GNSS SINGLE-FREQUENCY DEVICES AT OGS: LZER0 A COST-EFFECTIVE PROTOTYPE

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Low cost single frequency GNSS (Global Navigation Satellite Systems) receivers, usually developed for the mass market or for hobby use, recently (Eyo *et al.,* 2014) gained more importance in the surface or near surface process monitoring. Some studies have investigated the accuracy of single-frequency GPS receivers for landslide monitoring (Eyo *et al*., 2014; Squarzoni *et al.,* 2005; Janssen *et al.,* 2003). The big challenge in landslide monitoring is how to reduce the monitoring costs and the prospect of losing the equipment during a landslide event.

Dual-frequency apparatus can track at least two signals, L1 and L2, from the GNSS satellites and they are commonly used for the mentioned monitoring applications (Zuliani *et al.,* 2018) when their data are post-processed. Unfortunately they are expensive because of patents on L2.

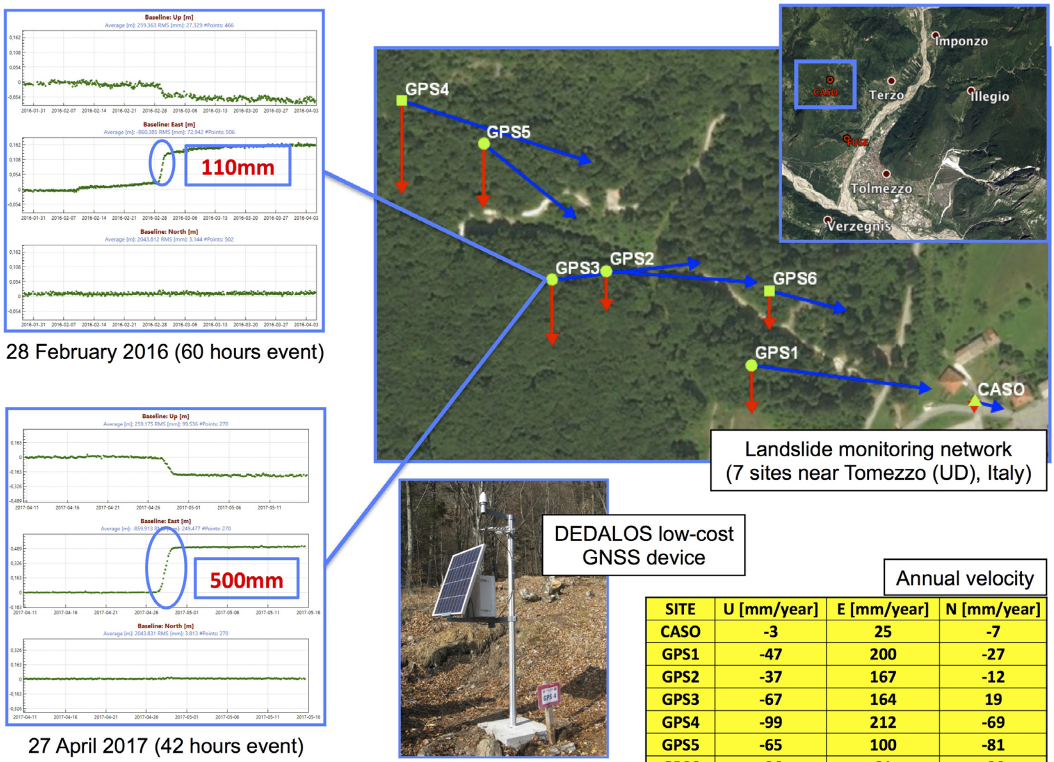
Single-frequency devices are less expensive because they just provide L1. With some limitations, respect to the dual-frequency models, they can be used anyway for positioning with sub centimeter accuracy in post-processing mode.

