GNSS OPEN SOURCE SOFTWARE RECEIVER

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Abstract

The CTTC's software defined radio (SDR) Global Navigation Satellite System (GNSS) demonstrator is the implementation of a complete real-time software based Global Positioning System (GPS) L1 C/A receiver. All the hardware and software blocks are based on open source solutions and standards. CTTC has contributed with an improvement of the receiver adding a double delta correlator and using the GPS Tool Kit libraries.

High level block diagram

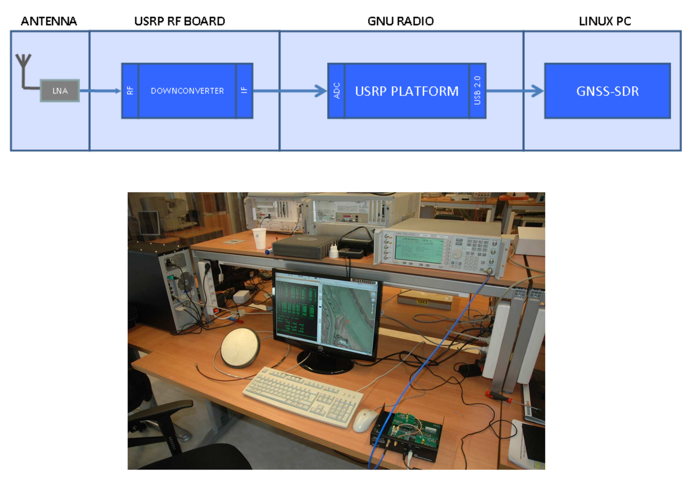

FIGURE 1: CTTC GNSS receiver testbed

The transmitted RF signals coming from the GPS satellite constellation are received by a standard GPS antenna with integrated Low Noise Amplifier (LNA) and then inserted into a RF downconverter board DBSRX which filters the signal and performs the downconversion to baseband (direct RF receiver). Next, the IF signal is sampled with inphase and quadrature analog-to-digital converter by the USRP board. The USRP board process the samples in order to transmit them at a suitable data rate to a software GNSS receiver running on a PC.

RF Front-end Hardware

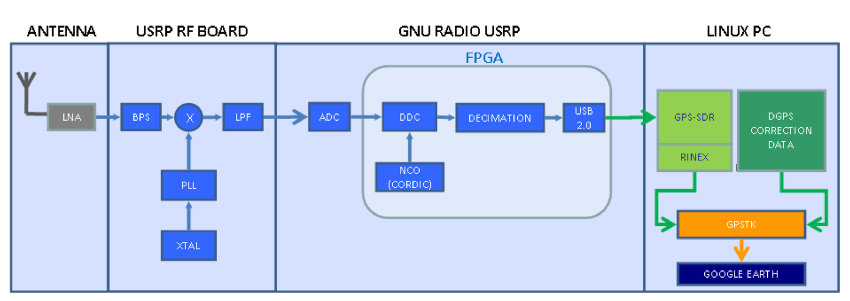

FIGURE 2: Hardware detailed diagram

RF frequency:	GPS L1 band 1.57542 GHz
RF Bandwidth:	10 MHz wide
Sampling parameters:	64 MSPS I/Q 12-bit.
Decimation out:	4 MSPS I/Q.
Baseband bandwidth:	2 MHz
USB 2.0 out:	32 Mbytes/s.

Open Source components

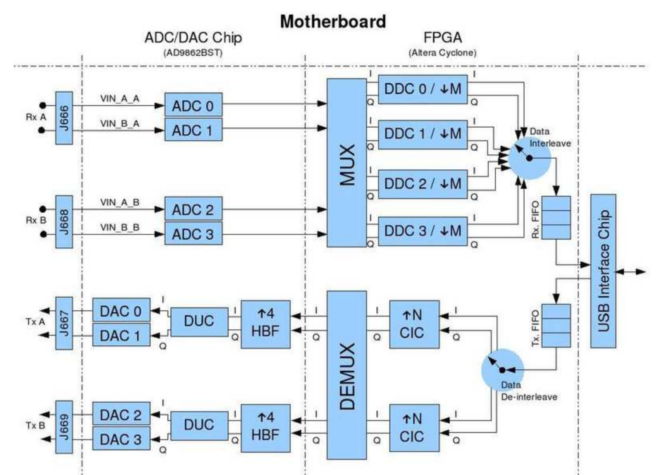

FIGURE 3: USRP Mainboard block diagram

The Universal Software Radio Peripheral (USRP) [2] is an open source software defined radio platform with enough flexibility to archive the requirements needed to implement a real-time GPS receiver without modifications.The high sample-rate processing takes place in the field programmable gate array (FPGA), while lower sample-rate processing happens in the host computer. The two onboard digital downconverters (DDCs) mix, filter, and decimate incoming signals in the FPGA. Daughterboards mounted on the USRP provide flexible, fully integrated RF front-ends. In addition to USRP, the GNU Radio project[1] libraries configure the USRP platform and provide a driver to read the signal samples and process them by GPS-SDR software. The GPS-SDR[4] is a complete GPS open source receiver running on a PC.

