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A Review and Insight on Various Indoor Positioning and Navigation Techniques

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Abstract— **Indoor positioning and navigation is emerging field in mobile computing. Indoor Positioning and Navigation Systems aim to get user's current position inside a venue. Based on user's current location, various servicescan be provided. Due to unavailability of GPS in indoor spaces, and demand of higher accuracy in location of user, separate techniques are required for indoor positioning. Indoor positioning is generally used by pedestrian users on their mobile phones, hence most indoor positioning and navigation systems uses various sensors available in mobile phones like, accelerometer, compass, gyroscope, etc. This paper is study ofGeomagnetic field based positioning, Li-Fi navigation, SONAR &RADAR techniques using ultra sonic audio, ultra wide band, infrared or laser signals, Inertial Navigation System, Wi-Fi positioning, Wi-Fi SLAM and Visual SLAM technique for indoor navigation and positioning.**

***Keywords*— Indoor Positioning, Indoor Navigation**

I. INTRODUCTION

People spend most of their time in indoor spaces like shopping mall, large retail store, school, college, university, library, airport, railway and subway (metro) station, hotel, restaurant, stadium, theatre, hospital, museum, multi story parking lot etc. All such places are not always easy to navigate through. For example, finding a place like ATM or restroom in a non-familiar building is headache if proper sign and map is not provided. Finding venue of interest in large scale public events is almost impossible. If you are looking for a product in large retail store than there is less chances that you will get your product without exploring most of store. Another example, suppose you are late for your flight and you want a shortest route to your boarding gate, without indoor navigation system you have to look for various signs and maps to figure out where you are, where your boarding gate is and what should be shortest path to there. Same problem arise in railway/subway and bus station while finding a platform. One more example, suppose you are visiting a large exhibit. There are grater chances that you will spend most of your time in exploring uninteresting stalls rather than stalls of your interest. To tackle all such problems indoor navigation system is required.

Indoor positioning and navigation is emerging field in mobile computing. The terms positioning and navigation refers to getting user's location on a map and guiding him to desired location. The core task of indoor positioning and navigation system is to determining user's location. Based on position of users, many other functionality and service like navigation, product/book searching, location based advertisement, and etc. can be provided.

There are number of techniques available for locating a person. Most popular technique for getting location of user is Satellite Navigation. Satellite Navigation can give current location of user using special purpose satellites. Global Positioning System (GPS) is widely used example of satellite navigation. GPS satellites transmits radio signals. GPS receiver receives radio signals transmitted by GPS satellites and calculates its location using trilateration. However radio signals cannot pass through walls. That means GPS cannot be used in indoor spaces. Indoor positioning and navigation applications demands higher accuracy in user's position. GPS provide a "worst case" pseudo range accuracy of 7.8 meters at a 95% confidence level. [1]The actual accuracy users attain depends on factors including atmospheric effects (ionospheric/tropospheric delays), sky blockage, receiver quality, signal arrival time measurements, numerical calculations, ephemeris and clock data, multipath signals, and natural and artificial interference. Real-world data from the FAA show that their high-quality GPS SPS receivers provide better than 3.5 meter horizontal accuracy.[1]Horizontal accuracy seems promising but vertical accuracy of GPS is not good. That means GPS cannot measure altitude of receiver as accurate as latitude and longitude. Accuracy of altitude measured by GPS is on the order of 10-25 meters. In indoor positioning, altitude measurement is as crucial as latitude and longitude because many times venues are multistorey buildings. Accurate altitude data can tell floor number of user's location.

This paper gives overview of currentlyused techniques for indoor positioning.

II. GEOMAGNETIC FIELD BASED POSITIONING

Earth's geo-magnetic field is not same at all places. Strength of geomagnetic field varies location to location. Strength of geomagnetic field on earth's surface ranges from 25 to 65 micro tesla. Lobsters and a lot of other animals, such as birds and sea turtles, have a nifty way of figuring out where they are. Not only they are able to detect the direction of the Earth's magnetic field, but they're also able to derive directional information from how the field changes due to local anomalies, thus establishing where they are relative to their target location. Geomagnetic field based positioning system exploits this feature of earth's magnetic field.

