PSEUDOLITE AUGMENTED NAVIGATION FOR AUTOMOTIVE APPLICATION

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Abstract

This paper presents the idea of the Local Area Navigation Systems (LANS) for automotive application in combination with standard GNSS navigation systems. The navigation system is based on four components: the widely available GPS, pseudolites located in areas where GPS signal is obstructed (tunnels, parking lots, city canyons), GPRS communication and supervisory informatics system. In this kind of system, reliable positioning is crucial. This article covers basic aspects of GPS single point positioning commonly used in navigation applications. Some information about differential positioning (DGPS/RTK) is also provided. A strong pressure is put on the application of pseudolite, its design and possible usability. This article presents authors own pseudolite design and the idea of pseudolite application to increase road safety in areas where standard GNSS signals are not available. The pseudolite presented in this paper is in the stage of development and testing. It is a device designed at the University of Warmia and Mazury in Olsztyn in cooperation with Canadian Center for Geodetic Engineering, University of New Brunswick, Canada. Different approach to the navigation in harsh environment is to move the source of the navigation outside of the vehicle and place it inside of the obstructions. It is much more efficient way to use in vehicles standard GPS receivers augmented with signals from the pseudolites, when the satellite signals are unavailable.

Keywords: *OBD, GNSS, pseudolite, navigation, road safety, road telematics*

1. Introduction

Intense development of informatics and telecommunication techniques finds direct reflection in road telemetry systems causing the increase of traffic safety. As an example, a lot of efforts are taken to implement telemetry into the third version of OBD (*On Board Diagnostics*), to gain the ability to transmit the data about current state of moving vehicle.

This exchange of data between supervisory informatics system and the vehicle can be assured for example by a number of transceivers located along the highway or a GSM/GPRS. The examples of such applications can be found in e.g. [5]. The “eCall” system presented in [4] (which is a part of “eSafety” project), developed in Europe since 2005 is a good illustration of the possibilities provided by this relatively young discipline.

The necessary element of such system is the ability to localize the event in space. Beyond the emergency situations such a system allows sending supplementary data to the supervisory system (e.g. Information about velocity, temperature, exhaust fumes emission). Using two way communications this data can be processed and returned to the vehicles in vicinity to augment the driver. In this aspect the application of GNSS positioning gains attention for OBD3.

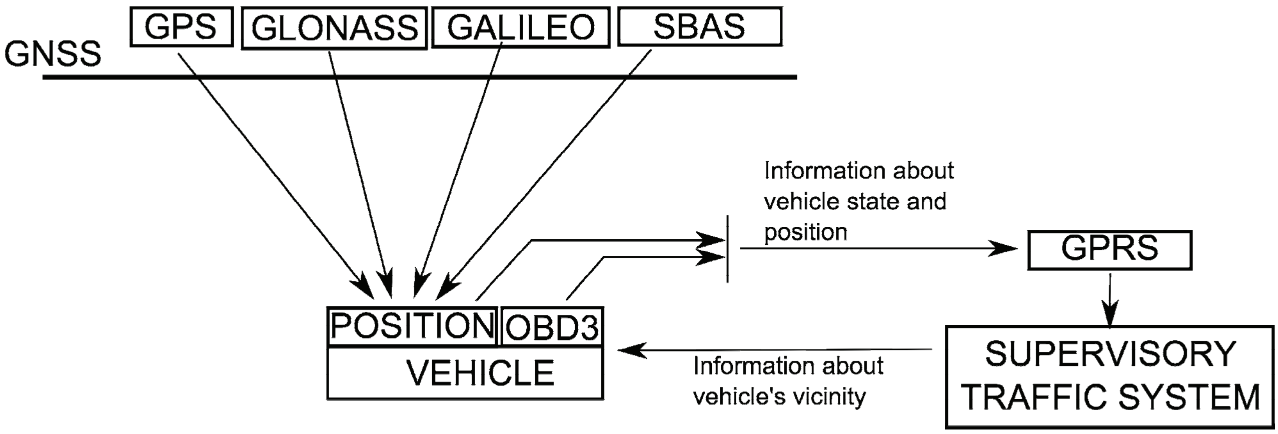

Fig. 1. The outline of the example of telemetry system

Networks containing the GPS/GNSS (*Global Positioning System/Global Navigation Satellite Systems)* navigation systems, delivering the information about the vehicle position can be used in wider area then navigation only. The combination of GSM communication, information obtained from OBD (*On Board Diagnostics*) and precise localization can be used in emergency alert systems, traffic control or to provide data for external information systems (such as various types of GIS (Geographic Information System)) and as a "shared" information about cars closest vicinity obtained from other vehicles in traffic (e.g. Information about ice on road or traffic jams).

