International Journal of Research in Engineering, Science and Management
Volume-2, Issue-5, May-2019
www.ijresm.com | ISSN (Online): 2581-5792

A Survey on iBaby: A Low Cost BLE Pseudolite based Indoor Baby Care System

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***Abstract*: This paper presents a survey on iBaby, a low cost BLE pseudolite based indoor baby care system.**

***Keywords*: ibaby**

1. Introduction

The infants aged between 6 months and 2 years have developed the ability of locomotion where they are usually seen crawling, walking and climbing, but the infants lack verbal communication and they cannot speak languages. As a result, their parents have a tough time monitoring their activities. And also as the infants at this stage tend to be unpredictable and the environment around them seems to build curiosity in the infant's mind. They tend to imitate what their parents do and learn new things. Their cognitive things are not content with just visual factors. They need a thorough examination of the object or the environment and this is done by the infants using two handed touch and taste. Because of this it is very hard to control the actions of the infants.

When the parents are in the washroom or answering a phone call and not concentrating on the babies, because of the infant's curious nature, it might enter into some of the dangerous areas of the house like the kitchen which has sharp equipment like knife, scissors etc. or they might enter into regions like washrooms where the floor is usually slippery and they also try to climb beds which might have sharp edges and this might lead to injuries. These are some of the dangerous areas present at home. As the infants have smaller body, the impact of these external risk factors which lead to injuries is greater on them. Accidental injuries are considered to be contributing majorly for the infant death. These accidental injuries might also lead to health issues in the infants. It is also said that 52% of the child accidents happen at home when the child comes in contact with the dangerous areas mentioned above.

In order to avoid this situation, the parents need to monitor the activities of the child effectively and a technology that can help the parents in pre-warning the potential dangers has a very wide use of demand and meets the market requirements and prospects. The recent monitoring technologies that are present in the market work on GPSS outdoor positioning technology. In order to create a system that can be used to access the indoor location accurately is the core technology that can be used for monitoring the infants and this technology is named as the indoor baby care system. Apple, google and other business giants have invested a lot of resources in this area.

Until now there is no such positioning solution which is practical, reliable and provides high –precision. The reasons why indoor positioning is hard is because of the reasons like weak signal strength inside the houses or no signal at all, it can also be because of the reason that the indoor topologies are not very simple and are prone to changes. Along with the above reasons the indoor care system should be user friendly as the user behavior is very unpredictable and the cost of maintenance should be as low as possible so that the consumers or users can afford.

In the present day scenario there are three major types of indoor positioning technologies available which work based on the smartphones:

1. The Radio frequency signal based positioning technology which makes use of Wi-Fi, Bluetooth, NFC and cellular signal for indoor positioning. The positioning methods of these different techniques are also different because of the variety of signal frequency, intensity and transmission distances available. Wi-Fi based indoor positioning is uses techniques like fingerprint matching, where in the methods mismatch rate is very high in the open position and it takes a lot of time and man power to establish and maintain the database. If we use the same technique that is, fingerprint matching, in case of Bluetooth technology then the disadvantage is that the signals strength is highly affected by the outdoor environment and also, if we use a single Bluetooth chip it leads to instability. The NFC technology lacks in providing a real time position in the indoor care system which is one of the important feature of the indoor care system. There is a technology called Quuppa in Finland where the positioning accuracy can be obtained over a few centimeters, but its coverage is small for each station and the cost of the device is high.
2. The second positioning technology is the sensor based positioning technology. As we know that the recent cell phones come with multiple built in sensors like accelerometer, magnetometer, barometer, gyroscope

and so on. The sensors can be used to locate the actual position of the device. And this can be achieved by methods like Pedestrian Dead Reckoning, geomagnetic matching etc. These methods have problems like heading estimation, difficulty in building an accurate magnetic fingerprint database in practical applications. These methods are usually complex, they require a lot of power because of which the power consumption is very high and some of these methods require a large number of hardware equipment and facilities.

