GuideMe: A Networked Application for Indoor Orientation and Guidance

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***Abstract*—Today's indoor navigational systems are more and more in demand, commonly used for applications such as smart cities, robots and visually impaired people. As far as outdoor navigation is concerned, the Global Positioning System (GPS) technology is still one of the most (if not the most) commonly used approaches. Even though it is still considered an ideal solution for navigating in outdoor areas, challenges and problems arise when GPS is considered for navigation inside buildings due to obstacles (e.g., shopping malls, hospitals, etc.) and because signals cannot be absorbed by the building walls. To tackle the aforementioned issue, other technologies have emerged aimed at indoor navigation, such as Wireless-Fidelity (Wi-Fi), Bluetooth and sensors. This paper's contribution is towards indoor navigation and, more specifically, it targets designing and developing a tracking and navigation system aimed at people that experience difficulties in indoor orientation using a wearable device. The user takes direction from the wearable device for the indoor orientation through voice commands helping him to avoid obstacles. The central part of the system is a device that provides the ability to navigate and find a route by voice commands, based on the device's location and orientation capabilities.**

Keywords-GuideMe; indoor navigation; trilateration; pathfinding; UWB; BLE: people with special needs.

I. INTRODUCTION

Undoubtedly, there is an increasing demand for efficient indoor navigation systems, demand that mainly derives from smart cities, robots and visually impaired people, only to name a few. As far as outdoor navigation and pathfinding are concerned, the Global Positioning System (GPS) is still considered among the most commonly used technologies. Yet, this is only efficiently applicable in outdoor locations, because when indoor navigation comes into play, issues do rise. Of course, indoor navigation is very important to us and has many applications for humans and robots. Two of the most common issues that arise are a) the fact that physical obstacles inside building cannot be labeled as obstacles from the GPS and b) the fact that signals cannot be absorbed by walls inside buildings. Multiple floors, rooms and obstacles inside each and every indoor area pose a major problem. Additionally, the inability to use the GPS technology inside buildings makes indoor navigation more complicated, for reasons already explained above [1].

On the good side, many recent studies have been and are still conducted in order to make indoor navigation more effective and efficient. The direct need for new applications and technologies that can efficiently tackle such issues can luckily be covered by other available indoor navigation technologies that do exist nowadays, such as Wireless-Fidelity (Wi-Fi), Bluetooth and sensors.

This paper provides the design and development of a tracking and navigation system for people with special needs for indoor locations. In its core, the system consists of a device that provides the ability to navigate and route by voice commands, based on the device's location and orientation capabilities. This device shall be connected to the server via the user's mobile phone (android). The overall system (when completed) will consist of the following components:

- Equipment permanently installed in selected areas.
- A cloud server that will synchronize and coordinate the various parts, store information about the facilities and users, and will be responsible for the accounting and invoicing parts.
- Portable devices.
- Software that will run on smartphones.

The rest of this paper is organized as follows. Section II describes the motivation behind our work. Section III provides a literature review of other current works on this subject. Section IV addresses the system's architecture whereas Section V goes into finer details in regard to the proposed algorithms for positioning and navigating in indoor spaces. Finally, Section VI summarizes our main findings and conclusions and suggests probable future work. The acknowledgement and conclusions close the article.

II. Motivation

Blindness is the condition of lacking visual perception due to physiological or neurological factors. Blind people face many problems in everyday life. They always depend on others. They cannot move easily from one place to another without help from others.

According to the World Health Organization, the following are the key facts regarding blindness and vision impairment [2]:

- Globally, at least 2.2 billion people have a vision impairment or blindness, of whom at least 1 billion have a vision impairment that could have been prevented or has yet to be addressed.
- This 1 billion people include those with moderate or severe distance vision impairment or blindness due to unaddressed refractive error, as well as near vision impairment caused by unaddressed presbyopia.
- Globally, the leading causes of vision impairment are uncorrected refractive errors and cataracts.
- The majority of people with vision impairment are over the age of 50 years.

