The Suitability of GPS Receivers Update Rates for Navigation Applications

Ahmad Abbas Al-Ameen Salih, Nur Liyana Afiqah Che Ahmad Zaini, and Amzari Zhahir

***Abstract*—**Navigation is the processes of monitoring and controlling the movement of an object from one place to another. Currently, Global Positioning System (GPS) is the main navigation system used all over the world for navigation applications. GPS receiver receives signals from at least three satellites to locate and display itself. Displayed positioning information is updated continuously. Update rate is the number of times per second that a display is illuminated. The speed of update is governed by receiver update rate. A higher update rate decreases display lag time and improves distance measurements and tracking especially when moving on a curvy route. The majority of GPS receivers used nowadays are updated every second continuously. This period is considered reasonable for some applications while it is long relatively for high speed applications. In this paper, the suitability and feasibility of GPS receiver with different update rates will be evaluated for various applications according to the level of speed and update rate needed for particular applications.

***Keywords*—**Navigation, Global Positioning System (GPS), GPS receiver, Update rate, Refresh rate, Satellite navigation, High speed GPS receiver.

I. Introduction

THE industry of navigation is developing in a fast manner to occupy the increasing needs for fast and safe applications. To achieve these needs, some effective programs, plans, and systems designs are required. Currently, Global Positioning System (GPS) is the main navigation system used all over the world for navigation applications. The commercial navigation applications systems can be tracking devices, location based servers (LBS), and fleet management systems. GPS receiver receives signals from at least three satellites to locate and display itself. Displayed information of positioning is continuously updated. The speed of update depends on receiver refresh rate (update rate). A higher data update rate helps to decrease display lag time and improves distance measurements and tracking especially when moving on a curvy route. The majority of GPS receivers used nowadays are updated every second (1Hz update rate). This period is considered reasonable for some applications while it is long relatively for high speed applications.

A.A.A. Salih is with the Faculty of Engineering, Department of Aerospace Engineering, University Putra Malaysia, 43400 Serdang, Selangor, Malaysia (e-mail: timemoon12@hotmail.com).

N. L. A. C. A. Zaini is with the Faculty of Engineering, Department of Aerospace Engineering, University Putra Malaysia, 43400 Serdang, Selangor, Malaysia (e-mail: nuy_yana@yahoo.com).

A. Zhahir is with the Faculty of Engineering, Department of Aerospace Engineering, University Putra Malaysia, 43400 Serdang, Selangor, Malaysia (e-mail: amzari@eng.upm.edu.my).

For low speed applications, an update rate of 0.1Hz could be appropriate whereas 5 or even 10Hz update rate is required for other high speed navigation. Positioning at a high update rate creates more detailed and higher resolution tracking capabilities but requires more processing operations and consequently higher power. For high update receiver, rails can be recorded with a higher resolution compared with the more traditional 1Hz positioning update rate. In this paper, the suitability and the feasibility of GPS receiver with different update rates will be evaluated for various applications according to the level of speed and update rate needed for particular applications. GPS navigation data with different update rate will be analyzed with respect to moving speed aiming to specify the best required update rate required for various applications.

II. Literature Review

Initially, GPS was developed by the Defense Department of the United States of America and was used in the beginning for military uses. Currently, it is the most utilized satellite navigation system all over the world, as early as 1987. The Aerospace Range Systems Architecture Study recommended the "transition from radar to the Global Positioning System (GPS) as the primary source of tracking" [1]. GPS utilizes the principle of TOA (Time of Arrival) ranging to calculate the user position[2].

In March 1977, testing of the first user equipment (UE) began at Yuma Proving Ground using ground transmitters to simulate the GPS satellites. As the Block I satellites were launched, ground transmitters and satellites were combined to be used for testing until December 1978 when availability of four satellites was achieved to provide 3-D navigation capability. Phase II for the (US) was divided into two parts. Starting in July 1979 (Phase IIA), four contractors were selected to execute performance analysis and preliminary design of UE. In Phase IIB, starting in 1982, two contractors of the four were selected to continue developing (UE) [3]. Block II full 24-satellite constellation of satellites was achieved in April 1994. In April 1985, Phase III production GPS User Equipment (UE) contractor was selected. The approval of full rate production of the UE was achieved of In January 1992. The Phase III production UE includes Receiver with5-channel for shipboard use, Receiver with 5-channel for airborne use, Receiver with 2-channel for helicopter use, and the RPU-1 for manpack and ground vehicle use.