3. In the present time due to the increased storage and computational capabilities of the cell phone it is possible to fuse multiple location technologies on the cellphone platform. This is known as the multi-source fusion positioning technology. The most common methods are based on the filtering methods like particle filtering, Bayesian filtering and UKF.

Here by making use of Pseudolite base station, which has an MCU and Bluetooth Low Energy chip in combination with a navigation message and by making use of the mutli-source fusion positioning technology which can be used as a reliable indoor positioning technology suitable for usage by the public. By using this, a design for the indoor baby care system can be achieved. The location of the infant can be obtained accurately and hence it effectively reduces the possibility of infant injuries.

2. Literature survey

BLE, abbreviated form of Bluetooth Low Energy is one of the protocols used in IoT technologies. This technology was developed by SIG. BLE is used because it is a low power and stateless protocol and it has low cost. It has less data throughput and low data rates as a downside which can be easily overcome by using multiple Bluetooth chips. A Pseudolite is obtained from two words combined together, which is pseudo and satellite. These are devices which are not exactly satellites but perform the functionalities commonly performed by the satellites. These Pseudolites are used to provide local ground based GPS provisioning. These are nothing but small transceivers.

A. Bluetooth Low Energy (BLE) crackdown using IoT. Crackdown of BLE protocol incorporated in IoT

Internet of things or the IoT is a computing concept that describes how the devices are connected to the internet and each other. Every device or the 'thigs' in the internet of things has an IP address associated to them. These devices help in detecting, collecting, processing and exchanging the data. The framework of IT simple strives to connect every other thing with different things in the network. There is n number of protocols available for n different results. Depending on the requirements a person can use different protocols and technologies to connect to the internet, which is the main aim of any IoT technology. The 'things' in Internet of Things include device specific embedded software, sensors, actuators and network supporting components. The IoT is used for establishing interaction between machines. The identification process can be done using technologies like RFID, sensor technology, wireless technologies or QR codes. There are many protocols used to establish communication between the devices incorporated in the network. Some of them are MQTT, CoAP, ZigBee, NFC and Bluetooth. The application of the IoT technology is plenty. It can be used in Home automation, Health Care, Environment monitoring, Transportation etc. BLE technology is used as one of the best options for communication with devices present in short range. It identifies the objects present in the radius and is known to it. It does so by advertising packet one per second which consumes less power [1].

Disadvantage- Even though BLE consumes low power and small form factor, the challenge is to achieve security and privacy. It has low bandwidth and limited storage. Testing more devices with BLE implementation will be challenging in the real world scenario.

B. Improving BLE based Localization Accuracy using Proximity Sensors.

Bluetooth Low Energy systems are one of the most popular solutions used for indoor localization. Narrow band localization systems based on Bluetooth or Wi-Fi are amongst the most popular solutions for indoor positioning. One way of improving localization accuracy is to use hybrid positioning algorithms employing measurement data obtained with different techniques or independent systems. Proximity sensors can be an addition to the typical BLE infrastructure. They can be integrated with Bluetooth anchors or can be mounted separately in locations, where propagation conditions may be difficult. The results obtained by using hybrid algorithm are more accurate than those obtained only with BLE results [2].

Disadvantage- the accuracy might not be sufficient for some kinds of applications. Locations calculated with the proposed hybrid algorithms are closer and median trajectory error is dozen centimeters. It doesn't take the sensor's FoV into consideration.

C. Low-Cost, Non-Sensor-Equipped BLE Beacons to Track People's Movements

A room level people tracking system, which is capable of determining people's movement is exceptionally useful in today's life. Knowing in which room the people are present has a variety of applications, and y using non-sensor BLE beacon this system becomes low-cost, easy to install and maintain. The BLE beacons broadcasts BLE advertisements when people are in motion. A beacon receiver which is installed at the door frame is used to determine the people who are entering, departing and passing by the room. It is based on the variations in the received signal strength over time.