The motivation of the GuideMe project [3] is to provide guidance and security for out-of-home travel. The central part of the system is a portable device that provides the ability to route and navigate by voice commands. The instructions will be based on the device's location and orientation capabilities. The device will be connected to the server via the user's mobile phone. The solution is built around a discreet portable device capable of indoor localization with an accuracy of 10 cm using Ultra-wideband (UWB) technology. The device can also determine the orientation, receive voice commands, and transmit voice instructions.

The motivation of the paper is to improve two areas of social life of the blind people and people with special needs in general: convenience and security. Specifically, with the use of the proposed system, users will feel more comfortable visiting public places, such as airports, shopping malls, stations, etc. as they will be guided by the system to reach their destination. At the same time, in case of emergencies involving both the user (accidents) and the building (fire, earthquake, etc.), the system will inform the users of the exact location of the users, whilst also guiding them to the nearest exit. The ultimate goal is to increase the presence of the population with mobility or other problems in buildings by 20%.

III. Related Work

There are several studies concerning indoor positioning techniques and systems. Previous works focus on the need to study the general way of positioning and then they propose algorithms and methods for indoor positioning. Daramouskas et al. [4] study methods for location estimation on Low Power Wide Area Networks (LPWAN). They also present Multilateration, Trilateration and Particle Swarm Optimization (PSO) algorithm, according to previous research, which constitute the three most commonly used methods to calculate the location of a moving object, based on distance measurements. Choliz et al. [5], gather all existing algorithms for UWB positioning and tracking systems and evaluate the performance in a realistic interior scenario. Next, Krishnaveni et al. [6] present an overview of indoor positioning based on UWB technology.

In the literature on positioning, machine learning algorithms are widely used to estimate position. Some of the machine learning algorithms used in indoor positioning are presented in [7]. Liu et al. [8], present a summary table with a comparison of recent systems and provide solutions about current wireless indoor positioning systems. A survey of the latest indoor positioning technologies is provided by Alarifi et al. [9], who analyze UWB technologies with an analysis of Strengths, Weaknesses, Opportunities, and Threats (SWOT). Unlike previous studies, Al-Ammar et al. [10] present new taxonomies and review some major recent advances on indoor positioning techniques. Finally, in [11], Mahida et al. deal with various positioning enabled wireless technologies and algorithms used in realistic scenarios to provide indoor navigation.

As far as indoor navigation is concerned, there exists a variety of significant work for people with special needs. More specifically, giving emphasis in works of the last years, we have found several similar approaches. Kishore et al. [12] provided a comprehensive solution for indoor public transport for people with disabilities. Beacons (small low-power devices, which are increasingly gaining recognition and application in malls and airports) were placed indoors and transmitted signals to the cell phone sensors via Bluetooth Low Energy (BLE) technology. Cheraghi et al. [13], BLE beacons-based indoor navigation was developed under the name GuideBeacon, where simulations showed that the GuideBeacon application reduces the time it takes for a disabled person to cross an unknown indoor area by 30%-50% and reduced the required distance they have to walk by at least 50%. Link et al. [14] suggested a system called FootPath, which obtains a geographic map from OpenStreetMap. After downloading the geographic map, the system uses the accelerometer and compass on the user's phone to calculate and detect the user's steps. The results showed that the FootPath system is very accurate to assist users with disabilities and indoors.

Megalingam et al. [15], proposed a system to find the best route for wheelchair users based on minimal changes in direction. The algorithm suggested is called Location-Aware and Remembering Navigation (LARN) and it depends on Dijkstra's algorithm to find the optimal path. The study carried out in [16] introduced a new method for dynamically changing the navigation path indoors. The proposed algorithm was named FPP and combined its internal path information and interior information. The FPP algorithm was compared with those of Dijkstra and Elastic and the results showed that FPP can provide the shortest route for in-house navigation faster than the other two algorithms. Goel, et al. [17], studied indoor navigation in order to reduce the time required for a user to get to its destination, using algorithm A*. The first section of the paper was devoted to a detailed presentation of A* algorithm, while in the second one, the authors successfully demonstrated why the A* algorithm is better than Dijkstra algorithm for indoor navigation with barriers. Comparing A* and Dijkstra for indoor navigation, A* achieves better results through heuristic searches and delivers better results faster.

