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SOFT-REC: A GPS REAL-TIME SOFTWARE RECEIVER WITH EGNOS AUGMENTATION

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This contribution describes a new approach to the design of a GNSS receiver (named SOFT-REC, SOFTware RECeiver), that focuses its attention on EGNOS signal and navigation processing. The architecture of SOFT-REC follows the well-known paradigm of software-radio. In other words, it performs all signal processing algorithms and positioning functions through a set of software routines running in real-time on a standard PC, integrated with an off-the-shelf analog/digital front-end. The paper, after a brief description of the main signal processing stages, discusses the accuracy improvements provided by EGNOS by performing a comparison between the results obtained using GPS data only and the positions computed with EGNOS corrections.

1. INTRODUCTION

With this paper we want to present and analyze the implementation of a GPS/EGNOS software receiver intended for land vehicles. As we will see, the only hardware parts needed to build SOFT-REC are an analog/digital front-end and a standard PC unit.

After the introduction, the *second section* of the paper presents hardware and software implementation. In particular, it describes the hardware characteristics, giving an overview of the software architecture and its relevant stages. The *third section* specifies the signal processing library, performed to recover GPS/EGNOS synchronisms and to detect the navigation data. The *fourth section* illustrates the Navigation Stage, showing the positioning and augmentation algorithms, while the *fifth section* provides test procedures and results achieved with and without EGNOS. Finally, conclusions are presented in the *sixth section*.

2. SOFT-REC DESIGN AND IMPLEMENTATION

As summarized in the introduction, the SOFT-REC architectural scheme is made up of two main components: an off the shelf analog/digital front-end (the Signal-Tap® by Accord) and standard PC unit. The hardware implementation is shown in Fig. 1.

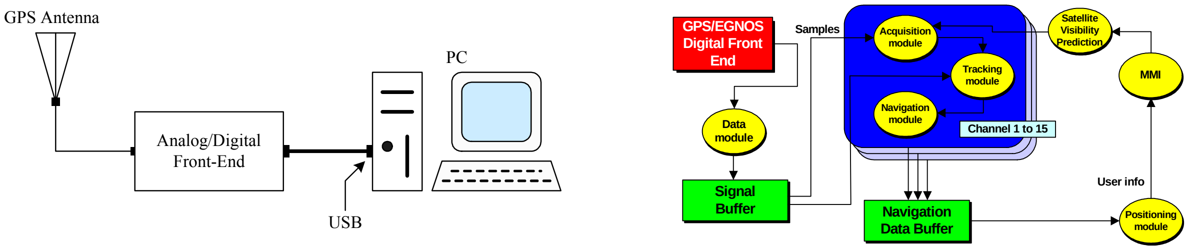


Fig.1: SOFT-REC Prototype Architecture and General Software Architecture.

The front-end performs a down-conversion from Radio Frequency (RF) to an Intermediate Frequency (IF), then samples and quantizes the IF signal on the L1 carrier (1575.42 MHz). The PC receives a digital signal from its USB port and processes it to detect the GPS/EGNOS data, used by the navigation algorithms to estimate the user position. Applying the Pass Band Sampling Theorem, it is possible to compute the sampling frequency. In our case [1], f_s is 4.796 MHz: considering 1 bit-quantization, we obtain 4.796 Mbit/s as front-end output rate. This result allows us to use a 1.0 USB connection.

As far as the software design is concerned, we remark that SOFT-REC has to process the input signal in real-time. In other words, all the receiver stages, that are normally executed in parallel by a hardware receiver, must be implemented by a set of low-complexity algorithms and executed under a real-time Operating System, as RTLinux. Regarding the development tools, it is possible to attain good performance by using the C programming language. A high level presentation of the SOFT-REC software architecture is also reported in Fig. 1. As seen, the bullets represent each main software modules and the boxes represent data exchange buffers. Basically, this structure can be described as a multithreaded and concurrent execution of the signal processing stage along with the modules dedicated to sampled data acquisition, the MMI, the positioning algorithms and so on [1].

