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Cloud & IoT based indoor positioning solution with intuitive AR guidance

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Abstract. GPS, the most frequently used outdoor navigation system used in the contemporary world in people's mobile phones, however, does not prove to be reliable in indoor settings. Neither do some wireless protocols such as Bluetooth and WIFI with RSSI do an effective job due to their susceptibility to physical obstacles such as walls and objects in the building. Our team came up with a solution utilizing UWB wireless communication protocol with SS-TWA to help users with an AR device, or similarly an AR application on smartphones, to navigate in indoor settings with clear graphic guidance, similar to the guiding systems already used by people in contemporary society. The map of the indoor setting and related calculations during the navigation process are all based on clouds, and we will show in detail how we implement our design. Finally, we discussed how our solution projects about indoor positioning can also be related to fields like ML, Open World and Metaverse.

Keywords: indoor navigation, ultra-wideband(UWB), machine learning, augmented reality (AR), cloud.

1. Introduction

Nowadays, people are spending an increasingly large amount of time in indoor environments. According to research done by the United States Environmental Protection Agency, Americans, on average, spend approximately 90 percent of their time indoors, which is a common situation for all people around the world [1]. Thus, there is a growing need for indoor position information and indoor navigation, especially in large indoor environments such as airports or exhibition halls where people easily lose their way because of unfamiliarity and shopping malls where people have specific, distinct destinations. Precise indoor location information and navigation guide given to users provide them with a basic understanding of their locations and direct demonstration of their routes to destinations.

Traditionally, the Global Positioning System (GPS) is used for outdoor localization. According to an official report in 2015, GPS-enabled smartphones are typically accurate to within 4.9 meters radius under open air [2]. In another official report from 2021, high quality, single-frequency GPS receivers attain horizontal accuracy of ≤ 1.82 meters, 95% of the time in 2020 [3]. However, its accuracy worsens near buildings, and GPS sometimes shows a wrong position in indoor environments. Therefore, in order to achieve precise positioning and navigation, we need to utilize other technology in indoor environments. What's more, many scholars mainly focused on indoor localization in one single room or floor, without potential implementation to a whole building. Thus, we would like to build an indoor positioning and navigation solution with intuitive AR guidance based on cloud and IoT.

2. Related work and literature review

There are many different kinds of technology used for indoor positioning. Common techniques include Bluetooth, WIFI, and UWB. Many scholars have applied Bluetooth and WIFI to indoor localization because of their low power consumption, ubiquitous presence, low cost and easy availability. One case of Bluetooth Local Positioning Application (BLPA) was designed and implemented in [4] with accuracy needed improvements for practical applications which is caused by unreliability of the Received Signal Strength Indicator (RSSI). In [5], authors presented an accurate method with Bluetooth and RSSI to locate an indoor position of a mobile robot. In [6], the authors used an improved RSSI-based trilateral localization algorithm by WIFI, achieving improved localization accuracy and reduced deviation without increasing complexity and cost. In [7], authors proposed a time-reversal method which achieved centimeter accuracy and robustness against dynamics with a single-pair of off-the-shelf WIFI devices. Though Bluetooth and WIFI have several advantages, the performance of this technique can be easily influenced by the presence or changes of physical obstacles, especially walls of buildings. UWB and SS-TWA, when applied to indoor navigation, are found to have much better performance.

3. UWB in our project

Along with the rapid development of information transmission technology, our team came up with the idea of application of UWB. UWB, namely ultra-wideband, is a short-range wireless communication protocol suitable for targeting positions in indoor environments [8]. It uses radio waves of short pulses over a spectrum of frequencies from 3.5 to 10.5GHz, with propagation speed the linear speed of light. This can make the signal transmission fast enough to locate the positions of the target and the user, constantly updating the user's location in relation to destination. The UWB is effective within a range of about 10-200m, with accuracy of 0.5-1m. This can make it available for indoor positioning and navigation. What's more important is that UWB is not susceptible to interference like Bluetooth and WIFI do. These protocols may be cheap to be established, but since its vulnerability to physical obstacles such as walls, a far more complicated system needs to be pre-established inside the building for them in order to achieve the same precision as the UWB, and is susceptible to the change of layouts of the building. Via UWB protocol, we can simply place tags on the building without worrying about any physical obstacles that may interfere with the transmission of signals. In our designed solution, we intend to set all UWB tags based on the floor number of the building, with tags on the same floor placed on the same altitude. The information about the map, the tags, with their id, location, and floor number, and calculation needed for navigation are all stored and performed in the cloud. Using Bluetooth design can either be susceptible to physical obstacles or needs to take much more storage to achieve the same level of precision as buildings need to be divided into uniform grids. Users with AR devices or mobile phones can prompt the destination, and then locate the map in the cloud. Then, users' positions are located via connecting nearby 4 tags and calculating the user's position with respect to these tags. In our solution design, the floor of users' location is critical, and this is achieved by computing the sum of the inverse of distance from the censoring tags. While the destination and user's position are identified, the AR device will provide the user detailed graphic description of guidance of the route leading towards destination. The device will constantly censor nearby tags to update the user's location during the guidance until reaching the destination.

