Global Navigation Satellite System functionality in Polar wearables

Dec 10, 2019, revised Aug 2022

Polar P&S, Devices

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1 Introduction

Since 1977 Polar Electro Oy has developed wearable bio signal measuring devices for sport enthusiasts. The most important feature has been heart rate measurement during exercises, competitions and nowadays during sleep and other daily activites. However, in addition to cardiac information, location and speed data have become as important parameters. In order to meet these demands, Polar has integrated GNSS (Global Navigation Satellite System) feature into wearable devices since 2009. Currently, location and speed data can be determined with nearly every Polar sport, outdoor and fitness device.

2 Theoretical Background

GNSS for civil positioning operates in the frequency range of 1164 MHz to 1215 MHz and 1559 MHz to 1610 MHz for Band-5 and Band-1, respectively. [1, 2] It is constructed of four main global navigation satellite systems; GPS (US), GLONASS (RUS), Galileo (EU) and BeiDou (CN). The number of operational satellites for GPS, GLONASS, Galileo and BeiDou are 31, 24, 22 and 35, respectively. Additional regional navigation satellite systems are NavIC based in India and QZSS based in Japan consisting of 8 and 4 satellites, respectively. With these satellite systems, it is possible to calculate location, time, speed and direction with certain accuracy limitations. In practice, location accuracy may vary between 1-20m due to 3D accuracy, i.e., variation in longitude, latitude and altitude. Detected time (UTC) can vary from 5 ns to 60 ns. Speed and direction of the receiver is derived from the location and time. This can be referred to a simple example of detecting lightning strikes. An observer sees the lightning earlier than they hear the sound. Based on the speed of sound and speed of light, the distance can be determined, Figure 1.

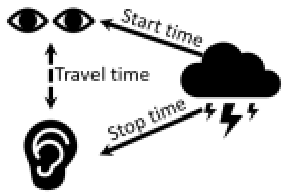

Figure 1. Detecting visual object based on speed of light and sound.

In the satellite system, the location is determined by known satellite location, time stamps and speed of light.

This is illustrated with the observer and two transmitters as shown in the Figure 2.

$$D = \Delta\tau \cdot c = \frac{(\Delta\tau_1 - \Delta\tau_2)\cdot c + A}{2}, \quad (1)$$

where D, $\Delta\tau$, c and A are distance, time difference, speed of light and separation between transmitters, respectively. [3]

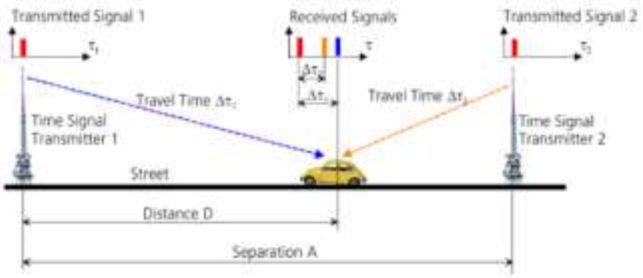

Figure 2. Detecting receiver location based on known locations of transmitters, time stamp and speed of light. [3]

Detected GNSS satellite signal levels are in the range of -160 to -120 dBm (Table 1), which are even in the best conditions millions of times weaker than received cellular signal levels of mobile phones (e.g., -60 dBm) (Table 2).In order to receive these weak signals, GNSS receivers need to be very sensitive, which on the other hand increases the sensitivity to disturbance.

Table 1. GNSS received signal levels and conditions.

Signal level [dBm]	Conditions
≥ – 120	Excellent
– 121 – 130	Good
– 131 – 140	Fair
≤ – 140	Poor

Table 2. LTE Cellular received signal levels and conditions.

Signal level [dBm]	Conditions
≥ – 70	Excellent
– 71 - 85	Good
– 86 – 100	Fair
≤ – 100	Poor

Errors in calculating the location can be caused by disturbance in the travel time of the signal, i.e., multipath propagation, atmospheric changes and satellite errors. Multipath propagation can occur due to geological and natural objects such as mountains and trees, as well as man-made objects such as buildings (Figure 3). Atmospheric effects can happen all the way from troposphere (0 – 15 km) to ionosphere (60 – 1000 km). The fastest effects to signal propagation however happen in the heights where rain and humidity exists the most. It is worth noting that water is extremely lossy material at these operating frequencies and thus signal attenuates totally e.g., when receiver is under water. In addition to these environmental changes, the error source can also be timing or position error of satellites. Furthermore, in practical use case where user wears GNSS receiver, the location of the device and use environment can increase the location error. For example, the body and metal objects can block the satellite signal or cause signal loss by coupling to the antenna.