3. SIGNAL PROCESSIONG STAGE

This section gives an overview of the signal processing algorithms needed to perform the signal synchronization and GPS/EGNOS data detection. In particular, it is possible to identify two main stages, the Acquisition and the Tracking Stage. The first one is dedicated to rough acquisition of GPS/EGNOS signals, while the tracking stage is needed to recover all the synchronisms and to decode the navigation messages.

3.1. Acquisition Stage Design

When SOFT-REC is turned on, the first algorithm to be run predicts the satellites in visibility. In this way, it can load the right PRN codes needed to perform coarse signal acquisition, with no need to perform an exhaustive search on all GPS codes. This feature does not involve EGNOS, of course, since the three GEO satellites are always visible.

When prediction is over, the coarse code acquisition stage is started. During this phase, each receiver channel performs a down-conversion from digital IF to near baseband. Then a correlation module despreads the input stream with local replicas of PRN code and finally a serial code acquisition unit [2] carries out a bidimensional search in frequency and time domain. When the correlation peak crosses a pre-set threshold, the GPS/EGNOS signal is acquired (with a course estimation of Doppler shift and code delay), otherwise another frequency or code delay is tried. Fig. 2 shows an example of EGNOS acquisition result on real data.

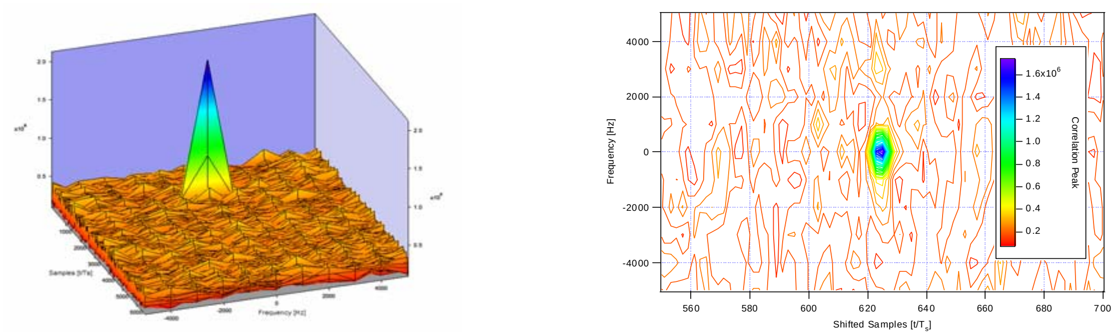


Fig. 2: EGNOS Acquisition.

3.2. Tracking Stage Design

The tracking stage begins to work at the end of the acquisition phase. In this case the channel architecture is quite different from the previous one. In particular, the digital baseband module is followed by the correlation module with a 2nd order DLL unit [3]. The DLL allows the code phase to be locked and tracked. The recovery of carrier frequency and phase is done using a 1st order FLL and a 2nd order Costas PLL, respectively [4]. Some EGNOS tracking results, obtained with real signals, are shown in Fig. 3.

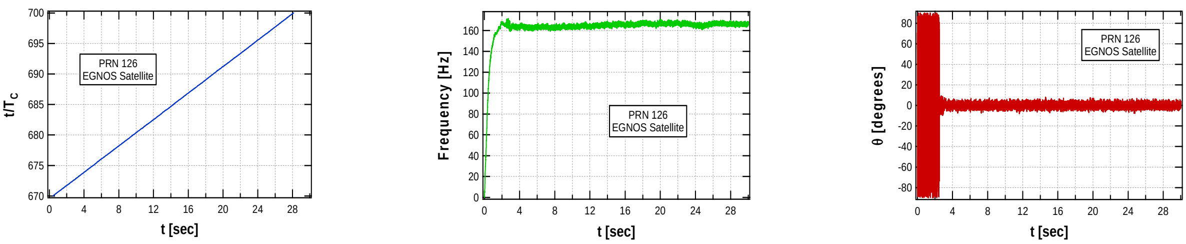


Fig. 3: Tracking of code timing, carrier frequency and carrier phase of an EGNOS signal.

