Monitoring system using low cost GNSS sensors: first experiments and performance evaluation

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Abstract

This work aims to assess the possibility to use a low cost GNSS instrumentation for structural monitoring purposes. Under the assumption that about one centimeter can be the magnitude of the displacements that we aim to detect, several instrumentations were compared at different baseline distances. All the tests have been performed considering one week of observations. Different observing session time spans have been considered, ranging from 1 hour to 24 hours. Tests demonstrate that by using a single frequency receiver is not possible to achieve the requested precision for baselines longer than a km, at least if observing sessions shorter than 6 hours are needed. Nevertheless, for a baseline within a hundred meters is possible to achieve effective precisions by using a couple of low cost stations also for observing sessions of one hour. The only configuration which does not respect such performances is the one using the default "patch" antennas that we discourage for precision purposes.

Key words: GNSS Low Cost, monitoring, GoGPS, time observation windows.

1 INTRODUCTION

GNSS technology is now one of the most useful techniques both for technical applications (such as cadastre survey, precision farming, etc..) and for scientific studies (geodynamics, geodesy, etc). Usually, to achieve very high accuracies dual frequency receivers coupled with geodetic antennas are used. These instrumentations allow precision at the centimeter level or even less if considering very long observation time spans. Despite instruments cost is continuously decreasing, these equipment are still quite expensive compared to other sensors in the field of structural engineering such as inclinometer, extensimeter and so on.
The equipment cost is not a great problem for some research fields but can constitutes an obstacle in the diffusion of the GNSS technology in structural monitoring. On the other hand, specially in seismic areas like Italy, the possibility to perform continuously operating monitoring of buildings and structures such as bridges, dams, skyscrapers, etc, should constitutes a fundamental element to prevent collapses and save lives. In the last years, several low cost GNSS receivers have became available on the market, consequently many experiments have been carried out by the scientific community in order to evaluate their performance (Cina and Piras 2015; Caldera et al. 2016).
INFRASAFE (http://www.infrasafe-project.com/) is the name of a project supported by Emilia-Romagna Region that aim to define a multidisciplinary platform able to monitor and manage

all the hydraulic infrastructures of the area, in particular bridges and riverbanks. One of the considered technologies is the GNSS but, because of the great number of objects to be monitored, only low cost instrumentations are taken into account.
In this paper we report some results obtained using a low cost GNSS receiver in different configurations. The tested receiver is the U-BLOX C94-M8P coupled with antennas of different types and class. Minding the specific purposes of INFRASAFE project about the use of these instruments for monitoring, we paid attention on two main aspects: repeatability of the measures and outliers detection. Because of the need to define a low cost system, we also chosen to evaluate one of the available free (and open-source) software packages for GNSS data processing, meaning the goGPS software package (Realini and Reguzzoni 2013; Herrera et al. 2015), developed by Milan Polytechnics (IT) together with Osaka University (JP).

2 PERFORMED TESTS

The performed test has considered several aspects such as:

- different combinations of receivers and antennas;
- different baseline lengths;
- different observation time spans;

For the test we considered three sites, two used as reference stations (BOL1 and BOGA) and one acting as monitoring station (TEST). Figure 1 shows the locations of the three points and the baseline lengths relating to TEST station, which are 80m and 1600m considering BOL1 or BOGA master station respectively. All tests were performed acquiring data with a 1Hz frequency and storing daily files for a week.