The single-frequency limitations can be described inside the GNSS data processing method subject (O'Keefe 2016): both single and dual-frequency GNSS data elaboration can be carried out using different techniques, the most common is called Double-Differences DD (Kaplan *et al.,* 1996; Hofmann-Wellenhof *et al.,* 2001). DD, in a standard single-baseline method, needs a Master GNSS station installed on a stable structure with respect to the Rover unit that is constrained to the monitored structure (landslide, building, bridge, road). Both Master and Rover GNSS data are combined by DD to assess the final distance, or baseline, between Master and Rover. The Use of a single-frequency dataset forces the baseline to be less than 5 km with at least 1 hour of data (Heunecke *et al.,* 2011) to reach a centimeter level accuracy. The influence of the baseline length on measurement accuracy is mainly due to the troposphere and ionosphere. Their effects can be reduced just using DD (both single and dual-frequency cases) only for the shortest baselines and when the GNSS sites are located at almost the same altitude (Malet *et al.,* 2002). However Dual-frequency equipment's con reach better performances in terms of baseline length: they provide both L1 and L2 signals to be combined before using DD to completely remove some effects such ionospheric errors. In this way the baseline limitation is extended from 5 km to different hundreds of km (Cina *et al.,* 2000).

With that difference in mind a cost-effective single-frequency GNSS receiver system can be used to monitor bridges, roads, dams, landslides when the supposed movements or deformations are within a sub centimeter level.

Centro di Ricerche Sismologiche (CRS) of Istituto Nazionale di Oceanografia e di Geofisica Sperimentale OGS, since 2015, directs a network of single-frequency GNSS sites (Zuliani *et al.,* 2016) to monitor a landslide near the Tolmezzo municipality (central Friuli, Cazzaso village). The system, called SENDAS (and now DEDALOS), achieves centimeter accuracy enough to detect the most important landslide slips (one main event in 2016 and one in 2017 as described in Fig. 1) but with a third of the dual-frequency device costs. The system can be accessed by a software Client that provides the position of each site with a minimum delay of 1 hour for near real-time monitoring.

Even precise GNSS real-time positioning techniques, RTK (Hu *et al.,* 2003), can benefit from cost-effective single-frequency devices. In real-time applications a GNSS receiver, the Rover can reach a centimeter precision in real-time if aided by RTK services such VRS, MAC or FKP (Landau *et al.,* 2002). The Rover receives GNSS corrections (double-differences approach)



SITE	U [mm/year]	E [mm/year]	N [mm/year]
CASO	-3	25	-7
GPS1	-47	200	-27
GPS2	-37	167	-12
GPS3	-67	164	19
GPS4	-99	212	-69
GPS5	-65	100	-81
GPS6	-36	81	-20

Fig. 1 - The Cazzaso landslide near Tolmezzo is mapped on the top right. 6 GNSS single-frequency devices (DEDALOS system, GPS1, GPS2, GPS3, GPS4, GPS5 and GPS6) and 1 GNSS dual-frequency device (CASO) are monitoring the phenomenon (top center map), the blue arrows show the horizontal velocities (combination of NS and EW components) and the red ones show the vertical velocities. On the bottom right the numerical annual velocities for each site. ON the left side two different plots about the same site (GPS3). They both include a huge landslide slip in the EW component caused by rainfalls. That information has been used by the municipality and by the Regional Civil Protection to alert the Cazzaso citizens and to temporarily close the access route to the village just under the landslide.

from a virtual reference station (i.e. a VRS services) placed less than 2 km away (O'Keefe, 2016). Corrections are applied to the GNSS data coming from satellites and tracked by the Rover, in this way a centimeter precision is still reachable even for single-frequency device.

CRS is currently developing and testing its proprietary cost-effective GNSS device called LZER0 for both post-processing and real-time applications. LZER0 is based on the well-known raspberry pi platform. The model we adopted is the PI ZERO W (https://www.raspberrypi.org/) with low power consumption but equipped with Wi-Fi and Bluetooth features. We decided to use this platform because of its wide range of applications and the huge user community. Raspberry is plugged to a U-BLOX GNSS single-frequency receiver (https://www.u-blox.com/en) with a Tallysman GNSS antenna (http://www.tallysman.com/). A circuit board has been developed by the CRS staff to connect raspberry to the U-BLOX receiver; furthermore the board implements a charging system for the internal LiPo battery (2000mAh) and a safe shutdown procedure (based on a PIC microcontroller http://www.microchip.com). The O.S. is a Linux Debian for raspberry called Raspbian Jessie and a 3D printed box has been project to include all the circuitry.