On of the main issues in this approach is a way to deliver a reliable position in the area where GNSS signals are obstructed. In many places with a lot of traffic the information about vehicle position can not be acquired from GNSS satellites – underground parking lots, tunnels, urban canyons, though GPRS communication is still available.

To resolve this problem one can use a well known device such as an INS (Inertial Navigation System). It is a navigation aid that uses various sensors (like inclinometers, accelerometers, gyroscopes) to continuously calculate the position via "dead reckoning". In many situations it is a satisfactory approach, however it has some disadvantages:

- the position error cumulates with time and distance travelled,
- it requires additional sensors in each vehicle,
- it is expensive to be mounted in every vehicle.

Figure 2 depicts the accuracy of few positioning system. As it is seen in case of INS the error can go up to few hundred meters after one hour which can happen for example when the car is in the traffic jam in the tunnel or between high buildings.

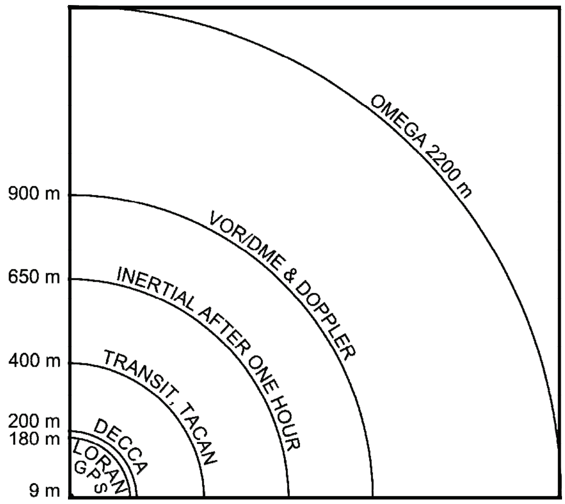

Fig. 2. The accuracy of navigation systems (2 dimensional) [figure by Johannes Rössel]

Different approach to the navigation in harsh environment is to move the source of the navigation outside of the vehicle and place it inside of the obstructions. It is much more efficient way to use in vehicles standard GPS receivers augmented with signals from the pseudolites, when the satellite signals are unavailable.

2. Basics of GPS positioning

Since vehicle navigation systems does not require sub meter accuracy, the single point positioning model is usually used (Fig. 3a). The differential models of positioning (Fig. 3b) is used only when higher accuracy is required – e.g. positioning of machines in road construction sites, surveying, civil engineering. Mathematical model for single point positioning using code data can be denoted as [3]:

$$R = \rho + c\Delta t + \Delta_{trop} + \Delta_{iono} + \xi \ , \qquad (1)$$

where:

R - GPS observation,
ρ - geometrical distance from the receiver to the satellite,
Δt - receiver clock error,
c - speed of light in vacuum,
Δ_{trop} - tropospheric correction,
Δ_{iono} - ionospheric correction,
ξ - noise.

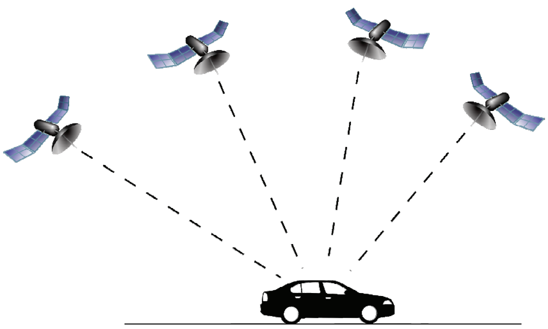

Fig. 3a Single point positioning

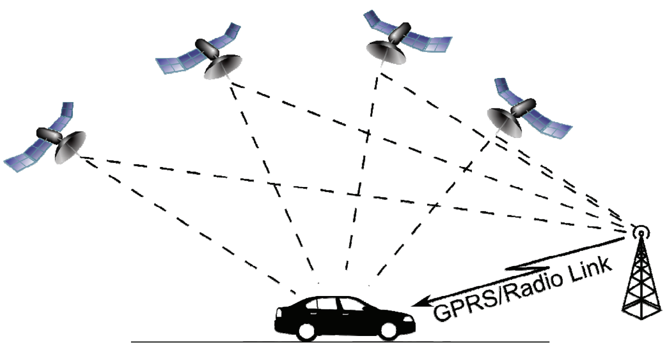

Fig. 3b Differential positioning

Since ρ is a geometrical distance in three dimensional space it can be denoted as:

