Performance of low cost Global Positioning System (GPS) module in location tracking device

S H Bujang, H Suhaimi and Pg E Abas*

Faculty of Integrated Technologies, Universiti Brunei Darussalam, Jalan Tungku Link BE1410, Brunei Darussalam

*Corresponding email: emeroylariffion.abas@ubd.edu.bn

Abstract. Recently, there has been increasing interest in the use of tracking devices for patients, sportsmen, children, as well as vehicles and robotics applications, for various reasons. Low cost Global Positioning System (GPS) device has been popular due to the increase in accuracy of this system as well as improved affordability. This paper designs a low-cost system for position tracking using common low cost off-the-shelf GPS module which is commonly used by developer in the design and prototype stages and studies its accuracy performance. Accuracies in terms of error between real and measured values, are measured whilst the system is stationary and in motion; particularly whilst walking and driving. The presence of obstacles and movement of the system has been identified as important factors which defined the performance of the system. It has been shown that average error distances from the system are minimal in the order of less than 7 metre (m), both whilst stationary and in motion. Using the system whilst driving gave highest average error of 6.66 m. The results are encouraging for system developer, as it points to the applicability of low cost GPS system for implementation in location tracking device.

1. Introduction

There has been a surge in interests in the usage of positional tracking system for implementation in various applications; including, but not limited to sports, health, criminal detection, vehicles detection and monitoring applications. These applications span both the civilian and military domains, with every application requiring their own requirements, in terms of size, cost and accuracy. An example in health application is for the location detection and tracking of dementia patients who suffer from memory loss problem [1]. Dementia patients have the tendency to wander off from their home, which may expose them to various dangers and it is envisaged that with the aid of this technological approach, their whereabouts may be monitored and their risk of harm may be reduced. Indeed, the trend of using positional tracking system has been increasing in the past few years as can be seen for its various implementation in most mobile phones and smartwatches.

Some of the systems that have been proposed for positional detection and tracking includes Radio-Frequency Identification (RFID) [2][3], Inertial Measurement Unit (IMU) [4] and Global Navigation Satellite System (GNSS); such as Global Positioning System (GPS) [5] [6] and Global Navigation Satellite System (GLONASS) [7]. Reference [2] proposes passive RFID system for the tracking of elderly in elderly homes, requiring placements of network of RFID readers around the area of interest. The proposed system is, however, limited by the needs to have many readers fencing around the area of interest, as well as by its inability to track once the patient goes out of the area. Although active RFID, such as in reference [3], can be used to reduce the requirements on the number of readers, using RFID system for position tracking is nevertheless still constrained by the need to pre-identify the area to be observed. IMU has also been used to give position tracking information for indoor tracking of automated guided vehicles (AGV) for warehouse applications [4]. Three low-cost (<USD$300) and one medium cost (<USD$5,000) IMUs were compared; to show that the low-costs IMUs perform equally well.
compared to the medium cost IMU, for the considered AGV’s application. However, due to its reliance on measured acceleration to derive its positional information, IMU suffers from cumulative error over time which tends to increase exponentially over time [4]. Alternatively, some authors have also used GNSS for positional information; especially for GPS which is more popular due to its coverage and better performance, in terms of accuracy and reliability [7]. GPS-based system has also been proposed in reference [6]; focusing on battery-life of common GPS trackers. In reference [5], the authors proposed low cost GPS location tracking systems (USD$180-USD$270 range) for tracking dementia patient using commercially off-the-shelf trackers and have shown via cost analysis that the system is more affordable as compared to the available commercial providers for tracking device. The popularity of GPS devices in the market is primarily due to the availability and affordability of its receiver [5].

