Using GNSS Observation for Mitigating the Impact of SODs and RODs on the Built Environment – Introducing the New SNIK Continuously Operating Reference Station and Its Applications

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Abstract. Continuously Operating Reference Station (CORS), based on GNSS observations, are widely used in many fields, both scientific and professional, related to the need of precise positioning. Several GNSS-based applications deal with the safeguard of the cities and, consequently, their inhabitants, from the effects of Slow-Onset Disasters (SODs), and Rapid Onset Disasters (RODs). With the focus of reducing the impact of these critical events on the built environment, by guaranteeing a more accurate and continuous monitoring, a new CORS, named SNIK, was installed by the research group Applied Geomatics Laboratory (AGlab) at the Polytechnic University of Bari, with the support of Stonex Italy. At the same time, an integrated test field, consisting of four GNSS rover receivers so far, was planned to be implemented on the new Rectorate building, currently under construction. The test field is set up to be upgraded with additional sensors, such as SAR corner reflectors, accelerometers, and weather stations. The availability of a continuous stream of GNSS observations will allow the development of new algorithms and approaches aimed at facing the consequences of potentially catastrophic events over the short and long-term period and implementing strategies aimed at mitigating their impact on the safety and the healthiness of the cities.

Keywords: Geomatics monitoring of structures · Displacement monitoring · Structural health monitoring · CORS · GNSS reference station · RODs · SODs · Tropospheric water content

1 Introduction

Due to heavy anthropogenic pressure suffered by large portions of our countries, natural events such as landslides, subsidence, earthquakes and heavy rainfalls with flooding are having a growing impact on structures and infrastructures, and the built environment in general. In most cases, these occurrences also cause a significant loss of human lives, especially in countries with a large presence of historic towns.

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Over the long-term period, very slow phenomena, such as the global warming, closely related with the climate of the cities, pollution and rainfall levels, energy requirement and ageing of constructions [1], add their negative effect on the safety of structures and the healthiness of our towns.

For instance, as a direct consequence of the climate change, heavy rainfalls (water-bombs) are becoming increasingly frequent, and, in some cases, may have a devastating effect on the territories, cities and population, as described in [2].

Such critical occurrences, with reference to the catastrophes they can lead to and how fast they can occur, are generally referred to as Slow-Onset Disasters (SODs), and Rapid Onset Disasters (RODs), as stated by United Nation [3].

The mitigation of the impact of SODs and RODs on the safety of territories and cities may be included among the major challenges of the coming years.

In the context of an integrated approach that must encompass multiple disciplines, innovative strategies implemented starting from data acquired by GNSS reference stations can help to develop tools aimed at tackling the effects of these occurrences on the built environment and their users.

To this end, a brand-new CORS is currently about to be installed at the Faculty of Engineering at the Polytechnic University of Bari (PoliBA), Italy.

Under the acronym CORS (Continuously Operating Reference Stations), reference is made to GNSS (Global Navigation Satellite Systems) permanent stations using the satellite systems orbiting the Earth for positioning and navigation purposes.

A continuously operating reference station consists of a high-precision GNSS receiver and antenna, placed on a safe mounting structure.

A CORS should guarantee:

- a full and non-stop operation (24/7);
- the logging and the (possibly redundant) storing of raw data;
- if included in GNSS networks aimed at providing positioning services [4], also the streaming of collected data useful to perform real-time positioning and/or observations for post-processing;
- its stability over a long-term period through an appropriate choice of the installation site.

Since 1990-ies, CORS started to be established around the world to support high-precision positioning applications. At the very beginning, GNSS reference stations have been used mainly in the framing of global geodetic networks, the monitoring of geodetic reference systems/frames [5–8] and crustal deformations [9–12]. In the last three decades, an increasing and extensive usage of GNSS data, both broadcasted in real-time or acquired and stored for post-processing, there has been in applications such as geomatics monitoring of structures [13–15], ground motion control [16–18], precise farming, machine guidance, and seismology [19–21]. In more recent years, GNSS data have also been widely employed in the automotive field for navigation and assisted/autonomous driving [22–25].

A very interesting application of GNSS observations in evaluating the effects of natural occurrences in structures can be recognized in the use of Precise Point Positioning (PPP) technique for assessing the seismic effects on constructions [26]. Focusing on

the study of the seismic risk, earthquake effects derive from the combination of local conditions (e.g., seismic micro-zonation) and different level of vulnerability as inherent qualities of buildings. Therefore, the GNSS monitoring process of weak areas (or buildings) naturally exposed to earthquake can help technicians in evaluating post-emergency damages (e.g., horizontal and vertical displacements).