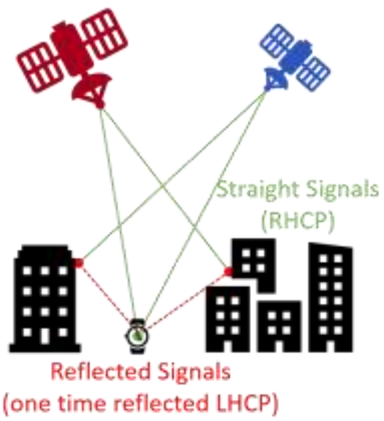

Figure 3. Multipath propagation due to buildings.

The accuracy of location calculation is affected also by the location variation of satellites i.e., if the locations of the satellites in the sky differ from the location information of GNSS database (AGPS) or the satellites are close to each other (high GDOP value) which cause calculation error (Figure 4) [4].
Furthermore, signal attenuation due to environmental objects can have effect on the accuracy.

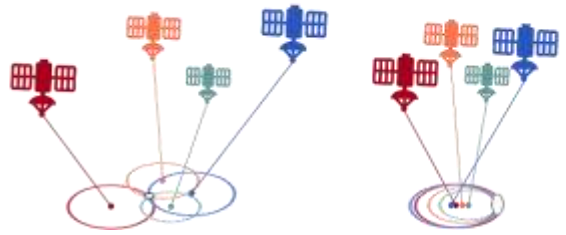

Figure 4. Location of the satellites in the sky affects to location calculation of the receiver.

The GNSS consists also of static ground station control segments which track the satellites. These stations monitor transmissions of the satellites and analyze their performance. [5, 6] In the northern hemisphere the determined location of the ground stations can vary due to the mentioned error sources. With the GPS, GLONASS and GPS+GLONASS the determined horizontal (and vertical) location errors, with 95% confidence interval, can be ± 7.5 m (± 14.3 m), ± 8.7 m (± 13.8 m) and ± 6.5 m (± 10.7 m), respectively [5, 7, 8, 9].

3 Technical Implementation

In order to meet consumer requirements, wearables, such as wrist watches and sport sensors, are designed to be small and light. When the lowest operation frequency of the GNSS is at 1176 MHz, the ¼ wavelength in the air is 6.4 cm, which should be achieved with the electrical length of the receiver antenna. Due to this fact, antenna technology,

material selections and electronics design have significant role in implementation of good antenna performance into the requested size of the wearable device.
When right hand circular polarized (RHCP) positioning satellite signal reflects from obstacles the signal polarization becomes a mirror image i.e., left hand circular polarized (LHCP). These reflected signals are affected by timing errors in propagation and should thus be minimized in the receiver. This can be achieved by maximizing right hand circular polarization of the receiver antenna (Figure 5) i.e., the gain and the beam width of the RHCP signal should be higher than the gain and the beam width of the LHCP signal.

Figure 5. Location of the GNSS antenna of Polar Vantage V.

The positioning system of the receiver includes four main electrical elements; antenna, filtering, low noise signal amplifier (LNA) and GNSS receiver IC (Figure 6).

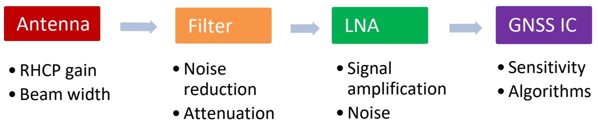

Figure 6. Main operating blocks in the GNSS receiver.

