Development of a software SBAS receiving module for a GPS receiver

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Abstract - Mankind has always been fascinated by the concepts of location and orientation. What started as a study of the moon and the sun has evolved to super precise software that can tell us anywhere in the world where we are with a precision of almost 100%.

The available solutions for location calculation are though not perfect and there is still room for improvement and is in this environment that the European Space Agency together with the European Commission and the EUROCONTROL decided to develop a component for the GPS, the European Geostationary Navigation Overlay Service (EGNOS), which would allow to calculate more accurate GPS' coordinates, enabling its users to benefit from better precision.

Key Words: Global Navigation Satellite Systems (GNSS), Software Defined Radio (SDR), EGNOS (European Geostationary Navigation Overlay Service), GPS (Gobal Positioning System), HPL (Horizontal Protection Level), VPL (Vertical Protection Level), SoftGNSS

I. INTRODUCTION

Created in the 1960's by the US, the first navigation system known as Transit, was first made for military use only and used the Doppler Effect to calculate the receiver's position, which means that, in order to calculate locations, satellites would travel on well-known paths and broadcast their signal on a well-known frequency and that was how we would get an idea of specific location.

With the passing of time, this location acquisition method evolved into something more modern and more accurate. At this moment, a trilateration method is the one used to calculate the receiver's location which means that three or more satellites will be used and only by knowing their distance to the receiver the actual location can be defined.

II. EGNOS, AUGMENTING THE GPS' ACCURACY

As every technology this days, the ultimate goal, is to make it better and better and that is no different for the navigation systems. Along the years, both the USA and Russia developed their own systems, the GPS and the GLONASS, respectively, and perfect them. China, India and the European Commission did not want to be out of this race and for that reason they are also working on their own navigation systems, the COMPASS, IRNSS and Galileo. While this three new systems under development are probably taking into account the limitations of both the GPS and the GLONASS, there is still space for new improvements to the two existing ones. Just think about the GPS. It is available anywhere in the world and is used worldwide for location definition. The technical and operational developments already exist so why not work on something that would complement it and make it a better navigation system? EGNOS is one of those improvements. Created as a joint-venture between the European Space

Agency, the European Commission and the EUROCONTROL, EGNOS was born with the objective of improving the performance and reliability of the GPS.

In fact, nowadays, and given its round-the-clock availability in any part of the globe, users come to want the GPS for specific applications for which it was not initially designed. As an example of those, we have aircraft landing, command and control systems for trains, geodesy, ship navigation and docking, etc., all of which require a high degree of integrity, which the GPS cannot deliver. Therefore the need for a new system to complement the GPS and improve its performance was needed and so the EGNOS was born.

The main idea behind the development of EGNOS was to create a software compatible with a GPS receiver that would augment the GPS satellite navigation system by calculating a certain position more accurately, to about one meter, when compared to the position got solely from a GPS receiver and also would make the GPS suitable for critical applications, due to its synchronization with the Universal Time Coordinated and its confidence thresholds which allows users to have precise and reliable time references.

III. Motivation

EGNOS, as said before, was created to be compatible with the GPS, and in fact, their hardware is the same, which allows the use the second for the EGNOS. Using a Software-Defined Radio system (SDR) to obtain the GPS and EGNOS signal it is possible to create a more flexible and less expensive location solution when comparing with a solution that needs a hardware-based receiver to get the location data. All this is a big help for the development of this work, since in order to achieve its main goal, which is to prove that the EGNOS receiver when implemented on a GPS system is able to get us more precise information on location, with an additional error factor and a confidence margin to the EGNOS data that can enhance and improve the results obtained from the satellite, we would only need to implement and EGNOS receiver on a SDR system.

In the end, after all the tests it was possible to achieve this thesis objective and by using three different locations, in this case Lisbon, Troia and Madrid, the conclusion was that the coordinates' variation to the actual coordinates was smaller when the EGNOS receptor was added to the GPS, in comparison to the variation got from comparing the actual coordinates with the ones got from the GPS receptor without EGNOS.

In order to get to this conclusion it was needed, along this thesis work, to adapt and develop a software program that would perform the signal acquisition and tracking and that would decode the navigation message from the three existing satellites. This being done, then the results had to be combined with a valid GPS signal to obtain the receiver location and protection levels.

IV. GPS and EGNOS: the differences

The first thing to be done as this study started was to **understand the way of work and differences between GPS and EGNOS** so that the best software and front-end could be chosen for the tests.

So, starting with the GPS, it is a continuously available space-based satellite navigation system that consists of three segments: one composed by satellites, known as the Space Segment (SS); a second one composed by a series of earth stations, the Control Segment (CS); and a last one composed by military, civil, commercial and scientific user receivers, called the User Segment (US). The GPS is able to provide a rather accurate position (better than 3 meters horizontal accuracy), velocity and time data, which combined will allow the users to get an idea of their location.

The EGNOS, in operation since mid-2005, was designed, as already mentioned, to complement the GPS system. In fact, if used on itself, the EGNOS receiver will not get us any positioning information since its only use is to augment the GPS signal when used as a complement to this system. It consists of three geostationary satellites at an altitude of 36,000 km and a network of more than forty ground stations.

In order for the EGNOS to work correctly, the first step is to collect the measurements and data from the GPS satellites. Once this has been done, then there is the need to calculate the differential corrections to the GPS' orbits, estimate the residual errors and generate the EGNOS messages. Only then are the EGNOS messages transmitted to the users via the geostationary satellites.