When GNSS is combined with Precipitable Water Vapor (PWV) measurements, retrieved by using the tropospheric delay parameter, it can provide support in the analysis of climatological events. It is the case of flash floods [27, 28], fast meteorological events caused by sudden rainy occurrences, that can increase the total risk for cities and their parts (not only near to basins) when combined with the low drainage capacity of urban surfaces. Here, the effects on the Built Environment can be amplified when buildings are already characterized by a poor state of maintenance or increased by local modification of the natural terrain profile [29, 30]. Thus, if PWV data can help in providing a quick alert system for people and local emergency groups when measurements are linked to a network system (pre-emergency relevance), their combination with GNSS data can help in recognizing the long-term effects on the built environment (i.e., horizontal translations and assessment of post-event damages).

Near such rapid events, GNSS observations can also be applied for the indirect evaluation of slow events related to climate changes [31]. The process of desertification is a direct effect of the modification of the precipitation mode/rate, as in the Mediterranean area. The monitoring process, over the long period, of PWV measurements can support the analysis of a) local variation of such local meteorological features when single stations are considered and b) wide territory when the monitoring is included in a coordinated network of measures.

In the context of the mitigation of the impact of potentially critical occurrences, the precise positioning and tracking of people acting in a built environment constitute a key factor in the improvement of high-resolution spatial models simulating the behaviour of people under certain constraints. For example, modelling approach for social system analysis suited for spatial simulations resulting from the dynamic development of multiple local interactions of heterogeneous human-like actors, such as the Agent-Based Model (ABM), can reproduce in a realistic manner human-scale behaviours, which are usually stochastic in nature, in order to capture complex macrophenomena of real-life systems [32]. ABMs are applied to study many types of collective complex systems, ranging from crowds of people, urban traffic networks, companies' market competition, emergency evacuations, to biological systems [33].

In this powerful model, which is helpful for describing the human behaviour during emergencies, GNSS observations could provide useful data aimed at validating risk analyses based on predictive model estimation of the combined impact of SODs and RODs on people.

The above-mentioned applications show how the availability of reliable GNSS data, provided by CORS networks, constitutes a relevant support in many scientific fields related to geosciences and, at the same time, how this methodology is constantly boosting the development of technologies devoted at monitoring and preserving the territory, its infrastructures, and their users.

2 The SNIK CORS

Following the EUREF permanent GNSS network indications (requiring a four-character abbreviation code for the unique identification of a CORS), the PoliBA Reference Station has been named SNIK.

The SNIK CORS is based on a high-precision Stonex SC2200 GNSS receiver equipped with a SA1500 choke-ring antenna (Fig. 1). Stonex Italy is supporting the AGlab, by supplying its high-end sensor, in developing innovative approaches and algorithms to be applied in the use of GNSS observations.

After the installation phase, PoliBA will start the procedure to include the CORS in the EUREF Permanent Network (EPN), that is the "federation of over 100 self-funding agencies, universities, and research institutions in more than 30 European countries working together to maintain the European Terrestrial Reference System (ETRS89), namely the single Europe-wide standard coordinate reference system adopted by the European Commission" [34].

Due to its capability to permanently get observations from most of the recent satellite constellations designed for positioning purposes, in addition to the "traditionally" available GPS and GLONASS positioning systems, SNIK will be the first institutional reference station in the Apulia Region able to track the European GALILEO and the Chinese BeiDou systems.

As widely demonstrated, [35–37] the opportunity to acquire and process multi-GNSS observations provides relevant benefits to the achievable positioning accuracy and consequently, the quality of the GNSS-based possible applications.

The analysis of GNSS dataset will also take advantage from the presence of rain gauge already installed in close proximity (about 50 m) of the SNIK station, framed in the Apulian Civil Protection weather station network (Bari Campus pluviometer [38]).

The main specifications of the SNIK CORS are summarized in Table 1.

Table 1. The SNIK CORS – Technical specifications

Receiver	Stonex SC2200
Satellite systems tracked	GPS/Glonass/BeiDou/Galileo
Position rate	5 Hz
Precision in positioning – Horizontal	3.0 mm
Precision in positioning – Vertical	3.5 mm
Antenna	Stonex SA1500 Choke Ring with RADOME
Noise	$\leq$2 dB
Waterproof/Dustproof	IP67

The SNIK permanent station will also contribute to develop the ResCUDE (RESilient Cultural Urban context to Disaster Exposure) project, aimed at facing RODs and SODs effects on the urban setting by mean of a holistic methodology that includes geomatics



Fig. 1. Stonex SC2200 GNSS receiver with SA1500 choke-ring antenna

disciplines, resilient urban methodologies, land-use and managing techniques and an agent-based approach, as better detailed in [1].