The GNSS elaboration running on the raspberry is performed with two packages:

- RTKLIB 2.4.3;
- BKG Ntrip Client (BNC).

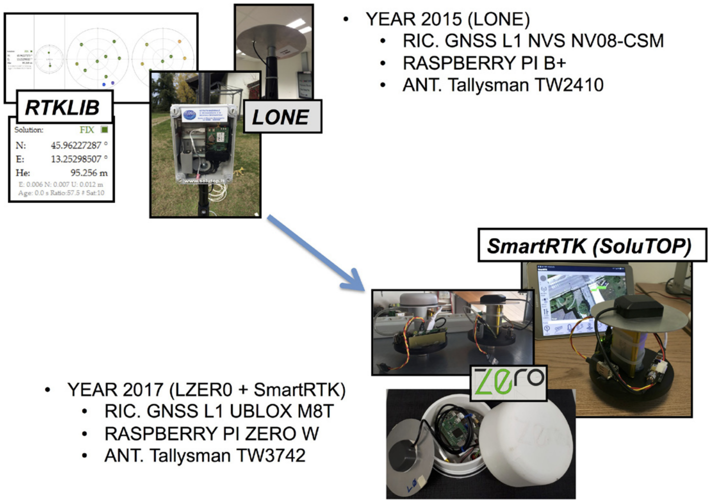


Fig. 2 - Different prototypes have been assembled before LZER0: LONE based on a raspberry Pi B+ and a NVS GNSS receivers (top left), 2 naked LZER0 versions (bottom right). All of them have been used to project the final version of LZER0 (bottom right, the circuitry included inside the white rounded box). LZER0 has been developed with the SoluTOP Company. SoluTOP has modified its geomatic software SmartRTK to include LZER0 as a real-time positioning source.

Linux shell scripts have been written to combine the RTKLIB and BNC features and to redirect GNSS data for simultaneous elaborations. Third parties software called *SmartRTK* has been adopted to collect LZER0 real-time results and to show them into a geomatic environment running on an Android Tablet (Fig. 2). As we have the full control of the FReDNet RTK engine (Zuliani *et al.*, 2018) we created specific RTK access points (called mount-points) to be used with LZER0 in real-time. The mount-points are VRASP0, VRASP1, VRASP2 and VRASP4, which enable 4 different VRS at various distances from the rover (0 km, 1 km, 2 km, 3 km and 4 km).

Currently we are testing the device on the National benchmark network called IGM95 maintained by the Istituto Geografico Militare IGM (https://www.igmi.org/). The coordinates of some regional (Friuli Venezia Giulia) benchmarks are measured with LZER0 both in real-time (with VRASP0 mount-point) and with post-processed data. Part of the tests (two of them) are made with a student of the "Istituto Tecnico I.T.G. G. Marinoni" high school of Udine included inside the Italian national teaching program "Progetto Formativo Alternanza Scuola Lavoro" for the year 2017. The results are encouraging (Tabs. 1 and 2) and differences between the known official coordinates and the results from LZER0 are within some centimeters even in post-processing with a Master station more than 5 km faraway.

Tab. 1 - IGM 025705 in Campoformido (UD) is an IGM benchmark used as references for the first LZER0 test. The Reference Frame used is ETRF2000 (2008.0), plane coordinates are UTM 33 and the quote is the ellipsoidal height of the benchmark. Differences between the reference coordinates and the LZER0 results (both post-processing mode and real-time RTK) are taken into account. LZER0 RTK coordinates are the average of 5 measures; each of them is taken after the reboot of the RTKLIB module RTKRCV. LZER0 POST-PROC coordinates are the result of a post-processing procedure performed with the Topcon Tools Ver.8.2.3. The Master station is CODR 14 km faraway and belonging to FReDNet. For the calculus a 30 min session of GNSS data, sampled at 1 s, has been used.

