inLoc : Location-aware Emergency Evacuation Assistant

Kaan Eksen, Tacha Serif
Department of Computer Engineering
Yeditepe University
Istanbul, Turkey
kaan.eksen@persystlab.org,
tserif@cse.yeditepe.edu.tr

George Ghinea
Department of Computer Science
Brunel University London
Uxbridge, UK
george.ghinea@brunel.ac.uk

Tor-Morten Grønli
School of Arts, Communication and Technology, Westerdals
Oslo, Norway
tmg@westerdals.no

***Abstract*— Healthcare services and research centre reports estimate that by 2050, Americans aged 65 or older will reach the 89 million mark; this is more than double the number of older adults in the United States in 2010. In an aging society, it is important to home care elderly and maintain their daily needs and provide safe evacuation alternatives in the case emergency. Hence, this paper aims to implement and evaluate a smart and location-aware indoor emergency evacuation system for elderly users. The prototype system employs multiple Bluetooth Low Energy and iBeacon sensors and a smartphone. The smartphone utilizes the beacon signals to estimate its location within the building and uses the sensor data transmitted by the iBeacons to identify the level of threat (if any) to the elderly user and guide him/her to a safe zone in the case of fire, earthquake etc. Our prototype was tested in three different locations utilizing two different types of sensors. The results show that our system can detect a threat and guide the elderly user with minimum 85.47 centimeters and maximum 239.8 centimeters distance error.**

Keywords*— *indoor, location estimation, context-aware, emergency, guide, elderly

I. INTRODUCTION

The total share of older people in the population is increasing and it is predicted that the share of persons aged 80 years or above in the European Union will more than double between 2013 and 2080[1]. Against this backdrop, the home care of the elderly and maintaining their daily needs becomes increasingly important. In the case of an emergency, however, detailed attention needs to be paid to appropriate evacuation methodologies that will help elderly people to exit their homes to a safer place– and this is the focus of the current paper.

Given that the Bluetooth SIG anticipates that in 2018 90%or more of Bluetooth-enabled smartphones will support Bluetooth low energy (BLE) [2], in our project BLE devices, which consist of an accelerometer and temperature sensor, are used to evacuate older people to safer zones.

The assumption is that elderly people will be carrying such a device and that it will use advertised environmental data to detect an emergency. If such an emergency occurs, the mobile device then guides older people to safer zone with multi model interaction methods like heat, sound, and vibration.

II. RELATED WORK

In Dey and Abowd's seminal work, context was defined as any kind of information related to situation of entity like time, location etc. [3], whilst context-aware systems use context to transform themselves in relation to changes in context [3, 4]. Four main types of context, namely location, identity, activity, and time have been identified [4] and recent developments in smartphone technology has meant that the building of context-aware applications ('apps') running on smartphones has migrated from the niche to the mainstream.

The proliferation of such apps has been facilitated by the fact that mobile use has been increasing in the last decade [5]. Moreover, recent Internet usage statistics show that mobile access is also growing and in 2018, it is expected to expand to 61.2% of all Internet usage [5]. Indeed, these statistics showing that mobile phones can be used in a variety of places and situations is one of the main drivers behind the popularity of context-aware apps. Indeed, with the development and incorporation of new sensor technologies (e.g. accelerometer and gyroscope) and positioning systems (e.g. GPS, Wi-Fi) in mobile phones, context awareness becomes essential in many areas. Many systems use information that is related to user for monitoring/navigating user actions, which give more life-entwined solutions to daily problems.

In healthcare, context awareness is particularly important; this becomes arguably doubly so in the case of emergency situations, when knowledge of the location of patient is essential for recovery in a timely and effective manner. Remotely monitoring a patient's location and guiding emergency personnel, such as firefighters [6, 7], security personnel [8, 9], and medical staff [10], to a patient's location is of significant important during emergencies. This is exacerbated by the fact that, emergency personnel have a very limited time frame in which to operate, so context awareness is fundamental in such situations. Having an efficient emergency evacuation strategy is thus one of the most important topics for elderly with disabilities [11]. These aged people need help to exit their homes and guiding them to safer places, in case of emergency, requires context awareness applications.