Disadvantage- As non-sensor BLE is used the information like acceleration or direction is not provided. The walls of the room cause signal attenuation and reduce the signal strength level of BLE advertisement that is, it is susceptible to obstructions.

D. Indoor Positioning with Pseudolites -The Effect of the Number of Receivers and Transmitters

Pseudolite is expected to be one of the best solutions for indoor positioning because of its compatibility with GPS and its positioning accuracy. To avoid the problem of cycle slips, there are two possible methods; increasing transmitters, which is known as an effective way for outdoor GPS, and increasing receivers. In addition, Pseudolite has the potential to achieve centimeter-level positioning, which is equal to GPS carrier phase-based positioning. In addition, Pseudolite has the potential to achieve centimeter-level positioning, which is equal to GPS carrier phase-based positioning. By increasing the number of transmitters and receivers the number of observation equations is more than that of a single receiver. Compared to other technologies like wireless LAN (WLAN), RFID and ultra-wideband (UWB), the Pseudolite is compatible with GPS.

Disadvantage-This method of using multiple transceivers and receivers doesn't provide a direct solution to the cycle slip problem and also causes redundancy.

E. An Improved Pseudolite-Based Indoor Positioning System Compatible with GNSS

In recent years, with the wide spread application of location based service (LBS), accurate user positioning information is required both indoors and outdoors. In an existing method, Pseudolites are set to simulate GNSS satellites and by processing the position output of GNSS receiver, user positions are then obtained. In an existing method, Pseudolites are set to simulate GNSS satellites and by processing the position output of GNSS receiver, user position are then obtained. Commonly Pseudolites generate and transmit GNSS-like signals. Since the Pseudolite positions cannot be transmitted in standard ephemeris format, GNSS-like signals should have different signal structure compared to real GNSS signals. These differences require firmware-level modifications of the common receiver, so such signal cannot be utilized by common receivers such as those in cellphone and other handheld devices. By taking the residual error of the receiver output into account, accurate results can be obtained in different situation.

Disadvantage: Major disadvantages are not determined in this approach.

3. Methodology

A. System design

1) System overview

The iBaby care system majorly consists of three components that is Pseudolite, server and client. Fig. 1. shows the system architecture. The Pseudolites are placed uniformly in the interior ceiling and its major functionality is to provide real time indoor high-precision location of the infant. Here the server is used to provide functionalities like data storage and web interface using which the location of the client interface can be accessed. The client is divided into parent's client and the baby's client. The functionality of the parent's client is to display the indoor map; the real-time display of the baby's indoor location; the setting of the dangerous area; getting reminder messages when the baby enters into the dangerous area; the display of the baby's activity track in a certain period of time; the statistical analysis of the baby's activities. The function of baby's client is to get its own location; which is nothing but the location of the baby and send the result to the backend server.

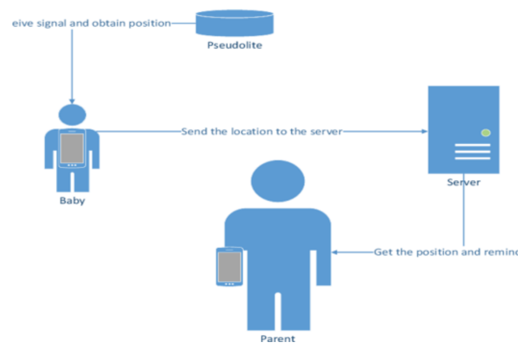

Fig. 1. System structure

2) Pseudolite

The Pseudolites consist of two types of components which are, multiple Bluetooth chips and a MCU. Here more than one Bluetooth chip is used to overcome the instability that is caused due to the usage of a single Bluetooth chip. The component MCU acts as a coordinator and helps in coordinating the work done by the Bluetooth chips. Fig. 2, shows the iBaby Pseudolite prototype.

