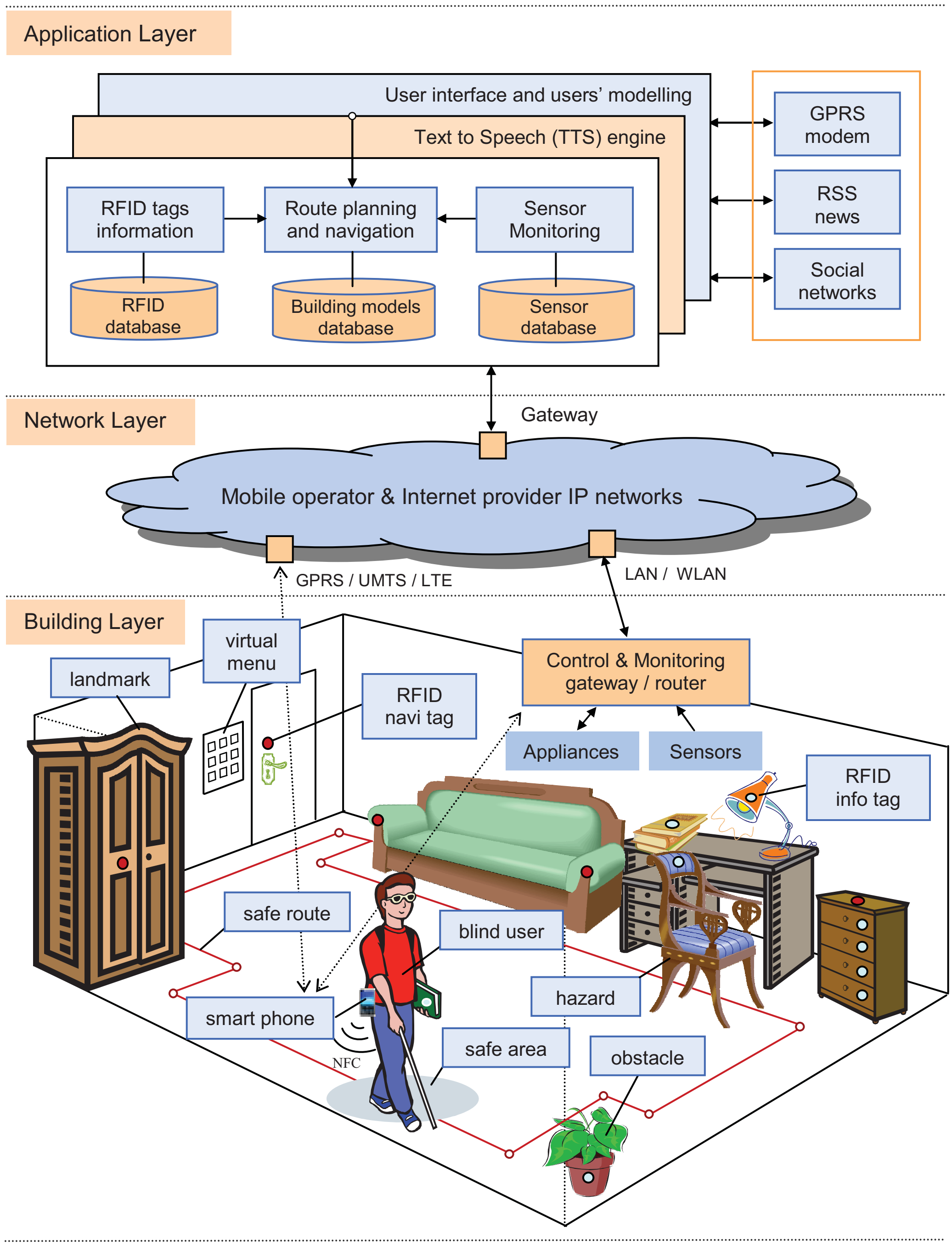


Fig. 1. RSNAVI architecture

RSNAVI navigation system uses several types of passive RFID tags: (1) navi tags: allow for user tracking, (2) pobox tags: enable users to leave audio messages, (3) object tracking tags: localization of objects in the building, (4) things information tags: identify-cation of smart objects, and (5) URI tags: contain the Uniform Resource Identifier (URI) to Internet-located services.

To create a virtual menu (group of RFID tags arranged in rows and columns, see Fig. 1) URI tags are used. When blind brings mobile phone close to menu tag he or she hears the name of the service to which the tag provides access, for example: get building model, access to control and monitoring gateway, search engine (looking for people, rooms and objects located in building), etc.