III. Methodology

There are two parts to the positioning process. The first is related to detecting the distance, whilst the other is concerned with calculating the position. We now show how these were accomplished in our work.

A. *Detecting Distance*

For finding the position, firstly, the distance between devices is determined. When there are two devices for finding the position, one of them is usually a mobile device whilst the other device has its position known in advance. If the distance between devices is known, the position of mobile device can be detected according to access points that have pre-determined locations. In addition, using wireless signals is the most commonly used method to detect distance.

Time of arrival (TOA), angle of arrival (AOA), received signal strength indication (RSSI), and time difference of arrival (TDOA) technique is used to detect the distance between two devices according to their signals [12, 13, 14]. These techniques are also used to find position of a mobile device.

B. *Calculating Position*

A mobile device can calculate its location after detecting the space between itself and access point. To do this, the location of mobile phone from three or more access points is required. Fingerprinting, trilateration are used to calculate mobile device location[15,16].

IV. ANALYSIS & DESIGN

In Bluetooth, at least three beacons are required to determine location. Fingerprinting and trilateration methods need RSSI or a similar indicator to detect location. Figure 1.0, details a general representation of the prototyped system. The app was developed on an Apple iPhone 5, running Apple's proprietary iOS8 operating system; and boasting a Dual-core 1.3 GHz Swift (Arm v7-based) processor and 1GB memory.

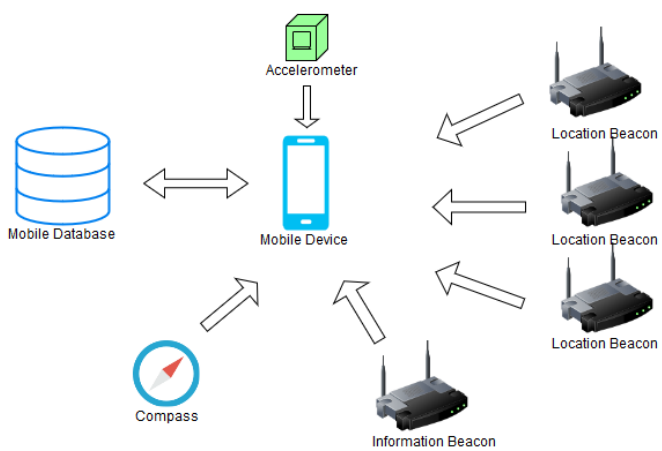

Figure 1. Architecture Diagram

There are two ways to get received signal strength indicator (RSSI) values in Apple devices. The first way is to get RSSI values without connecting to the device. Using this method, the operating system will scan all the available signals and return basic information such as RSSI, name, and advertisement data etc. In this method, there will be considerable energy loss due to a continuous scan. In the long term, it can cause unwanted events like draining battery in emergency situation. The second way consists of connecting to a device and pulling RSSI values. In iOS8, the operating system uses a delegate to communicate with application. In some cases, when the application request updates, the system may or may not answer. Another problem with pulling is that it requires more time than scanning. In pulling, there is a slight chance of getting old values when requiring too many RSSI values. Lastly, when one device is connected to a beacon, other devices cannot connect and scan the device.

This is precisely why the system will contain two types of beacons. The first type is used for location detection with a continuous scan. The second type of beacons will be transmitting contextual data such as accelerometer, temperature.

The functional requirements of the prototype are as follows:

- Device location should be calculated in area.
- User should be able to monitor location.
- Navigating user to a pre-defined exit and safe site.
- Detecting emergency situations

The non-functional requirements;

- Location should be calculated thorough user movements.
- In indoor navigation, the localization error should be less than 1meters.
- Application should work on all Apple devices (iDevices).

