Global Navigation Satellite System functionality in Polar wearables

Polar P&S, Devices

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1 Introduction

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

2 Theoretical Background

GNSS operates in the frequency range of 1164 MHz to 1215 MHz and 1559 MHz to 1610 MHz for L5 and L1, respectively. [1, 2] The system is constructed on four main satellite implementations; GPS (US), Glonass (RUS), Galileo (EU) and BeiDou (CN). The number of satellites for GPS, Glonass, Galileo and BeiDou are 31, 24, 18 (24 by year 2020) and 23 (35 by year 2020), respectively. By the system it is possible to calculate exact position, exact time, speed and direction with certain accuracy limitations. In practice, position 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 out from the position and time. This can be referred to a simple example of detecting lightning strikes. An observer sees the lightning before hearing the sound of thunder. Based on the facts of speed of sound and speed of light, the distance can be determined, Figure 1. In the GNSS 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.

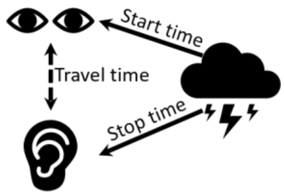

Figure 1. Detecting a visual object based on speed of light and sound.

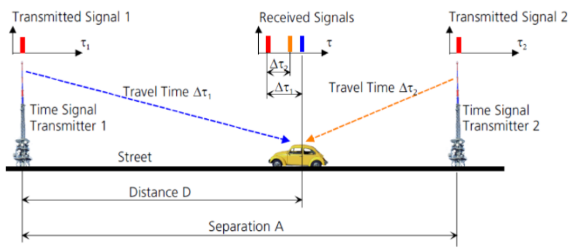

Figure 2. Detecting receiver location based on known locations of transmitters, time stamps and the speed of light. [2]

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

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

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

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

Errors in location determination can be caused by disturbance in the travel time of the signal, i.e., multipath propagation, atmospheric changes, and satellite errors, respectively. Multipath propagation can occur due to geological and nature objects, such as mountains and trees, and buildings (Figure 3). Atmospheric effects can happen all the way from tropospheric (0–15 km) to ionospheric (60–1000 km). The fastest effects to signal propagation however happen at those heights where rain and humidity are most abundant. It is worth notice that water is an extremely lossy material at the operating frequency and thus the signal attenuates totally, e.g., when the 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 where the person wears the GNSS receiver and what kind of clothing they have can affect the magnitude of the error, e.g., how the body and clothing either block the satellite signal or cause signal loss by coupling to the antenna, respectively.

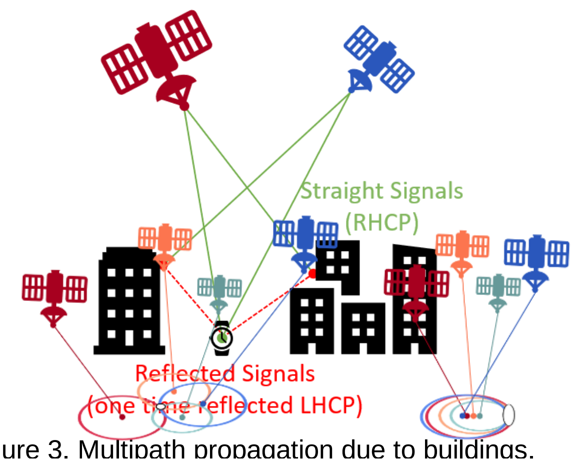

Figure 3. Multipath propagation due to buildings.

Figure 4. Geostationary location of the satellites affects to location determination of the receiver.

The accuracy of the location determination is affected also by the location variation of satellites, i.e., geostationary locations (constellation) of the satellites differ from the location information of the GNSS database (AGPS) or the satellites are close to each other (low DGOP value) which causes a calculation error (Figure 4) [4].

Furthermore, signal attenuation due to environmental objects and GNSS receiver quality can affect to the determined accuracy.

