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A COMPARATIVE ANALYSIS OF INDOOR NAVIGATION SYSTEMS

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ABSTRACT

This short paper discusses various techniques of indoor navigation for an autonomous vehicle or a human user. It explains the architecture and work-flow of each method in detail. The paper can be looked at as a comparative study between the technologies, in order to choose the most efficient process for a specific purpose. The pros and cons of each technique have been mentioned, for the same purpose. Research papers, previously published have been referred to, to build a core foundation of the reader's knowledge.

Keywords: Personal Digital Assistant, Beacon, 3D Multi-Lateration, Wi-Fi Based IPS, Extended Kalman Filter.

I. INTRODUCTION

Indoor navigation system is the process of location and tracking the movement of a device indoors. The global positioning system, commonly known as the GPS, fails to give accurate location or fails entirely when used in confined spaces like buildings, basements, garages and so on. This gives way to the use of indoor positioning or navigation system. Although there are multiple new methods of indoor navigation available, they do not come with significant downsides. This paper discusses three of these navigation techniques describing their working in detail. The specific requirement of each of these systems are mentioned along with the advantages and disadvantages. Their precision and outcomes have been mentioned as well. We aim at showing a comparative study between these processes for the readers to be able to decide the technique that best suits their work needs.

II. METHODOLOGY

We have looked into three different indoor navigation techniques. Each of them, uses different concepts and has a different architecture. As a result, the use-cases for each would be different. This is done to understand how different systems can be utilized to their utmost potential.

Sound Based Navigation System:

Audible sound has been used in multiple ways to locate the position of a device in an enclosed space. As locating a device forms a crucial step in the indoor navigation system, it has to be perfect. The concept behind sound-based system is that of "3D multilateration" to determine an object's coordinated. For this system, the following equipment are needed: acoustic sensors (minimum four to give accurate results), wireless network, central servers and the user's roaming device which must have wireless communication compatibility (mobile phones, PDA, desktops).

Geometric Beacon Technology:

Beacons are discreet wireless transmitters that communicate with neighboring smart devices using low-energy Bluetooth technology. The beacon technology was first introduced by Apple in the year 2013 at the World-Wide Developer Conference. A major development in this field was done by Google in 2017. Beacon can be used for detecting locations of the object in a known and unknown location. Geometric beacons are a characteristic of the environment that occurs naturally, is detectable by good sensor measurements, and is precisely characterized by a condensed geometric parametrization

Wi-Fi based Navigation System:

Wi-Fi based indoor positioning systems (IPS) use wireless technology to pinpoint a device's location inside a building or another enclosed area. Numerous applications, such as asset tracking, facilities management, and location-based services, can benefit from these systems.

III. MODELING AND ANALYSIS

Sound Based Navigation System:

In this system, whenever a user wants to detect their position, they send a signal through their roaming device, which is received by the sensors nearby after passing through a set of digital filters. A time of flight triangulation technique is used by the sensors to detect the exact position of the users, hereafter. The sensors receive messages through the wireless networks, from the device. This signal must have few key features to be able to detect accurate positions. A single frequency signal of frequency 4KHz is used, which is transmitted for about 100milliseconds. This duration is good enough for the signal to be spotted in the presence of noise. Once the signal is received, the distance of the user from the sensor is calculated by multiplying it with the speed of sound. Each of the signal follows this process and makes a note of the user from itself. This information is then forwarded to the central server that performs 3D multi lateration to detect the user's precise location.
A major problem in this process is that the system creates problems if multiple users, in close proximity to each other, send the signals in a very short time span, leading to a collision. This problem is solved by coding the central server such that it assembles the signals in a queue; hence every signal waits for its turn to be processed. The triangulation is done using 3D multi lateration process, which considers the time delays involved in the entire process. The time-of-flight calculated based on the signals sent by devices like PDA, can have a slight delay caused by soundcard. Due to this process, the reported time turns out to be greater than the real time. So, in order to avoid this problem, an iterative approach is followed which shrinks the "range" of each sensors, thus showing accuracy in the signal time.