4. Solution implementation

Before actually using this system to do in-door navigation, it has to be properly deployed in both the building and the cloud. The (blueprint of each floor of the building is needed to decide where the UWB

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tags should be placed and to build a map for guiding the users. The placement of the UWB tags should meet the following requirements:

1. The density of tags of each floor should be similar to reduce the possibility of mis-judging the current floor of the user.
2. The tags in the same floor should be placed on the same height so that even if the system meets the situation of multiple results when calculating the position, the x and y coordinate will always be correct.

As for the map, it can be built by adding several key points and linking them together as the valid paths. The length of each path, the coordinate of each key point and the obstacles should be recorded in the map. The map and the information of all the tags will be recorded in the cloud.

Once the system is properly deployed, the cloud will start waiting for connections from users. Once a user gets into the building, his device will first communicate with the tag at the entry, which stores the id of the building. With the building id, the user can establish a connection with the cloud and the cloud will be acknowledged with which building the user is in. After that, if the user asks for a navigation service, he will search for the place in the building and send a request with this destination to the cloud, where the actual coordinate of the destination will be found out. Once making sure that the server has received the navigation request, the process will get into the following loop:

1. First the device of the user will try to get the distances to at least 3 tags with SS-TWR technology [9]. It will send a signal to all the surrounding tags, which contains an id (S1) and a time stamp (T0). The tags that receive the signal will hold it for a certain time (D) and send back a signal with the same id, same starting time stamp (T0), the holding time (D) and the id of the tag itself (S2). Through this response from the tag and the current time tag (T1), the device of the user can calculate its distance to tag with id S2 ($distance = \frac{(T1-T0-D)\times c}{2}$). The SS-TWR technology itself is not perfect since its accuracy will be affected by the clock drift caused by different clock frequencies between the user device and the tag. Rathje & Landsiedel have also mentioned several methods like Carrier Frequency Offset or the TDoA Extraction to improve the accuracy [9].
2. Then the device of the user will estimate the current floor number locally. This step is not performance intensive but can reduce the size of messages sent to the cloud, so we design it to be calculated locally. In this step, the responded tags will be divided into different groups based on the floor they are placed on and each group represents one floor. Then for each floor, calculate a value by the sum of the inverse of the distances to all the tags on that floor and the floor with the largest value will be chosen as the estimated floor of the user. Here whether the density of tags of each floor are similar may influence the accuracy. If the density of tags of a certain area on floor 1 is small while that of the area with the same (x,y) coordinate on floor 2 is large, the user on floor 1 may be asserted to be at floor 2 since the device may get more response from floor 2. After getting the floor number, the device will remove all the responses from tags that are not on the same floor. Only the response from tags on the same floor will be used to calculate the position.
3. After getting all the distances to tags needed and the floor number, these data will be sent to the cloud to calculate the position and path. The position will be calculated by solving the following equations:

$$\begin{cases} \sqrt{(x-x_1)^2 + (y-y_1)^2 + (height-height_1)^2} = d_1 \\ \sqrt{(x-x_2)^2 + (y-y_2)^2 + (height-height_2)^2} = d_2 \\ \sqrt{(x-x_3)^2 + (y-y_3)^2 + (height-height_3)^2} = d_3 \end{cases} \tag{1}$$

Where $(x_n, y_n, height_n)$ is the coordinate of tag_n and d_n is the distance between the user device and tag_n. It is clear that this equation has more than one solution. However, since all the tags on the same floor have the same height, the two solutions will have the same x and y values, which is all the system needs.