Smartphones comes with built-in compass sensor. This sensor can measure strength of earth's magnetic field very accurately. In addition, these sensors can measure this strength on 3 axis. That means sensor gives three values. Each value is strength of earth's magnetic field on X, Y and Z axis. This capability can be used to measure user's orientation.

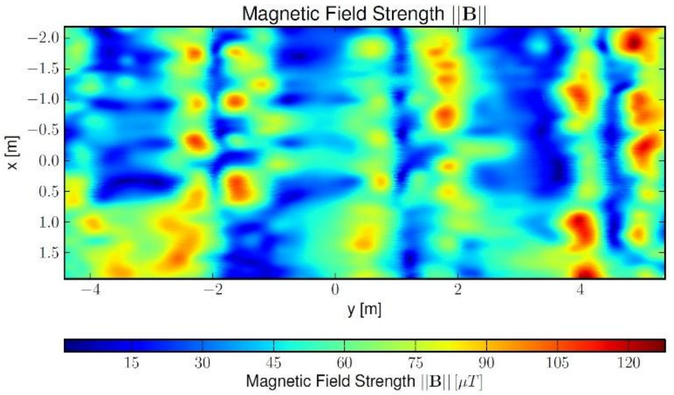

Figure 1: Magnetic field in building

Geomagnetic Field based navigation system uses ambient geomagnetic field map. This map is simple measurement of geomagnetic field on all area of map. This is also called geomagnetic fingerprint. Figure 1 shows minor variations in geomagnetic field inside a building. Ambient geomagnetic field map is captured with sensitive magnetic sensors. Such sensors accurately map the magnetic field property of venue. One big challenge with this system is that magnetic map must be aligned properly with actual venue map. That means database of magnetic field data must be accurately linked to physical map of venue. If this is not done properly, than unusual drifts may occur during actual use.

User will measure strength of magnetic field using smartphone, and send this to location server. Location server will reply user's location by comparing sensor data and ambient geomagnetic map.[2]

This technique can provide user's position with accuracy of 1 meter. Only drawback of this system is, accuracy depends on Ambient Geomagnetic Field Map, which is expansive to generate and maintain.

III. LI-FI NAVIGATION

All Li-Fi (Light Fidelity) is a subset of visible light communications (VLC). Visible light communication system uses light from light-emitting diodes (LEDs) as a medium to deliver data. Data is encoded in light signals such a way that human eye cannot detect. For example, by turning LEDs ON and OFF within a few nanoseconds OR by changing intensity of light. To receive these data from light source, specially designed electronic devices generally containing a photodiode is used, although in some cases a cell phone camera or a digital camera is sufficient.[3] A phone camera is in fact array of photodiodes (pixels).

Li-Fi navigation uses ceiling mounted LED bulbs. This LED bulbs constantly emits a unique ID. User receives this ID and sends it to location server. Location server contains mapping of unique ID of bulb with its physical location. Location server returns real-world position of that bulb to user. User calculates its position based on position of bulb.

This system is cheap and accurate. It can provide accuracy of 1 meter.[4] It requires little modification in infrastructure. There is no requirement of purchasing special LED bulbs, existing LED bulbs can be used with this system. By adding a small chip in every LED light bulb of venue, we can achieve high accuracy indoor location. This technique can also work in day sunlight. During day sunlight, LEDs can be dimmed. Dimmed LEDs are still able to transmit data. Only drawback of this system is that user must have his mobile outside of his pocket and LED must be in field of view of camera.