An example scenario for using the proposed navigation system is follows: (1) The blind user reaches desired building, for example via GPS-based outdoor navigation system. Than the user needs to find URI tag, located on the entrance door, before entering the building. The activated service (WEB-located service in global mode or Control & Monitoring Gateway in local mode) finds in database building model and generates information for client in XML format (floors, hallways, doors, escalators, offices, rooms, etc.); (2) The user selects the destination point (floor, apartment or office, room, zone, etc.). The user can choose preferred destination point if there are several possible destination points (toilet for example). Then activates the algorithm for route planning. It returns optimal route from current user position to selected destination point; (3) The navigation service generates the sequence of instructions (environmental and sensor status dependent) to orient and navigate the user to the destination point.

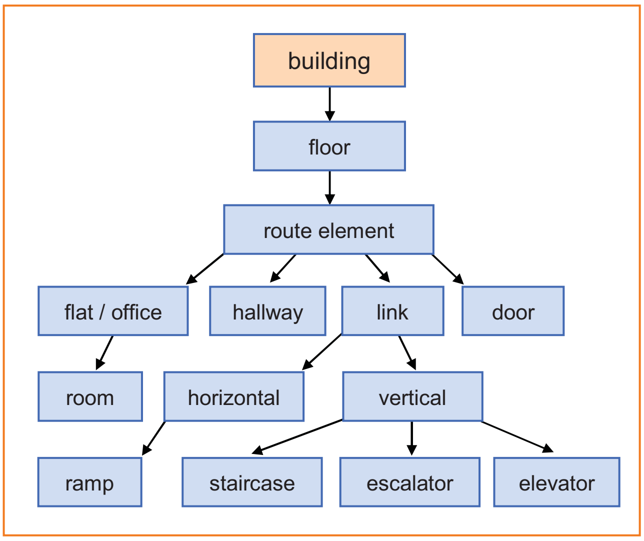
BUILDING MODEL

Most often, geometric models to describe the buildings are used, for example Computer-aided design (CAD) models, 3D Geographic Information System (GIS) data models, and object-oriented 3D Building Information Modelling (BIM). The last models have been developed to cover all stages of the building life cycle and describe both geometric and semantic information. In blind navigation, to represent infrastructure of buildings graph or network models are usually used. The "room-door" relation is converted to "node-edge" relation. These models are not suitable for very large number of nodes.

One of the advantages of the proposed indoor navigation system, in comparison with other similar systems, is the use of the 4D non-network-based building model. In this case, conversion of the building geometry to the graph or network presentation is not necessary. In addition to 3D geometric dimensions of the building, the status of all sensors over time is modelled. This information is necessary, since the selection of optimal route depends on the status of doors (open, closed, locked, blocked) and status of sensors. We use seman-tically rich object-oriented modelling of buildings (see Fig. 2). The model contains infor-mation about all route elements (rooms, hallways, links, and doors) and interior objects (its position and attributes).

ROUTE PLANNING

In route planning, different groups of algorithms are used, for example: potential fields-based, grid-based, computer network routing, Voronoi diagrams, dynamic progra-mming, etc. Most of the indoor navigation systems use Dijkstra's or A* shortest path algorithms to obtain an optimal route from all possible routes. Unlike the general case for the sighted, distance and travel time are not the only criterions that determine the optimal route. In [16] total number of landmarks and clues are additional criteria that should influence the optimal route selection. In the proposed system, we use multi-parametric optimization to obtain the optimal route. The navigation system analyzes five parameters: (1) number of landmarks on the route, (2) number of obstacles and hazards on the route, (3) number of doors through which user must pass, (4) number of turns (user change its heading), and (5) route length. The weight of all parameters was determined after an interview with a control group of blind individuals. There is a possibility for users to set their weights for each of the five parameters. The navigation system allows automatic re-routing if there is a change in the status of sensors, such as blocking the room due to fire.



building:
id, name, city, metrics, position [GPS coordinates]

floor:
number [-n, 0, 1, 2, 3 …, m], route-elements

flat / office:
id, name, rooms

room:
id, name, area, parts [coordinates],
access [public, private, blocked, man, women],
components [flooring, wall, window, object, zone, sensor], exposure [N,S,W,E, etc.]

hallway:
id, name, parts [coordinates],
components [flooring, wall, window, object, sensor]

flooring:
coordinates [polygon points], material [parquet, terracotta, carpet, linoleum, stone, etc.]

door:
id, name, virtual [yes, no], position [coordinates], width, access [automatic, manual], link [n, m], class [room, floor, building], evacuation [yes, no], status [open, closed, locked, blocked], type [sliding, turning], direction [entrance, exit, entrance-exit], components [sensor]

wall:
id, coordinates [polygon or segment points], height, material [plaster, stucco, wallpaper, etc.]