The system contains three essential parts. In the first part, administrator-specific operations will be placed, like adding Beacon, images. In the second, user locations in normal mode will be placed. The last part will be active if only and only if there is an emergency situation.

A. *Offline Phase*

In first instance, beacons are detected and recorded to the database. After detecting wanted beacons, the purpose of the beacon inserted. There are two types of beacons. In information type devices, location information is set because in emergency, location will be used as path changer. In the second type of device, location and reference points (RPs) are used based on the location detection algorithm. RPs are created in small intervals to detect location as smoot as possible.

Multiple RSSI values are collected in the record of an RP because there is a possibility that some unwanted/corrupted RSSI values could be collected. That is why average of multiple RSSI values recorded. All computations are based on three RSSI values, but in reality, increasing the number of collected RSSI data will improve accuracy. Since getting more

RSSI values causes more setup time and energy, limiting the average value to five or more will be reasonable. The average RSSI value is recorded with universally unique identifier (UUID). For each device, the recording of RPs has to be done one by one.

Sensor and beacon registration is a one-time process that has to be undertaken by the administrator since every device has a different unique UUID, which has to be registered to the database. As soon as each peripheral device is registered to the system with the required information, the mobile device will be able to interact with them and collect sensory data or calculate location through them. Following the sensor and beacon setup, the administrator can draw the possible paths and pinpoint the exit points for emergency evacuation.

B. Online Phase

In the online phrase, the location is determined and displayed by the phone. This will be the main part of the application since the user will only be able to display this part most of time. To determine the location, the nearest neighbor in signal space (NNSS) is used.

First, the application scans all available beacons then collects advertisement data. After progressing the data, it connects information devices and scans location devices for RSSI values. The number of collected RSSI values is selected based on the device and visible beacon count. Then, based on the collected RSSI and stored RP`s RSSI values (Signal Map), the Euclidean distances are calculated. Based on the closest three RP, Triangulation used to detect location.

Direction is another piece of information, which should be calculated. Magnetometer data is used to get direction. Based on true north, user direction is calculated. Since the true north value of room is known, the user’s exact direction can be calculated.

User location and direction calculation is repeated for the rest of the application. Since getting the exact location is important, calculation interval of location and direction should be as much as possible but since calculations cause battery draining, optimal value should be found. Optimal value is set based on RSSI value intervals.

C. Emergency Phase

In the emergency phase, detection of emergency is important. Since there are two types of beacons, information beacons will be essential since they are the connected ones to drive environment information.

In application start up, some basic settings has to be made. Firstly the initial training data that was collected in the offline phase will be loaded to the memory. Then, the connection with the surrounding Bluetooth beacons will be made. After connection, device specific settings will be set, such as temperature sampling intervals. Then, notifications will be opened based on predefined event prediction.

Since sampling intervals are important to detecting changes and predicting the possible emergencies, battery of beacon is another important value because in terms of our possible user types, changing battery could require special knowledge. Since all beacons will collect data all the time, even a little reduction in sampling intervals result in important battery savings.

After detecting an emergency, the most important step is identifying the nearest. There are various ways and algorithms of calculating the shortest path to a certain location. However, due to its algorithm efficiency and implementation speed in this application we opted to use Dijkstra's algorithm. Providing every path a weighted value based on the data collected from the sensors the algorithm sets the safest path for the user, which will enable him/her to avoid any endangered areas. A* search is a possible candidate for the same use, which will enable fast development and rapid algorithm output. However, this algorithm can be implemented and tested in the future versions of our application.

After displaying the path, location is estimated utilizing beacon RSSI values. To get more accurate location information, in conjunction to RSSI calculations the step count data can also be merged. This will reduce location hopping that may occur due to RSSI signal reflections. However, this is a two-ended sword, if there the pedometer skips any steps this may cause larger errors in terms of accuracy.

