

GNSS Orientation for kinematic applications

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Abstract

GNSS systems are a well established technique for guiding machines or the machine's operator along predefined routes. Such GNSS applications have been successfully integrated into the design of construction machines and farming equipment. While a GNSS-equipped machine moves straight ahead conventional GNSS systems with only one antenna show good performance. However, the system reaches its limits when the machine turns on its own axis, such as an excavator does.

This causes the GNSS receiver to be unable to determine its bearing, as a compass could do. A common single-antenna GNSS receiver can only estimate its moving direction (heading) using previous positions. Since a turn around its own axis does not change the coordinates, but changes the orientation of the machine, the orientation can not be calculated by this means.

A common solution to this problem is the implementation of two GNSS antennas. Two antennas allow the bearing of the baseline between the antennas to be defined. A new approach with only one antenna required is under development at the ETH Zurich. This new system uses the satellite positions as a reference for orientation. For that purpose the direction of each satellite's signal has to be known in relation to the antenna. In order to obtain orientation the signal strength of each satellite is measured. A well defined shading of the received signals allows estimating the required orientation. After full implementation of our approach, the second GNSS antenna found on most construction machines will not be required anymore.

Keywords

Antenna orientation, GPS compass, GNSS compass, azimuth, GNSS direction finding

1 INTRODUCTION

The goal of this research work is to determine the orientation of a GNSS antenna. The opportunities of the GNSS system should be exploited instead of using additional sensors. The state of the art provides three options to achieve an orientation, or heading information in coherence with GNSS receivers.

- Using more antenna systems
- Using the movement of the antenna
- Using additional sensors

The application of GNSS systems for orientation was an object of research from the very beginning of the GPS technology. In a patent specification of 1989, Jablonski [1] described a method to "acquire accurate compass heading information without being affected by magnetic anomalies and without being dependent on the elapsed time since a previous position fix". He uses two antennas with a specific distance between them. The receiver switches between the two antennas automatically thereby measuring their absolute positions. Based on the knowledge of these coordinates a compass heading is calculated. The accuracy of the calculated heading relies on satellite geometry, performance of receiver, baseline configuration and attitude, and in particular on the distance between the antennas. It is evident that an estimation of the heading is no longer possible when the baseline is vertical. Consequently it is advantageous to mount the baseline in a horizontal position for applications where heading determination is of interest. To obtain a more precise heading, a longer baseline has to be chosen. (Park et al.) [2]

Another approach calculates the orientation directly by the differences of the carrier phase. The two antennas receive the signals from the same satellite. The carrier phase received by each antenna has an offset caused by the baseline between the antennas. To solve the ambiguities, the two antennas are turned around the same centre of rotation. (Tu C.-H et al.) [3] After this initialisation a rotation of the antenna is no longer necessary.

A good solution for navigation applications is to calculate the orientation, better referred to here as heading, by the direction of movement. The current heading is determined using previous positions. Using methods such as Kalman filtering, which make use of several previous positions, can lead to good results. While the GNSS receiver is mounted on a vehicle like a car, train or an aircraft, the pre-known dynamic of the movement can be used to improve the actual orientation information. The better the dynamic of the movement is known, the better the orientation can be determined. Nonetheless, this method works only on moving objects.

2 USING THE SATELLITE'S POSITION FOR ORIENTATION

All the measuring methods described above either require additional equipment or are fixed to a specific measurement job. But none of them exhausts all possibilities offered by GNSS. GNSS provides us far more information than simply the time for the signal to reach the receiver. It indicates the actual position of all satellites at any time. This information is definitely needed to calculate the coordinates; in addition it could be used to determine the orientation too! As soon as we know the position of any satellite in the field of view, assumed the knowledge of our own position, the azimuth of the satellite can be calculated. Analogue to an astronomical direction determination, the orientation of a GNSS antenna could be obtained using satellites instead of stars (Figure 1).

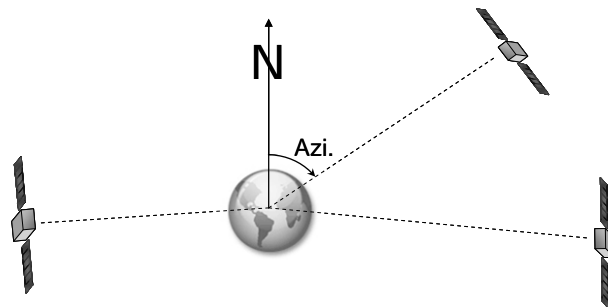


Figure 1: Satellites as direction indicator

3 WHICH DIRECTION THE SIGNALS COME FROM

3.1 Signal detection

For the further development it is essential to know from which direction the broadcasted satellite's signals enter the antenna. Because this direction is not directly measurable, it has to be estimated using other measurable quantities.