4. The path can now be calculated with the current coordinate of the user, the coordinate of the destination and the map using A* Searching Algorithms. The straight line distance will be chosen as the heuristic function in this case. Before the searching, the current coordinate of the user and the coordinate of the destination will be added to the map temporarily as two new key points and linked to all reachable existing key points in the map based on the obstacles information on the map. They will be the starting state and the goal state of the A* Algorithms
5. Send the calculated path back to the user's device.

A demo project with Unity can be found at https://github.com/Star-Lord-PHB/NS-Summer-2022, with an explanation of how to use it in the README.md file. Due to some limitations, the demo has several discrepancies compared to the implementation above:

1. There are no actual tags, so several objects in Unity is used as replacement and the distance will be directly calculated by Unity rather than SS-TWR technology
2. The server has not been designed for or deployed to the cloud. It is used as a normal server locally.
3. Before doing A* Searching, the destination coordinate and the coordinate of the user device will not be added as two new key points. Instead, the closest key points to them will be selected as the starting state and the goal state of the A* Searching.

4.1. Potential improvement & implementation of technology

In this section, we will discuss some of the possible future applications of programs and existing new technologies.

4.2. Machine learning

In the design of any program, user interaction level, we must consider the convenience in using. For visually impaired users, or considering the efficiency of human-computer interaction, one of the most important functions is speech recognition. As for the solution of this program, we believe that navigation and consultation information can be provided to users based on cloud computing and data analysis through the existing mature Automatic Speech Recognition technology, combined with the Natural Language Processing technology of Google Natural Language AI, for instance. By considering the inconvenience of visually impaired users, these two articles, Helal, Gawari and their team provide potential solutions by combining external devices and navigation systems that combine the voice recognition [10,11]. Although we are not consistent in the localization and implementation technology, its navigation scheme for the visually impaired external devices is still worthy of our reference.

Since the program involves the introduction of architectural blueprints and information processing, we believe that there is a possibility that image recognition technology could be used in the process of information processing to establish a 3D model combined with the picture of the building itself. To take an instance, like what Rory Clifford and his team describe in their paper [12], we could use computer vision techniques to allow system automatically creates 3D building models from 2D diagrams with creating vertex point data from the distinct features that found in 2D blueprints or virtual walls by extruding found line segments.

4.3. Open world & IAN

In the open world thinking, to combine the existing function of the navigation software, we can use the AI software related Suggestions according to the reality and the outside world, such as user in diet food information retrieval (around), building information (architectural style, architectural history), the exhibition information (history of cultural relics or antique, the author introduction). To be more detailed and specific in explanation, our program is to provide the ability of fuzzy searching for users' navigation requests. In the navigation process, the system needs only the coordinate of the destination, which is not the direct input from the user. Usually the user input may be the name of a certain indoor area (The Nike shop or The Starbucks) or even just the functionalities of a certain indoor area (place that sells ice-cream or place to settle accounts). So the system should also be able to observe the current indoor environment and automatically communicate with existing databases about it to process such fuzzy searching and find out the coordinate of the destination.

In addition, considering the different platforms owned by different users, we still need to think about the commonality and adaptability of software. Considering the different situations of different software, further research and practice are needed in this aspect.

4.4. Metaverse & blockchain application

Considering that our algorithm only requires precise coordinates for calculation, the implementation of the program is even more convenient in the virtual world. In both PC and VR games, this technology could easily be turned into a navigation system within the game or Metaverse. With a range of game engines such as Unity, it is easy to achieve navigation signs, precise positioning within 3D or 2D models of maps, or path guidance between different destinations. In other words, since in our ideal vision, we are building 3D models, or virtual world models, based on reality for navigation and guidance, then the transition to the virtual world is more practical in implementation. Since the specific structure of many buildings involves the privacy of uploaders and building owners, as well as the security of buildings, such as malicious tampering of building blueprints and models, and the sensitivity of user positioning system information storage, should we use encryption systems for storage? Considering that blockchain is not modifiable, it is a good way to protect data. When building information needs to be iterated, the generation of building models only needs to provide blueprints instead of complicated manual modeling, so the problem of cumbersome re-modeling for iteration in the case of blockchain storage can be solved.