A contract was awarded in 1989 for 2-channel SPS C/A-code receivers to be used primarily for training and demonstration. These receivers are suitable for vehicle mounting or handheld use. In November 1990, a contract was awarded to develop a 5-channel size Miniature Airborne GPS Receiver (MAGR) for use in airplanes. In February 1993, a contract was awarded to produce PPS GPS hand-held receiver. In the 1990s activities continued improving GPS antennas anti-jamming performance, processing of receiver's signal, and electronics units of the antenna. Efforts implemented Receiver Autonomous Integrity Monitoring (RAIM) where enhanced GPS integrity or compatibility with civil aviation is desired. GPS integrity and availability was enhanced by adding differential GPS (DGPS) to GPS receivers, to support new applications, such as aircraft precision approach and precise positioning [3].

Manufacturers from many countries have developed a wide variety of commercial UE to be used for many different and advanced applications. Some of these receivers have been acquired by Government and Military authorities for non-tactical applications such as test support, training and surveying.RTK technology was developed by Trimble In 1992 to allow moment-to-moment GPS updates while moving. This was revolutionary for surveyors. GPS equipment made it possible for them to do stakeout, topographic mapping and GIS data acquisition in real-time.

Receiver solution update rates may be quite slow far high seed applications; i.e., in the 1Hz region due to the complex processing of the radio frequency signals into a velocity or position solution. Since GPS introduction, the convention receivers update rate was 1H [4]. A 1Hz update rate is sufficient for most navigation applications. However, some advanced avionics systems and modern weapons require much higher update rates. Nowadays, there are fast GPS receivers increasing numbers that have an update rate exceed 1Hz.A machine that operates at high speeds or in small spaces requires sensors that are more accurate and have higher update rates. Machines operating in larger spaces at lower speeds can often operate effectively with lower accuracies and slower update rate [3].

Since GPS was introduced and used as Satellite navigation system, most aircraft navigation and landing systems have been turned off. The major issues with GPS are: guidance accuracy and integrity of the system which has not been able to meet ICAO standards and practices. Aircraft update rates are accelerated to reduce time lag between two updates since the speed of the aircraft is high and the risk for aircraft to be drifted out the route when relying completely on GPS may lead to disasters. VBOX Company manufactured a GPS with 100Hz update rate for high speed applications. It combines test repeatability and high-level accuracy with the ability of slip and pitch/roll angles measurements at 100Hz.

One of the downfalls with GPS receivers is the low refresh rate. Current GPS receivers have increased the refresh rate, making GPS more useful in more applications. One of the highest refresh rates found on a GPS receiver is 20Hz because of the high amount of signal processing and data configuration required [5]. Recently, GPS commonly has become a 20Hz update rate [5]. The Aircraft Integrated Meteorological Measuring System 20Hz (AIMMS-20) has been used by the Hong Kong Observatory (HKO).A high GPS update rate ensures reliable and accurate mapping results with high resolution. Nowadays, GPS receiver update industrial revolution can reach to 400Hz and they are developing in a fast manner to fulfill the increasing needs.

III. Navigation Systems

Navigation is an approach concentrates on the processes of monitoring and controlling an object movement of from one place to another. Navigation Systems involve navigational techniques to locate object's position compared to known locations [6].

GPS navigation device receives signals from satellites for the purpose of calculating the current location. It provides latitude, longitude and altitude. Navigation systems may be on board entirely, or they may be located elsewhere and communicate via radio or other signals, or they may use a combination of these methods. An automotive navigation system is a satellite navigation system used by automobiles. It uses a receiver to acquire position data to determine user's location on a road in the unit's map database. The use of road database gives directions to other locations.

IV. Satellite Navigation

Satellite navigation (SATNAV) system is a system of satellites that provides geo-spatial positioning covers the globe. It enables GPS receivers to determine their location (latitude, longitude, and altitude) using radio signals broadcasted from satellites. Satellite navigation has become a critical component of the emerging worldwide air traffic management (ATM) infrastructure [7].