An estimable base quantity is the current signal strength of all received satellites. The signal strength derives from the measurable signal to noise ratio, which depends on the signal quality. Since this quality is a function of several outside influences, it can vary strongly. Nevertheless, assuming homogeneous conditions in the nearer antenna field permits to assume the outside influences on the same level for a short moment. This means that all signals will be influenced in a similar manner.

To find the direction the signal comes from, there must be a way to manipulate the signal strength particular. A modulation of the signals can be achieved by holding an absorbing material between satellite and antenna. The absorbing material provides a measurable reduction of the received signal strength.

3.2 Signal modulation

For the modulation of the signals in the proximity of the antenna a suitable material has to be found. This material has to have specific characteristics to reduce the intensity of an electromagnetic wave in the 1.5GHz band. On the other hand, it should not absorb the signal completely, because the signal still has to be detectable.

When electromagnetic waves hit any material, one of the following can occur:

- The material reflects the energy. This occurs when the material consists of a highly conductive surface, such as metal.
- The energy is transmitted through the material. This occurs when the material has non-conductive characteristics.
- The energy is absorbed. In this case, the material is able to absorb the wave completely or partially. In the absorption process the energy is converted into heat.

Using reflective materials as a cover provides a simple possibility for signal reduction. Nevertheless, the reflected part of the signal can cause problems. In the worst case, the reflected signals will be reflected again by another surface, and reach the antenna indirectly. Tests with reflective materials have shown this effect.

As a result the use of absorbing material is the better choice, although such material is more costly. Generally speaking the use of both, reflecting or absorbing material can influence the signal strength.

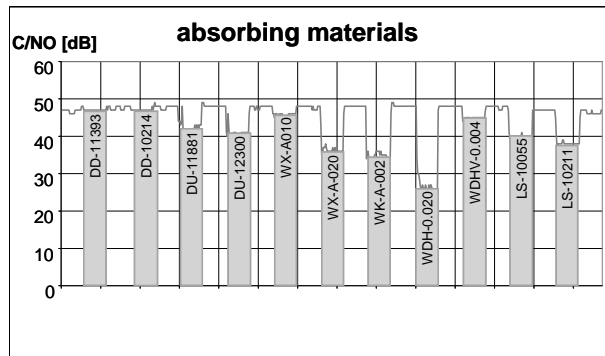


Figure 2: signal to noise ratio for different absorbing materials

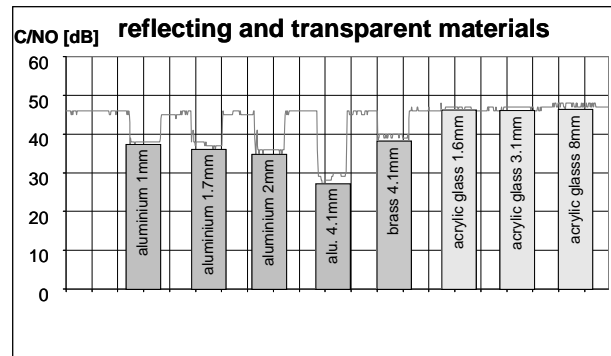


Figure 3: signal to noise ratio for different reflecting and transparent materials

Figure 2 shows 11 samples of absorbing materials. Figure 3 shows 5 samples of reflecting and 3 samples of transparent materials. The curve shows the signal to noise ratio. In the time between the samples, the signal intensity rises to the normal value of nearly 50dB. Figure 3 shows clearly the signal permeability of acrylic glass. The absorbing materials are especially developed and designed for electromagnetic influence suppression and absorption. The absorption rate is dependent on the wave length of the signal. Figure 4 shows exemplary the electromagnetic absorption performance of the WX-A-020 material.

