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Technical Limitations of GNSS Receivers in Indoor Positioning

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Abstract. *This paper presents an overview of aspects that have to be taken into account in use of GNSS receivers for positioning in the difficult environment, for example indoors. The performing position determination and navigation tasks in such environments come nowadays more and more in the focus of the GNSS community. The GNSS signal indoor reception is affected by strong attenuation and due to the nature of the environment by strong multipath. The paper discusses both of them and their possible impact to the navigation tasks. The effect of the user movement is discussed and the experimental measurements are presented. The measurements were realized with use of experimental GNSS software receiver, described in the paper as well.*

Keywords

GNSS, GPS, indoor navigation.

1. Introduction

The use of satellite navigation systems broadens nowadays to wide range of applications and environments. The addition of new Galileo system to modernized GPS and planned GLONASS revitalization will result in more than 60 satellites whose ranging signal can be used. The concept of Global Navigation Satellite System (GNSS) together with the development of the integrated chipsets for all systems for mobile equipment open broad spectrum of possible applications. Examples can be a position determination for E112 emergency calls, hazardous material transport monitoring, public transport services optimization and synchronization, position based lock of the classified data or position based advertising, just to mention some of Location Based Services (LBS) that are supposed to use satellite navigation. A lot of navigation receivers intended for personal oriented LBS use will be also integrated into mobile phones and handhelds.

The mentioned applications have one in common: navigation receivers are supposed to work under various circumstances, even under the difficult conditions. For example inside of the store-house, high-rise building or roofed station, simply any place where the user or cargo position demand occurs. The users of all applications expect the stable quality of LBS no matter to the environment the service is used in, i.e. also indoors. That's why indoor environment brings new challenges in the GNSS signal processing and receiver design.

The topic of the paper is to describe influences of the indoor environment to the GNSS signals and consequences for signal processing. It will focus mainly to the issues of the common user movement and its influences to positioning signal.

2. GNSS Signal in Indoor Environment

2.1 Indoor Environment

A navigation task performed by the GNSS receiver in “classical” outdoor environment is well known. The searching in two domains, frequency and time (delay), brings estimates of the Doppler frequency and code delay.

In case of clear visibility there are several strong satellite signals present and the tasks of acquisition, tracking, and position computation are relatively easy.

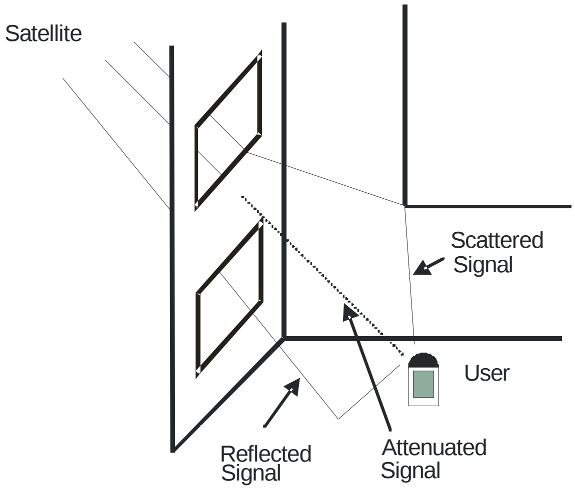

Fig. 1. Example of indoor GNSS signals reception

The other situation is for the case of user receiver location in difficult environment, i.e. urban canyon or indoors. The signals coming from the satellites are obstructed by foliage, walls, and other structures. The signal that can be used by the user receiver in such environment is mostly consisted of strongly attenuated direct signal and reflected (and/or scattered) signals coming usually by path of the least resistance (Fig. 1). That’s why two main phenomena, which indoor receiver has to count with, are signal attenuation and multipath effect.

2.2 Signal Attenuation

The signals coming from direct path on the clear view to the sky are already weak, about –160 dBW (for example GPS C/A code L1 signal is specified by IS-GPS-200 to arrive to the user receiver at not less than –158.5 dBW). The signal indoors is further attenuated according to the nature of the obstructing material. For example the plywood wall attenuates GPS signal by about 2.3 dB, while cinder and concrete induced attenuation is ten time higher. The wooden house for instance performs attenuation of about 10 dB while residential house with brick walls brings attenuation of 20–25 dB. The similar situation is even in outdoor difficult environment represented by dense foliage because the vegetation canopy is highly variable depending on the type of foliage, year season, meteorological conditions etc. That’s why the receivers have to deal with signal acquisition and tracking at levels form –160 dBW to –190 dBW. If we consider present sensitivity of the consumer grade receivers, summarized in the Tab. 1, the above mentioned tasks are rather complicated.

