Implementation and Test of a Low Cost GBAS Subset Airborne Receiver Experimental Platform for UAVs

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Abstract
A Ground Based Augmentation System (GBAS) provides differential corrections to Global Navigation Satellite Systems (GNSS) using VHF Data Broadcast (VDB) Equipment. This paper discusses development and test of an experimental low cost single frequency (GPS L1) GBAS airborne subset receiver. The objective of the design is to serve as a research platform for implementation and testing of different measurement processing architectures and integrity monitoring algorithms suitable for new potential user types such as small Unmanned Aerial Vehicles (UAVs). Following a brief discussion of platform architecture and component selection, preliminary results from a field test carried out near to the Zurich airport with its operational GBAS Approach Service Type (GAST) C GBAS station are presented. We describe an experimental low cost prototype receiver to implement GBAS with adaptive carrier smoothing for a single frequency Global Positioning System (GPS) and VDB receiver. Our results demonstrate how low cost GNSS receiver sensitivity can be increased to make it more robust, and viable via additional signal analyses focused on the receiver RF block's messages.

Keywords
Ground Based Augmentation Systems (GBAS), VHF Data Broadcast (VDB), GNSS, GAST-C

1. Introduction

The Ground Based Augmentation System is a GNSS based precision approach guidance system for the final approach phase. The system is intended to be used for safety critical operations (e.g. zero visibility operations including autoland) and is therefore designed to support very stringent integrity, continuity and availability requirements. As shown in Figure 1, the system architecture is comprised of three basic components, i.e. the navigation satellite constellation(s), ground station and the aircraft/airborne user. GNSS satellites send the ranging information that is received by the aircraft and the ground receivers. In the ground station, the information is treated in the processing unit and the correction signals are sent through a freely accessible VHF data broadcast (VDB) [1] to the airplanes. The aircraft receives both the navigation satellite signals and the GBAS VDB signals which together supply the navigation output/guidance to both the pilots' display and to the autopilot.

Evolution of GBAS and its Approach Service Types (GASTs) as well as development of new concepts/system architectures is a complex and resource intensive process since the development has to be carried out in accordance with rigorous standards. At the moment, relevant standards for implementation are available only for GASTs C and D Categories I and III respectively, both based on the use of GPS L1 only. At the same time, a number of research activities are focusing on developing new generation architectures targeting the use of multiple constellations and multiple fre-

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quencies [2].

GBAS offers several benefits for its intended users in terms of reduced separation of aircraft on final approach, flexibility in the definition of the approach trajectory and usability of the service for multiple runway ends [3], Rapid evolution of autonomous systems and operations and their demanding performance requirements, the interest in potential use of GBAS for the Unmanned Aerial Vehicle (UAV) navigation leads to increasing. Development of a UAV-borne GBAS receiver has been earlier addressed in [4] and [5] where a simplified system concept has been proposed to account for the limitations of low-cost GNSS receiver characteristics and UAV flight dynamics. Application of GBAS for use-cases other than precision approach guidance of large aircraft, namely the Differentially Corrected Positioning Service (DCPS) have also been investigated [6] considering different airborne platforms including UAVs [7].

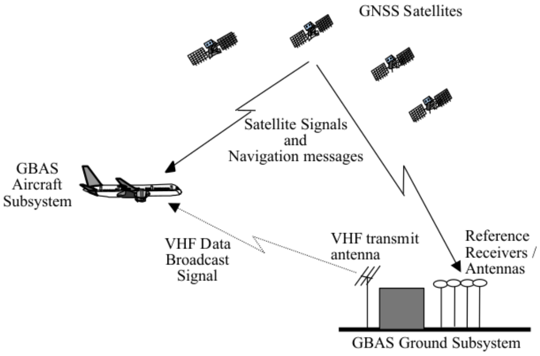

Figure 1: Ground Based Augmentation System principle [8].

The focus of this paper is on design and testing of an experimental GBAS airborne receiver platform including live VDB signal reception and processing using low cost, low weight, non-aviation Commercial Off The Shelf (COTS) components including RTL-SDR for VDB signal/message reception, a u-blox receiver for GNSS signal reception/raw measurement generation, and an Intel NUC for VDB message decoding, measurement processing and basic integrity monitoring. The design is flexible in that it allows for both real-time signal processing as well as post-processing of the prerecorded or simulated data. While the implemented system supports both the basic GAST C and GAST D dedicated processing, results obtained using only the GAST C mode of operation are presented in this paper. This is due to the availability of experimental signal testing options from only GAST C implementations during the scope of this activity.