$$\rho = \sqrt{\left(X_{rec} - X^{sat}\right)^2 + \left(Y_{rec} - Y^{sat}\right)^2 + \left(Z_{rec} - Z^{sat}\right)^2} \ , \qquad (2)$$

where X, Y and Z are coordinates in Earth centered, Earth fixed coordinate system, subscript "*rec*" stands for receiver and superscript "*sat*" stands for satellite. Substituting (2) into (1):

$$R=\sqrt{\left(X_{rec}-X^{sat}\right)^2+\left(Y_{rec}-Y^{sat}\right)^2+\left(Z_{rec}-Z^{sat}\right)^2}+c\Delta t+\Delta_{trop}+\Delta_{iono}+\xi\ . \tag{3}$$

Xrec, *Yrec*, *Zrec* and Δt are unknown, while R is measured, tropospheric and ionospheric corrections are modelled using well known models [1, 7]. The position of each satellite is calculated at the receiver on the basis of almanac data transmitted by satellites. Having four unknowns the receiver needs observations from at least four satellites to calculate its position.

The data from the receiver (position, velocity, navigation status) is transferred to the vehicles on board computer for further processing (navigation, data logging etc.). It is usually done using the NMEA (*National Marine Electronics Association*) protocol, however some receivers can use a propriety communication protocols (SiRF, UBX), which can carry more information then NMEA.

3. Pseudolites

Pseudolites are ground based, GPS – like signal transmitters placed on the points with known coordinates. Usually they transmit GPS L1 frequency signal with C/A (Coarse Acquisition) code. Pseudolite acts like an additional satellite, it transmits the same signal with the same frequency. It must be distinguished from the differential positioning with reference station (however the spare space in pseudolite navigation message allows transmitting differential corrections). Therefore such parameters as positioning sample rate or time to first fix are still receiver dependent. This kind of device can be used either to augment GPS positioning or to design pseudolite – only navigation systems. The mathematical model for the pseudolite observations differs slightly:

$$R=\sqrt{\left(X_{rec}-X^{pl}\right)^2+\left(Y_{rec}-Y^{pl}\right)^2+\left(Z_{rec}-Z^{pl}\right)^2}+c\Delta t+\Delta_{trop}+\xi\ . \tag{4}$$

Since pseudolite signal does not travel through ionosphere, there is no Δ_{iono} term in the equation (4). Additionally different models for tropospheric correction must be used [8]. Also the pseudolite coordinates must be transmitted as “raw coordinates” instead of standard almanac data. The idea of pseudolite positioning in “tunnel” is depicted in Fig. 4.

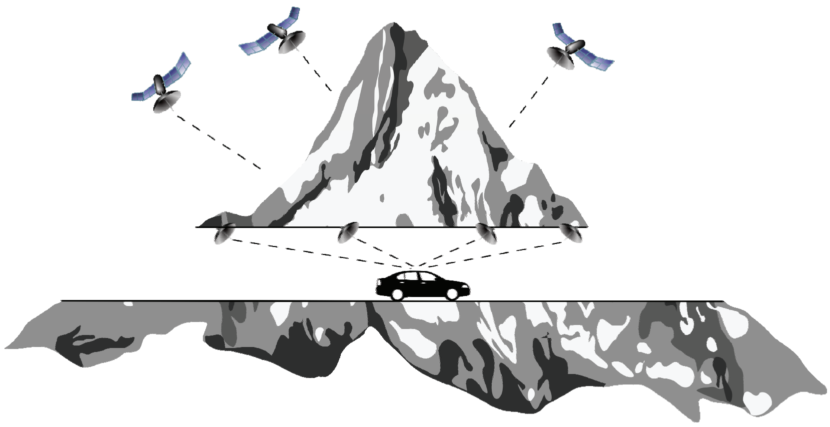

Fig. 4 Pseudolite positioning in the tunnel

4. Pseudolite development at UWM

First, and so far only one, use of pseudolite in Poland took place at the unused airfield in Gryźliny near Olsztyn in 2006. The IntegriNautics IN200 pseudolite was borrowed from Canadian Center of Geodetic Engineering in Fredericton, Canada. It was used in static application, the detailed description of the survey can be found in [6]. The IN200 pseudolite did not provide the possibility to modify its software and hardware, which would allow finding the optimum configuration of transmitter. To design a pseudolite navigation system, there is a necessity to find best combination of transmitted signal power, pseudo random code, frequency, signal time division, synchronization of time with GPS system. For this reasons the survey engineering group of Institute of Geodesy decided to build their own pseudolite.