Inside GPS receiver

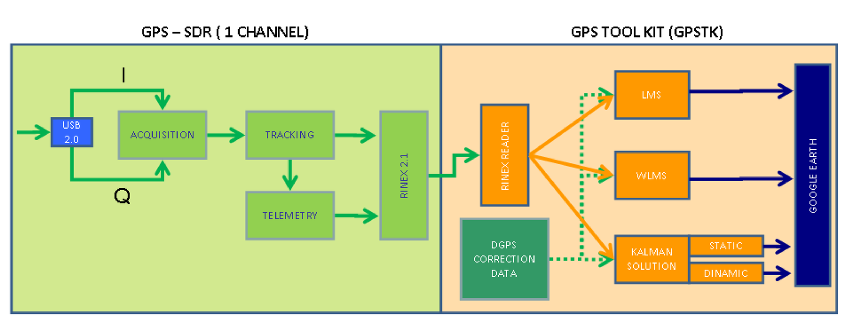

FIGURE 4: simplified block diagram for the software GPS receiver

- **Acquisition:** Performs a coarse synchronization process, giving estimates of the code offset and Doppler shift of the received signal.
- **Tracking:** Starts with the roughs approximations of the synchronization parameters and consists of a software defined single delta Delay Locked Loop (DLL) for the fine code delay search and a Phase Locked Loop (PLL) for the fine carrier Doppler search. Both components are intercommunicated to feedback the synchronization information. CTTC has implemented a double delta correlator in order to mitigate the multipath effect.
- **Telemetry decoding:** The navigation message is contained in the telemetry data, obtained after despreading the signal with a local generated and synchronized code.
- **RINEX output:** The pseudorange observations and the navigation messages are obtained and conveniently written in the Receiver Independent Exchange (RINEX) 2.1 format.

Double-Delta correlator

The atmospheric-dependant sources of accuracy degradation can be greatly mitigated by differential systems external to the receiver's operation but the multipath effect is location-dependant and remains as the most important cause of accuracy degradation in time delay estimation, and consequently in position estimation.

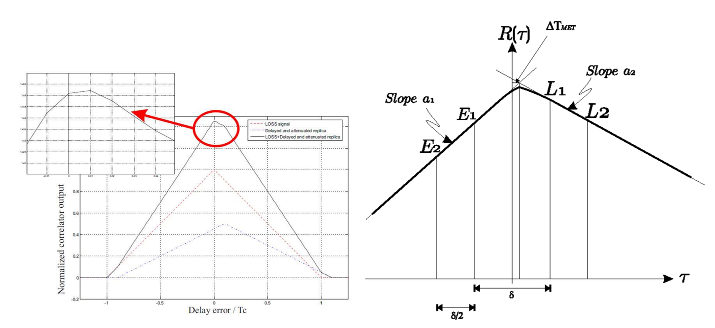

FIGURE 5: Autocorrelation of multipath-affected LOS signal and the double delta correlator

The natural extension of this effort in multipath mitigation is using a more accurate approximation of the derivative by means of more complex finite differences, pointing to the use of more correlator pairs instead of only one. Figure 5 represents the double delta correlator.

Real-time correlator implementation using SIMD instructions

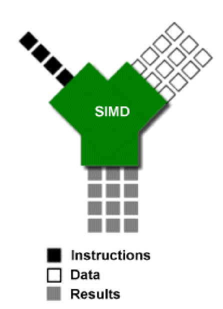

FIGURE 6: Single Instruction, Multiple Data

The real-time double delta correlation on a standard PC has been implemented using Single Instruction, Multiple Data (SIMD) SSE2 assembly instructions. The basic unit of SIMD is the vector, which is suitable to perform the vector multiplications for the correlation algorithm exploiting data parallelism properties. The SIMD correlator algorithm is shown here:

1. Generate inphase(COS) and quadrature(SIN) carrier wipeoff vectors.
2. Generate the C/A code replica, PRN.
3. Multiply IFxPRN vector (SIMD enabled function).
4. Multiply IFxPRN by COS/SIN, accumulate to generate the I/Q correlation (SIMD enabled function).

GPS Tool Kit features (GPSTk)

The goal of the GPSTk project is to provide an open source library and suite of applications to the satellite navigation community–to free researchers to focus on research, not lower level coding.The GPSTk suite consists of a core library, auxiliary libraries, and a set of applications. The CTTC GNSS receiver uses GPSTk classes to obtain the position from different approaches:

- **SolverLMS/WMS:** Least Mean Squares (LMS) and Weighted LMS Solution.
- **CodeKalmanSolver:**Code-based solution using a Kalman filter.