Following the previous studies, in this section we will present similar projects to GuideMe. Indoo.rs and San Francisco International Airport worked together to create an app for visually impaired passengers. The Entrepreneurship-in-Residence (EIR) project is an Edwin M. Lee collaboration with the White House and other San Francisco business partners. At the beginning of 2014, they chose to help the San Francisco Airport (SFO) create a tool to assist blind and visually impaired travelers [18]. Recommendation ITU-T F.921 [19] sets out how audio-based network navigation systems can be designed to ensure that they are dedicated and responsive to the needs of people with visual impairments. The aim is to provide network visual system designers with the audio data they need in the early stages of development to anticipate and overcome any constraints and obstacles that prevent vision impaired users from making full use of the built environment. The purpose of [20] was to implement a module-based application developed in the context of preliminary projects for the mobile mass market. Through an appropriate user interface that responds to the needs of the visually impaired, the blind user should be able to use public transport independently in a secure manner and navigate complex public transport terminals. The system combines real-time communication to and from public transport vehicles with precise positioning and guidance while it also provides additional navigation assistance.

INK 2016: Indoor Navigation and Communication in ÖPNV for blind and visually impaired people [21] combines real-time communication to and from public transport vehicles with precise positioning and guidance and has additional video call navigation assistance where the person can communicate with a professional operator. Arikovani UK's WeWalk, Imperial College London, Astra Terra and the Royal National Institute of Blind People (RNIB) will cooperate to mitigate indoor wayfinding challenges by developing an indoor navigation system that is both reliable and fully accessible for visually impaired people and anyone that may struggle to navigate the built environment [22]. Project Ways4all [23] is a new personalized indoor navigation system that can increase public transport accessibility for all passengers and especially the visually impaired, who will be able to access public transport and the necessary up-to-date traffic information in a very simplified way. Finally, Project "Using An Integrated Techniques for Developing Indoor Navigation Systems to Allow the Blind and Visually Impaired People to Reach Precise Objects" [24] uses a set of different technologies (WIFI, Bluetooth, and RFID) to help the user reach a micro element in the navigated environment. It constitutes an intelligent interface for precise indoor navigation for blind and visually impaired people using a smart phone.

IV. System Architecture

In this project, the main component is a small wearable that helps in the user's positioning through UWB technology. This technology provides very accurate positioning, up to 10 cm divergence. This device, apart from the ability to locate the user, can also determine the orientation of the user, receive voice commands, and transmit voice instructions to guide the visually impaired people.

Specifically, as it is shown in Figure 1, in our proposed system, our smart device can communicate to anchors via UWB technology, in order to locate the user. This device has the ability to provide route and navigation information to the user via voice commands. The anchors are calculating and measuring the distance between the user and the anchor. The distance data (between the user and the anchors), is transferred to a local server in order to measure the exact position and run positioning algorithms, that in our case will be trilateration. The positioning algorithms are described in the Section V. Furthermore, there is a remote server that has a map of the building. This remote server, having the details of the building and the position of the user and the destination of the user, can provide guidance to the user by giving directions. The directions are given by the smartphone to the user through wireless headphones, using voice commands.

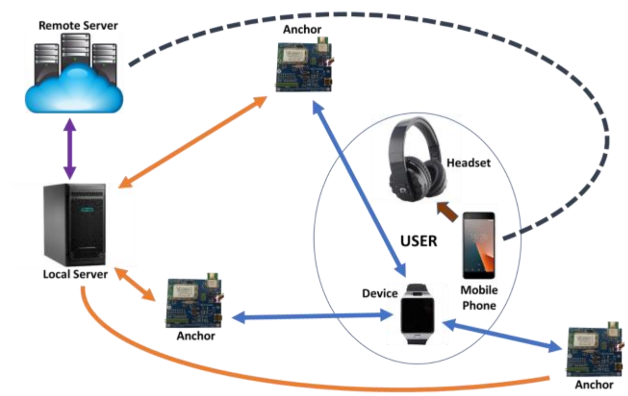

Figure 1. Overview of the proposed architecture.