Since the 1960s, navigation has increasingly moved to satellite navigation systems [7]. International Civil Aviation Organization (ICAO) defines the GNSS as "a worldwide position and time determination system that includes one or more satellite constellations, aircraft receivers and system integrity monitoring, augmented as necessary to support the required navigation performance for the intended operation"[8].

A. Global Positioning System (GPS)

The Global Positioning System (GPS) (NAVSTAR system) is a space-based satellite radio-positioning and navigation system consists of 24 active orbiting satellites. GPS provides the information of the location and time to the user worldwide [9]. Currently, NAVSTAR GPS is the most system used for satellite navigation[10].GPS uses the principle of TOA (time of arrival) to calculate the position of the user[2]. TOA concept determines time lag (propagation time) for signal transmitted by satellite to reach receiver, this time is multiplied by the speed of the signal (speed of light) to calculate the distance between the satellite and receiver. Four ranges are required to determine the user position precisely.

As a system, GPS contains three major segments, which are: space segment, control segment and user segment. These segments are working together to provide the full support of navigation and positioning for the user. Pseudo-range is The fundamental observable of GPS[11]. This pseudo-range can be obtained from measuring the signal flight time from the satellite to the receiver. User's position can be determined by obtaining ranges from four satellites.

The development of GPS project was achieved in 1973 to overcome previous navigation systems limitations. By 1994, it became fully in operation. Technology advances and new demands on the GPS revolution and new systems have led to modernize and implement the next generation of GPS III satellites. In soon future, GPS satellites will broadcast new codes for civilian and military users with improved accuracy, availability, integrity, and anti-jam performance[1].

1. Basic Concept of GPS

A GPS receiver determines its position by timing the signals broadcasted by GPS satellites precisely. Each satellite continuously broadcasts data messages that include:

- Time of broadcasting data message.
- The satellite position in the time of broadcasting the message.

The concept of positioning in GPS is based trilateration which based on measuring ranges from four satellites to determine receiver's location. The range ρ traveled by a radio wave signal is calculated by multiplying the propagation delay Δt with the speed of light c. For the (k)th satellite, the range can be calculated as:

$$\boldsymbol{\rho^k = c \,.\, \Delta t^k}$$

In order to determine the transmission delay (Δt) for the radio signal to the receiver, each satellite sends navigation data message contains precisely GPS time when the signal was sent. GPS receive compares between its clock and the clock of the satellite since the clock of the receiver is synchronized with the satellite's clock. In typical GPS operation, visibility of at least four satellites is required by receiver in order to obtain an accurate positioning [12].

2. GPS Components

GPS is a system has three components: space segment (satellite constellation), control segment (monitoring network) and the User segment (receiver). All these components work together as one system to provide the global coverage[13].

Generally, GPS receiver consists of an antenna, Baseband processor and a processing unit. A receiver is often described by its number of channels. At beginning, they were limited to four or five. Nowadays, the number is increased progressively so that currently receivers have between 12 and 20 channels [14]. The conventional GPS receiver update rate is 1Hz. GPS industrial revolution involves GPS receiver with very high update rates for various applications.

3. GPS Signals

GPS satellites broadcast signals at two frequencies, 1575.42MHz (L1 signal) and 1227.6MHz (L2 signal). The L1 carrier is modulated by both the Coarse/Acquisition (C/A) codes and Precision (P) codes, while L2 carrier is only modulated by the P code. Recently, new frequencies have been added to improve the GPS performance (Table I).

TABLE I
GPS SATELLITES FREQUENCIES

Band	Frequency
L1	1575.42 MHz
L2	1227.60 MHz
L3	1381.05 MHz
L4	1379.913 MHz
L5	1176.45 MHz

C/A code was assigned for the civil use, while the P code was assigned for the military use only.

4. GPS Receiver Update Rate

Update rate (refresh rate) is the times per second that a display is illuminated. It is the number of GPS fixes delivered by the sensor per second.GPS receiver calculates current position which will be updated periodically according to receiver's update rate. Receiver continues outputting the same position until a new position is calculated. Fast update rate reduces time interval between updates. It helps to decrease display lag time and improves distance measurements and tracking especially when moving on a curvy route. The majority of GPS receivers used nowadays are updated every second. This period is considered reasonable for some applications while it is long relatively for high speed applications. For low speed applications, an update rate of 0.1Hz is sufficient whereas 5 or even 10Hz update rate is required for other high speed navigation.