GPS is an US-based system that is able to provide positioning information as well as timing; by utilizing the system’s more than 31 GPS satellites which are continuously moving at an altitude of approximately 20,200 km above the earth surface. It consists of three main components: space, control and user components. The space component consists of GPS satellites; which continuously transmit one-way signals, in continuous constellation around the earth, and the control component consists of monitoring stations to ensure proper operations of the orbiting satellites. Finally, the user component is the GPS receivers, which receive the transmitted signals from the space components [8]. Received signals are then used to calculate its three-dimensional positions; in the form of longitude, latitude and altitude, via triangulations as well as to determine accurate timing information. To determine positioning information, the GPS receiver needs to receive GPS signals from at least four (4) different GPS satellites [9] to allow proper triangulation in three-dimensional space. GPS signals are also influenced by distance attenuation, multi-path and shadowing [10]. Movements from the satellites and the GPS receiver, as well as blocking objects such as buildings, trees, etc., may cause variation in the received GPS signal at the GPS receiver. Furthermore, performance and quality of the receiver also affect the received GPS signal. Due to these many factors, GPS information may suffer from error and inaccuracy.

Naturally, different applications may have different accuracy requirement. Applications in the military domain, for example, would especially require a high level of accuracy and in turn, cost more [11], in contrast to other applications in the civilian domain [5]. Therefore, studies on its accuracy performance are crucial in order to satisfy some requirement.

The aim of this paper is, therefore, to design a low-cost system using low-cost GPS receiver that is commonly found and used especially by developer, which is capable of providing positional information. Performance of the designed solution is also measured, in terms of accuracy. The paper is divided into several sections, with Section 1 providing brief literature review on the location tracking system. This is followed by the proposed system design as well as the procedure to test the performance of the system, in Section 2. Results and discussions are given in the following Section 3; and the final Section 4 concludes the paper.

2. Methodology

2.1. System design

Figure 1 shows the block diagram of the low-cost system; consisting of a micro-controller, off-the-shelf GPS module, GSM module and a server. Excluding the server, the system cost less than USD$50, much cheaper than the system proposed in reference [4][5]. Server is excluded from the system cost calculation as it can be shared by many device trackers simultaneously and to make the cost comparable to other systems [4]. NodeMCU micro-controller has been selected as the micro-controller for the system as it is a low-cost and user-friendly programmable micro-controller that is capable of handling both hardware and software components. Furthermore, it also consists of ESP8266 WiFi-enabled chip; allowing WiFi connection in areas with WiFi signal, instead of the more expensive GSM connection and hence, reducing operational cost of the system. GSM SIM900 module is also used for communications, for operations in areas without WiFi reach. GPS Neo-6M, a low-cost and commonly used GPS module compatible with NodeMCU micro-controller is used for receiving positioning information from GPS satellites. It functions by tracking the number of satellites and signal parameters in the GPS system; to
derive current locations. The system is programmed to read GPS signal and send them to a server database for storage at regular intervals. The information stored in the server can be accessed via any suitable front-end system, which shall be used for analysis. Additionally, a small switch is also added to allow manual transmission of data to the server. Flowchart of the operation of the system is given in Figure 2.

**Figure 1.** System design; consisting of NodeMCU Micro-Controller, Neo-6m GPS module, GSM Module sending positioning information to a Server, accessible via front-end webpage.

**Figure 2.** The flowchart shows the system design flow in reading and extracting the GPS data.
2.2. Analysis
This paper studies the performance of the low-cost GPS Neo-6M module, in terms of accuracy in determining its position. The GPS Neo-6M module outputs its information according to the National Marine Electronics Association (NMEA) format, which are then converted into three dimensional position by the microcontroller; in the form of $(\lambda_r, \phi_r, h_r)$ where $\lambda_r, \phi_r$ and $h_r$ are latitude, longitude and altitude calculated by the GPS receiver, respectively. It is noted that $-90^\circ S \leq \lambda_r \leq 90^\circ N, -180^\circ W \leq \phi_r \leq 180^\circ E$ and $h_r$ is given in metre (m). It is expected that this positioning information that is derived from the GPS receiver may not correspond accurately to the actual three-dimensional positions of the system.