IGM 025705 Campoformido benchmark

TYPE	NORTH [m]	EAST [m]	H. ELL. [m]
IGM reference	5097336,565	356202,294	120,466
LZER0 POST-PROC.	5097336,578	356202,349	120,543
DIFF.	-0.013	-0.055	-0.077
IGM reference	5097336,565	356202,294	120,466
LZER0 RTK (FIX)	5097336,572	356202,327	120,525
DIFF.	-0,007	-0,033	-0,059

Tab. 2 - IGM 040801 in Palmanova (UD) is an IGM benchmark used as references for the second LZER0 test. The Reference Frame used is ETRF2000 (2008.0), plane coordinates are UTM 33 and the quote is the ellipsoidal height of the benchmark. Differences between the reference coordinates and the LZER0 results (both post –processing mode and real-time RTK) are taken into account. LZER0 RTK coordinates are the average of 5 measures; each of them is taken after the reboot of the RTKLIB module RTKRCV. LZER0 POST-PROC coordinates are the result of a post-processing procedure performed with the Topcon Tools Ver.8.2.3 from Topcon. The Master station is UDI1, 15 km faraway and belonging to FReDNet. For the calculus a 30 min session of GNSS data, sampled at 1 s, has been used.

IGM 040801 Palmanova benchmark

TYPE	NORTH [m]	EAST [m]	H. ELL. [m]
IGM reference	5084917,016	368909,649	71,181
LZER0 POST-PROC.	5084917,015	368909,651	71,256
DIFF.	0,001	-0,002	-0,075
IGM reference	5084917,016	368909,649	71,181
LZER0 RTK (FLOAT)	5084917,113	368909,598	71,346
DIFF.	-0,097	0,051	-0,165

Furthermore, repeatability tests have been made on a single benchmark (installed on the roof of the CRS venue in Udine) to test both reliability and performance of the system (see Fig. 3). LZER0 is still a prototype to be improved and developed but inexpensive and easy to command, useful for research and teaching activities.

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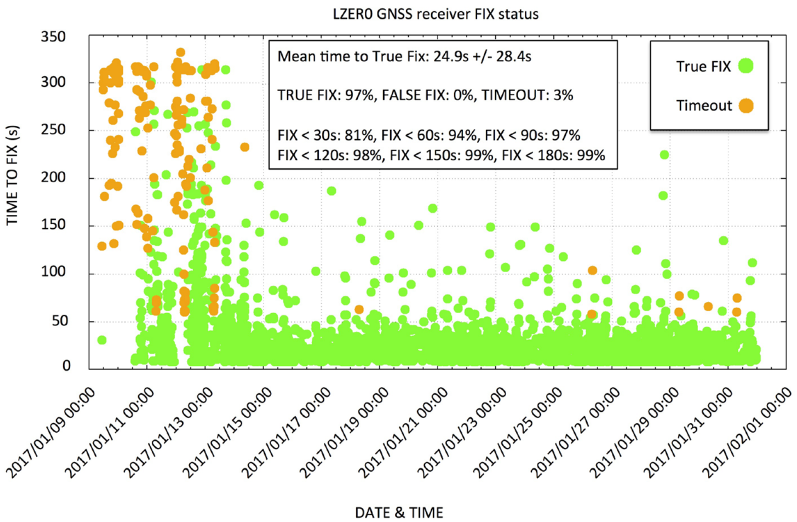

Fig. 3 - A Linux tcsh script has been written to repeatedly check the RTK engine inside LZER0. LZER0 during the tests is fixed on a benchmark with well-known coordinates. Every dot represents a single test where LZER0 is forced to restart its RTKRCV module and to reach a final solution within a given timeout. Timeout is 5min and includes not only the RTK search algorithm but also the connection to the RTK service available on the remote server. A green dot is a FIX status representing a correct solution found within the timeout and matching the benchmark coordinates. The yellow dot represents an incomplete solution because of the reached timeout. No false FIX is present. False FIX usually appears when a solution is reached within the timeout but it does not match the right coordinates of the given benchmark. Some statistics are given about the time needed to reach a correct solution.

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