1Hz updated rate means that the GPS device sends data to the navigation program once a second. For faster update rat, to be able to fit that information in the data stream, the device needs to talk to the processor at a faster rate (known as baud rate or, really, bit rate) The basic 4800bps baud rate can only carry data fast enough to support a refresh rate of once per second. Under normal vehicle navigation situations, 1Hz update is sufficient (4800 bit rate). If the baud rate is set to 4800 that means only 4800 bits (1s and 0s) can travel from the receiver to the processor every second. For 5Hz, it can be set to send that data up to 5 times every second and the baud rate will be 38400. With a fix update rate of 5, new location updates every second (5Hz) and a baud rate of 38,400 bits per second, the data uses 38,400 bits every second. For faster update rates, bits will be more and will be pushed to processor faster.

Positioning at a high update rate creates more detailed and higher resolution tracking capabilities but requires more processing operations and consequently higher power. For high update receiver, data can be displayed with a higher resolution compared with the more traditional 1Hz positioning update rate. Update rate fitness for various applications depends on the level of speed which leads to change object position and the update rate needed for particular applications regarding resolution required and phase sensitivity. Figures below (Figs. 1 and 2) show GPS navigation data with different update rates (1Hz and 5Hz):

Fig. 1GPS receiver with 1Hz update rate

Fig. 2 GPS receiver with 5Hz update rate

In (Fig. 1) positioning at a 5Hz update rate (five times per second) creates more detailed and higher resolution vehicle tracking capabilities. Trails of the moving object can be recorded with five times the resolution compared with the more traditional 1Hz positioning update rate as shown in (Fig. 2). In (Fig. 1), position update rate is five times more frequent, the record of the trail is much smoother in 5 Hz position update than in 1 Hz position update.

In Figs. 3 and 4 below, the comparison is taken while driving on a mountain curvy road. GPS receiver with 5Hz position update rate is capable of obtaining a smoother trail with more updated positions.

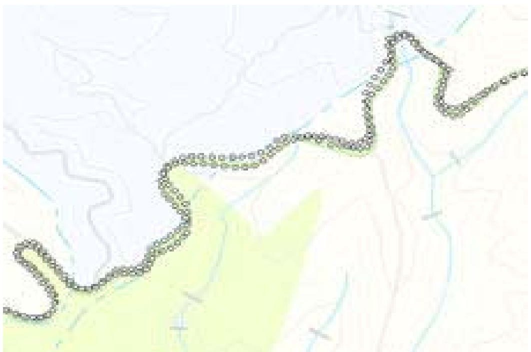

Fig. 3 GPS receiver with 1Hz update rate

Fig. 4 GPS receiver with 5Hz update rate

For automotive navigation, an update rate faster than 1Hz is not a necessity. Fast update rate has many advantages; it enhances decreasing the display lag time and improves distance measurement and receiver tracking especially for route with many curves. The only disadvantage for a faster data update is that it increases processing load. However, low update rate makes more blind areas between two updates keeping GPS receiver uninformative during lag time. GPS receiver could be anywhere in a circle with radius proportional to moving speed until receiving the next update. The next figures (Figs. 5 and 6) indicate the difference in a resolution between very low update receiver and standard update rate GPS receiver.

Fig. 5 GPS receiver with 0.1Hz update rate

Fig. 6 GPS receiver with 1Hz update rate

When comparing between the two figures (Figs. 5 and 6), it is clearly shown that in Fig. 5 GPS receiver receives updates every 10 seconds which is considered a long period. For a vehicle with speed of 100km/h, it means keeping the driver uninformative about current position for a distance of 27.778 meter before next position update. Using this receiver is not feasible even for walking positioning because the normal person speed is about 6km/h which means a blind area with a radius of 1.667 meter.

