Collaborative RTD for Precise and Reliable GNSS Based Positioning for Land Management

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Abstract Global Navigation Satellite Systems (GNSS) easily allow precise determination of position, velocity and time (PVT) enabling hundreds of different applications in almost any field of modern life, from transportation to logistics, from surveying to disaster management, from natural resources monitoring to services for citizens. In this field, the collaboration involving the NavSAS group at Politecnico di Torino and Fondazione LINKS (former ISMB) together with the NAVIS group at HUST is lasting since more than 10 years. Besides focusing on basic research aspects that provide knowledge and skills, which are essential for achieving excellence and expertise, a considerable effort has been devoted to the development of technological solutions that allow precise and reliable PVT determination, which is crucial in land management and environmental applications. In particular, a low-cost prototype GNSS receiver named NavisA has been developed. The equipment can ensure an accuracy in the range of some centimeters and is therefore suited for land management applications. The equipment was tested in different conditions by independent investigators that verified its performances confirming that it can contribute to the modernization of the land management sector in Vietnam, where traditional time-consuming total station measurements are still widely used.

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1 Introduction

International collaboration has been widely promoted at Politecnico di Torino since long time. In a first stage, it was mainly directed towards European and North American institutions. However, with the general progress of culture and science in a globalizing world, at the end of last century, collaborations with institutions of other regions became more frequent. This change was also facilitated by the European Union that started funding educational and RTD collaborative projects involving institutions based in countries that were not traditional partners of previous RTD activities. It is in this framework that, in the late nighties, just at the time in which Vietnam was restoring its links with western economies, Politecnico di Torino started its collaboration with the Hanoi University of Science and Technology (HUST) in the framework of different EU funded projects.

Almost in the same period in which the first connections between Politecnico di Torino and HUST were setup, the European Union (EU) decided to develop its own Global Navigation Satellite System (GNSS) Galileo. Several reasons suggested this move that had a very important practical impact on RTD in Europe, since it became urgent to increase the European expertise in GNSS technology to support the considerable effort needed to setup the new system. Important funding was allocated to promote the growth in Europe of this field of study and technology development. To support the setup of the Galileo System and facilitate its future adoption by potential users, the EU supported also several awareness raising actions aimed at providing better knowledge of the new system under construction, of its features and advantages. Preliminary studies and testing of new applications were also promoted to prepare market opportunities for the time in which Galileo would have been fully operational. Europe has obviously been the first and more important recipient for these actions; however, considering the global nature of the foreseen Galileo system and the European positive attitude for international cooperation, considerable energies and resources were also devoted to international collaboration.

In the first years 2000, at Politecnico di Torino and at Istituto Superiore Mario Boella (ISMB), a research institution strictly related with Politecnico that became operational at that time, a very active joint research group (NavSAS) focusing on GNSS technology and related applications was setup and started working actively in research and education. Leveraging the existing links with HUST and the European support for international collaboration, in 2004 the first collaborative project in the field of GNSS was setup. It involved ISMB, Politecnico di Torino and HUST together with Universitat Politecnica de Catalunya, and Southeast University in Nanjing, China.

In following years, the collaboration in the field of GNSS between Politecnico di Torino and ISMB on the Italian side, and HUST on the Vietnamese side, strengthened and grew quite considerably. With the support of the SEAGAL Project, an initiative funded by the EU in the FP7 framework, the NAVIS Centre was setup at HUST and started its operations in October 2010. Its mission was, and is, to act as linking entity between Europe and South-East Asia (SEA) in the field of Global Navigation Satellite

Systems, promoting European technology by reinforcing cross-links between EU and SEA actors and facilitating international collaboration among players.