2. Platform Architecture

The core of the developed experimental platform consists of a low cost u-blox ZED F9P GNSS receiver with up to 25 Hz data logging and streaming capability, an active GNSS antenna, an RTL-SDR Software Defined Radio dongle based on the RTL2832U chip with a VHF antenna, and a Linux OS installed Intel® NUC Mini PC. Other generic components include cables, SMA connectors and a signal combiner. Approximately 6000 lines of Python code were written, simulated and tested on the prototype for GNSS and VDB message reception and analysis. The developed code supporting GNSS receiver operation logs all the necessary data including satellite ephemeris, psuedorange and carrier phase measurements, as well as the receiver hardware status parameters (i.e. noise level, Automatic Gain Control (AGC) and CW jamming indicator outputs). The VDB receiver segment captures the VHF signal and decodes the necessary VDB messages to provide corrections for the GPS L1 signal as well as the required integrity parameters. The entirety of the system software including navigation solution calculation runs under Ubuntu 20.04 LTS Linux on a Intel NUC. To be more specific, to process the u-blox receiver data software developed in Python 3.8.10 was run in the Ubuntu Linux environment. For processing the VDB signal and data, software developed using the GNU Radio toolkit was used also in the Ubuntu Linux environment. Figure 2 shows a diagram of the basic concept of operation and platform components.

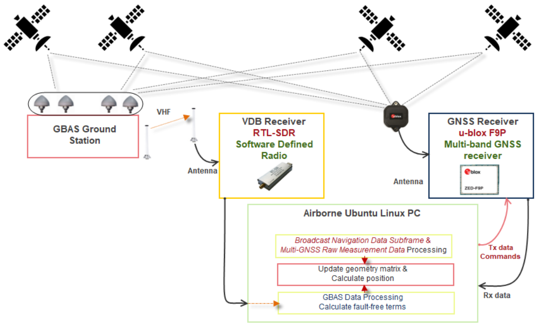

Figure 2: Basic platform components and operation concept.

The platform can be configured to receive, decode and perform the basic processing for either live or pre-recorded GNSS (currently only GPS L1 is supported) and VDB data. The implemented VDB message decoder supports options for both GBAS GAST-C and GAST-D (i.e. MT1, MT2, MT4, MT11 and MT3). At the moment, the platform supports both 100 second and 30 second carrier phase smoothing as well as the general navigation solution calculation steps required for GAST-C and GAST-D service types with only basic monitoring algorithms to detect sudden measurement changes and/or cycle slips (Measurement Quality Monitor) and RF interference that might not be observable at the ground station. While the basic Protection Level (PL) calculation steps are also implemented in software, PL performance is not addressed in this paper and is left for future work. The developed platform also supports GNSS RTK processing that is carried out on the Intel NUC by running the open source RTKLIB [9] software, which at the current stage is meant mainly to serve as a reference solution for performance evaluation exercises.

3. Platform Validation and Testing

To evaluate the performance of the developed experimental GBAS airborne receiver platform first a number of lab tests were performed to verify the ability of the system to process GNSS data and generate a correct navigation solution. Next, a data collection near the Zurich airport with its operational GBAS GAST C station was carried out to test the performance of the complete system including the VDB receiver segment.

3.1. In Lab Validation

To validate the performance of the GNSS data processing and solution generation part, a number of tests using GPS L1 signal generated by a Spirent GSS8000 HW simulator were carried out considering scenarios with both static and dynamic user platforms. For simplicity, no atmospheric, multipath or other effects were simulated. In the case of the scenario with a dynamic user, a simple constant velocity motion along a linear trajectory was considered. As shown in Figures 3 and 4 where the results obtained by the implemented solution are compared with both the simulated data (orange) and the solution generated by the ublox F9P receiver itself (green), good performance was achieved in both cases.

3.2. Live Signal Testing

To evaluate performance under realistic conditions, a data collection near Zurich airport where live VDB signals are accessable was carried out. The selected test location was within