Table below shows the distance moved by GPS receiver with different speeds before performing the next update for different update rates:

TABLEII
DISTANCE MOVED BEFORE NEXT UPDATE (SPEED = 1KM/H = 0.2778 M/S)

Update rate (Hz)	Distance (cm)
1	27.778
5	5.556
10	2.778
20	1.389

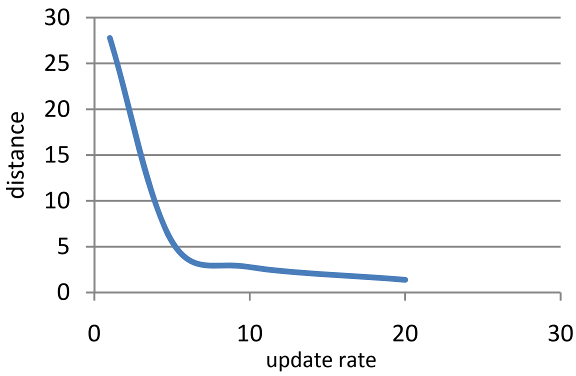

Fig. 7 Distance and update rate relationship

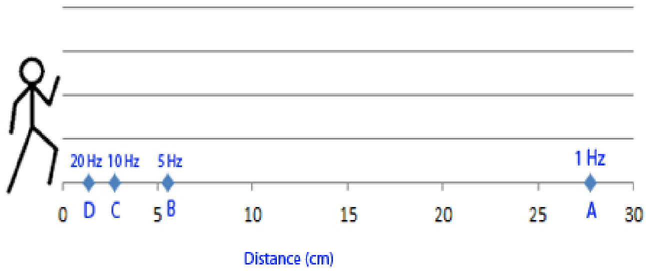

Fig. 8 Blind distances before next update

For a very slow GPS receiver moving speed (1km/h), the use of low update rate is feasible. However it depends on the sensitivity of the application and the level of accuracy required. When moving with speed of 1km/h, blind distance until receiving next update for 1Hz update rate is 27.778cm (Fig. 8, point A). Similarly, Fig. 8 shows blind distances for 5, 10, and 20 update rates are 5.556, 2.778, and 1.389cm respectively. Fig. 7 shows the relationship between the blind distance and the update rate. Blind distance is inversely proportional to update rate. When update rate is doubled, blind distance is halved. Table III shows blind distances for GPS receiver moving with speed of 10km/h. we can observe that as speed is increased, consequently, blind area is increased.

TABLE III
BLIND DISTANCE BEFORE NEXT UPDATE (SPEED = 10KM/H = 2.778M/S)

Update rate (Hz)	Distance (cm)
1	277.778
5	55.556
10	27.778
20	13.889

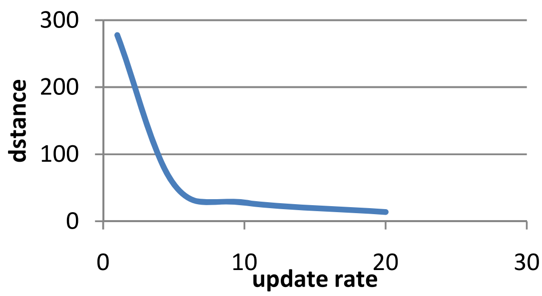

Fig. 9 Distance and update rate relationship

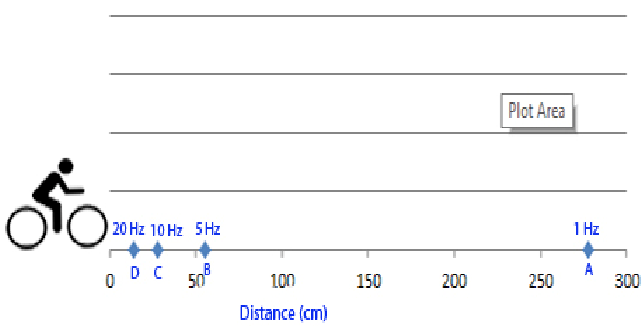

Fig. 10 Blind distances before next update

For normal navigation that does not need a high accuracy, the use of standard GPS receiver update rate is feasible. Blind distance is 227.778cm (Fig. 10, point A). Next table shows blind area for a speed of 50km/h.