The differential corrections mentioned above, together with the GPS' clocks and the ionospheric corrections are what make it possible for the EGNOS to better the GPS' location information with an horizontal accuracy of 1 to 3 meters and 2 to 4 meters of vertical accuracy.

V. THE CHOICE OF FRONT-ENDS

Having studied both the GPS and the EGNOS structures, signals, accuracy and navigation message types it was then time to **start analyzing the different front-ends available** to help reach the goal of this thesis and afterwards choose the one most efficient and suitable for this particular scenario.

The open source program that has been chosen for this thesis to implement the EGNOS functionalities was the SoftGNSS version 3.0, not only because it is an open-source software that enables users to add functionalities to it and adapt the software with new features, but also because it is a GPS receiver with all its functionalities that is prepared to receive different inputs which makes it a bit more flexible than the alternatives. Also, this Soft-GNSS version is very popular and is used for a lot of different projects and studies which makes the learning curve low and the availability of help high.

Additionally, there was the need to find a front-end to be used on the test and the first choice was the GN3S Sampler v2, which is a 100% compatible with the chosen software and therefore makes it the perfect choice for the job. However, the estimated time of arrival was of 4 months after ordering which was not viable and for that reason this FE was abandoned. The ARCODE's ACGNS-L1 E1-F1-V1 was the second choice and the one that was then used for the tests and basically consists of a GNSS FE with an USB interface optimized for real-time SDR applications and signal recording.

This FE though had one small issue: the signal it was able to save is not compatible with the chosen software for this thesis, the Soft-GNSS and that would require a couple of changes either to the software itself or to the saved signal. The final choice was to create a script to be run before the main program, which converts the saved signal to a new signal that is recognized by the software.

To be able to complete the required tests, there was still one piece of the puzzle missing and that was an antenna. The one used was the u-blox ANN-MS-0-005 which has a built-in low noise amplifier, five meters coaxial cable, a magnetic base and an industrial temperature range from -40ºC to 85ºC.

VI. EGNOS SIGNAL ACQUISITION

Now that all the necessary equipment were chosen and obtained, it was time to **acquire the EGNOS signal**, which is no more and no less than the combination between the signals of all the visible satellites to the user.

For this phase, one of three methods, all of them based on search procedures, could have been chosen. Either it could be the Serial Search method of signal acquisition, the Parallel Frequency Space Search or the Parallel Code Phase Search. In the end and after studying each methods' repetitions and complexity, the Parallel Code Phase was the one with a higher level of complexity and fewer repetitions, and those, the chosen method for the procedure.

VII. Signal Decryption and Navigation Message obtainment

The next step on the line was to **decrypt the EGNOS signal** acquired since what was done so far was acquire rough estimates of the frequency and code phase parameters and in order to use them there is the need to refine this values, keep track and demodulate the navigation data. Technically, what is done at this stage is multiply the incoming signal by a replica of the carrier with the same Doppler frequency and then multiply the result by a code replica with the same delay as the incoming signal. As a result we will **get the navigation message** which, unlike the GPS's navigation message, is encoded with a Forward Error Correction (FEC) and there is the need to use a Viterbi decoder in order to get to the final goal of reaching a corrected location.

The first decoder used was one from Matlab present in the Communications System Toolbox which would have seamless integration with the Soft-GNSS v3, however the use of this decoder did not allow for any results collection and although a series of theories were tested in order to understand the reason for this to be happening, none of them lead to any real conclusion. The ESA SISNet User Application was then used as a work-around in order to proceed with the flow and calculate the position. Using solely an internet connection, this application allows the recording of the live uncoded navigation messages from the three satellites. As this is shown on a live stream, the user can select which navigation messages he wants to see and also all the necessary post-processed information such as the EGNOS Message Type, the GPS Week and the GPS Time. All this information can then be logged on to a text file that will be read by the program serving as a substitute for the information that should have been acquired directly from the satellite.

VIII. Position and Protection Levels' Calculation

Last but not least, there were two remaining things to do at this stage to get to the final output. The first one is to **calculate the correct position** of the user by calculating a series of corrections to the obtained GPS signal which will then be used to **calculate the protection levels HPL and VPL** and in the end will help us measure the position's error since each one of this levels describes a region assured to contain the indicated position. The HPL, also known as Horizontal Protection Level is the radius of a circle in the horizontal plane, with its center being at the true position and the VPL, the Vertical Protection Level, is the half length of a segment on the vertical axis with its center being also at the true position of the user.

IX. Result Analysis

After doing all the necessary tests, described above for the already mentioned locations of Lisbon, Troia and Madrid, it was time to **analyze the obtained results and take the necessary conclusions**.

In order to get to the main goal of this thesis, which was to show that the location obtained with the GPS with the EGNOS complement was more precise than the output got from the GPS alone, satellite images of all three location were used to compare with the results.

The Lisbon location coordinates (latitude 38.746435, longitude -9.164540 and altitude 155.5), for example, where more precise, in other words, nearer to the real position ones when the GPS with EGNOS was used to obtain the coordinates (38.746439, -9.164528, 168.7) versus the ones obtained with the GPS alone (38.746446, -9.164519.7). Besides this more accurate results obtained with the EGNOS, it was also possible to get additional information such as the protection levels with the EGNOS complement, something that the GPS alone is not able to give.

X. CONCLUSION

Summing up, and although facing some difficulties and having to put in place a couple of work-arounds, this thesis was still able to serve its purpose and to prove its initial goal. For all three locations under study, it was clear that the results gathered using a GPS with the EGNOS receptor were without a doubt more precise, which means, closer to the real location coordinates, that the output obtained by the GPS alone.