The outline of the design is depicted in Fig. 5. The psedudolite design is divided into two parts – digital (D) and analog (A).

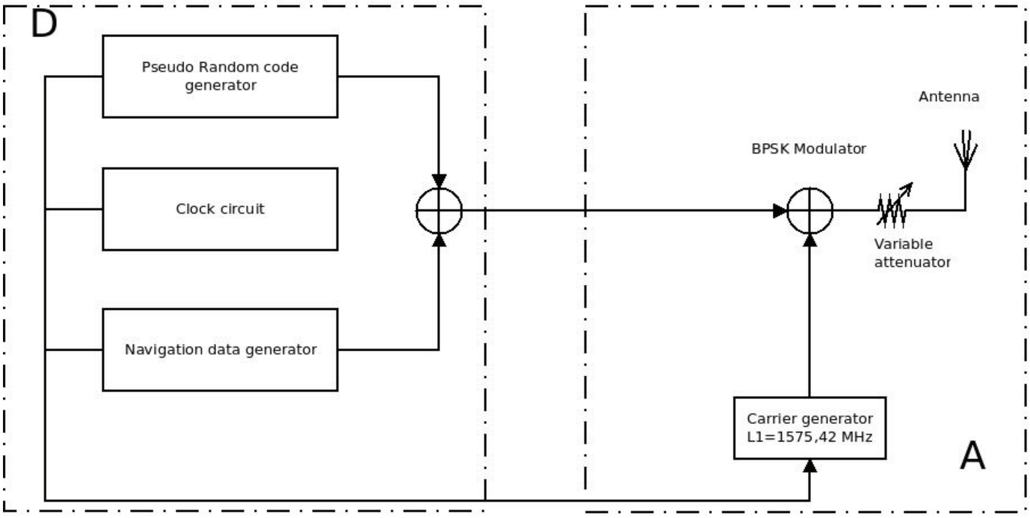

Fig. 5 Outline of the pseudolite design

The digital part is used to generate the C/A code and navigation message. C/A code is a pseudo – random noise generated with a 1.023MHz frequency by both transmitter and the receiver [2]. The receiver can compare received code with exactly the same code – produced by it, and calculate the signal travel time. The navigation message contains all the data required to compute transmitter's position and is sent with 50bps. The digital part is implemented on the Altera Cyclone III FPGA. The analog part of the pseudolite consists of the carrier wave generator and the BPSK modulator. Carrier wave (1.575420GHz) is modulated with C/A code generated by FPGA with BPSK modulator. First bits of the C/A code generated by pseudolite for PRN 1 are depicted in Fig. 6 while Fig. 7 depicts the spectrum of the signal (carrier with and without modulation). In Fig. 6, top line is a 1.023MHz signal while bottom line is a C/A code. In Fig. 7 marker 1 shows the carrier wave frequency while marker 2 shows the edge of the main leaf of modulated signal.