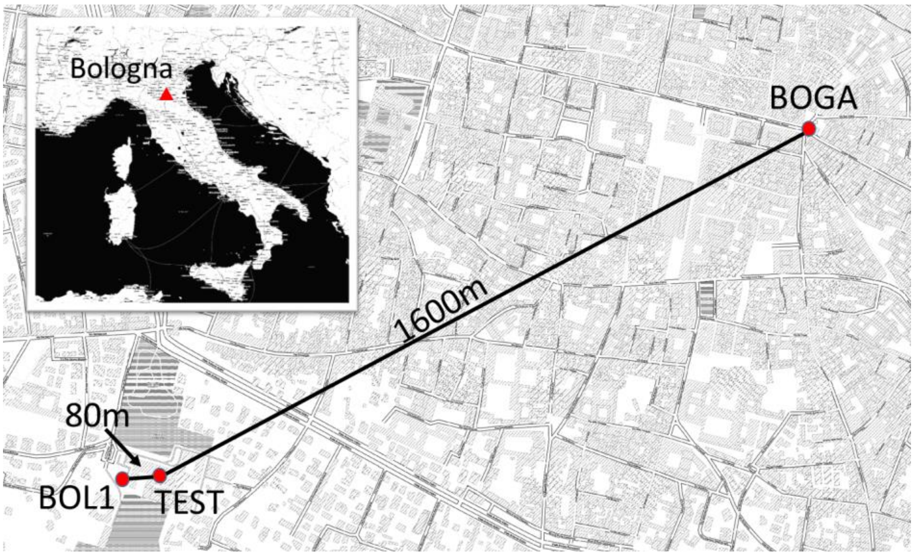

Fig. 1 Map of the baselines considered for the experimentation. BOL1 and BOGA are two permanent station equipped with a Leica GX1230GG receivers and AX1202GG antennas, while TEST is the location of the test site.

In order to design a monitoring system able to detect quite small movement (at the centimeter level), a critical aspect is the delay between the movement and the measure able to detect it. This delay mostly depends on the length of the observing session in which raw data are acquired: the longer is time span the higher should be the precisions. RTK technique by using

low cost receiver does not allow to obtain precisions at the centimeter level, but a quite higher redundancy should improve the solutions. On the other hand, a system that only allow a daily solution cannot be able to detect sudden movements due to the too long observing session. For that reason, in this test we investigated the repeatability of the solutions obtained from different length of observing sessions. The different lengths of observing session were simulated by split the daily files in shorter ones, in particular considering also time spans of: 12 hours, 6 hours, 3 hours, 2 hours and one hour.
As for the goGPS software package used for data processing, this is designed to process single-frequency codes and phase observations for both absolute and relative positioning. This software package works on a Matlab environment or in other operative system being a Java version also available. For our tests we adopted the default options suggested by the developers for carrier phase based calculations.
In the following, two different tests based on the acquired data are reported. In particular, the section 2.1 shows the comparison between 80 m and 1600m baseline lengths. Dual frequency geodetic receivers were used on master stations whereas the low cost receiver, coupled with two different antennas, was used for the TEST station. Section 2.2 reports a comparison among different combinations of instruments both for the BOL1 master and for the monitoring station. In both the sections the results are shown for all the different observing session time spans.

2.1 TEST 1: PERFORMANCES EVALUATION OF U-BLOX C94-M8P COUPLED WITH A GEODETIC GNSS RECEIVER.

A first experimentation concern the use of the low cost receiver installed on TEST site and geodetic receivers located on the master stations of BOL1 and BOGA sites. The low cost receiver has been tested using two type of antennas: the geodetic class Leica AX1202GG and the low cost "patch" antenna included in the U-BLOX *evaluation kit*.

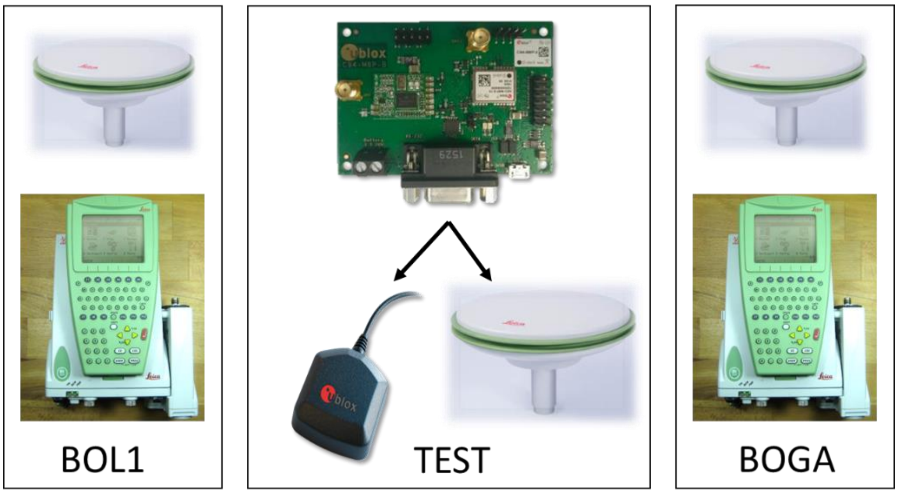

Fig. 2 Equipment considered for the Test 1.