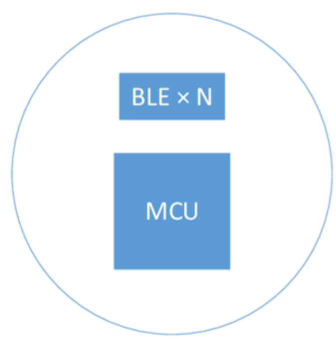

Fig. 2. iBaby Pseudolite protocol

When the Pseudolite works the RSSI is sent from the Bluetooth chips and by making use of the distance equation (eq1), the distance between the two Pseudolites can be calculated.

$$d = 10^{(abs(RSSI)-A)/(10*n)} \quad (1)$$

Here d represents the calculated distance between the Pseudolites, RSSI stands for received signal strength, A is the signal strength at one meter apart from the transmitter and receiver, and n is the environmental attenuation factor. Every single Bluetooth chip is calibrated in order to measure the distances accurately. Broadcasting is used to send the messages to the user and the information that is the navigation message is stored in the Bluetooth chip.

This navigation information is present in an encrypted format and if the user wants to access the information then that user can do so by decoding the message. The UKF contains the information such as set of Pseudolite distances navigation information, the velocity obtained from the phone and the previous positioning results. By making use of this data, we can get the position of a particular Pseudolite. The positioning accuracy of the Pseudolite obtained from experiments is shown to be 1mo. Fig. 3, shows the process of Pseudolite positioning.

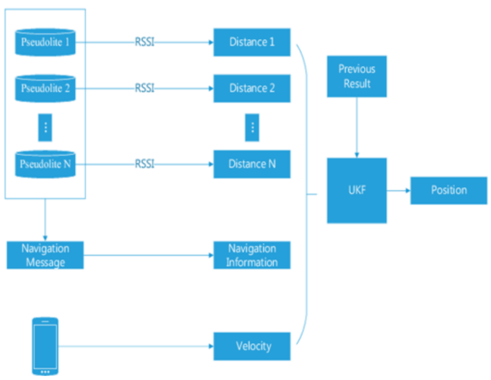

Fig. 3. Positioning process

3) Server

The server provides data storage and web interface. It uses Python language for setting up the web interface and services, the data is stored using MySQL and in order to improve server performance when using multi-threaded deployments, the server uses Gunicorn and finally to reverse the proxy or server load balancing Nginx is used. Fig. 4, shows the iBaby server's workflow.

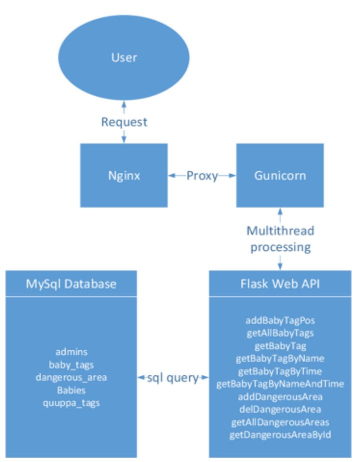

Fig. 4. iBaby Server's workflow

After the user sends the request, the corresponding Web API is accessed through Nginx and Gunicorn, and the result of the SQL operation on the table in the MySQL database inside the API is returned to the user.

4) Baby client

An Android device is used as the baby client. This device is shaped either as a button hanging on the back of the baby or a bracelet that stays on hands or feet. This baby client has a Bluetooth receiver module for receiving the Bluetooth signals that are transmitted by the Pseudolite. After receiving the transmitted Bluetooth signal from the Pseudolite, it obtains the navigation information by decoding and later on calculates the location information which is sent to the server. This workflow is depicted in Fig. 5, as shown below.