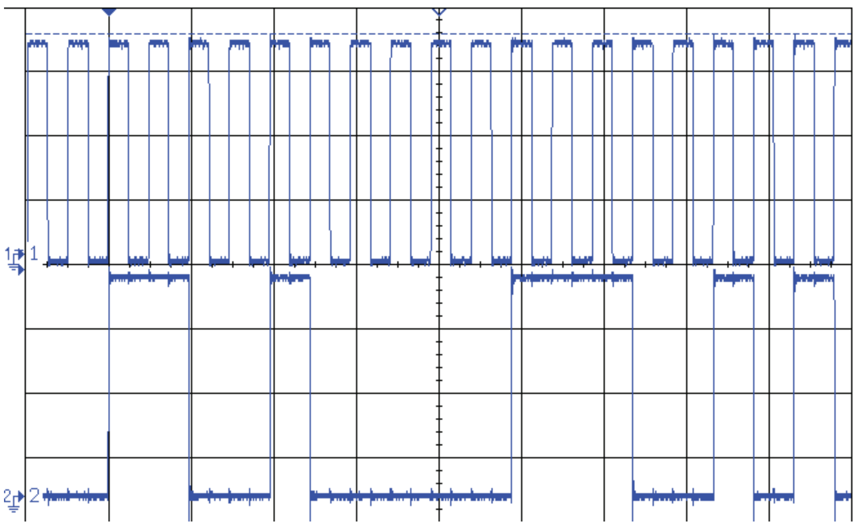

Fig. 6 C/A code generated by pseudolite

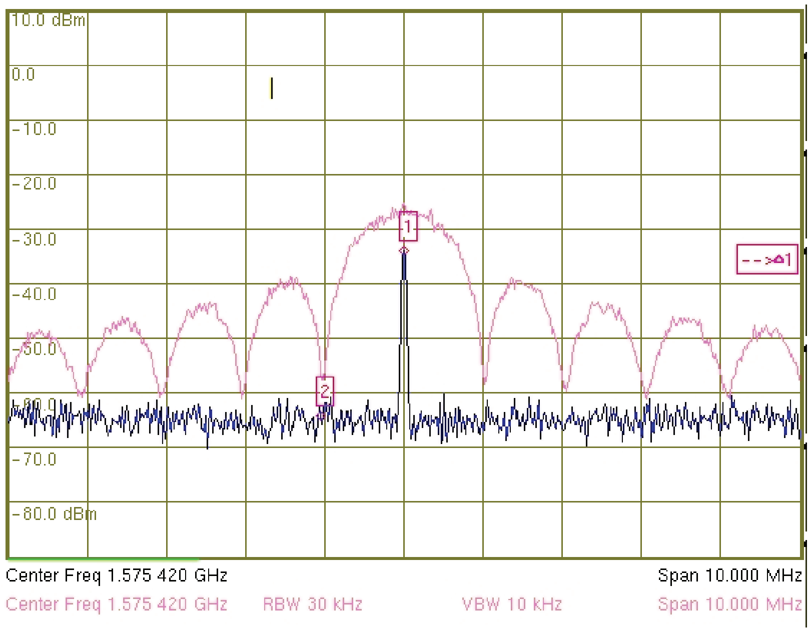

Fig. 7. Carrier wave generated by pseudolite

At the time of writing this paper, the pseudolite is in the stage of the prototype testing, thus first attempts of tracking its signal with a commercial receiver were successful. Garmin CX12, Mio200 navigation receivers and Javad Triumph geodetic receivers were able to track the pseudolite signal.

The power of the GPS signal at the receiver is approximately -120dBm. In the Fig. 7 the pseudolite signal power without antenna attenuation is about -30dBm. Applying the antenna gain of about -30dBm the pseudolite signal power is still on the level of 1nW which is 12500 times stronger then satellite signal. This is why additional attenuation of pseudolite signal is required. Without attenuation the pseudolite signal would saturate the receiver's antenna and no other signal would be tracked. For this reason and to prevent the possibility to disrupt the GPS signals, the first tests were performed inside of the building with one pseudolite. To resolve the problem of the signal strength the variable attenuator and the time division pulsing scheme will be applied.

5. Summary

The ability to track the pseudolite signal by the off shelf receivers, the compact size of the device and low power consumption (about 500mA) could lead to development of a local area navigation systems placed in the environment with no GNSS signals visibility. Relatively low cost of the device encourages mounting such a system in various locations eliminating the necessity to invest in many vehicles equipment.

The use of pseudolite in GPS positioning augmentation improves the geometry of satellites constellation which leads to increases in the positioning accuracy and allows faster ambiguity resolution in precise application where phase observations are required. It could allow the use of GNSS in the vehicle dynamics tests.

First trials of pseudolite signal tracking in UWM were successful. The development of the device is in progress thus a lot of real environment tests are planned.

References

[1] Allain, D., Mitchell, C., *Ionospheric delay corrections for single-frequency GPS receivers over Europe using tomographic mapping*, GPS Solutions, 13(2), pp. 141-151, 2009.

[2] Borre, K., Akos, D.M., Bertelsen, N., Rinder, P., Jensen, S.H., *A software defined GPS and*

Galileo Receiver, a single-frequency approach, Birkhauser, Boston 2007.
[3] Hofmann-Wellenhof, B., Lichtenegger, H. GPS Theory and Practice. Springer-Verlag, 1992.
[4] Merkisz, J., Mazurek, S., *Pokładowe systemy diagnostyczne pojazdów samochodowych,* Wydawnictwa Komunikacji i Łączności WKŁ, Warszawa 2007.
[5] Nowacki, G. (red.), *Telematyka transportu drogowego*, ITS, Warszawa 2008
[6] Rapinski, J., *Zastosowanie pseudo satelitów w pomiarach GPS*, Dr. thesis, University of Warmia and Mazury in Olsztyn 2008.
[7] Schüle, T., *On Ground-Based GPS tropospheric delay estimation*, Dr. thesis, Universität der Bundeswehr München 2001.
[8] Wang, J. J. et al. *Tropospheric Delay Estimation for Pseudolite Positioning*, Information Systems Journall, 2004.