IV. SONAR AND RADAR TECHNIQUES USING ULTRA SONIC AUDIO, ULTRA WIDE BAND, INFRARED OR LASER SIGNALS

Sonar (SOund Navigation And Ranging) is a technique that uses sound propagation to navigate, communicate with or detect objects in surrounding environment. Sonar emits pulses of sounds and listens for echoes. The acoustic frequencies used in sonar systems vary from very low (infrasonic) to extremely high (ultrasonic). Sonar technique uses speaker and microphone of user's smartphone as transmitter and receiver. Also, separate ultrasonic transmitters can be placed in venue. Special devices required for using this technique effectively. To measure the distance, the time from transmission of a pulse to reception is measured and converted into a range by knowing the speed of sound in air is constant. To pinpoint user's location multiple transmitters are used for trilateration.[5] This technique is highly accurate but its

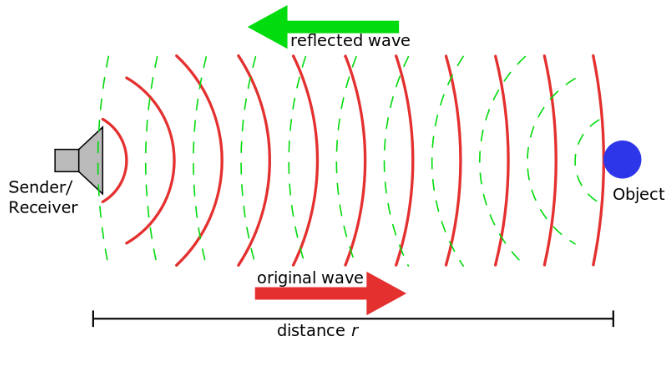

Figure 2: SONAR Principle

accuracy decreases with change in temperature and humidity. Also peoples and furniture can reduce the accuracy because of multipath propagation of sound pulse.

Similarly RADAR (RAdio Detection And Ranging) is technique for determining the range, altitude, direction, or speed of objects and mapping surroundings using radio waves like Infrared waves or Laser or Ultra Wide Band (UWB) signals. All these signals are of very high frequency hence accuracy of all this are high. Also these signals works within small ranges. Likewise SONAR, this technique uses time of flight technique to measure distance because all radio waves travel at speed of light.

V. INERTIAL NAVIGATION SYSTEM

An inertial navigation system (INS) uses motion sensors (accelerometers) and rotation sensors (gyroscopes) to continuously calculate via dead reckoning the position, orientation, and velocity (direction and speed of movement) of a moving object without the need for external references. It is used on vehicles such as ships, aircraft, submarines, guided missiles, and spacecraft. This technique is also called Sensor Fusion because it fuses data from various sensors. Sensor fusion is the combining of sensory data or data derived from sensory data from different sources such that the resulting information is in some sense better than would be possible when these sources were used individually. The term better in this case can mean more accurate, more complete, or more dependable.

A. Dead Reckoning

In navigation, dead reckoning is the process of calculating one's current position by using a previously determined position, or fix, and advancing that position based upon known or estimated speeds over elapsed time and course.

The words dead reckoning are also used to mean the process of estimating the value of any variable quantity by using an earlier value and adding whatever changes have occurred in the meantime. Often, this usage implies that the changes are not known accurately. The earlier value and the changes may be measured or calculated quantities.

Dead reckoning can give the best available information on position, but is subject to significant errors due to many factors as both speed and direction must be accurately known at all instants for position to be determined accurately. For example, if displacement is measured by the number of rotations of a wheel, any discrepancy between the actual and assumed diameter, due perhaps to the degree of inflation and wear, will be a source of error. As each estimate of position is relative to the previous one, errors are cumulative. Or compounding, multiplicatively or exponentially, if that is the co-relationship of the quanta.

B. Inertial Navigation System in Detail

Inertial navigation is a self-contained navigation technique in which measurements provided by accelerometers and gyroscopes are used to track the position and orientation of an object relative to a known starting point, orientation and velocity. Inertial measurement unit (IMUs) typically contain three orthogonal rate-gyroscopes and three orthogonal accelerometers, measuring angular velocity and linear acceleration respectively. And some also include a magnetometer, mostly to assist calibrate against orientation drift. By processing signals from these devices it is possible to track the position and orientation of a device.