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. They are used for parameter correction due to atmospheric conditions and satellite location and timing variation. [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 watches and sport sensors, are made to be small and light. When the lowest operation frequency of the GNSS is at 1.176 GHz, the ¼ wavelength in the air is 6.3 cm, which should be met with the electrical length of the receiver antenna. Due to this, technologies, material selections, and electronics designs have significant role in implementation of an adequate positioning performance into the requested foot print of the wearable device.

When positioning the satellite signal, which is right hand circular polarized (RHCP), reflects from obstacles, the 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

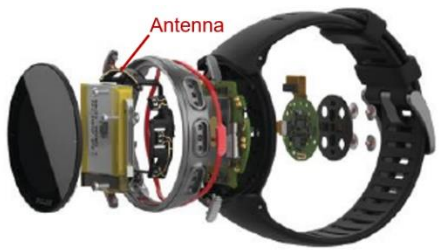

Figure 5. Location of the GNSS antenna of Polar Vantage V.

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 >> the gain and the beam width of the LHCP.

The positioning system of the receiver includes four main elements; antenna, front end filtering, low noise signal amplifier (LNA) and GNSS receiver IC, respectively (Figure 6). Main requirement for the antenna is to maximize RHCP signal reception. In order to achieve the wanted antenna properties, modern simulation tools and accurate measurements (Figure 7) tools are utilized in the design process. Filter and LNA block unwanted and amplify wanted signals, respectively. However, both will come with unwanted properties such as an attenuation and additional noise concerning the filter and the LNA, respectively. Thus, the component comparison for gaining the best performance is relevant. The last and the most significant element is the GNSS receiver IC. In

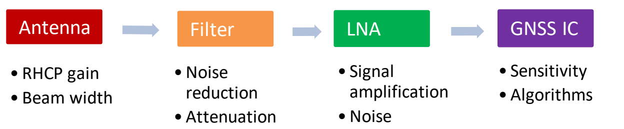

Figure 6. Main operating blocks in the GNSS receiver.

addition, the electrical parameters such as sensitivity for the weakest signals, the IC includes all the intelligence, i.e., algorithms and assisted GPS (A-GPS) information how received signals are processed and which of the satellite signals are used in the most

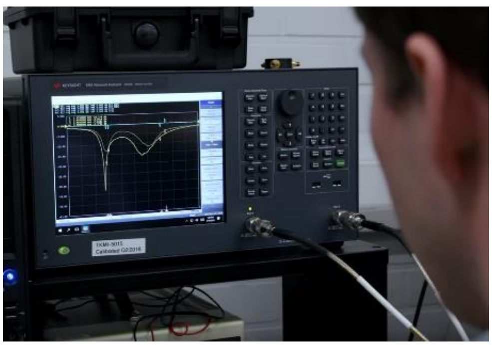

Figure 7. Antenna matching measurements using Vector Network Analyzer.

accurate location determination of the end user, respectively. Currently there are GNSS ICs that can cover all possible satellite system combinations, i.e., GPS, GLONASS, GALILEO and BeiDou, and thus the best setup for certain continents can be defined. In order to ensure the maximum signal levels with the lowest attenuation and the noise, matching of the whole signal path into the same impedance is mandatory.

4 Performance and validation

Usage environments for the wearables can vary between very dry and hot environments to very moist and icy conditions. Furthermore, wearable devices are

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

used in urban areas and wilderness which can include mountains, dense forests, canyons, high buildings and reflective sea coasts. Performance validation is done to cover all possible use cases. The devices are tested both in pure laboratory conditions (Figure 8), under the sky in stable jigs and also in real use cases with real challenges (Figure 9). With this, all design nuances and performance details can be determined and validated, and the design can meet the set targets. A novel research by Gilgen-Ammann *et al.* showed that GNSS performance of eight different sports watches can have relevant errors in determined distances in different usage 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]

5 Summary

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

Figure 9. Device validation in a real environment.

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