Chipset	sensitivity [dBW]
EverMore BP 1202	**-165**
Furuno GH-80	**-171**
SiRFstar IIe/LP	**-172**
Xemics SlimGPS™ RGPSM202	**-173**
Nemerix NJ-1030 v2	**-177**
Analog ADSST NAV2400	**-178**
u-Nav uN8031B/2100	**-180**
Sony CXD2951GA-2	**-182**
Maxim MAX2741	**-185**
uBlox TIM-LH	**-188**
SiRFXTrac	**-188**
SiRFstar III	**-189**

Tab. 1. Sensitivity of the consumer grade receiver chipsets

The more important value for weak signals acquisition and tracking is SNR (power of the signal to power of the corresponding noise) or even more often Carrier to Noise Power Density C/N0, the ratio of the power level of a signal carrier to the noise power in 1 Hz bandwidth. The acceptable C/N0 is a key parameter for evaluation of the GPS receiver performance. The signal strength of –160 dBW corresponds to C/N0 of 41-45 dBHz. Nominal C/N0 values what should be classical GPS receivers able to work with are in the 33 to 35 dBHz range.

The signals are acquired and tracked by correlation and integration usually in interval in units of milliseconds. In case of attenuated signal, the integration time can be extended to get required processing gain to achieve sufficient SNR because for coherent integration the noise bandwidth is reduced in inverse proportion to the integration time. However, the extension of the integration time is affected by the problem of GPS data bits width of 20 ms. If the integration period goes through the boundaries of data bits the integration is affected and SNR drops. One of the commonly used solutions is non-coherent integration with squaring the signal to remove BPSK data. However the squaring is performed also on the noise resulting in presence of squaring loss affecting processing gain. The squaring loss is also the reason for rapid increase of non-coherent integration time in case of received signal level drops. An advantage should be the future existence of dataless signal as planned for modernized GPS and Galileo.

The mechanism of the non-coherent integration time extension to achieve sufficient SNR is provided under a basic assumption that the Doppler error remains constant or small enough during the whole integration period. The Doppler error caused by instability of the receiver frequency standard and receiver antenna movement can then limit integration time due to caused phase changes.

In previous discussion we were assuming stand-alone GNSS receiver not considering advanced acquisition techniques, for example Assisted GNSS. The use of AGNSS assumes existence and particularly the accessibility of the data for provision of supporting information, e.g. initial approximate position of the receiver, the decoded satellite ephemeris, and clock information. After that, the reduction the searched space or increase of integration time by data removal and thus possibility of processing weaker signal levels is possible.

2.3 Multipath

The ranging signal in common outdoor environment is usually composite of direct path signal and the reflected signals usually described as multipath propagation. Outdoor applications usually meet less harmful form of the multipath, when the direct signal is stronger than reflection.

In indoor environment the situation gets worse, the impact of multipath is strongly increased by presence of much more reflected, scattered and/or diffracted signal components. The user can meet very frequently situation when reflection can exceed direct line-of-sight signal or the direct signal can completely vanish.

Almost all multipath mitigation techniques consider the first case, the dominant direct path. The assumption of simple free space model with one or more reflected signals is then insufficient and other techniques, e.g. estimates of the non-stationary indoor channel impulse response should be considered.

3. Software Receiver for Tests

The analysis of the indoor signal characteristics started with investigation of the phenomenon related to user movement in the environment, a change of the correlator output signal. A set of experimental measurements was done to get knowledge of satellite signal behavior in case of typical user movement in indoor environment.

The measuring equipment was based on experimental GNSS software receiver, developed at the Department of Radio Engineering of the Czech Technical University in Prague. The receiver consists of analogue three channels RF part providing down conversion of the RF signal to intermediate frequency. The signal at 140 MHz is then transformed to a digital domain by set of A/D converters. The rest of signal processing is provided by DSP unit based on FPGA device Virtex-II Pro equipped besides programmable logic by two PowerPC processor cores. The architecture of the receiver is shown at Fig. 2.

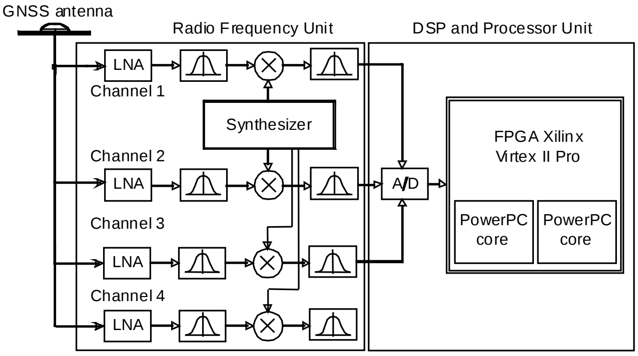

Fig. 2. Experimental GNSS software receiver architecture

The main parameters of the receiver can be summarized in Tab. 2.