Inertial navigation is used in a wide range of applications including the navigation of aircraft, tactical and strategic missiles, spacecraft, submarines and ships. Recent advances in the construction of microelectromechanical systems (MEMS) have made it possible to manufacture small and light inertial navigation systems. These advances have widened the range of possible applications to include areas such as human and animal motion capture.

An inertial navigation system includes at least a computer and a platform or module containing accelerometers, gyroscopes, or other motion-sensing devices. The INS is initially provided with its position and velocity from another source (a human operator, a GPS satellite receiver, other positioning systems, etc.), and thereafter computes its own updated position and velocity by integrating information received from the motion sensors using dead reckoning. A computer continually calculates the vehicle's current position. First, for each of the six degrees of freedom (x, y, z, and θx, θy, and θz), it integrates over time the sensed acceleration, together with an estimate of gravity, to calculate the current velocity. Then it integrates the velocity to calculate the current position. The advantage of an INS is that it requires no external references in order to determine its position, orientation, or velocity once it has been initialized.

An INS can detect a change in its geographic position (a move east or north, for example), a change in its velocity (speed and direction of movement), and a change in its orientation (rotation about an axis). It does this by measuring the linear acceleration and angular velocity applied to the system. Since it requires no external reference (after initialization), it is immune to jamming and deception.

C. Foot Mounted IMUs

Inertial measurement sensors are inaccurate, also because of double integration requirement for getting position in 3D space, it introduces huge drift with time. If somehow we can measure the accuracy of sensed data at given time, drift can be reduced significantly. Each person has a unique gait. Gait study measures the pattern and style of walking habit of person. Gait study includes step length, movement of toes, movement of foot between each steps, speed of these movement at various stages, etc. All such parameters are unique from person to person. Also, each person efficiently make all steps exactly same way.[6] Hence gait information can act as good ground truth for comparing accuracy captured sensor data.

This technique is same as simple INS, in addition of knowledge that IMUs are mounted on foot. User wears shoes with inertial measurement sensors. These sensors are connected with user's mobile phone. Sensors constantly sends data to user's phone. Phone will calculate the trajectory similarly with simple inertial navigation system, but this time trajectory calculation algorithm will consider the knowledge that sensors are foot mounted. Algorithm will try to recognize gait of user and correct any drift using that. Gait are different from user to user.[7] With enough training data, algorithm can get exact gait for current user. This gait data is used for future steps taken by user.

D. Problems with Inertial Navigation System

A major disadvantage of using IMUs for navigation is that they typically suffer from accumulated error, including Abbe error. Because the guidance system is continually adding detected changes to its previously-calculated positions (dead reckoning), any errors in measurement, however small, are accumulated from point to point. This leads to 'drift', or an ever-increasing difference between where the system thinks it is located, and the actual location.Measurement of orientation is accurate but measurement of position is not, because it requires double integration. Even if sensors is steady, double integration of noisy sensor data generates drift continuously. The inaccuracy of a good-quality navigational system is normally less than 0.6 nautical miles per hour in position and on the order of tenths of a degree per hour in orientate.

Because the devices are only able to collect data in a finite time interval, IMUs are always working with averages. So if an accelerometer is able to retrieve the acceleration once per second, the device will have to work as if that had been the acceleration throughout that whole second, although the acceleration could have varied drastically in that time period. Of course modern devices are able to collect data much faster than once per second, but over time that error increases exponentially.

Therefore the position must be periodically corrected by input from some other type of navigation system.

VI. WI-FI POSITIONING SYSTEM

Wi-Fi-based positioning system (WPS) or WiPS/WFPS is used where GPS is inadequate due to various causes including multipath and signal blockage indoors. Such systems include indoor positioning systems. Wi-Fi positioning takes advantage of the rapid growth in the early 21st century of wireless access points in urban areas.