The GPSTk solvers can improve the accuracy using the differential GPS (D-GPS) correction data. A specific RINEX file obtained from a reference station is used in the process. D-GPS is an enhancement to GPS that uses a network of fixed, ground-based reference stations to broadcast the difference between the positions indicated by the satellite systems and the known fixed positions.

Simulation platform

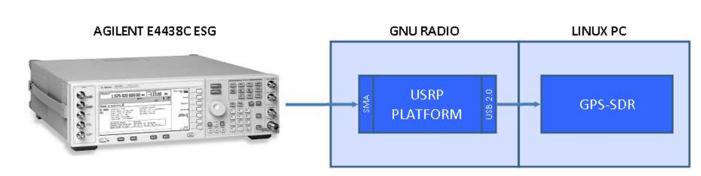

FIGURE 7: E4438C ESG connection

The testing equipment consists of a GPS real-time signal generator Agilent GPS Personality for the E4438C ESG Vector Signal Generator capable of generating a variety of pre-defined GPS scenarios with up to 8 satellites in view. The RF signal is feed into the USRP RF downconversion board at GPS L1 frequency, providing accurate control to test the receiver sensitivity, accuracy and cold-warm-hot start time in a variety of situations.

Real scenario results

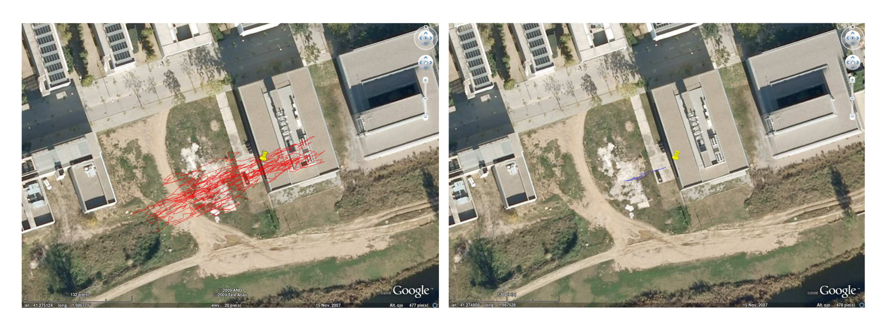

FIGURE 8: 120s static receiver position evolution for LMS (left) and Kalman (right) Solver

The accuracy of different solvers has been compared using the Google Earth tool. A Kalman filter based solution smooth the result using a priori statistical characterization of the process archiving a better accuracy.

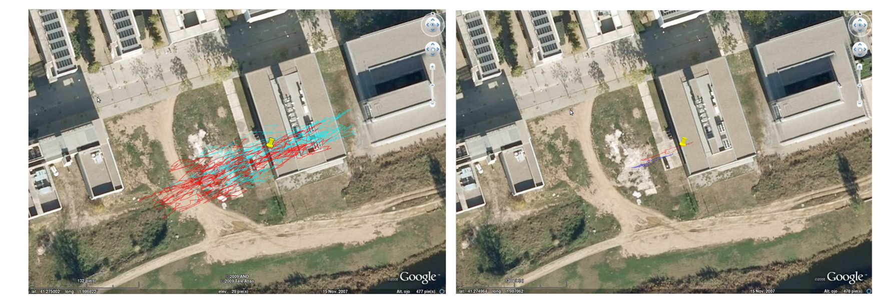

FIGURE 9: Left picture: LMS D-GPS (Blue) vs LMS GPS (Red), right picture: Kalman GPS (Blue) vs Kalman D-GPS (Red)

The use of D-GPS data on LMS solver has shown a small offset (bias) correction but the variance of the position results is maintained at the same levels. This result indicates that the sources of the remaining error are not correlated to the atmospheric effects.

Conclusions

In this work, a complete implementation of a real-time GPS receiver using open source hardware and software has been accomplished. The developed platform is modular and easy to upgrade. The GPSTk libraries have shown very interesting results with a moderate learning curve. The implementation of the double delta correlator in real-time has inspired the development of a high optimized code written in assembly language using the latest SIMD instructions and combining them with multithreading techniques. Considering this development as a starting point, CTTC has planned an evolution of the receiver platform with several ongoing PhD theses.

Acknowledgments

This work has been partially supported by the European Commission in the framework of the FP7 Network of Excellence in Wireless COMmunications NEWCOM++ (contract n. 216715) and COST Action IC0803 (RFCSET).

References

[1] GNU Radio comunity. *"GNU Radio project."*."http://www.gnu.org/software/gnuradio/

[2] Ettus Research Universal Software Radio Peripheral (USRP). *"http://www.ettus.com/"*.

[3] Gregory W Heckler. *"GPS-SDR open source GPS receiver project"*.http://www.gps-sdr.com/.

[4] GPS Tool Kit comunity. *"GPSTk project"*.http://www.gpstk.org/.

[5] C. Fernández-Prades *"Advanced Signal Processing Techniques for Global Navigation Satellite System Receivers."*.PhD thesis Universitat Politècnica de Catalunya.