One of the biggest problems in using step count for indoor location detection or estimation is the starting point. To maximize the starting point accuracy, when identifying the starting point, multiple location estimation and identification methods (WiFi triangulation, iBeacons, BLE and/or Barcode/QR-Code) should be utilized and the average of all should be used as the actual starting point.

After the step size is increased, the algorithm should give more priority to RSSI since missing some steps may cause further error. In the inLoc design, priority is given to a circular area. Based on current location, steps are added to determine a new location. Direction information is used to determine the step’s angle. In every new location, a new circular area is calculated. If the RSSI value is inside the circle then the new location is set in there; however, if the RSSI location is outside of the circle, then the circular boundary’s top limit is set as the location. The radius of the circle is calculated using the following formula:

$$\text{Radius} = \text{total}_{\text{StepCount}} \text{ x } \text{U}_{\text{userStepSize}} \text{ x } \text{Ratio}_{\text{StepSize}} \quad (1)$$

Multiple improvements were added to the existing location estimation algorithm. Such as: (a) We utilize the iBeacon technology to set the starting point every time the user passes close by a beacon. By doing so, we reduce the size of the area for the location to be calculated and, hence, reduce the error margin. (b) All the collected RSSI values are time stamped so that the old collected data is dismissed and only recently collected RSSI values are used in the calculations. (c) Finally, the location estimation calculations are executed, only and only, if the signal data can be collected at least from four beacons. This improves the quality of the signal data that is used in the calculations and as a result increases the precision of the result.

D. Interaction Models

There are three interaction models in inLoc: (a) Vibration is used for warn the user if diverts from the set route. For example, vibration with little intervals indicates right and vibration with large intervals indicates left. (b) Light is used for proximity information about exit. Accordingly the brightness of the light will increase when a user gets close to exit. Last but not least; (c) Sound is also used as a proximity information relaying method.

E. Beacon

In most of commercial device, power saving is important. To fulfill the requirement of project, some changes were made to the Texas Instruments Bluetooth 4 Sensor (CC2650). CC2650 always try to save energy as much as possible. Accordingly, in advertisement mode, the CC2650 advertises for one or two minutes. After that, it turns itself to sleep mode, which makes it impossible to detect without any physical connection. In our project, changes were made to make its advertisement permanent so users can connect or use advertisement data whenever they want

V. IMPLEMENTATION

The initial implementation of this prototype was on iPhone 4S and the operating system version iOS 8.0, which was the latest version at the time. However, after implementation the application was also tested on iPhone 5S with iOS version 9.0.

inLoc was implemented using a combination of Swift (roughly 99% of the code) and Objective-C programming language. As Swift is main development language for iOS and Mac platform, it was used intensively to create the interfaces and application logic. However, Objective-C programming language code was deployed where low-level development was required. Compared to open source mobile application operating system platforms, iOS, due to its proprietary framework and privacy-toughened architecture, sets multiple restrictions and limitations to the developer. Hence, in order to overcome the iOS operating system's low-level limitations, such as manipulating device vibration patterns and screen backlight management, Objective-C libraries were implemented.

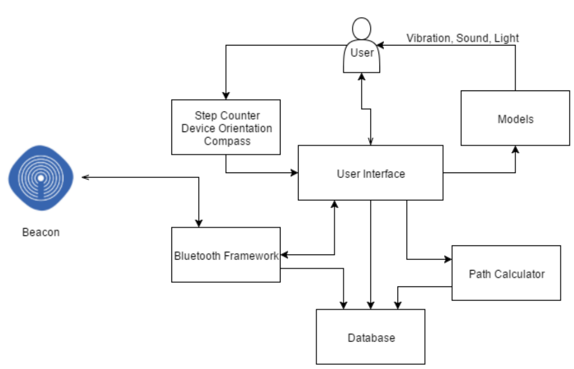

Figure 2 General iPhone Design

There are two modes of use of the application, namely administrator and end-user. The administrator mode is only accessible by authorized users and the administrator interface requires the user to authenticate using a username and a password. In the administrator mode, an authorized user can set new facility map, routes to existing maps and register new beacon locations. However, the end-user interface is a one-screen view of the vicinity map that is used to navigate the user from point A to point B.