A Wi-Fi network offers several advantages. It supports the ability to send data at a faster rate, has a large range, is low maintenance, and is Omni directional. An Omni directional system does not require line-of-sight, so it can operate through walls. However Wi-Fi signals can partially penetrate through walls and get reflected several times. Unfortunately, the Wi-Fi spectrum is a limited and regulated resource; it is therefore an expensive resource prone to congestion and interference.

Wi-Fi networks have traditionally been used for data connectivity only, but you can use these networks for tracking and locating mobile users as well. The localization technique used for positioning with wireless access points is based on measuring the intensity/strength of the received signal (received signal strength RSS) and the method of "fingerprinting".[8][9] Received Wi-Fi signal strength from an access point (AP) varies as a user with mobile Wi-Fi receiver changes his position. Not surprisingly, the signal received at the mobile device is strongest when the receiver is close to the AP and weakest when further away. This trend is exploited by WiPS to estimate the mobile device's location inside a building.

The WiPS system works using a radio map. A radio map is a lookup table that holds collections of received signal strengths and the building locations where these signals were measured. This is also called Wi-Fi fingerprint of building. To locate the user's position, the user's wireless device measures the signal strength from the APs within its range and then searches the radio map to determine the signal strength entry that best matches the measured signal strength. Typical parameters useful to locate the Wi-Fi hotspot or wireless access point include the SSID and the MAC address of the access point. The accuracy depends on the number of positions that have been entered into the database.[10] The possible signal fluctuations that may occur can increase errors and inaccuracies in the path of the user. Fluctuations can occur due to dynamic changes such as temperature, the number of people present in building, and any other environmental factors which will affect the radio map. To minimize fluctuations in the received signal, there are certain techniques that can be applied to filter the noise. In the case of low precision, some techniques have been proposed to merge the Wi-Fi traces with other data sources.

A. Problems with WiPS

The main problem with WiPS is that it requires Wi-Fi fingerprint of whole venue. This is very tedious and time consuming process. Also a huge amount of fingerprint data will be collected. We have to store and maintain all fingerprint data. If range of AP is large, then it will take more time to figure out location of user. Process of determining user's location is more complex. Because of received signal strength will not be same as database entry every time, large computation resources are required to interpolate the possible location of user.

In an IEEE 802.11 system, received signal strength is implemented using "Received Signal Strength Indicator (RSSI)". RSSI is a measurement of the power present in a received radio signal.[11] RSSI is the relative received signal strength in a wireless environment, in arbitrary units. RSSI is an indication of the power level being received by the antenna. Therefore, the higher the RSSI number, the stronger the signal. There is no standardized relationship of any particular physical parameter to the RSSI reading. The 802.11 standard does not define any relationship between RSSI value and power level in mW or dBm. Vendors and chipset makers provide their own accuracy, granularity, and range for the actual power (measured as mW or dBm) and their range of RSSI values (from 0 to RSSI_Max).[12] One subtlety of the 802.11 RSSI metric comes from how it is sampled—RSSI is acquired during only the preamble stage of receiving an 802.11 frame, not over the full frame. A study in 2009 showed that RSSI cannot necessarily be used to reliably gauge distances in a wireless sensor network.[13]

VII. Simultaneous Localization And Mapping (SLAM)

In robotics, Simultaneous localization and mapping (SLAM) is the computational problem of constructing or updating a map of an unknown environment while simultaneously keeping track of user's location within it. Popular approximate solution methods include the particle filter and extended Kalman filter.

A. Particle Filter Basic Concept

Particle filters or Sequential Monte Carlo (SMC) methods are a set of on-line posterior density estimation algorithms that estimate the posterior density of the state-space by directly implementing the Bayesian recursion equations. Particle filtering technique can handle following situation: (1) There is something we want to know, (2) We can measure something, related to what we want to know, (3) We know something about relationship between the measurements and what we want to know.