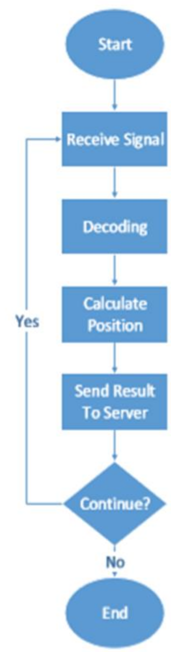

Fig. 5. Baby client's workflow

Fig. 6. Baby client's interface

The system simulation uses an Android phone as the baby client. Here both Pseudolite and Quuppa are joined for comparison purpose. Fig. 5, shows the baby client interface. Quuppa is a costly when compared to a Pseudolite.

5) Parent client

A common Android phone is used as the hardware by the parent client. The parent is required to set the dangerous areas beforehand. When this parent client works, the location information is obtained from the server after decoding the navigation information and displays the region on the house map. Fig. 6, shows the workflow of parent client.

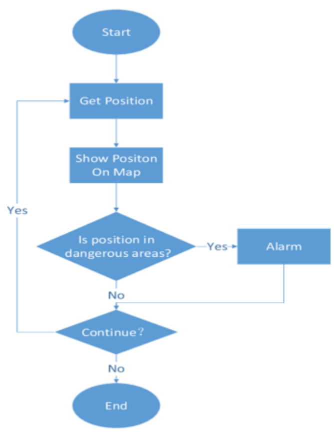

Fig. 7. Parent client workflow

If the obtained locations are present at the re-set dangerous areas then an alarm rings. The fig. 7, shows the parent client interface.

Fig. 8. Parent client interface

4. Experimentation

The experiment was conducted in a room with an area of 120 square meters. 6 Pseudolites and 3 Quuppa stations are evenly arranged on the top of the room. The blue point shows the location of the Pseudolite and the red points is the location of the Quuppa base stations. Fig. 8, shows the map of the laboratory where the experiment was conducted.

The function of the iBaby system is to alert the parents when the infant moves into the dangerous areas. Three important indicators are considered here; they are false negative rate, false alarm rate and alarm response time. False negative rate refers to the rate that the system doesn't alarm when the baby is in dangerous area. False alarm rate refers to the rate that the system alarms when the baby is not in dangerous area. Alarm response time is the time difference between when the baby enters the dangerous area and when the system alarms. According to the apartment layout chart, the upper left corner of the kitchen and bathroom is set to be a dangerous area. Fig. 9, shows the status when system alarms for baby entering the dangerous area.

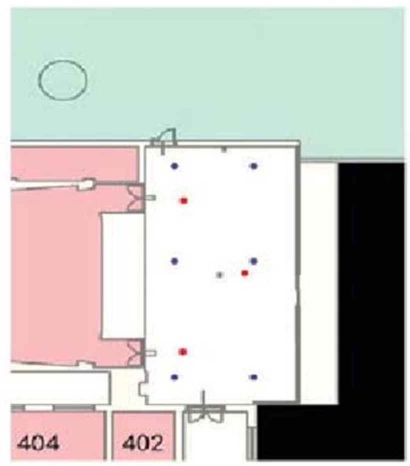

Fig. 9. Map of laboratory

Fig. 10. System alarms status

In order to test the indicator false negativity, the experiment holds baby client to walk inside the dangerous are for a period of time. The number of system positioning points is recorded. The points which locate outside the dangerous area are the omissions reported points. The result of the number of omissions reported points divided by the total number is the false negative rate. The same experiment was conducted using Quuppa as well.

The next test was conducted to determine the false alarm rate. In this test the baby client is made to move around the dangerous areas and the number of system positioning points is recorded. Among the system alarm points recorded, those points which are shown outside the dangerous areas is considered and counted as the false alarm points. The total number of false alarm points divided by the total number gives the false alarm rate. The same test is done using Quuppa and the results are obtained.

The final test conducted is to determine the alarm response time. The experimenter walks from outside the dangerous area into the dangerous area, record the moment into the dangerous area and the system starts alarm, the difference between them is the alarm response time.

A. *Performance evaluation*

False negative rate

The above experimentation was conducted for both the Pseudolite as well as Quuappa under the same environmental conditions. The figure 3.10 shows the experimental positioning data.