Hereafter we report the results obtained by calculating through goGPS software all the baselines concerning the two couples of receivers and related to the different time spans of observing session, basing on one week of raw data.

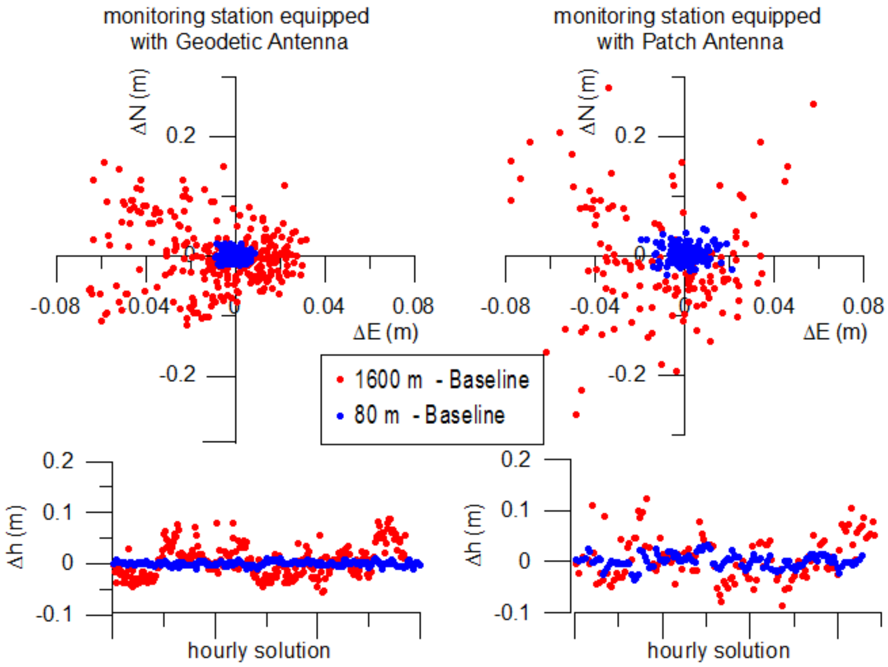

Fig. 3 Scattering of the solutions related to 1 hour of observations. Blue and red dots represent the solutions obtained using a short (80m) and a long (1.6kms) baselines respectively. Left figures are the solution obtained using a U-BLOX C94-M8P coupled with Leica AX1202GG antenna. The right figures relate the solutions given by the U-BLOX C94-M8P coupled with the default (patch) antenna.