When all the synchronisms are recovered, the GPS/EGNOS data are detected, decoded, and their parity check is tested. In particular, as far as the EGNOS data are concerned, they are firstly processed by a Viterbi decoder [5], then the parity is controlled and, finally, the frame is sent to Navigation Stage.

4. NAVIGATION STAGE

The first task of this module is to store the information: a smart management of the massive amount of parameters is necessary to handle the position solution algorithm correctly under real-time elaboration constraint.

The most critical aspects are represented by EGNOS message, owing to its non-fixed structure and a relatively short length of its frame (250 bits). These latter features lead to a wide use of masks, in order to coordinate accurate information across different messages, and the employment of correction time-outs [6]. Moreover, being EGNOS an augmentation system, the Navigation stage must check the consistency between GPS data and EGNOS corrections, avoiding to apply adjustments to the wrong set of parameters. The last operation to be accomplished is represented by the synchronization between GPS and EGNOS time: in fact, once GPS time is obtained by decoding any subframe 1 of GPS frame, the Navigation stage shall set an internal clock, in order to associate the right transmission time to each received EGNOS frame and to properly check for correction time-outs.

As far as the storage of GPS data is concerned, from the point of view of position solution, the only critical aspect is represented by clock and ephemeris parameters update: the navigation module shall handle this situation to keep on providing solutions even during parameters updates.

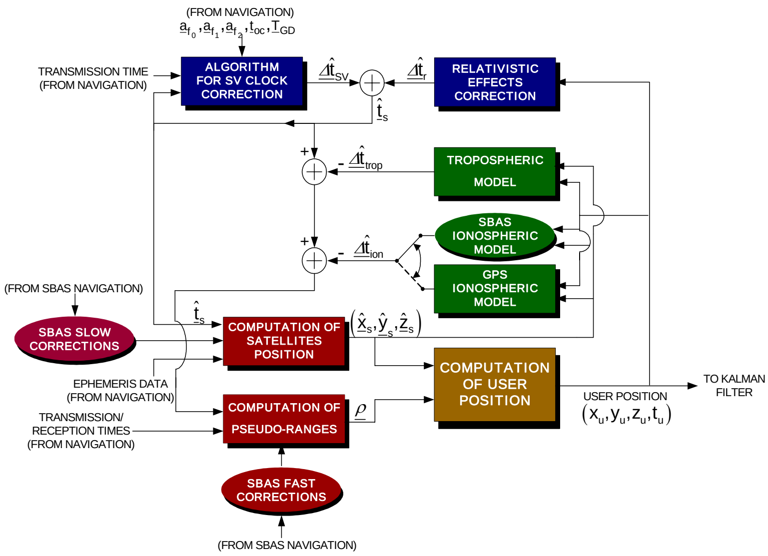


Fig.4: Positioning stage.

Every time the receiver has ephemeris data and arrival time of at least four GPS satellites, the positioning module is run. Fig. 4 shows the block diagram of the iterative algorithm: the boxes represent the steps of the positioning solution using GPS data only, as illustrated in [7], while the bullets depict the corrections provided by the augmentation system. As shown in Fig. 4, three corrections are applied:

- Fast Corrections (Message Types 1, 2-5, 6, 7, 24)
- Slow Corrections (Message Types 1, 24-25)
- Ionospheric Corrections (Message Types 18, 26)

The first two corrections are quite simple to apply: Fast Corrections consist in adding a corrective term directly to the pseudorange measurements provided by Tracking and Navigation stages, in order to remove the effects of Selective Availabilty (SA) of GPS, whilst Slow Corrections modify satellite position and clock offset, accounting for precision loss due to linearization of orbital parameters. Anyway, at the moment the impact of these corrections is quite weak, owing to the absence of the SA.

The greatest improvement provided by EGNOS is represented by the estimation of ionospheric delay broadcast within Message Types 18 and 26. When EGNOS ionospheric corrections are available, the receiver can use the interpolated vertical delay in substitution of the one obtained by the Klobuchar model provided by GPS. The application of EGNOS ionospheric model is quite complex, because the Navigation stage shall collect information for each active Ionospheric Grid Point (IGP): owing to the splitting of the IGP Mask over several messages (up to 14 messages for each of the 11 Bands) and an highly hierarchical flow diagram (described in Appendix P of [6]), the amount of code of the library performing SBAS ionospheric corrections represents 62% of the total code for the Navigation stage.