The prototype was coded as one application, which is made of three mobile application interfaces. The administrator interface, in additional to the functionality mentioned before, is also used to conduct the Offline Phase – an administrator can create an offline signal map of the area using this interface. On the other hand, the location estimation interface corresponds to the Online Phase, were the mobile device calculates user's current location using the signal map created in using the administrator interface. Lastly, the Emergency Interface is activated when an abnormal activity is detected from the sensors and this interface navigates the user to a safe zone.

A. Administrator Interface

Implementation of the administrator part requires background of connecting and transferring of data between device and beacons. In our initial approach, generalized beacon scanner is one of the requirements; in reality developing such a system requires professional development because of a multitude of reasons.

Firstly, beacons have no global standard. Although Bluetooth 4.0 specifications are the same irrespective of deice, in specific sensors access and data process changes from device to device. That is why making it impossible to standardize for all beacons. Secondly detecting beacons is another problem because for every device Apple uses system-wide hiding so that all UUIDs are different in every device. In some cases, device-specific information could be obtained from a device if it implements Bluetooth protocols. Thirdly, most producers prefer their own sensor characterization, which makes it hard to track all the UUIDs for all characteristics. Finally, characteristics have their own length and protocols so bitwise communication is necessary to set the characteristics.

In inLoc, Bluetooth framework is implemented using Apple's Bluetooth API. This framework undertakes two main functionalities - communication and profiling. The framework is used to make a meaningful communication between mobile device and the peripheral devices – sensors and beacons.

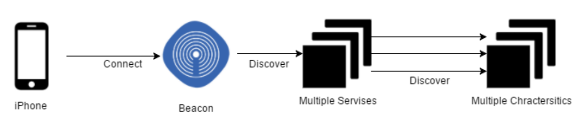

Figure 3 General Bluetooth Structure

The communication functionality can be split into three segments see Figure 3. In the first segment sits the central manager, which connects and transfers data to and from the peripheral. The second segment is the peripheral itself, which corresponds to the individual beacons. In the last segment are the services of the peripheral, which corresponds to a beacon's individual sensors.

Profiler consists of three elements. The first element is the manager, which holds a list of known services. The second element is the service profile, which has the general name and list of characteristics. The last element in the profiler is the characteristics, which hold the ID for identification, name, and type for specific calculations. For efficiency purposes, in our implementation we have used hash maps to keep the relation between Peripheral UUID and service profile.

General scanner can scan any type of beacon and display all the services and characteristics. It can denote the characteristics specifications like writeable, readable, etc. With online database, it can fulfill its profile manager and display names and purposes of characteristics and services.

After generating framework, one shared Bluetooth is created so that user interaction could be specified with scanner. User oriented design made to display list of beacons. Connection is indicated with global Bluetooth symbols. Connection and disconnection can be done with long gestures like pressing beacons for specific time, which require administrator credentials.

Device specific information can be viewed and edited using the device setup screen. On this screen, an administrator can create a new location for a device; set the device type or an alias for a device. Furthermore, an administrator can view and edit the services and characteristics provided by the sensors and beacons – see Figure 3.

In background, inLoc connect to device if it is information device and set up its characteristics based on profile manager. If it is Location device, it is not connect and start constantly monitoring its RSSI values. Device service and characteristic scans are limited to specific types so that battery will be used more efficiently. Based on user perspective, less knowledge will require to set up inLoc

Reference points are embedded to Bluetooth Framework since location detection algorithm and devices recorded in framework. RP are record in list. For every position, device RSSI values can be acceded with hash maps, which increase the calculation speed. UI design for RP record is made with time-oriented manner. Administrator can select devices and start recording RPs.