window:
id, position [coordinates], height, type [sliding, turning], status [open, closed, blocked]

object:
id, name, position [coordinates], position-type [fixed, float], material [textile, wood, metal, leather, etc.], type [landmark, obstacle, hazard]

staircase:
id, name, position, link [n, m], components [flooring, wall, window, sensor], steps [number], incline [degrees], handrail-position [left, right, both]

elevator:
id, name, position, link [floor range], button-position, accessible [yes, no], components [flooring, wall]

escalator:
id, name, position, link [n, m], direction [up, down]

zone:
id, name, position [coordinates]

sensor:
id, name, position, type [door, window, light, appliance status, fire alarm, temperature, etc.], value, status [on, off, open, closed, alarm, etc.]

ramp:
id, name, position, link [n, m], components [flooring]

user:
id, name, gender, location [indoor, outdoor], indoor-position [building, floor, route element, last known coordinates], outdoor-position [GPS coordinates], type [visitor, staff], deviation-history [normal, often, too-often], outdoor-activity-status [velocity, heading], indoor-activity-status [standing, walking], impairment-type [none, blind, mobility], preferences [spatial-representation, route- weights], mobile-phone [last know model, number], social-networks [facebook, twitter], history [date, building-id, route-elements-id].

spatial-representation [clock, compass], route-weights [path-length, number-of-turn-points, number-of-landmarks, number-of-obstacles, number-of-doors]

Fig. 2. RSNAVI building and user models

Finding the optimal route is realized in several steps:

1. Coarse estimate of the optimal route. We find all possible routes from start room to destination room. The routes are described as a sequence of identification numbers of rooms and doors through which blind user must pass. For example, 5-3-1-4-10 is interpreted as follows: from the starting room 5 goes into a room 1 through a door 3. To destination room 10 is reached through a door 4.

2. Accurate estimate of the optimal route. We calculate the optimal routes within all rooms and hallways, which belong to the routes calculated in step 1. The algorithm, that finds optimal route in the rooms and hallways realizes and obstacle detour. It is assumed that the position of obstacles is known. The route calculation relies on fact that blind users prefer to walk in unfamiliar buildings along the walls and handrails on stairs. The route-planning algorithm finds route whose points are at distance 0.5 m from walls and obstacles.

3. The final route is obtained as a sequence of all optimal routes within the rooms, which the blind must pass.

Fig. 3 shows the results obtained after route planning in an apartment. With the dashed line are shown pre-calculated safe for the blind routes along the walls of the rooms and fixed objects. *Route 1*: Movement from start point located in room 1 to destination point located in room 10. As the door 5 is blocked, route goes through an opening to room 6. *Route 2*: Walk from point located in room 2 to staircase in hallway 1. *Route 3*: Walk from start point located in room 9 to destination point located in room 5. This is an example for detour of not-fixed obstacles. *Route 4*: Start and destination points are located in room 11. In this case, the distance between start and destination points is too short and the route calculated directly detour obstacle 1.