Focusing on the safety of people and the built environment, the opportunity to take advantage from a comprehensive database of high-precision position data and additional information that can be retrieved from GNSS permanent stations (e.g. precipitable water vapor content in the troposphere [39]) will permit to implement innovative algorithms and strategies useful to improve:

- the geomatics monitoring of building/structures (control of displacements, implementation of early warning alert systems, structural health monitoring - SHM purposes);
- the monitoring of subsidence, both natural and induced by human activities (e.g. excavations, construction works);
- the reconstruction of earthquake waveshapes to retrieve information for the seismic risk;
- the short-term forecast on heavy atmospheric precipitation (waterbombs) by evaluating the tropospheric water content;
- the tracking of pedestrian paths using mobile devices to be used in innovative agent-based models;
- the accuracy in vehicle positioning/tracking in applications related to assisted/autonomous driving;
- more in general, to boost the analysis in the field of the positioning and navigation-related issues.

In this long-term program, the SNIK permanent station will be the core of a test field which includes the installation of four additional GNSS rover receivers on the roof of the new Rectorate Building (currently under construction), and the future integration with

different sensors (Table 2). To date, accelerometers, active SAR (Synthetic Aperture Radar) corner reflectors and a weather station are planned to be installed in the next year(s).

Table 2. Sensors planned for the test field

Sensor	Application
GNSS	Displacement and acceleration detection, SHM
SAR corner reflectors	Subsidence, SHM
Accelerometers	SHM
Weather station	Metereological parameters to be related with observations

The scheme of the test field is showed in Fig. 2.



Fig. 2. Location of the SNIK CORS (red square) and the new Rectorate Building (blue square) (Color figure online)

3 A First Application for Structure Monitoring – the Geomatics Monitoring System of the New Rectorate Building at PoliBA

As aforementioned in Sect. 1, four high-precision Stonex SC600A GNSS receivers will be placed on the roof of the new Rectorate building at the PoliBA, currently under construction. The four receivers will act both as rovers (in differential positioning applications with the SNIK station) and single monitoring points.

These sensors constitute the first piece of a multi-sensor test field useful for the assessment of innovative algorithms to be used in the evaluation of SODs (e.g. climate change, slow subsidence, ageing) and RODs (e.g. earthquakes) on a structure. The receivers will be installed on the building as soon as the construction works will end, introducing a good practice aimed at the preventive monitoring during its whole life cycle.

The need of a new paradigm in the control and maintenance of the built environment, which is essential for ensuring its safe fruition and avoiding potentially critical events (i.e. large deformations or, at worst, collapses) arises, especially in light of the destructive occurrences that interested the Italian infrastructural asset during the last years (e.g. the recent collapses of the road bridge between Albiano Magra and Aulla (Tuscany), Italy, in April 2020, of the Morandi bridge in Genoa, Italy, in August 2018.

In this frame, an effective management strategy should include a real-time geomatics monitoring of our cities; this approach can be easily implemented (in particular on newly constructed buildings) and can now rely on a new generation of low-cost GNSS receivers which can be simply architecturally integrated in the structure and remotely controlled.

Additional sensors will be gradually added, giving the opportunity of correlating different information (e.g. accelerations with displacements, rainfall with tropospheric delay).

Main technical specifications of the GNSS receivers are listed in Table 3.

Table 3. Technical specification of the GNSS receivers

Receiver	Stonex SC600A
Satellite systems tracked	GPS/Glonass/BeiuDou/Galileo,
Position rate	10 Hz
Precision in positioning – Horizontal	3.0 mm
Precision in positioning – Vertical	5.0 mm
Antenna	Stonex SA65
Noise	$\leq$2 dB
Waterproof/Dustproof	IP67

4 Conclusive Remarks

The increasing accuracy of high-precision GNSS receivers and their decreasing cost is favouring the establishment of continuously operating reference stations. GNSS observations acquired by CORS (and CORS networks) constitute a consolidated and powerful tool for the understanding of issues related to the need of a precise positioning.

In this frame, the mitigation of the impact of RODs and SODs on the built environment and their users can strongly benefit from the analyses of extensive GNSS dataset, by taking advantage from the opportunity to obtain the position of a receiver (stationary or mobile) with high precision and retrieve additional information on parameters directly related with the climate. The SNIK permanent station will allow to have available a continuous stream of observations and develop new approaches to face the consequences of potentially catastrophic events over the short and long-term period.

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