At an update frequency of 1 Hz, the algorithm provides the four unknowns (x_u, y_u, z_u, t_u): the first three components are the WGS-84 ECEF coordinates of the user, while the latter one is the clock offset with respect to system time; in order to increase position accuracy, the raw position solution is post-processed by an Extended Kalman filter [8] and finally converted into LLA coordinates and UTC time and displayed through MMI.

5. TEST RESULTS

This section contains typical performance achieved by a testing campaign of the SOFT-REC at specified locations certified by the Italian Military Geographic Institute (IGMI). Test procedures consist in post-processing the data collected at these known points, in order to provide a fair comparison between the positions obtained using only GPS data and the ones corrected by EGNOS, according to the algorithms described in [6] and applied as illustrated in the previous section. Offline data allow us to evaluate the performances of SOFT-REC making use of EGNOS Media Server (EMS) archive. We remark that testing was performed off-line just to be able to compare GPS-only positioning with GPS+EGNOS positioning on the very same sets of data. The receiver can in fact track 12 GPS channels + 3 EGNOS channels real-time.

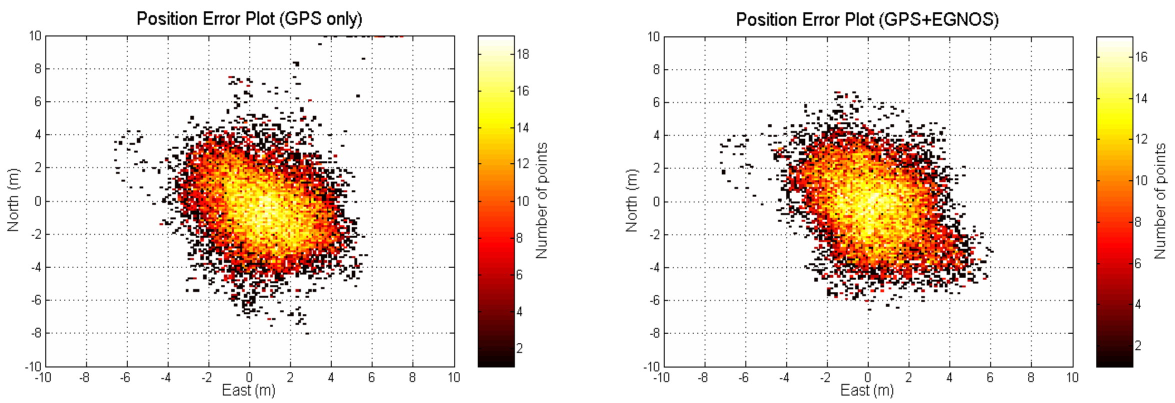


Fig. 5: Positions on the horizontal plane.

The first relevant result is shown in Fig. 5. The first plot reports the measured GPS standalone position accuracy, while the second one is obtained by applying EGNOS corrections. As we can better appreciate in Fig. 6, performances with EGNOS corrections are better than the ones achieved using only GPS data, but the improvement is very slight: in other words, without a precise standalone GPS receiver, we cannot achieve the accuracy requested by precision approaches (especially on the horizontal plane).