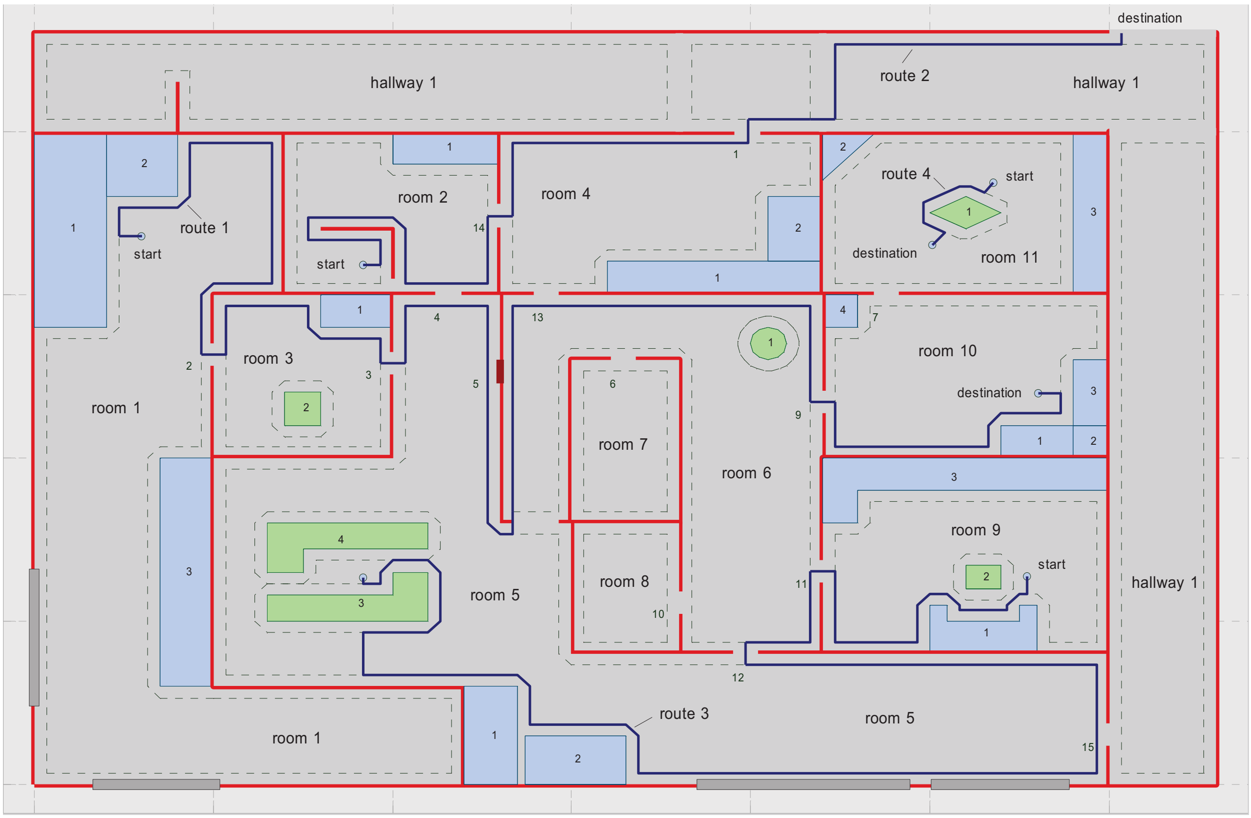


Fig. 3. Route planning example

EXPLORATION AND NAVIGATION

To make possible exploration and navigation modes, the navigation system must know the current position of user. For this purpose, in RFID database are recorded positions of all navi tags. They are used as reference points in the buildings. Navi tags are placed on each door, object and walls. To obtain the position of a blind user in time (user tracking) he or she needs to touch your mobile phone to navi tag. When the blind moves between two reference point dead reckoning technique is used to update the current user position. When the blind user deviated from the current route and touches to a navi tag, navigation system calculates new route (automatic re-routing).

In *exploration mode*, the blind user receives information about the characteristics of the current room and objects in surrounding environment. Blind prefer two basic methods for spatial representation [6, 7]: *Allocentric*. It is assumed that the reference direction is one of four cardinal points (north, south, east and west) or clock's hour hand (12 o'clock). An example for allocentric bearing follows: turn east, door at nine o'clock. *Egocentric*. In this case, information about user current heading is obtained from the sensor. RSNAVI indoor navigation system supports both methods for spatial representation. In exploration mode, the blind receives information about: (1) Apartment or office: name, area, number of rooms, names of the rooms. (2) Room: name, area, exposure, obstacles and hazards. (3) Elevator: floor range, accessibility, position of buttons. (4) Door: automatic or not, sliding or turning type, status (open, closed, locked, blocked). (5) Description of all objects (names and distances) in current user heading. (6) The names of the nearest surrounding objects (front, back, left, right).

After route planning, a sequence of waypoints, which describe the route from starting to destination point, is obtained. In *navigation mode*, blind user receives commands how to reach each waypoint, for example "follow the wall to your left side until you reach a door", "after five steps turn left." We use landmark-based navigation in long hallways and combination of landmark and metric-based navigation in rooms. During the navigation from start to destination point blind user receives information about material of the floors and walls along which he or she moves, for example: flooring - parquet, moving along the wall with latex coating. The system generates information and about the objects, which the blind user detours, for example: leather sofa, wooden wardrobe, turned on laundry machine.

CONCLUSION AND FUTURE WORK

In this paper, the architecture of an RFID-based context-aware indoor navigation system for the blind called RSNAVI is presented. The primary features of the proposed navigation system are as follows. *Fist*, the 4D context-aware model of buildings allows adaptation of exploration and navigation modes to the status of the sensors in the building (status of doors, windows, fire sensors, etc.) *Second*, the algorithm for route planning takes into account important for the blind user information: landmarks, obstacles and hazards in building, doors, walls and handrail's position. To obtain the optimal route for the blind individuals multi-parametric optimization algorithm is used. The system allows automatic re-routing when the status of sensors is changed and when the blind user deviated from the current route. *Third*, an algorithm for obstacle detour is used. The algorithm is independent of the number and positions of obstacles and their geometric shapes. *Finally*, the blind user can search persons and objects that are located in the building.

The system is in testbed phase and it is experimented in local mode. In the future, we will: (1) test the system in global mode and (2) calculate the position of not-fixed objects more precise (at this moment, position of these objects is estimated from the current position of the blind).

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ABOUT THE AUTHOR

Assoc. Prof. Rosen Ivanov, Ph.D., Department of Computer Systems and Technologies, Technical University – Gabrovo, E-mail: rs-soft@ieee.org.