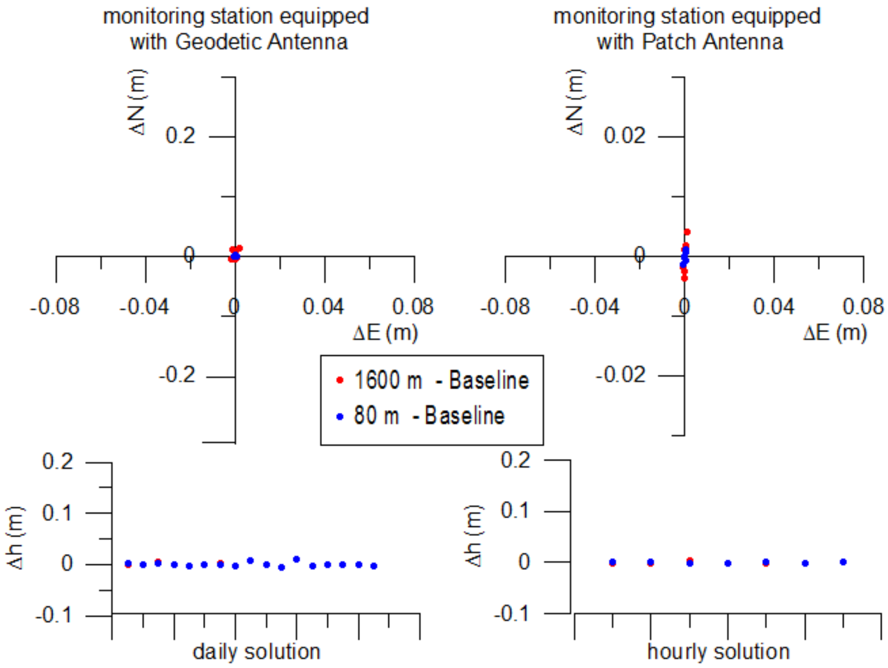

Fig. 4 Scattering of the solutions related to 24 hours of observations. Blue and red dots represent the solutions obtained using a short (80m) and a long (1.6kms) baselines respectively. Left figures are the solution obtained using a U-BLOX C94-M8P coupled with Leica AX1202GG antenna. The right figures relate the solutions given by the U-BLOX C94-M8P coupled with the default (patch) antenna..

In figure 3 and 4 we report a couple of examples related to hourly solutions and daily solutions. Each one comparing the results obtained using different baseline lengths and antennas. In these data all the outlier has been removed using a classical iterative 3σ approach that can be briefly described in the following steps:

a. for each coordinate component we estimate regression straight line using a classical least square approach;
b. we calculate the residual value of each coordinate with respect to the related straight line;
c. for each coordinate component we calculate the sample variance and the RMS of the residuals. The RMS is than used for normalizing each of the residuals;
d. considering all the coordinate components we search for the maximum of normalized residuals. If this one is major than 3 it is considered as an outlier and thus the related solution is removed. Under the hypothesis of a normal distribution of the residuals the value of 3 represent the threshold beyond which only the 0,03% of the normalized residuals should lay;
e. we iterate the whole process until none of the normalized residuals is major than 3.

Figure 5 shows a summary of the scattering of the solutions depending on the observing session time span, the baseline length and the antenna type. The scattering is represented in terms of RMS of the time series after the outliers rejection process.