Operating frequency	**1 – 2 GHz**
Intermediated frequency	**140 MHz**
Channel bandwidth	**24 MHz**
Automatic gain control (AGC)	**>40 dB**
External frequency reference	**10 MHz**
Number of 8 bit ADC converters	**4x**
Sampling frequency	**80 MHz**
Reference frequency	**10 MHz**
Stability	**0.3 ppm**

Tab. 2. Main features of the experimental GNSS receiver

The receiver prototype mounted in the 19-inch rack is shown at the Fig. 3.

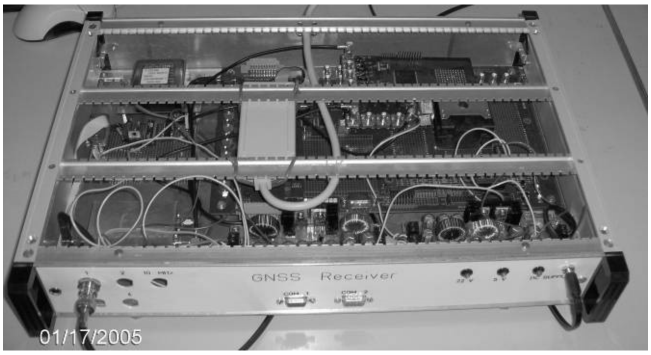

Fig. 3. Experimental GNSS software receiver prototype

The receiver FPGA part blocks layout and definition is described by the VHDL language as a output of the blockset design done in the Matlab Simulink using Xilinx Blockset add-on. The example of the GNSS correlator design is show at Fig. 4.

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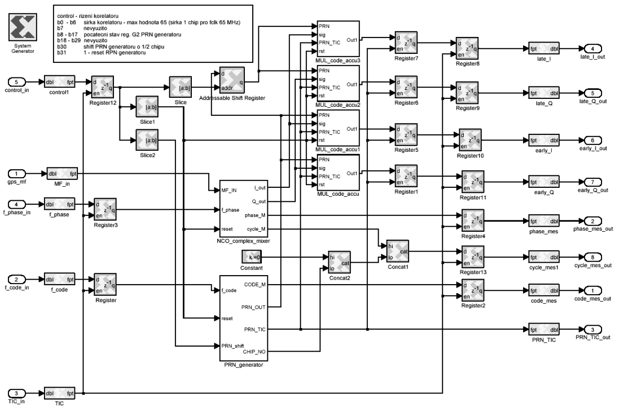

Fig. 4. Simulink model of GNSS correlator

4. Receiver Movement in Indoor Environment

In previous text there was discussed that extension of the integration period is done under assumption of the constant or small Doppler error affected by the frequency standard behavior and/or user movements. We have executed sets of experimental measurements to study impact of the user indoor movement with mobile equipment (mobile phone, handheld).

If we assume the Doppler error caused by satellite movement resolved, the other changes in the spectrum of the correlator output can then be caused by following phenomena:

- User receiver antenna movement
- Reaction of the receiver frequency standard to the movement, jerk stress
- Natural instability of the frequency standard

The experiments were based on the transmitted L1 carrier signal indoors from the generator and reception and processing with experimental GNSS receiver described in the previous chapter. To study impact of the user antenna movement we had to separate other two sources of error. The instability of the consumer grade frequency standard was overcome by use of experimental receiver with higher grade frequency standard. The impact of the movement on frequency standard itself was simply removed by movement of the antenna only.

Two sets of measurements were done within the same transmitted power level, with and without movement of the receiver antenna. The inphase and quadrature outputs of the receiver correlator were sampled with the frequency 200 Hz and stored for further processing. The samples of the recorded measurements can be seen at figures 5 and 6. The computed power spectral densities are depicted at the figures 7 and 8.