TABLE IV
DISTANCE MOVED BEFORE NEXT UPDATE (SPEED = 50KM/HR = 13.889M/S)

Update rate (Hz)	Distance (cm)
1	1388.889
5	227.778
10	138.889
20	69.44

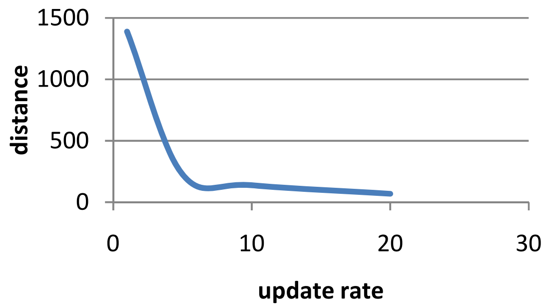

Fig. 11 Distance and update rate relationship

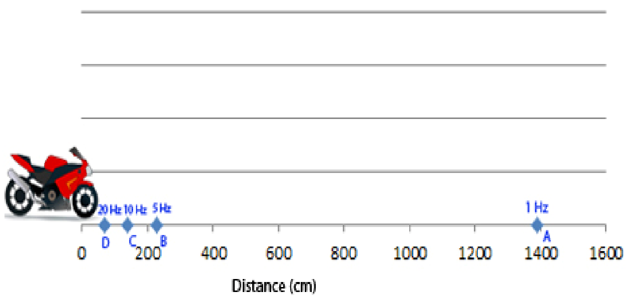

Fig.12 Blind distances before next update

For 50km/h speed, the use of standard update rate is considered feasible. Blind area is 13.88 meter (Fig. 12, point A). A higher update rate could be used for more precise applications such as robots which require more accuracy.

As the speed is increased, more update rate is required to reduce blind area between two updates. Table V shows blind distances for a speed of 100km/h.

TABLE V
DISTANCE MOVED BY BEFORE NEXT UPDATE (SPEED = 100KM/H = 27.778M/S)

Update rate= (1 Hz)	Distance (cm)
1	2777.778
5	555.556
10	277.778
20	138.889

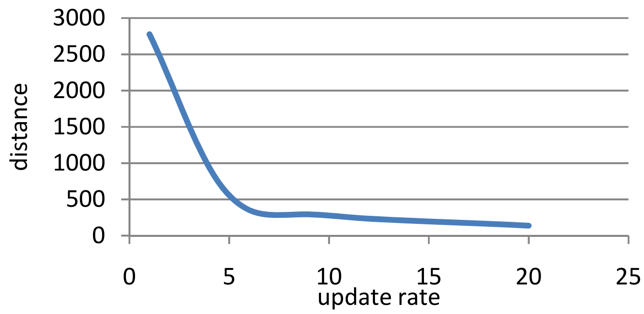

Fig. 13 Distance and update rate relationship

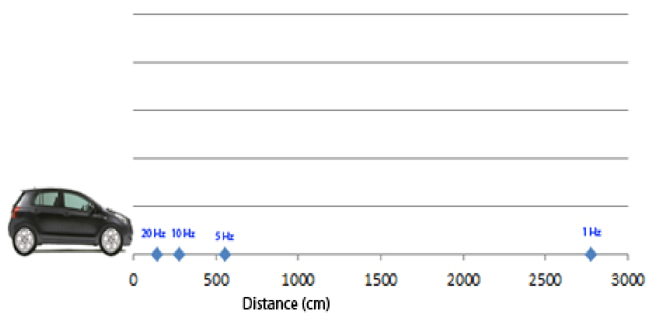

Fig. 14 Blind distances before next update

Standard update rate (1Hz) results a blind distance of 27.778m for a speed of 100km/h (Fig. 14). An update rate faster than 1Hz is required to minimize the display time lags and to improve distance measurement and tracking especially in curvy routes. The use of 5Hz update rate is suitable for not high accurate applications such as automotive navigation. Trails of the moving object can be recorded with five times the resolution compared with the more traditional 1Hz positioning update rate. For a 5Hz receiver, a car with a speed of 100km/h moves to next point and receives update in 0.2 second. High speed applications such as aircrafts with a speed reach to 500km/h needs update rate more than 5Hz. Table VI shows blind distance when moving with speed of 500km/h.