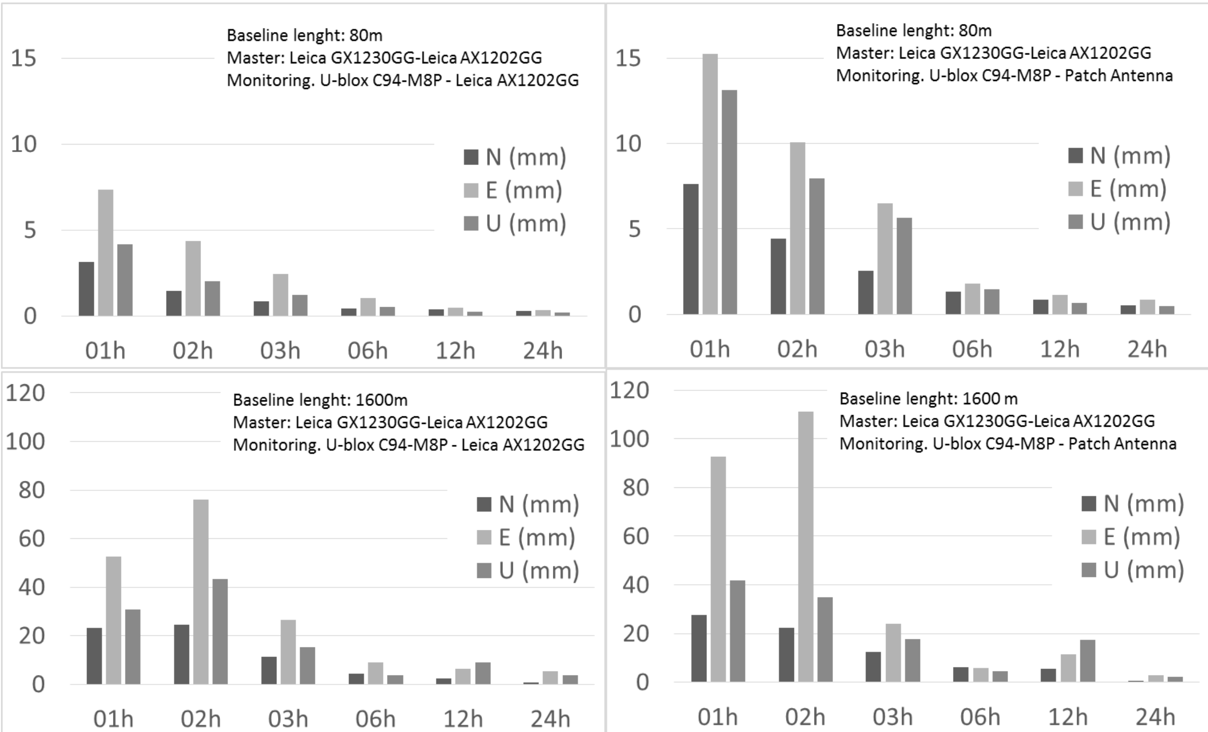

Fig. 5 Histograms of the scatterings of the time series expressed in terms of RMS for each coordinate component. Values are reported for each of the considered observation time spans. Histograms on the left relate to the use of the geodetic antenna, whereas histograms on the right relate to the use of default "patch" antenna. Top histograms relate to the shorter baseline and bottom ones relate to the longer baseline.

Figure 5 clearly evidences that the baseline length impacts dramatically on repeatability of the coordinates for both considered antennas. In particular the repeatability obtained using two geodetic class antennas varies from few mm for observing sessions longer than 3 hours up to several centimeters for shorter observations. Minding that the movements that we aim to monitor have magnitudes about one centimeter, the test demonstrate that a single frequency low cost receiver is not suitable for the purpose if the baseline length overcome the km, unless considering 6 hours of observations or more.

Completely different results were obtained concerning the shorter baseline length. In particular, also for time spans shorter than 6 hours the geodetic antenna provides a repeatability within few millimeters of RMS both for plane and height, whylst the "patch" antenna provides a precision about the centimeter level. This means that in order to detect centimetric movements a very short baseline has to be used thus requiring to find a suitable stable point as close as possible to the monitored structure.

The test shows that also the antenna type strongly impacts on the precision of the solutions. For this reason a further test has been performed in order to investigate another type of antenna, meaning a high quality low cost antenna. In particular, the Trimble Bullet^{TM} 360° was chosen for the test.

2.2 TEST 2: COMPARISON OF DIFFERENT RECEIVERS AND ANTENNAS IN THE ESTIMATION OF AN 80 M BASELINE.

For the second test we compared two different couple of instrumentations using the BOL1 and TEST sites. In particular, the TEST site has been equipped with the same U-BLOX receiver of section 2.1 and a Bullet 360° antenna by Trimble. For a first week of data acquisition the BOL1 station has been equipped with the Leica geodetic instrumentation also used in the first test, while for a second week the BOL1 data were acquired through the same instrumentation used for the TEST site.

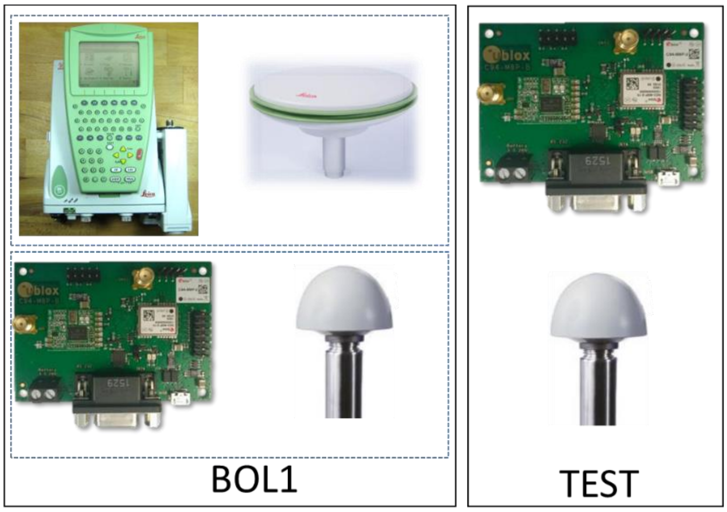

Fig. 6 GNSS equipment considered for the Test 2.