When we think about the application of positioning technology in the virtual world, combined with the emerging NFT art, VR art and A series of new art forms, we believe that the existing art exhibition hall can be scanned by 3D, combined with virtual artworks for art exhibition. In the Metaverse world and the real world, like Hee-soo Choi and Sang-heon Kim discussed in their paper [13], by connecting a beacon installed in real space to an HMD, or use the model created by 2D-3D modeling, combined VR and AR are respectively implemented, Immersive Tours with VR goggles and field Tours in AR mode through HoloLens or mobile phones. Meanwhile, in the realization of virtual art exhibition at the same time, now its binding through the blockchain cryptographic virtual currency trading system then has a practical application.

Based on the idea of 3D modeling architecture by image processing, combined with the idea of a virtual world tour guide, we believe that we can realize the virtual processing of the buildings of scenic spots and historic sites for preservation. Just as Ubisoft's Assassin's Creed perfectly recreates the Notre Dame Cathedral in Paris that collapsed during the fire, the importance of virtual preservation of buildings should be promoted and appreciated.

5. Conclusion

With the UWB and SS-TWA technology, our system can implement accurate indoor positioning from the distance information from the user to at least 3 tags. And with the map and tags information in the cloud, a path can be calculated with A* Searching and sends back to the user. Our solution has encountered some difficulties such as handling multiple solutions when calculating the position, which is solved by limiting the height of the tags of the same floor to be the same so that the x, y coordinate will always be correct. UWB was invented in the 1920s, but it has not been as widely used as Bluetooth and WIFI. Now, when it comes to indoor navigation, UWB appears to have more advantages than many other wireless communication protocols and more problems can be overcome in order to achieve a higher precision of indoor navigation. With our proposed solution design, UWB does seem to have a prospective future in the field of indoor navigation.

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References

[1] Wallace, Lance A. *Total exposure assessment methodology (TEAM) study: summary and analysis. Volume 1*. No. PB-88-100060/XAB; EPA-600/6-87/002A. Environmental Protection Agency, Washington, DC (USA). Office of Acid Deposition, Environmental Monitoring, and Quality Assurance, 1987.

[2] Van Diggelen, Frank, and Per Enge. "The world's first GPS MOOC and worldwide laboratory using smartphones." *Proceedings of the 28th international technical meeting of the satellite division of the institute of navigation (ION GNSS+ 2015)*. 2015.

[3] "Federal Aviation Administration." *GLOBAL POSITIONING SYSTEM STANDARD POSITIONING SERVICE PERFORMANCE ANALYSIS REPORT,* https://www.nstb.tc.faa.gov/reports/2020_Q4_SPS_PAN_v2.0.pdf.

[4] Kotanen, Antti, et al. "Experiments on local positioning with Bluetooth." *Proceedings ITCC 2003. International Conference on Information Technology: Coding and Computing*. IEEE, 2003.

[5] Raghavan, Aswin N., et al. "Accurate mobile robot localization in indoor environments using bluetooth." *2010 IEEE international conference on robotics and automation.* IEEE, 2010.

[6] Zhu, Xiuyan, and Yuan Feng. "RSSI-based algorithm for indoor localization." *Communications and Network* 5.02 (2013): 37.

[7] Chen, Chen, et al. "Indoor GPS with centimeter accuracy using WiFi." *2016 Asia-Pacific Signal and Information Processing Association Annual Summit and Conference (APSIPA)*. IEEE, 2016.

[8] Bakr, M, *Introduction to UWB Technology*, All About Circuits, 2020 https://www.allaboutcircuits.com/technical-articles/introduction-to-ultra-wideband-uwb-technology/, Accessed Aug 11. 2022.

[9] Rathje, Patrick, and Olaf Landsiedel. "Time Difference on Arrival Extraction from Two-Way Ranging." *arXiv preprint arXiv:2204.08996* (2022).

[10] Helal et al, *Drishti: an integrated navigation system for visually impaired and disabled*, 2001

[11] Gawari, H & Bakuli, M, *Voice and GPS Based Navigation System for Visually Impaired*, Int. Journal of Engineering Research and Applications, 2014

[12] Clifford, R et al. *Using augmented reality for rapid prototyping and collaborative design to model 3D buildings*[C]//Proceedings of the 12th Annual Conference of the New Zealand Chapter of the ACM Special Interest Group on Computer-Human Interaction. 2011: 117-120.

[13] Choi, Hee-soo, and Sang-heon Kim. *A content service deployment plan for metaverse museum exhibitions—Centering on the combination of beacons and HMDs*. International Journal of Information Management 37.1 (2017): 1519-1527.