Fig. 11. False negative rate experimental positioning data

In the fig. 10, the positioning of data depicted to the left is that of the Pseudolite and the positioning data depicted to the right is that of the Quuppa device. The number of green points depict the number of system positioning points which are located outside the dangerous areas are the false negative points. In case of the Pseudolite, the number of false negative points is less when compared to that of the Quuppa. The table 1, shows the false negative rate statistics.

Table 1
False negative rate statistics

Positioning Source	Total Number	Ommisions Number	False Negative Rate
Pseudolite	249	2	0.8%
Quuppa	162	54	33%

1) *False alarm rate*

After the experimentation the false alarm rate was observed for both the Pseudolite as well as the Quuppa. Fig. 11, shows the experimental positioning data for both the Pseudolite as well as the Quuppa.

Fig. 12. False alarm rate experimental positioning data

In fig. 11, the positioning data depicted to the left is that of the Pseudolite as the positioning source and the one toward the right is that of the Quuppa device as the positioning source.

Table 2
False alarm rate statistics

Positioning Source	Total Number	False Alarm Number	False Alarm Rate
Pseudolite	358	25	7%
Quuppa	183	0	0%

The table 3.2 shows the statistical data of the false alarm rate.

2) *Alarm response time*

The experiment conducted to calculate the alarm response time gave certain values for both Pseudolite and Quuppa and this is depicted in the form of a graph as shown in the fig. 12.

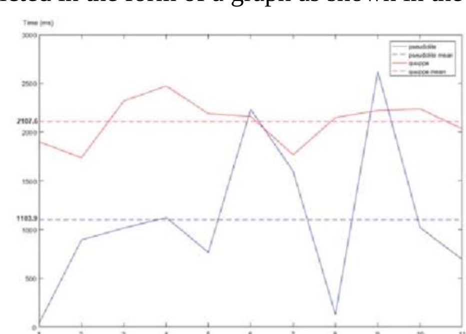

Fig. 13. Alarm response time

In the fig. 12, the blue line indicates the use of Pseudolite as the positioning source, and the red line in the graph indicates Quuppa as the positioning source. The solid line indicates the response time and the dotted line indicates the average response time. The average response time using Quuppa as the positioning source is 2107.6ms and the average response time using the Pseudolite as the positioning source is 1103.9ms.

A comparison table for the results of the experiment is shown below,

Table 3
Comparison table

S. No.	Features	Pseudolite	Quuppa
1	False negative rate	The rate of failure is 0.8% (low)	The rate of failure is 33% (high)
2	Positioning accuracy	Low compared to Quuppa	The positioning accuracy is high in comparison with Pseudolite
3	Response time	Better response time when compared to Quuppa	Response time is low when compared to Pseudolite
4	Cost	The cost of 6 Pseudolites was determined to be 1000 yuan (cheap)	The cost of three Quuppa was said to be 24000 yuan (costly)

5. Conclusions and future works

The stimulation experiments were carried on the two different positioning sources that is, the Pseudolite and the Quuppa. Both of them can basically meet the needs of the system for positioning accuracy. In order to achieve the factors like usability, practicality, reliability, low cost and high-precision, the Pseudolite is the better choice. And also, the cost of Pseudolite is only 1/20 of that of the Quuppa and hence it is more acceptable to consumers. This particular application is easy to install and no maintenance is required. It is practical and the response rate is very high. It is a reliable product as it can run for very long durations. The client doesn't need additional equipment and hence it is acceptable by the customers. It can easily achieve meter level accuracy; that means it provides high-precision at low cost. As multiple Bluetooth chips are used, the problem of instability is removed in this case. This product is not a mature product on the market. In order to put the system to market, there is a need for improvising on the factors like positioning accuracy similar to Quuppa, reduce the power consumption so that it lasts for very long duration are a few challenges of this system.

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