In RP record, parallel programing logic is applied. Since beacons advertisement cycle is unknown, Device wait for specific type and if its RSSI value is changed then it is record that RSSI if not it is pass that cycle. After specified number of RSSI values record trial, it takes averages based on number of RSSI values, which are recoded.

The administrator can register the interconnecting paths that can be taken by the user in the case of emergency. The paths can be created using a finger and drawing a straight line on the screen. The start and end points of the line are used to create the path and are registered to a local database. Using the same method, the paths can be deleted from the database. Also, in order for the algorithm to navigate the user to a safe area, the administrator must also indicate the exit points. The exit points can be only one, e.g. the main door of the building, or multiple points, e.g. main door, emergency exit or street-level window.

B. *Location Determination*

Location detection is default interface where user is welcomed. User is not able to view another part from this. User interaction is limited because it is the only simplified view to use by anyone.

In location detection, there are timers, which calculate location with specific intervals. After finding location, it will set location to appropriate location in room picture. Since accuracy of location is important, location determination intervals based on iPhone 4S scan capabilities. iPhone 4S selected to be ground phone because it is the oldest phone sported by apple which means that currently our application support about 350 million devices.

There are some problems with scan capabilities in iOS. It is decrease the advertisement detection. Probably, device itself try to save energy even application itself does not act according to documentation of Apple. That's why, inLoc use another timer to open and close scanning at specific time intervals, which fix iOS protection.

C. *Emergency Interface*

The emergency interface is only triggered by some emergency activity that is detected though the sensors scattered in the environment. In inLoc utilized two types of sensors to identify state of emergency; these are thermometer to detect fire and motion sensor to detect earthquakes. Since it is not possible to set threshold limit on CC2650 so that it signals the mobile device after it reaches a certain level, temperature data is collected constantly by the mobile device and evaluated for any abnormality in the temperature. Second sensor is MPU9250, which is also known as know as second-generation 9-axis MotionTracking device. Unlike the thermometer sensor, a threshold can be set for this sensor. Hence, our set up uses the wake-On-Motion approach so that both the beacon and the phone can save energy.

When Bluetooth framework detect an emergency, it inform user interface, which change its mode to emergency. After emergency mode is activated, user models interface changes to navigation mode. In every location change, shortest path calculated and user models changes according to location. There is a timer, which observes movement of user. If user inactive for long time, it could be used to change mode which give sends current location to authorities and changes model to get attention from emergency personal such as using flashlight to give SOS signals.

Apple iPhone's embedded step counter latency was so high that it was impossible to use in any emergency situation. Therefore, as part of the implementation of the application a footpath step counter is implemented and used to detect steps [17]. User direction is always calculated in any change of magnetometer. Since magnetometer error could be up to 30 degrees, inLoc footpath pedometer divides the directions to 4 types such as forward, backward, left, and right. Using this approach, we were able to cover 90 degrees of error.

In emergencies, users usually secrete a lot of adrenalin, which put brain in hide or fight mode. In this mode our moves control by brain one of the oldest part the amygdala. Therefore, users are not able to act rational. That is why using multiple safety measures should be added.

VI. TESTING AND EVALUATION

A number of experiments were conducted to evaluate whether the app's indoor location estimation system can locate the user with an acceptable deviation. Three different test locations were used for our experiments – two of them were laboratories sized 42.03 m² and 46.48 m² at the department of computer of our university and the third was 25.48 m^2 room of an the elderly person's, which was accounted for a home-like environment

First two experiments were concluded in our university laboratories and last experiment in the home-like environment. In every experiment, couple of random test point in the room was selected and the app was used to identify the user's location. At each test point, five beacon signal measurements were collected and recorded to a local database. This approach was taken because the beacons transmit intermittently and this is the only way to capture the required number of beacons in order to estimate user's location.