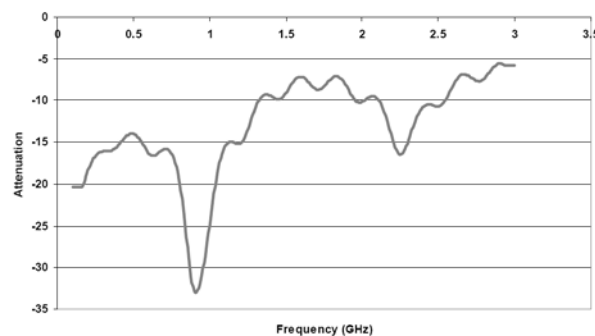


Figure 4: electromagnetic absorption performance of WX-A-020 [5]

3.3 Direction detection

Using absorbing material as a cover is the first step to achieve a specific detectable influence of the signal measured. This influence should clearly indicate the angle of incidence of the satellite's signals. As this influence effects a reduction of the signal intensity, it is a form of shading. To determine the direction, the shading has to be brought in a geometrically relation to the antenna. This relation is necessary to know which signal belongs to which satellite. To determine this relation, the cover is designed small enough not to cap the whole antenna at the same time. This allows rotating the cover around the antenna, and so to influence the signals from different satellites at different times.

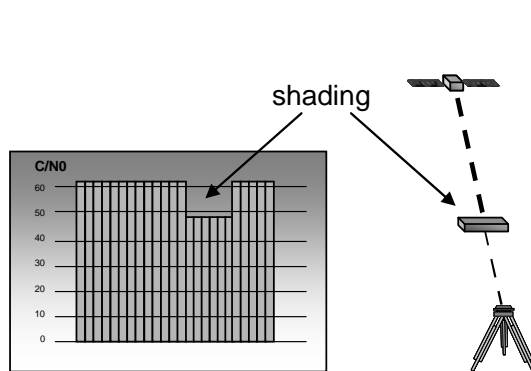


Figure 5: signal shading

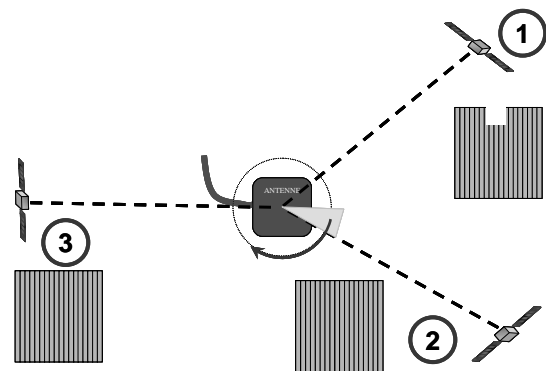


Figure 6: rotating shading

Figure 5 shows the principle idea of signal shading. On the right side on the top a GNSS satellite is shown. The broadcast signal is received by the GNSS receiver, situated at the bottom. The pane on the left side presents the received signal strength during the last period of time. The signal strength is measured as signal to noise ratio and indicated in dB. After some unrestricted measurements, a shading material is placed between the satellite and the receiver. This causes a loss of signal strength, indicated in the vertical bar chart with an arrow. Figure 6 shows the GNSS Antenna and three satellites viewed from above. Here the shading material is arranged as a rotating pointer. During a rotation, the signal of each satellite is shaded sequentially. Beside the satellites a schematic bar chart indicates the actual signal strength. Consequently the signal strength of the satellite① shows a temporary loss, where the shading is just passed.

3.4 Experimental setup

For verification of the theory above, an experimental setup has been assembled at ETH as shown in Figure 7. Its principal part consists of a small GPS patch antenna. The used antenna receives the L1 signal [4]. The navigation sentences are transmitted over RS232 using the NMEA standard to an especially developed software. A NMEA parser extracts the signal to noise ratio and shows the signal strength for each satellite in dependence of time. Additionally, the position of the shading bracket is read out.