Given that $(\lambda_a, \phi_a, h_a)$ are the actual latitude, longitude and altitude of the system, error $e_d$ from the system can then be derived as,

$$e_d = \sqrt{(\lambda_r - \lambda_a)^2 + (\phi_r - \phi_a)^2 + (h_r - h_a)^2}$$

where $F = 1.1132 \times 10^5$ m/$^\circ$ is the conversion factor from degrees ($^\circ$) to metre (m).

Tests were conducted to measure error performance of the system when it is stationary and moving. For stationary test, positioning information $(\lambda_r, \phi_r, h_r)$ were obtained from the GPS module at regular intervals for a given period of time, with errors $e_d$ calculated from $(\lambda_r, \phi_r, h_r)$ and actual position $(\lambda_a, \phi_a, h_a)$ of the system. On the other hand, paths were chosen to test the system’s performance whilst moving; either walking or driving. The paths were clearly marked to allow repetitions and waypoints laid down at multiple locations along the paths before the start of the experiment, with GPS data and time transmitted manually using the switch at every waypoint. Given that $(\lambda_1, \phi_1, h_1)$ and $(\lambda_2, \phi_2, h_2)$ are the latitude-longitude-altitude coordinates of two different waypoints, with $t_1$ and $t_2$ representing times where the system is at the two waypoints, respectively, travelling speed $S_{1 \rightarrow 2}$ of the system between the two waypoints can be approximated by:

$$S_{1 \rightarrow 2} = \frac{\sqrt{(\lambda_2 - \lambda_1)^2 + (\phi_2 - \phi_1)^2 + (h_r - h_a)^2}}{t_2 - t_1}$$

Errors $e_{d}$ are calculated at every waypoint to measure the performance of the GPS module whilst walking and driving.

3. Results and discussions
Experiments to measure the performance of the low-cost GPS module were conducted at selected locations at Universiti Brunei Darussalam (UBD), Brunei Darussalam. Five (5) different locations were chosen to test when the system is stationary, with GPS data taken and transmitted to the server for a total period of 180 seconds at 5 second intervals. Figure 3(a)-(e) show the maps of the 5 locations (marked with red markers) where the proposed system was tested. The experiment was repeated three (3) times at each location, and average taken. These locations were specifically chosen due to their locality and differing surroundings. Location 1 is near a tall building, location 2 in the parking area near a forest, location 3 is at an empty parking area on top of the hill far from any building, location 4 near building and trees, and location 5 at the spacious parking area, with nearby trees.
Figure 3. Locations for stationary tests, a) Location 1 at the parking area, close to nearby tall buildings, b) Location 2 at a parking area close to nearby forest and buildings, c) Location 3 at an empty parking area on top of the hill far from any building, d) Location 4 near building and trees, and e) Location 5 at the spacious parking area, with nearby trees.

3.1 Performance whilst stationary

Figure 4 shows average error distance $e_d$ computed using equation (1), at regular intervals for a 180-second period, at the different locations. It can be seen that average error distances $e_d$ are very much dependent on the locations and with time. These are very much expected; as the movement of the transmitting satellites and the presence of objects around the GPS receiver may cause different shadowing and multi-path effects. It can be seen that error distance $e_d$ at location 1 fluctuated the most over time, with highest average error distance $e_d$ of 9.96 m over the 180-second period. These may be
explained by the varying level of shadowing and multipath effects [10] due to the presence of tall buildings at location 1, as illustrated in Figure 3.

![Figure 4](image-url)  
*Figure 4. Error distance (m) against time (s) for stationary GPS receiver at 5 different locations.*

Table 1 shows the average, minimum and maximum error distance at the different locations. Highest error distance of 13.1 m was calculated at location 1, due to the presence of tall buildings, whilst the lowest error distance of 1.1 m was calculated at location 3. In fact, location 3 recorded the lowest average error distance of 2.46 m; due to its location which is on top of the hill and away from tall buildings, as shown in Figure 3. It is worth noting that average error distances are less than 10 m for all locations.