TABLEVI
DISTANCE MOVED BEFORE RECEIVING NEXT UPDATE (SPEED = 500KM/H = 138.889M/S)

Update rate (Hz)	Distance (cm)
1	13,888.889
5	2,777.778
10	1,388.889
20	694.444
200	69.444

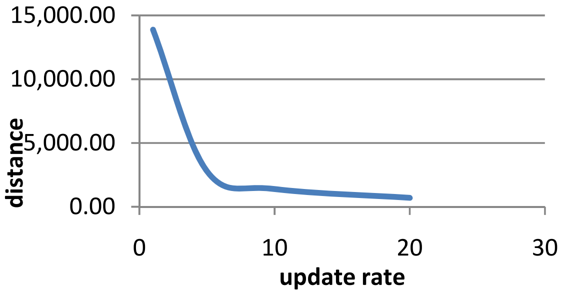

Fig. 15 Distance and update rate relationship

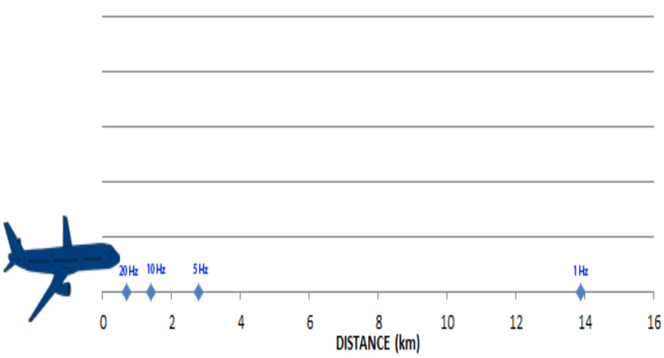

Fig. 16 Blind distances before next update

For applications with a speed of 500km/h, standard update rate blind distance is 138.889m. This speed is the speed of light aircraft. Heavy aircraft flies with a speed approximately reach to speed of sound (331m/s). The danger for aircraft to crash other aircrafts or building is high especially in lading phase. The accuracy for landing should not exceed a meter level due to the possibility of mismatching the runway touch point. For aircraft application, the use of 20Hz update rate results a 6.944m of blind area. Recently, many manufacturer produced GPS receivers with an update rate more than 200Hz. The use of 200Hz update rate could be feasible since the blind distance will be less than 1 meter (exactly 0.694 meter). Fighter aircrafts flies with speed more than the speed of sound (more than 1 Mach number). Table VII indicates the blind distance for objects move with speed (1,000km/h).

TABLE VII
DISTANCE MOVED BEFORE NEXT UPDATE (SPEED = 1,000KM/H = 277.778M/S)

Update rate (Hz)	Distance (m)
1	277.778
5	55.556
10	27.778
20	13.889
200	1.3889
300	0.926
400	0.569

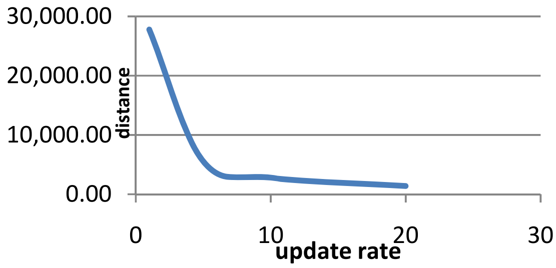

Fig. 17 Distance and update rate relationship

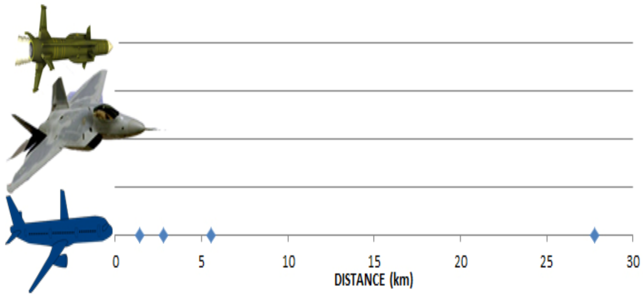

Fig. 18 Blind distances before next update

Obviously, low update rates are not suitable for high speed application due to superior sensitivity and high accuracy needed (as shown in Table VII). For aircraft maneuvers, accuracy in sub-meter is required. In bad weather situation when there is no visibility, aircraft land relying on automatic landing system. Fighter aircrafts land on ships requires precise accuracy and very high update rate. Missiles directed using GPS signals requires very high update rate to destroy their target precisely. For objects moving with speed of 1,000km/h, GPS receiver with update rate more than 200Hz must be used.