The advantage of using Sound based navigation systems is that they use the user's roaming device to detect the location, hence cutting costs on the infrastructure needed. Also, the user decides when their location would be detected. Hence, the user's privacy is maintained. This process has a very high accuracy, with an error distance of 2-3 feet. A disadvantage of this system is the signal noise produced by the roaming device which can be annoying at times.

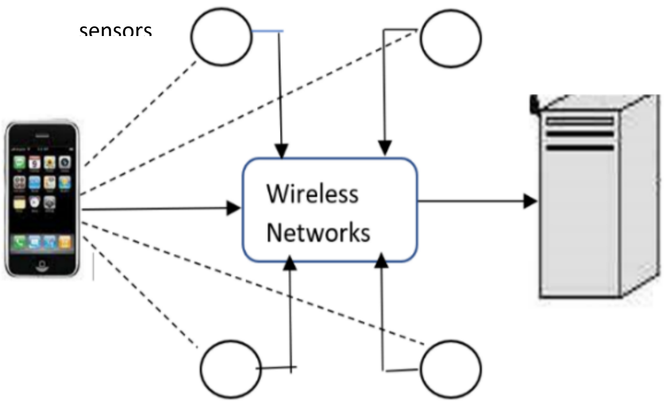

Figure 1: Architecture of Sound Based Navigation System

Geometric Beacon Technology

The Beacon technique has been looked as an option for building autonomous robots or vehicles since its establishment. But the major problem with this process is the extraction of information about navigation beacons from sensor data and the automated correlation or correspondence of this with some navigation map, is quite tedious. The setup of this process is based on the extended Kalman Filter (EKF), which is extensively used for the navigation in closed space. In this process, it is assumed that the user (or a vehicle) is located in a closed space. Their location is defined using Cartesian Coordinates. The initial position of the user is known and they are provided a map of the existing beacons in their environment. A timer is maintained, so that at regular intervals the readings of the beacons are noted. This helps in keeping track of the user's position constantly.

This process has four steps in it: Prediction, observation, matching estimation. Kalman's Plant model is referred to, in this process. It shows the user's position change with respect to noise disturbance in the environment and time. In the prediction step, the user's new location is found; then the variance connected with this reading is predicted and then it is correlated with the beacon's observation. The Observation step, collects the reading of each beacon and then compares it with the prediction step reading. If there are discrepancies, then it is called innovation covariance. Hereafter comes the Matching phase. A validation threshold is set, which tests each prediction made till now. If one single prediction satisfies this concept, then it is used for localization, otherwise discarded. Final step is that of estimation. This step uses the observations and matched predictions to compute the updated location of the user. To do so, the approved readings are combined together to form a "composite" measurement, which also has the innovation covariance designated. This composite measurement is then used with EKF to get the User's position estimate.

One of the major downsides of this method is that it shows uncertainty in the readings. The beacons are usually placed on the walls surrounding the users. The only part of the user that is visible to the sensors, is that surface if the wall which is perpendicular to the incident signals. So, when the walls move away from the user or is not perpendicular to the beam, the uncertainty in the observation grows.

Wi-Fi based Navigation System:

The received signal strength indicator (RSSI) of the Wi-Fi signal is one popular technique for creating an IPS while using Wi-Fi. The RSSI measures the strength of the received signal and can be used to calculate the separation between a device and a Wi-Fi access point (AP). It is feasible to pinpoint the device's position by measuring the RSSI at various APs.

This method has the drawback that a number of variables, like as the distance between the device and the AP, the presence of barriers like walls, and the presence of other electrical equipment that could interfere with the signal, can affect how strong the Wi-Fi signal is. It is frequently required to calibrate the system to increase its accuracy by gathering a sizable dataset of RSSI measurements at different points throughout the building and using machine learning techniques to predict the link between the RSSI and the location.