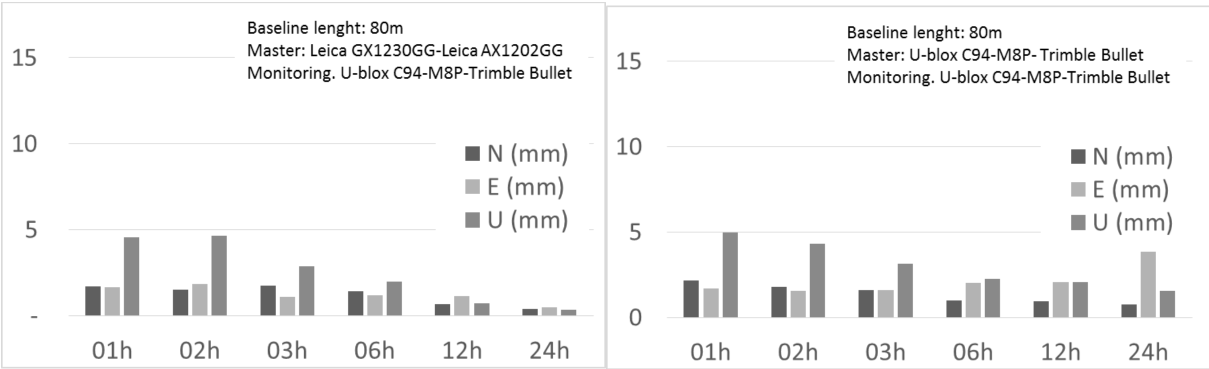

Fig. 7 Histograms of the scatterings of the time series expressed in terms of RMS for each coordinate component. Values are reported for each of the considered observation time spans. TEST site is equipped by low cost instrument: U-BLOX receiver and Trimble Bullet antenna. Histogram on the left relates to the use of the geodetic instrumentation on the BOL1 site, whereas histogram on the right has been obtained acquiring data through the low cost instrumentation on both sites.

Figure 7 reports the results obtained for the second test that shows how the use of a geodetic instrumentation on the master station does not influence significantly the precision of the baselines, in particular considering the shorter observing sessions. The two histograms show results comparable specially for short window observation times that still at a few millimetre level of repeatability. Only if we consider the 24 hours of acquisition the use of geodetic class instrumentation instead of a low cost one strongly improve the precisions.

3 DISCUSSION AND CONCLUSIONS

This work aimed to evaluate the performance of different GNSS instrumentations for structural monitoring applications, therefore considering short baselines. We assumed that the requirement for such applications is a centimeter level precision with an observation time span shorter as possible.

In the performed tests, for the rover station were used single frequency low cost receivers coupled with different antennas. A first result is that the most impacting parameter is the baseline length, that must be as short as possible (about 100 m), because considering a baseline 1,6 km long the obtained results are not suitable for the monitoring purposes with any of the tested antennas. These evidence leaded us to consider very short baselines only and investigate different antenna types: a low cost "patch" antenna provided with the U-BLOX receivers, an high quality low cost antenna and a geodetic class one.

By using a Trimble Bullet antenna on the rover receiver the obtained precisions are comparable to ones obtained by using a geodetic antenna. Moreover, also testing a different master station, equipped with low cost instrumentation (U-BLOX receiver and Bullet antenna) showed that the repeatability of the measures is quite the same obtained using a geodetic master station, at least for the observing sessions shorter than 12 hours.

Finally, the package of two U-BLOX C94-M8P receivers and two BulletTM 360° antennas has a cost within a thousand euros (dollars?), much lower with respect to a single geodetic receiver. Using these instrumentations for baselines not longer than a kilometer the test demonstrates that precisions suitable for monitoring purposes can be obtained also for observation time spans of one hour. Further tests are on going using a micrometric sleigh in order to assess the actual capability of the low cost GNSS instrumentations to recognise sudden movements about one centimeter.

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