V .CONCLUSION

The rapid increase in navigation application demands parallel effective plans, designs and programs for new systems to fulfill the increasing needs nationwide.GPS revolution is developing in a fast manner offering simple and brilliant navigation solutions. Currently, GPS is the most utilized system for satellite navigation all over the world. Since GPS introduction the standard GPS receiver update rate was 1 Hz. The number of GPS receiver is increasing providing intelligent technologies, more facilities and cheaper prices. GPS receiver update rate plays significant rule to provide clearer view with more resolution. The update rate controls the time that the new position will be presented. Low update rate increase time between previous location and current location which leads to increase the blind area where GPS receiver does not kept informative bout current location. Update rate depends on the type of navigation undergoes and the level of resolution accuracy and precision needed. Conventional update rate could be considered suitable and feasible for the majority of navigation applications with speed below 100 km/h and when accuracy is not taken into account. Precise applications with accurate missions require very high update rate to minimize the error source of mismatching targets. For high speed applications, more update rate is required to minimize blind area and to reduce time between two updates because of long distance moved with high speed and data is needed in short times continuously. Distance moved by GPS receiver before receiving the next update governs the level of update rate required to perform traditional, precise or high speed navigation. Fig. 19 shows that blind area and update rate are reversely proportional; as the update rate increases, distance before receiving the next update decreases. Doubling update rate results halving blind area.

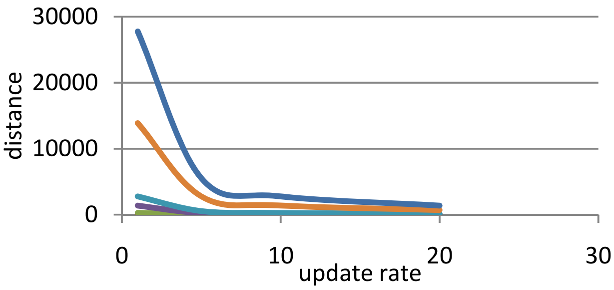

Fig. 19 The relationship between distance and different update rates

ACKNOWLEDGMENT

We would like to express our gratitude to Universiti Putra Malaysia (UPM) for granting the Research University Grant Scheme (RUGS) with Project No. 05-05-11-1560RU, in which this research work is made possible.

REFERENCES

[1] S. Lazar, Modernization and the Move to GPS III. Crosslink, 2002.
[2] DOBERSTEIN, “Fundamentals of gps receivers,” 2011.
[3] P. R. Version and P. R. Version, “USER EQUIPMENT INTRODUCTION,” no. September, 1996.
[4] W. Hundley, S. Rowson, and G. Courtney, “Flight Evaluation of a Basic C / A Code Differential GPS for Category I Precision Approach.”
[5] J. A. Farrell, S. Member, T. D. Givargis, and M. J. Barth, “Real-Time Differential Carrier Phase GPS-Aided INS,” vol. 8, no. 4, pp. 709–721, 2000.
[6] L. Chittaro and S. Burigat, “3D location-pointing as a navigation aid in Virtual Environments,” in Proceedings of the working conference on Advanced visual interfaces, 2004, pp. 267–274.
[7] T. Murphy and T. Imrich, “Implementation and operational use of Ground-Based Augmentation Systems (GBASs)—A component of the future air traffic management system,” Proceedings of the IEEE, vol. 96, no. 12, pp. 1936–1957, 2008.
[8] J. ICAO, International Standards and Recommended Practices, Annex 10 to the Convention on International Civil Aviation, Volume 1, Radio Navigation Aids. 1996.
[9] P. Daly, “Navstar GPS and GLONASS: global satellite navigation systems,” Electronics & Communication Engineering Journal, vol. 5, no. 6, pp. 349–357, 1993.
[10] W. Lechner and S. Baumann, “Global navigation satellite systems,” Computers and Electronics in Agriculture, vol. 25, no. 1, pp. 67–85, 2000.
[11] T. Moore, “An introduction to the global positioning system and its applications,” in Developments in the Use of Global Positioning Systems, 1994, pp. 1–1.
[12] K. Borre, D. M. Akos, N. Bertelsen, P. Rinder, and S. H. Jensen, A software-defined GPS and Galileo receiver. Birkhhauser, 2007.
[13] A. M. Hasan, K. Samsudin, A. R. Ramli, R. S. Azmir, and S. A. Ismaeel, “A review of navigation systems (integration and algorithms),” Australian journal of basic and applied sciences, vol. 3, no. 2, pp. 943–959, 2009.
[14] V. Daita, “Behavioral VHDL implementation of coherent digital GPS signal receiver,” University of South Florida, 2004.