In the experiments, various combinations where implemented. These are: (1) two different location estimation algorithms were used to estimate users location; (2) three different beacon set up was utilized – only TI CC2541, only SensorBug and both TI CC2541 and SensorBug; (3) two different device models were used in the experiments – Apple iPhone 4S and Apple iPhone 5S.

TABLE I. TEST RESULTS

Type	Environment	Area(m²)	Error(cm)	Beacon	Device	Location
Trilateration	495.5 cm to 525 cm	25,48 m²	137.14 cm	SensorBug	iPhone 4S	Home-Like
Trilateration	495.5 cm to 525 cm	25,48 m²	118.95 cm	SensorBug and CC2541	iPhone 4S	Home-Like
Fingerprint	495.5 cm to 525 cm	25,48 m²	85.47 cm	SensorBug	iPhone 4S	Home-Like
Fingerprint	560 cm to 830 cm	46,48 m²	223.6 cm	SensorBug	iPhone 4S	Universitiy
Trilateration	560 cm to 830 cm	46,48 m²	239.8 cm	SensorBug	iPhone 4S	Universitiy
Fingerprint	560 cm to 830 cm	46,48 m²	162.5 cm	CC2650	iPhone 5S	Universitiy
Trilateration	560 cm to 830 cm	46,48 m²	225.3 cm	CC2650	iPhone 5S	Universitiy
Fingerprint	568 cm to 740 cm	42,03 m²	225.3 cm	CC2650	iPhone 5S	Universitiy

As can be seen in Table 1, fingerprinting algorithm gives better results than trilateration independent of the environment. On the other hand, the distance error is nearly proportionate to the size of the room where the experiment was conducted. The biggest difference between home-like and university environments was furniture type. In the university environment, there were reflective furniture like blackboard and computers. On the contrary, in the home-like environment there were wooden materials like chairs and couch, which absorbed the radio signals. Absorbed but not reflected radio signals reduce the false RSSI detection and as a result improves the location estimation precision.

VII. CONCLUSION AND FUTURE WORK

There are many technologies for indoor positioning. However, Bluetooth is the one of most promising technologies for the indoor location estimation [18]. Bluetooth can be coupled with other location estimation techniques and could create the ultimate solution for indoor positioning.

In some of our experiments, our application successfully estimated the location of mobile device with less than a meter error. On the other hand, in some test environments error margin went up to 2.5 meters, which is not acceptable when the aim is to navigate users indoors.

Our evaluation results showed that in rooms with multiple corners Bluetooth-based location estimation algorithms does not perform so well. Therefore, it might be further research topic to analyze the physical environment radio wave reflections, refraction and diffractions using simulations. As a result, better locations can be identified for the beacons to be scattered so that signal related issues could be avoided.

Other solutions could be hybrid algorithms to improve accuracy such as using pedometer. In early results algorithm could give more accurate solutions then conventional algorithm in start but after expansion of cycle it error rate is close to conventional algorithms such as fingerprint. New hybrid systems could be developed to reduce Bluetooth hot spots [19].

In terms of user interface, it is hard to produce a solution that is one-fits-all. Especially when the target users are elderly and in some cases also have non-age related disabilities. Hence, from interaction point of view much more detailed field studies has to be conducted to have full understanding of their needs and requirements.

Global Bluetooth scanners require professional development. Their maintenance could be costly since there are hundreds of producers. Global database could be created by producer, which makes it continent to use by developers.

By increasing the number of adaptive Bluetooth devices, it is possible to develop much more accurate location-aware emergency evacuation system. However, this is beyond our paper's objective, which aims to implement and evaluate a BLE-enabled location aware evacuation system prototype.

REFERENCES

[1] Eurostat, Population structure and ageing http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Population_structure_and_ageing

[2] Bluetooth Special Interest Group Retrieved January 16, 2014. http://www.bluetooth.com/Pages/Mobile-Telephony-Market.aspx.