Main requirement for the antenna is to maximize signal reception in the designed use cases. In order to achieve the wanted antenna properties, modern simulation tools and accurate measurement tools are utilized in the design process (Figure 7). Filters and LNA block unwanted signals and amplify wanted signals, respectively. However, both will come with unwanted properties such as an attenuation and additional noise. Thus, the component comparison for gaining the best performance is relevant. In order to ensure the maximum signal levels with the lowest attenuation and noise, impedance matching of the whole signal path is mandatory. The last and very significant element is the GNSS receiver IC. In addition to the electrical parameters such as sensitivity for the weakest signals, the IC includes all the intelligence, i.e., algorithms and assisted GPS (A-GPS) feature, information on how received signals are processed and which satellite signals are used to achieve the most accurate location calculation. Currently there are GNSS ICs that can cover all possible global satellite system combinations i.e., GPS, GLONASS, Galileo and BeiDou as well as regional satellite systems i.e., NavIC and QZSS. Simultaneously covering as many satellite systems as possible gives the GNSS IC more satellites to choose from to improve the location calculation especially in the most difficult use environments. The ICs can also be configured to simultaneously use Band-1 and Band-5 for GPS, Galileo, BeiDou and QZSS to reduce the multipath propagation and atmospheric error and to improve location calculation. It is also crucial for the GNSS IC to have very low power consumption to increase the battery lifetime of the wearable device.

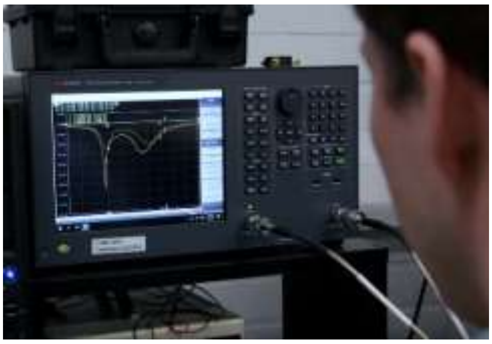

Figure 7. Antenna matching measurements using Vector Network Analyzer.

4 Polar solution for positioning

Polar shows to user the positioning data as speed, distance, route and altitude data. This data is used also as an input data to multiple other Polar product features. The data is shown real-time in the wearable display and afterwards in Polar Flow. The route data is typically combined with 3rd party map when shown to user.

To achieve high accuracy for positioning data, also other sensor data are used in combination with GNSS measurement. Depending on the specific wearable device the data from accelerometer, gyroscope, magnetometer, and barometer can be used. The data from GNSS and other sensors are processed with algorithms to generate the final positioning data to the user. Typical situations where the positioning is significantly supported by other than GNSS sensors are e.g. when the GNSS signal is temporarily lost (underpass, tunnel, etc.) or if the environment is challenging for the GNSS measurement (high buildings, dense forest, etc.). In good GNSS measurement conditions there is less support from other sensors. However, for altitude measurement the barometer provides usually better estimate than GNSS and barometer is used as a major source for altitude data even if the GNSS is measured in good conditions.

5 Performance and validation

Conditions for wearable use environments can vary from very dry and hot to very humid and cold. Furthermore, wearable devices are used in urban areas and wildernesses which can include, e.g., mountains, dense forests, canyons, high buildings and reflective seacoasts which cause difficulties for positioning. Performance validation is done to cover all possible use cases. The devices are tested both in laboratory conditions in stable jigs (Figure 8) and in real use cases with real challenges. All types of sports e.g., running, cycling, swimming and motorsports need to be tested since they all have their own challenges.

Figure 8. Antenna radiation property measurements using anechoic RF chamber.

With this approach, all design nuances and performance details can be determined and validated, and the design can meet the set targets. Novel research by Gilgen-Ammann *et al.* showed that GNSS performance of eight different sports watches can have significant distance error in different use environments. In the research, recorded distances were underestimated by up to 9% whilst Polar devices represented the most accurate devices having the error less than 5%. [10]

Figure 9. Device validation in a real environment.

6 Summary

Accuracy of location and speed data is always a summary of antenna and electrical components as well as software algorithms, which all can be affected by the use environment and use case. With the current materials, hardware components and software it is possible to design a wearable device with performance that can meet the user demands also from industrial design point of view. In the validation, all relevant use cases in varying environments and conditions and types of sports, such as cycling, running, swimming and motorsports are considered. With the latest software updates, regular A-GPS data synchronization and a proper use of the device the best user experience regarding location and speed accuracy can be achieved.

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