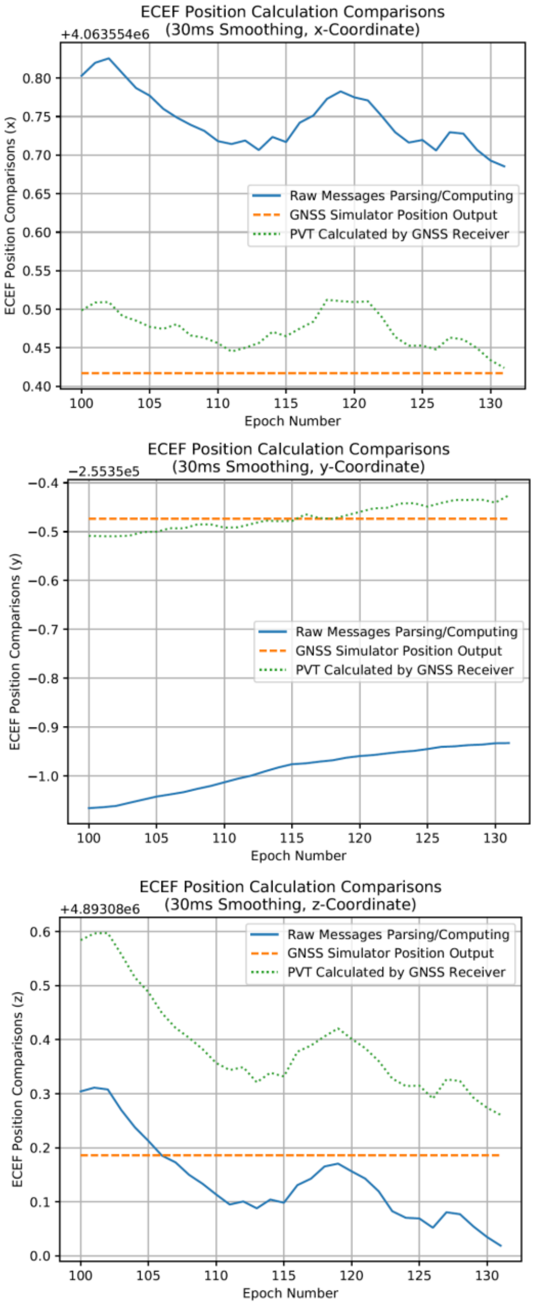

Figure 3: GNSS navigation solution test results, static user scenario. Navigation solution calculated based on the 30 s carrier smoothed code measurements.

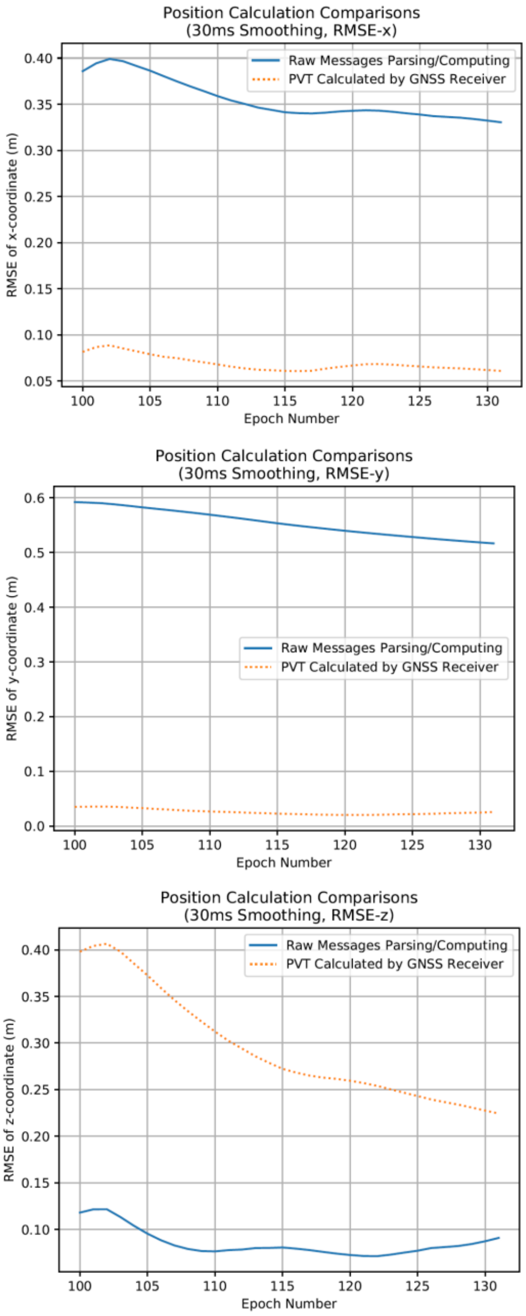

Figure 4: GNSS navigation solution test results, dynamic user scenario. Navigation solution calculated based on the 30 s carrier smoothed code measurements

Table 1
u-blox ZED F9P GNSS receiver configuration parameters

C/N_0 threshold (dB-Hz)	30
Minimum elevation angle	5.0^o
GNSS receiver start mode	Cold start

line-of-sight to the VDB transmit antenna ensuring good signal reception (see Figure 5). The Zurich GAST C station was in regular operation at the time of test providing corrections and integrity parameters for the approach service and supporting Category I (CAT-I) operations to the main landing runway (i.e. Runway 14). As figure illustrates, data collection was carried out in static mode. The tests were configured to allow us to evaluate the system in two separate operating modes from the same testing process. The first of these modes was the previously discussed post-processing mode of operation where the data logged during the test from both the GNSS receiver and the VDB message parser was run through the processing pipe line after the fact. The second processing mode was real time combination and processing of both data streams to produce a low-latency GBAS-like solution as would be needed on a hypothetical airborne platform.

Figure 5: Test setup and location at Zurich Airport. GBAS VDB antenna location indicated with a yellow circle.