| From Figure 3 | (a) | (b) | (c) | (d) | (e) |
|---------------|-----|-----|-----|-----|-----|
| Avg (m)       | 9.96| 9.65| 2.46| 3.18| 5.98|
| Min (m)       | 5.81| 8.87| 1.13| 2.71| 4.76|
| Max (m)       | 13.11| 10.22| 3.51| 4.69| 8.05|

### 3.2 Performance whilst moving: Walking and driving

To test system performance whilst the system is moving, two (2) flat paths were marked around the university; with designated waypoints laid at regular intervals along the paths. It is noted that path 1 and 2 are around the vicinity of locations 2 and 5 in Figure 3, respectively. Upon reaching every waypoint, positioning information \((\lambda_r, \phi_r, h_r)\) were obtained from the GPS module and transmitted manually, by pressing the switch button. \((\lambda_r, \phi_r, h_r)\) and then compared with the actual positions \((\lambda_a, \phi_a, h_a)\) of the waypoints, as well as error distances calculated using equation (1). Two experiments were performed on each path; once with the system moving with a walking speed, and another with a slow driving speed. Speeds between waypoints can be calculated using equation (2). Each experiment was performed three (3) times for averaging purposes. Figure 5 and Figure 6 show the latitude-longitude coordinates of the two paths chosen; with \((\lambda_r, \phi_r, h_r)\) and \((\lambda_a, \phi_a, h_a)\) clearly marked. It can be seen that there are errors present in estimating the true positions of the system. Average error distances recorded at every waypoints for the two different paths whilst walking and driving, are shown in Figure 7. It can be seen that average error distances are generally lower for walking than driving. This is because the faster motion of the system during driving results in greater multipath fading. Table 2 gives the average, min
and max error distance for path 1 and 2. For path 1, average error distances are 5.39 m and 8.38 m for average walking speed of 0.80 m/s and average driving speed of 1.52 m/s, respectively. Average error distances for path 2 are even lower, with 2.08 m and 4.94 m, respectively, with average walking speed of 0.96 m/s and average driving speed of 1.65 m/s. For both paths, average error distances are below 8.5 m for walking and driving activities.

**Figure 5.** Latitude-Longitude coordinates for path 1; showing the actual coordinate, \( P_a \), and coordinates received from walking, \( P_w \) and driving, \( P_d \) using the proposes system.

**Figure 6.** Latitude-Longitude coordinates for path 2; showing the actual coordinate, \( P_a \), and coordinates received from walking, \( P_w \) and driving, \( P_d \) using the proposes system.

It is noted that the system generally experienced less error at path 2; despite the slightly higher speeds of motion for both walking and driving. This may be due to less structure being available in path 2 which is in the vicinity of location 2 in Figure 3, and hence, reducing shadowing effect of the received GPS signals.

Figure 7 also shows sudden spikes in error distance at some waypoints; most notably at the 19th and 20th waypoints for walking and driving at path 1. Careful examinations of data obtained from the GPS module indicated that this was due to a decrease in the number of received satellites signals; which most probably resulted from the effect of shadowing from nearby buildings.
Figure 7. Average error distance (m) for path 1 and 2, at waypoints by walking ($loc_{1w}$ & $loc_{2w}$, respectively) and driving ($loc_{1d}$ & $loc_{2d}$, respectively).

Table 2. The average (Avg), minimum (Min) and the maximum (Max) error distances of the two paths, whilst walking and driving.

|          | Path 1 | Path 2 |
|----------|--------|--------|
|          | Walking | Driving | Walking | Driving |
| Avg (m)  | 5.39    | 8.38    | 2.09    | 4.94    |
| Min (m)  | 1.75    | 5.17    | 0.37    | 0.75    |
| Max (m)  | 19.00   | 15.67   | 4.15    | 8.57    |

Summary of the average error distances from the different activities are given in Table 3. Average distance error whilst driving gives the highest average error distance of 6.66 m. However, it has been found that the average error distance whilst the system is stationary, is relatively higher than whilst walking. However, it should be noted that whilst walking and driving activities are comparable due to both following the same paths, the same cannot be said for the system whilst stationary. The higher error distance may be explained due to the presence of obstacles at the different locations. Overall, average error distance from the system are minimal in the order of less than 7 m; whilst stationary and in motion.