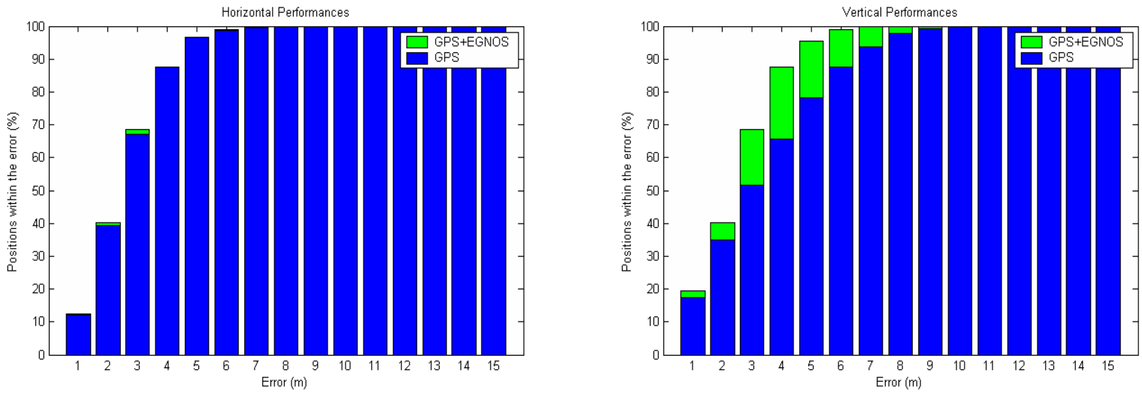
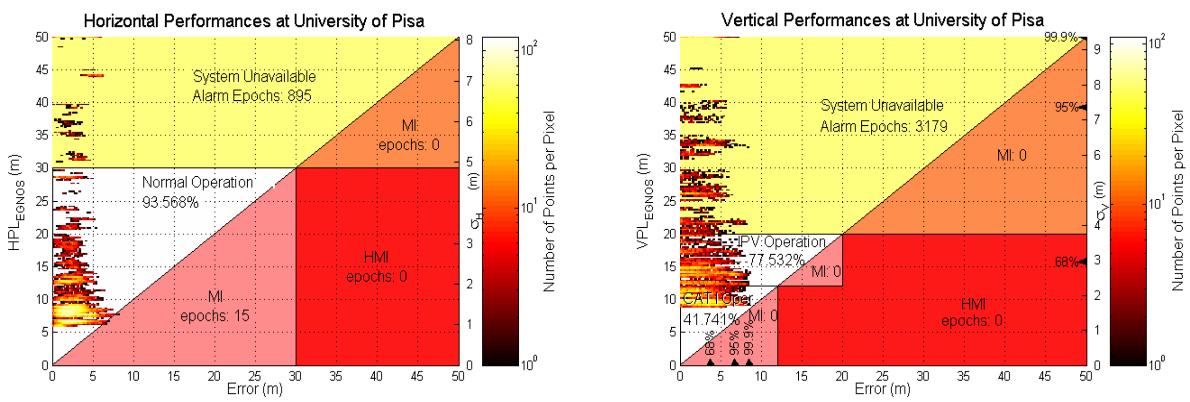


Fig.6: Horizontal and vertical performances.

In order to be able to analyze the qualitative impact of EGNOS corrections, integrity information broadcast by EGNOS has been used. Horizontal and vertical performances are reported in Fig. 7(a) and 7(b), respectively. No dots right of the diagonal are seen in Fig. 7(b), while Fig. 7(a) shows 15 results (representing 0.106%) in the region of Misleading Information (MI). As far as the system unavailability is concerned, at the present time our position (Pisa, Italy) is approximatively at the border of the EGNOS coverage area for ionospheric corrections. Since the protection levels are strongly dependent on the variance of ionospheric delay (smaller when EGNOS ionospheric corrections are available and larger when only GPS model is applicable), the pair (error, protection level) falls in the region of normal operation only if the critical IGPs, i.e. IGPs at Italian longitudes, are switched from Not Monitored to Monitored status.



(a) (b)

Fig. 7: Integrity Performances.

6. CONCLUSIONS

The main goals of SOFT-REC, that is, real-time operation and standard accuracy performances, have been achieved; in addition, like all software-defined platforms, the receiver is easily reconfigurable according to future improvements and developments of positioning systems.

At the same time, we remark that SOFT-REC is a prototype, and that future improvements are needed. Firstly, in order to lower the computational cost, code optimizations must be done. Then, in order to exploit EGNOS capacities, integration information can be used in the real-time version, making the receiver able to supply measurements reliability to the user. Moreover, additional features, e.g. the employment of GEOs in the positioning algorithm, using navigation data broadcast in Message Type 9, can be easily added. Finally, SOFT-REC can be improved adopting more efficient filtering methods, both in measuring the pseudoranges and in modelling different navigation modes.

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