SMC methods use a sampling approach, with a set of particles to represent the posterior density. The state-space model can be non-linear and the initial state and noise distributions can take any form required. SMC methods provide a well-established methodology for generating samples from the required distribution without requiring assumptions about the state-space model or the state distributions. However, these methods do not perform well when applied to high-dimensional systems. SMC methods implement the Bayesian recursion equations directly by using an ensemble based approach. The samples from the distribution are represented by a set of particles; each particle has a weight assigned to it that represents the probability of that particle being sampled from the probability density function. Resampling step included before the weights become too uneven. In the resampling step, the particles with negligible weights are replaced by new particles in the proximity of the particles with higher weights.[14]

B. Wi-Fi SLAM

Wi-Fi SLAM is similar to WiPS. Problem with WiPS is that it cannot estimate, location of user accurately. In WiPS, accuracy of location varies from user-to-user. Wi-Fi SLAM technique improves fingerprint based WiPS. WiPS is memory less positioning system. That means user does not consider his previous location while asking/calculating his current location. Wi-Fi SLAM keeps track of user's previous position and using supporting sensors like inertial measurement sensors it determines his current location. Inertial sensors are more accurate over small period of time. Wi-Fi SLAM utilizes this feature of inertial sensors to estimate his location using dead reckoning. While determining new location from previous location, this technique also collects estimated location using Wi-Fi fingerprinting. Eventually, using particle filter or similar algorithm, user will get most accurate location. Apple Inc. recently got a patent which implements Wi-Fi SLAM.[15]

When a gadget using Wi-Fi SLAM wants to know its location, it analyses the signal strengths and unique IDs of all the Wi-Fi networks around it. That is matched against a reference data set for the area either accessed over the Internet, or stored on the device. The estimate of location can be sharpened if a gadget moves slightly, because Wi-Fi SLAM's algorithms can gather multiple fingerprints. Compass data and accelerometer signals capturing a person's footsteps are also used to refine the accuracy of subsequent location fixes as a person moves around. Wi-Fi SLAM needs similar data to be gathered in advance inside a particular building before it can offer location fixes. A person running another special app must walk around a building a few times, entering every room at least once.

C. Visual SLAM

Visual SLAM is technique for SLAM using camera. A video camera can capture surrounding environment at very high speed. Traditional camera can capture video of 30 frames per second. That means there will be 30 different images of surrounding will be available per second. Cameras cannot see depth in captured scene. To locate a camera in room using just one image is hard. Visual SLAM can measure and estimate camera motion using just video captured from camera.

Visual SLAM technique identifies special features and objects in scene and tracks their movement. As camera moves through surrounding, identified features will be changed. This change can reveal, depth and shape of object. Visual SLAM technique generally consist two parts. One for special feature detection and second for motion and pose estimation.[16][17]

Visual SLAM is used in autonomous robots. This technique can be used as indoor navigation technique using camera of user's smart phone. How-ever continuous use of camera and high processing power can drain mobile battery quickly.

Table 1: Limitation / Demerit

Technique	**Limitation/Demerit**
Geomagnetic Fingerprint	High cost for initial geomagnetic fingerprint measurement
Li-Fi Positioning	Requires additional hardware
SONAR & RADAR	- Requires additional hardware - Accuracy varies with environmental interferences
Inertial Navigation System	Drift reduces accuracy
Wi-Fi Fingerprint	High cost for initial fingerprint measurement

Wi-Fi SLAM	High cost for initial fingerprint measurement
Visual SLAM	- Requires relatively high computing power - Battery will be drained quickly due to continuous usage of camera

VIII. CONCLUSION

Indoor Positioning and navigation requires high accuracy in users measured location. Any one of the above mentioned system can be chosen based on the parameters like,required accuracy, cost of implementation, target audience, scalability, performance,etc. There is a scope of further improvement in the results, if the best of each can be combined and the resulting approach is feasible to implement with all other aspects. As we have seen in this paper, these systems highly depends on sensors. Betterment in sensor technology can definitely make these systems more accurate and feasible. Here we have also listed the limitation and demerits of indoor navigation and positioning techniques in Table-1.

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