For these tests, an elevation angle and the carrier-to-noise ratio C/N_0 masks were applied to GNSS measurements as shown in Table 1. The C/N_0 mask was introduced to accommodate for the use of a high sensitivity GNSS receiver as part of the platform (tracking and navigation sensitivity of the ZED F9P module according to [10] is as low as -167 dBm). The mask was applied mainly to remove noisy low power and potential non line-of-sight measurements.

First the performance of the stand alone GPS L1 based solution generated by the experimental receiver was tested to ensure that all platform segments were operating as expected. Figures 6 and 7 show the results obtained compared to the solution generated by the u-blox receiver in stand alone mode. Then, performance of the complete system was evaluated using live GPS L1 signals together with the broadcasted GBAS GAST C VDB signal. As mentioned above, operation both in real-time and post-processing modes was verified. Figures 8 and 9 show the results obtained in the post-processing mode. In both cases, the results obtained by the experimental receiver platform are noisier than the ones produced by the u-blox receiver, this is as expected and is due to the experimental receiver platform using the simple weighted least squares approach to calculate the position solution', as well as using values for parameters such as σ_{pr_air}, that are quite conservative for the u-blox receiver and static scenario.

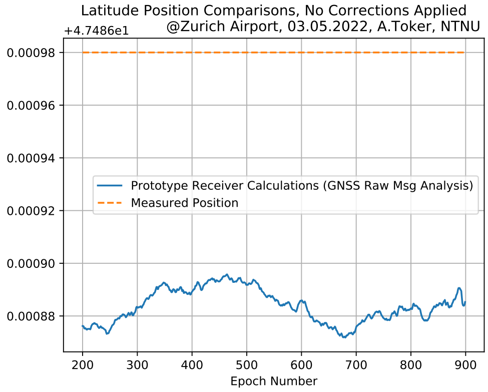

Figure 6: Navigation solution results, latitude. Experimental receiver solution with no GBAS corrections applied.

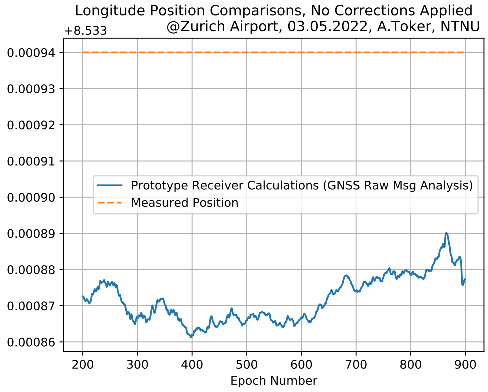

Figure 7: Navigation solution results, longitude. Experimental receiver solution with no GBAS corrections applied.

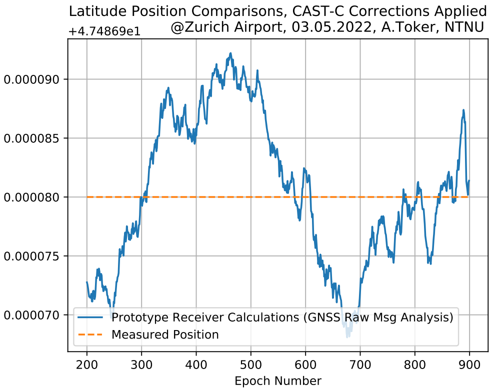

Figure 8: Navigation solution results,latitude. Experimental receiver solution with GBAS corrections applied.

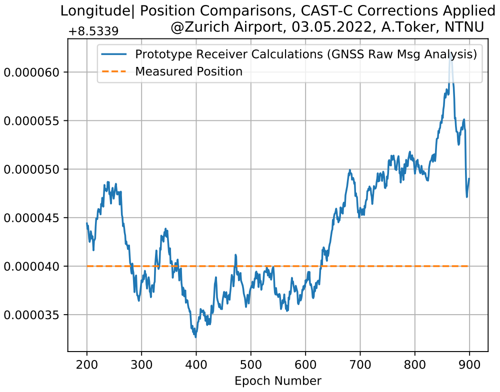

Figure 9: Navigation solution results, longitude. Experimental receiver solution with GBAS corrections applied.

4. Conclusions

In this study, a simple low cost GBAS airborne subset receiver system was developed. It supports both real-time GNSS and VDB signal capture and processing, but can also record the data for post-processing or use synthetically generated/simulated data as input if desirable. This approach has been used to allow flexibility in testing. Initial test results indicate that it is feasible to develop a GBAS airborne receiver core using low cost COTS components. As only static testing has been carried out in this study, future work includes performance evaluation in dynamic conditions. The current implementation includes only a small subset of the required integrity monitoring algorithms which is planned to be extended in the future. Platform extension to support additional frequency and constellations will also be considered.

5. Acknowledgments

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