Table 3. Average (Avg), minimum (Min) and the maximum (Max) error distance for the system whilst stationary and moving (walking and driving).

|          | Stationary | Walking | Driving |
|----------|------------|---------|---------|
| Avg (m)  | 6.25       | 3.74    | 6.66    |
| Min (m)  | 1.13       | 0.37    | 0.75    |
| Max (m)  | 13.11      | 19.00   | 15.67   |
4. Conclusion

Low cost Global Positioning System (GPS) has been used in many applications such as for tracking and robotic applications, primarily due to its improved accuracy and affordability. In this paper, a simple and low cost tracking device; consisting of NodeMCU micro-controller, commonly used Neo-6m GPS module and GSM module, which transmits its positioning information to a central server, has been designed. Consequently, performance of the system, in terms of error distance, has been tested whilst the system is stationary and moving with walking and driving speed, at several locations. It has been shown that the performance of the system is indeed dependent on locations; with the presence of obstacles such as high buildings, tall trees, etc. reducing the accuracy of the system, movement of the GPS receiver as well as the number of GPS satellites’ signals that the GPS receiver can receive. Result of the system whilst stationary has shown that open areas at high altitude gives the most accurate positioning information with average error distance of less than 2.5 m. Nevertheless, average error distance of less than 10 m is achievable irrespective of locations. Furthermore, it has also been shown that faster driving movement produces relatively higher average error distance as compared to slower walking movement. Average error distance of less than 8.5 m has been reported at the two paths chosen for the test for both activities. On average, average error distances for the system whilst stationary, walking and driving are less than 7 m. These results are very encouraging for system developers, especially for applications which do not require a very high level of accuracy and for civilian applications, such as crowd-control, education purpose, etc.

Acknowledgments

The main author would like to thank the Ministry of Education, Brunei Darussalam for awarding scholarship for her to pursue a BEng programme in General Engineering at the Faculty of Integrated Technologies (FIT). The work in this paper is made possible with funding from Faculty Research Grant (UBD/RSCH/1.3/FICBF/2018/01) of Universiti Brunei Darussalam.

References

[1] Kasliwal M H and Patil H Y 2017 Smart location tracking system for dementia patients 2017 International Conference on Advances in Computing, Communication and Control (ICAC3) pp 1–6
[2] Miura M, Ito S, Takatsuka R and Kunifuji S 2008 Aware Group Home Enhanced by RFID Technology BT - Knowledge-Based Intelligent Information and Engineering Systems ed I Lovrek, R J Howlett and L C Jain (Berlin, Heidelberg: Springer Berlin Heidelberg) pp 847–54
[3] Lin Y-J, Su M-J, Chen S-J, Wang S-C, Lin C-I and Chen H-S 2007 A Study of Ubiquitous Monitor with RFID in an Elderly Nursing Home
[4] Cramer M, Cramer J, De Schepper D, Aerts P, Kellens K and Demeester E 2019 Procedia CIRP 86 204–9
[5] Paiva S and Abreu C 2012 Procedia Technol. 5 793–802
[6] Hadwen T, Smallbon V, Zhang Q and D’Souza M 2017 Energy efficient LoRa GPS tracker for dementia patients 2017 39th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC) pp 771–4
[7] Manzino A M, Dabove P and Gogoi N 2018 Geod. Geodyn. 9 439–48
[8] U-blox 2017 NEO-6 GPS Modules Data Sheet www.u-blox.com
[9] Morris G and Conner L M 2017 PLoS One 12 e0189020
[10] Gurcan M K, Abas A E P and Imran M A 2004 Graph theoretic multiple access interference reduction for CDMA based radio LAN 2004 IEEE International Conference on Communications (IEEE Cat. No.04CH37577) vol 7 pp 4147–4151 Vol.7
[11] Ha Q P, Yen L and Balaguer C 2019 Autom. Constr. 107 102934