As far as the wearable device is concerned, the processor that is chosen is the module made by Econais, the EC32L13 [25]. The EC32L13 is a 32-bit processor of the product family STM32 processors. This processors in this family of processors are energy efficient, in order to expand the battery life. A WiFi module is also integrated into the wearable device. For the connectivity through UWB, we have chosen the module DWM1000 of Decawave.

In Figure 2, we present the general architecture of the wearable device. The device consists of some sensors such as, the magnetometer and accelerometer sensors, the UWB module, the WiFi module, the Main Computing Unit, which in our case is the EC32L13 and module for the battery management as well, in order to expand the battery life as long as possible.

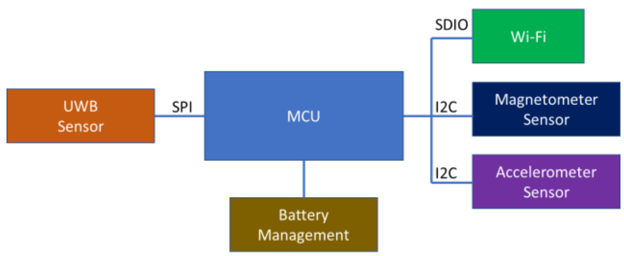

Figure 2. Overview of the device's architecture.

V. Proposed Algorithms

In this section, we will present our indoor positioning algorithms and the indoor navigation algorithm we used and integrated in our system.

A. *Indoor Positioning*

As far as indoor positioning is concerned, as part of the GuideMe project, it was decided to implement the trilateration algorithm that combines simple implementation and sufficiently precise positioning beyond the project requirements.

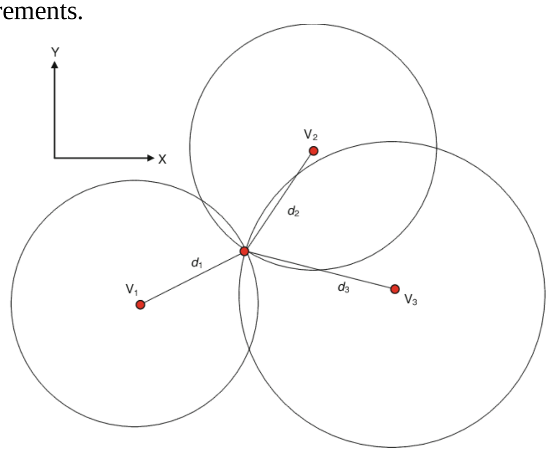

Figure 3. Represenation of trilateration.

The trilateration algorithm is a fairly common and easy to understand algorithm and is used extensively in various applications. Also, the DW 1000 module used in the project supports Time Difference of Arrival (TDoA), a method that gives a very good distance estimation. The high data rate and speed of the UWB can reach 100 Megabits per second (Mbps), which makes it a good solution for indoor positioning. Thus, the trilateration algorithm can give a very good estimate of the user's position. The logic that is followed is: for each anchor the user communicates with, a circle is created with its center being the position of the user and the radius the distance between the user and the anchor. This should be done for at least 3 anchors. The point where the circles intersect is the location of the user. Before we begin the description of the implementation and the code, we give an image describing the three cases considered in the trilateration method, in Figure 3. In Algorithm 1, our approach of the localization of the user is described.