[3] Anind K. Dey and Gregory D. Abowd. Towards a Better Understanding of Context and Context-Awareness. HUC '99 Proceedings of the 1st international symposium on Handheld and Ubiquitous Computing (1999) 304-307

[4] Abowd, G.D., Dey, A.K., Orr, R., Brotherton, J. Context-Awareness in Wearable and Ubiquitous Computing. 1st International Symposium on Wearable Computers (1997) 179-180

[5] Statista, Number of mobile phone users worldwide from 2013 to 2019 (in billions),http://www.statista.com/statistics/274774/forecast-of-mobile-phone-users-worldwide/

[6] Lauro Ojeda and Johann Borenstein. "Non-GPS Nav igation for Security Personnel and First Responders".

In: *Journal of Navigation* 60 (03 Sept. 2007), pp. 391–407. doi: 10.1017/S0373463307004286.

[7] P. Womble, A. Barzilov, and J. Paschal. “A tracking technology for security personnel and first responders”. In: *Proceedings of SPIE - The International Society for Optical Engineering*. Vol. 5778. PART I. Orlando, FL, United states, 2005, pp. 51–56.

[8] J. Rantakokko et al. *Positioning of emergency personnel in rescue operations – possibilities and vulnerabilities with existing techniques and identification of needs for future RD*. Tech. rep. Swedish Defence Research Agency, Royal Institute of Technology, Lule˚a University of Technology, Swedish Defence Materiel Administration, SAAB Bofors Dynamics AB, SAAB Aerotech AB, Swedish Rescue Services Agency, Rescue Service in Linkoping, National Criminal Police, Army Combat School, 2007.

[9] M. Scholz, T. Riedel, and C. Decker. “A flexible architecture for a robust indoor navigation support device for firefighters”. In: *INSS 2010 - 7th International Conference on Networked Sensing Systems*. Kassel, Germany, 2010, pp. 227–232.

[10] D.M. Do, M.H. Hyun, and Y.B. Choi. “RFID-based indoor location recognition system for emergency rescue evacuation support”. In: *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*. Vol. 7861 LNCS. Seoul, Korea, Republic of, 2013, pp. 899–906.

[11] C. Cahalan and J. Renne “Emergency Evacuation of the Elderly and Disabled”. In: InTransition Magazine, Spring 2007, North Jersey Transportation Planning Authority

[12] He, Jie, et al. "A realtime testbed for performance evaluation of indoor TOA location system." Communications (ICC), 2012 IEEE International Conference on. IEEE, 2012

[13] Yamasaki, Ryota, et al. "TDOA location system for IEEE 802.11 b WLAN." Wireless Communications and Networking Conference, 2005 IEEE. Vol. 4. IEEE, 2005.

[14] Do, Trong-Hop, Junho Hwang, and Myungsik Yoo. "TDoA based indoor visible light positioning systems." Ubiquitous and Future Networks (ICUFN), 2013 Fifth International Conference on. IEEE, 2013.

[15] Bahl, Paramvir, and Venkata N. Padmanabhan. "RADAR: An in-building RF- based user location and tracking system." INFOCOM 2000. Nineteenth Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings. IEEE. Vol. 2. Ieee, 2000.

[16] Wang, Yapeng, et al. "Bluetooth positioning using RSSI and triangulation methods." Consumer Communications and Networking Conference (CCNC), 2013 IEEE. IEEE, 2013

[17] A. B. Link, P. Smith, N. Viol, and K. Wehrle, "Footpath: Accurate map-based indoor navigation using smartphones," in Proceedings of the 2011 international conference on indoor positioning and indoor navigation (IPIN), 2011, pp. 1-8

[18] Bandara, Udana, et al. "Design and implementation of a bluetooth signal strength based location sensing system." Radio and Wireless Conference, 2004 IEEE. IEEE, 2004.

[19] Baniukevic, Artur, et al. "Improving wi-fi based indoor positioning using bluetooth add-ons." Mobile Data Management (MDM), 2011 12th IEEE International Conference on. Vol. 1. IEEE, 2011