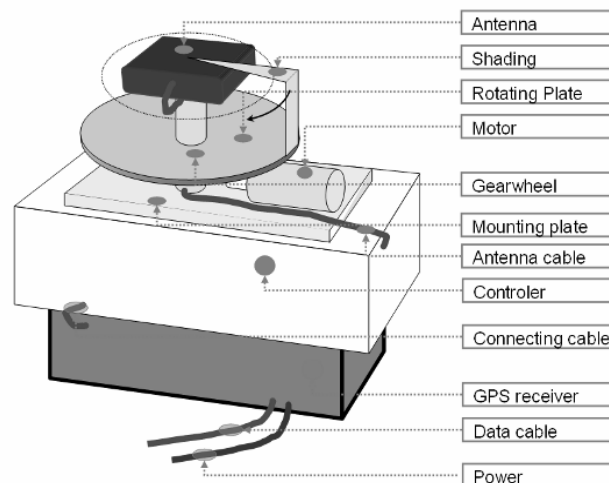


Figure 7: measurement setup

4 ANALYSIS

In order to analyse the accuracy of the detected direction the geometry of the satellites can be used. The time when the measured signal has its minimum, differs depending on the azimuth of the satellite. In fact the measurement delivers for each satellite a modulated curve, which should follow a sinus curve, since the shading of the signal is continuous and keeps turning by a constant speed. The shown curve of SV 9 (Figure 8) is shifted to the curve of SV 28 (Figure 9). This shift is caused by the azimuth difference of both satellites. By taking two time series of measurements from two different satellites, this shift can be calculated using a cross correlation function. The cross correlation function moves the two time series against each other and detects the best fit.

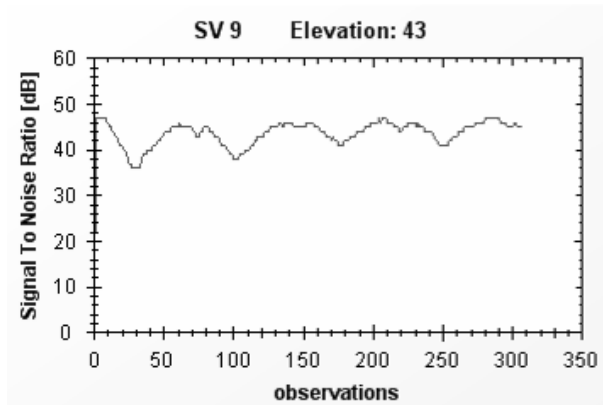


Figure 8: SV 9 during rotational shading

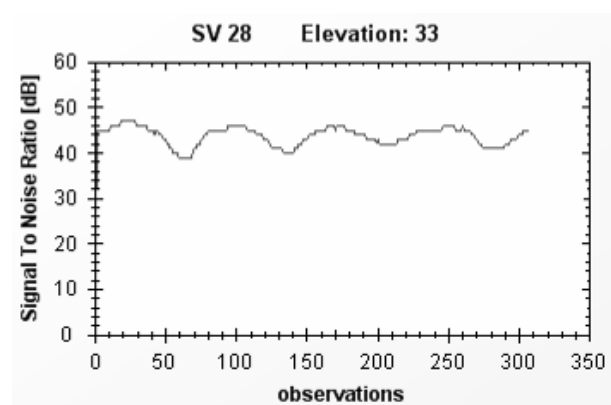


Figure 9: SV 28 during rotational shading

In Figure 8 and Figure 9 the influence of the rotating shading can be seen. The curves describe the measured signal to noise ratio on the y-axis in dB, plotted by the time on the x-axis. Here the shading was rotated 4 times. One rotation generates circa 80 observations. Furthermore the time shift of the minima is visible. The cross correlation in Figure 10 shows a significant correlation between the two time series. The maximal value in Figure 10 indicates the offset of -31 lags.

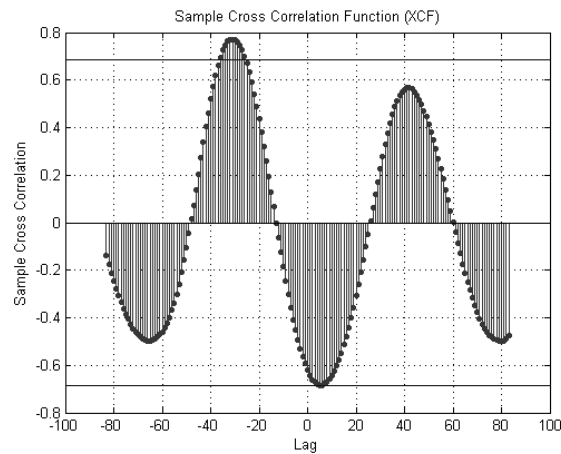


Figure 10: cross correlation between SV9 and SV28

5 CONCLUSIONS

The shown data demonstrates, that a specific modulation of the measurable signal to noise ratio is possible. Furthermore it seems to be cohesive to the rotating shading. To improve this work and to solve the uncertainties, this project is still ongoing at ETH. In a next phase, similar measurements will be carried out with a geodetic antenna of better quality. In further research work, the effects in the near antenna field will be investigated. Together with further tests with rotating shading, a new test series with a turning antenna is planned. Although there are only preliminary results until now, the initial results are encouraging. It is worth to further research in order to be capable to determine the antenna orientation by using the satellite's constellation as a reference.

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