Algorithm 1: Trilateration Algorithm for indoor positioning

```
Class circle(point,radius){
    this.point=point;
 }
 function Locate(x1, y1,distance1, x2, y2,distance2, x3, y3,distance3){
    create circle objects;
    circle_list={c1,c2,c3}
    get_all_intersecting_points(circle_list);
    center=Get_center_of_polygon(intersected_points_list);
    }
    function get_all_intersecting_points(circle_list){
    //intersecting points of every circle with the other circles
  find_interecting_points_by_two_circle(circle(i), circle(k));
    }
  function get_polygon_center(points){
       center = point(0, 0);
       num = len(points)
      for i in range(num){
         center.x += points[i].x
         center.y += points[i].y
      }
      return center
     }
```

B. *Indoor Navigation*

For the needs of the project, it was decided to use Algorithm A* for indoor navigation (based on [16], Algorithm A* is an optimal algorithm for indoor routing). Algorithm A* is a pathfinding algorithm that is widely used because of its completeness and optimum efficiency. In systems where navigation through barrier is required, A* is still the best solution for the majority of cases. This algorithm is based on structured graphs. It defines an initial node of the graph as a start node and attempts to find the path to the final node at minimum cost. The minimum cost does not necessarily have to do with the minimum number of moves, as it could e.g., UWB indicates the shortest path length.

To implement the algorithm, a path tree is constructed that starts from the start node and extends the tree paths, one edge at a time, until the algorithm termination criterion is met. At each iteration, the set of paths to be expanded must be specified, and to do so, the travel cost is used in conjunction with an estimate of the costs required to extend to the final node. Therefore, the algorithm will select that path that minimizes:

$$f(n) = g(n) + h(n) \quad (1)$$

where n is the next extension node in the graph, g(n) is the path cost from the original node to n and g(n) the cost of the minimum cost from the extension node n to the terminal node. The algorithm terminates when an acceptable extension is found from the start node to the terminal node, otherwise extensions to the node are not available. As for the efficiency of A*, as long as this algorithm never overestimates the actual cost to reach the terminal, then the returned path will always be of minimal cost.

At the programming level of the algorithm, the Javascript library Easystar.js will be used [26]. Based on this library, we will first need to set a grid where the accepted values will be 0 or 1, depending on which cells are accessible and which are not (the matching can be done as we wish). Having defined which cells are accessible, by defining the (x,y) start and stop coordinate pairs, the path of algorithm A* can be calculated, if it exists.

The pseudocode of algorithm A* is presented below (we accept the Wikipedia approach for the algorithm [27]):

Algorithm 2: A* Algorithm for Indoor Navigation

```
begin
function reconstruct_path(cameFrom, current)
   total_path := {current}
   while current in cameFrom.keys:
      current := cameFrom[current]
      total_path.prepend(current)
   return total_path
 function A_Star(start, goal, h)
   openSet := {start}
   cameFrom := an empty map
   gScore := map with default value of Infinity
   gScore[start] := 0
   fScore := map with default value of Infinity
   fScore[start] := h(start)
   while openSet is not empty
      current := the node in openSet having the lowest fScore[] value
      if current = goal
         return reconstruct_path(cameFrom, current)
      openSet.Remove(current)
      for each neighbor of current
         tentative_gScore := gScore[current] + d(current, neighbor)
         if tentative_gScore < gScore[neighbor]
            cameFrom[neighbor] := current
            gScore[neighbor] := tentative_gScore
            fScore[neighbor] := gScore[neighbor] + h(neighbor)
            if neighbor not in openSet
               openSet.add(neighbor)
   return failure
end
```

VI. Conclusion and Future Work

This work refers to the project of GuideMe. The state of the art of existing approaches and the algorithms that were implemented to complete the project in terms of navigation and indoor routing were presented. By providing a wearable device, the project is contributing to indoor navigation and positioning assistance for people with difficulties. The user takes direction from the wearable device for the indoor orientation through voice commands that help with avoiding obstacles. This work is the basis of the next step of the project that relates to transmitting the correct instructions to the user using the information of the algorithms of the position of the mobile device as well as the path to follow through voice commands. Future work may include an extension of this current work by also covering outdoor areas through the application.

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