Using time of flight (ToF) measurements is another method for creating an IPS using Wi-Fi. In this method, the device monitors the amount of time it takes for each pulse to arrive after the APs send a series of pulses. Similar methods as with RSSI can be used to triangulate the position of the device by measuring the ToF at various APs. ToF measurements are typically more precise than RSSI measurements, but they may also be more prone to interference and require more specialist technology.

Additionally, there are a number of hybrid techniques that combine RSSI and ToF data to raise the IPS's accuracy. As an illustration, some systems use ToF measurements after using RSSI data to more precisely determine the device's location.

Regardless of the method employed, an IPS employing Wi-Fi often necessitates the installation of a network of APs across the facility. The APs can be linked to the internet to enable communication between the device and the IPS server, which determines the device's position using the data gathered by the APs. When necessary, the server can subsequently give the location data to other programs or gadgets.

Overall, an IPS employing Wi-Fi can be a helpful tool for a range of indoor applications, but when designing and deploying such a system, it is crucial to carefully evaluate the trade-offs between accuracy, cost, and complexity.

IV. RESULTS AND DISCUSSION

For the sound-based system, the concept is tested in s a small confined room by placing the signal emitting microphones on the ceiling. The path traced using the sensors are compared to the real path travelled by the users. The range of error is usually found to be within 2feet of the real time errors. This testing is done to ensure technical correctness of this method. The results are more accurate when taken along the X-Y plane. When the user moves vertically (along the Z-axis), the readings are less precise. To test if this method is fool-proof, the multiple readings are taken at the same set of points. Hence, it can be inferred that when the movement is 2-dimensional, the results are more accurate (over 95% accuracy), than if a 3-dimensianl movement is assumed.

Through the Beacon technology, two different observations are noted. If the signal emitting devices (Sonars) are mounted on a server, the user or the autonomous vehicle has to be stopped to take a dense scan of the area around it. This consumes a lot of time. On the other hand, if the sonars are mounted on a ring, the range of orientations increases and quick position estimation can be done. One downside of the latter method is that a single measurement of the area is not enough to interpret the path as there are angular uncertainties with ring. As a result, a densely sampled set of sonar scans from a still location are used. Due to this the user does not need any prior idea of the area. This may take time, but is efficient than a servo-mounted sonar.

V. CONCLUSION

The sound-based system has a very high accuracy of around 95% (range of distance error is less than 2feet). One condition to be fulfilled is that the roaming device needs to have wireless network capabilities. Hence only a personal digital assistant (PDA) or similar devices are compatible on this system. Downside of this method is that the noise made by the signal can get annoying at times, and that this method shows highest accuracy only on a desktop. The system finds difficult to show results in noisy environments, but it can be overcome by emitting a range of signals instead of a signal frequency signal. The accuracy also can be improved, which would make it more reliable in public spaces like malls and retail stores.

Beacon technology, densely sampled sonar scans are combined to give an idea of the surrounding environment of the user. The sensors have to be rotated to take the scan. But his model is not fully functional in all surroundings, thus demanding the need for prior information of the environment. Advancements in navigation in unknown locations have to be made. On the other hand, the principle applied on sonars, can also work on other sensors, making this technique more widespread. If geometric beacons are replaced with artificial ones, the price per beacon (if bought in bulk) can be around $10 to $15. So, it is not the cheapest technology.

The WI-FI based location detection model has a lot of benefits. Most of the commercial spaces have Wi-fi already installed, thus cutting down on any additional infrastructure cost. The signal range can be very wide (around 150 meters) and the ecosystem in general can be expanded without manual intervention. Downsides of this method is that the latest Android versions limit the extent of use of it. Also, Apple products do not support this technology due to privacy issues. This limits the customer base sharply.

In conclusion, it can be said that each indoor positioning and navigation system has its pros and cons, and each one suits a different purpose. If the area has continuous uninterrupted Wi-Fi access, then the Wi-Fi based system would be the most sensible to use. For quite spaces where Wi-Fi may not be readily available, sound-based processes can be useful. Areas with multiple users and with loud noise disturbance, Beacon technology can be beneficial, even though it may have relatively higher cost.

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