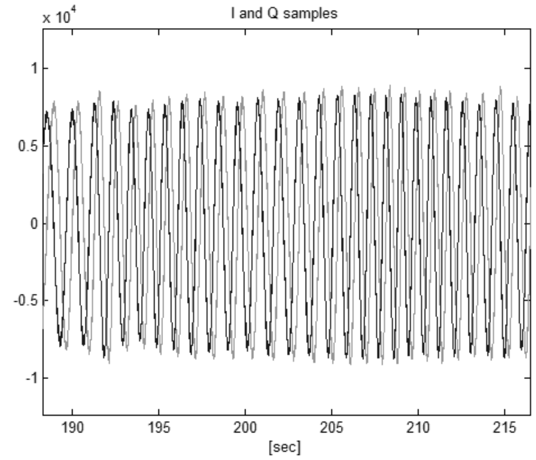

Fig. 5. Inphase (pale) and quadrature (dark) samples of the correlator output for stationary measurement

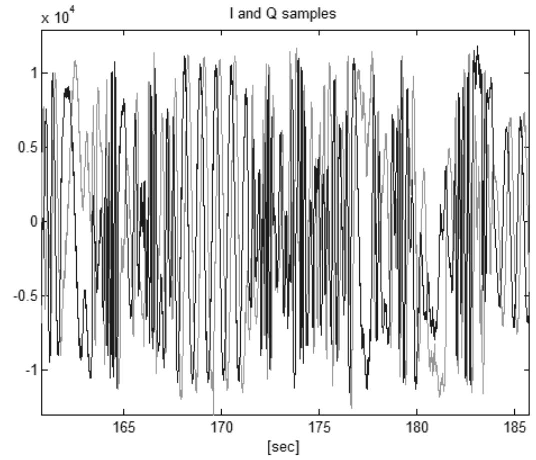

Fig. 6. Inphase (pale) and quadrature (dark) samples of the correlator output for measurement during user movement

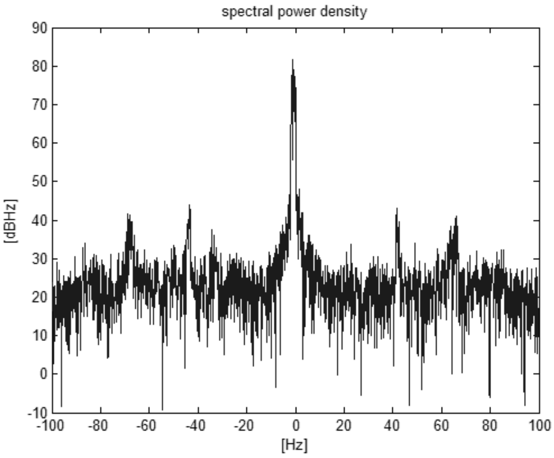

Fig. 7. Spectral power density for stationary measurement

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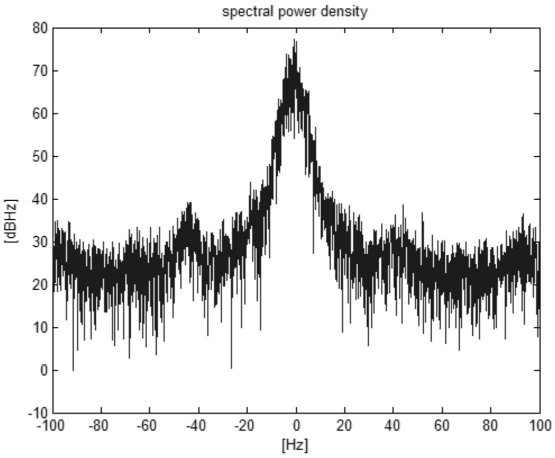

Fig. 8. Spectral power density for measurement with user move

If we consider bandwidth of the DLL filter in range of units of Hz suitable for multipath mitigation (for example bandwidth used for narrow correlator concept is about 2 Hz), we can see the possible loss of SNR due to user movement because of the notable widening of the power spectral density main lobe together with drop of its level. The wider bandwidth of the loop filter means raise of the noise and thus mentioned decrease of the SNR. Moreover, the user movement produced wider spectral power density is related to small but quick changes of the Doppler shift that has to be taken into account during frequency/delay search in acquisition phase.

5. Future Tasks

In the frame of the presented task we would like to extend the project work to incorporate impact of the user movement to the frequency standard itself, The study should continue to the more detailed analysis of the user indoor movement to the performance of the receiver (signal to noise ratio, tracking error), and construct the model of the typical user movement in the indoor environment.

6. Conclusion

The paper presented topics related to use of GNSS in difficult environment. It discussed main aspects of the indoor signal reception and use. The main problem is strong attenuation and heavy presence of multipath. The attenuation of the signal can be compensated by increase of the integration time. The new signals coming with modernized GPS and Galileo providing dataless channels and about 3-5 dB higher level should ease the indoor signal processing. The user indoor movement can affect receiver performance threatening assumption of constant Doppler error during integration period causing possible drop of SNR.

Acknowledgements

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