From 2010 onwards, the collaboration between the NavSAS Group in Torino and the NAVIS Centre in Hanoi has continuously developed and increased, also thanks to different EU funded projects as well as to activities funded by the Italian and Vietnamese Governments in the framework of the Executive Programme of Scientific and Technological Cooperation between the Italian Republic and the Socialist Republic of Vietnam. A timeline reporting the main research projects in which the NavSAS Group and the NAVIS Centre have been involved is reported in Fig. 1, where also the main steps in the setup of the Galileo System are reported. While developing its activities, the NAVIS Centre has setup important research links with outstanding institutions such as the European Space Agency (ESA), the Institute for the Protection and Security of the Citizen of the European Commission Joint Research Centre (JRC-IPSC), the Japanese Space Agency (JAXA), the Australian Centre for Space Engineering Research (ACSER) and has reached some important technical achievements like being one of the first 50 users in the world of the Galileo system, as certified by ESA.

Besides being engaged in research projects, the NAVIS staff has always devoted keen attention to technology transfer actions that can contribute to the growth of the Vietnamese society and to its technological development. Among them an important activity has been the development of a low cost GNSS receiver which anyway provides good accuracy and can be customized to fit the needs of local Vietnamese users.

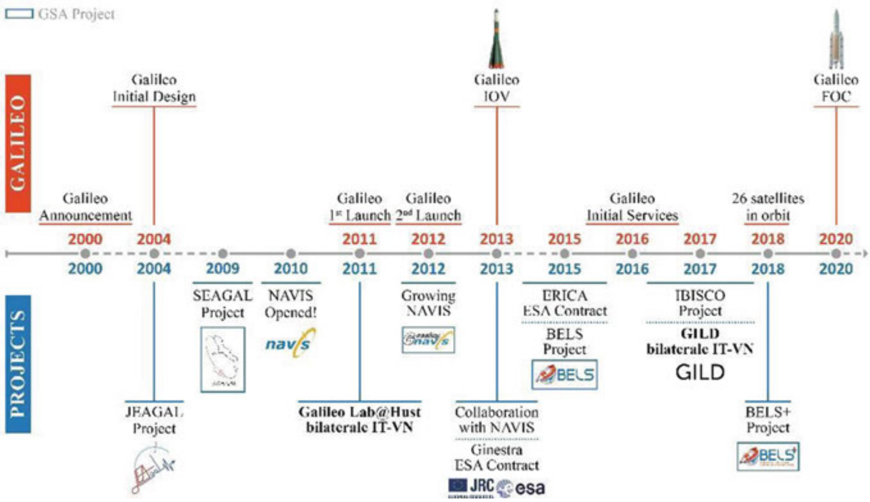

Fig. 1 Main joint research activities linked to the major steps in the development of the Galileo System

Different prototypes of this receiver, named NavisA, have been developed in past years always improving its functionalities. The target applications for this equipment are those in the field of surveying and mapping as well as land monitoring in which centimeter level accuracy is commonly required and large amount of measurements are often needed. The NavisA has been also used for setting up a small research-oriented CORS network before the Department of Surveying, Mapping and Geo-Information of Viet Nam started deploying the Vietnamese CORS network that is now operational. With this equipment and with its related applications, the NAVIS staff won the first prize at the Vietnam Talent Award 2015.

In this paper, the NavisA GNSS receiver is presented together with the research oriented NaviNet CORS network that was setup for research purposes at the NAVIS Centre. The outcomes of some tests performed on the NavisA receiver for testing its performances are reported as well.

2 Background

In Vietnam, surveying, mapping and land monitoring are still conducted to a large extent through traditional methods (total stations and trilateration). With this approach, the points where measurements are performed need to be in view from each other. This is indeed a quite strict requirement that can increase the complexity of a survey measurement. On top of this, considerable time is needed to collect measurements and to elaborate them. When instead GNSS technology is used, often this is done with static receivers that need to stay for long time in each measurement point in order to ensure acceptable accuracy. This solution is obviously time consuming and not efficient.

However, GNSS technology nowadays provides better solutions based on the use of receivers which can provide good accuracy also in dynamic conditions in which the receiver is moved around almost continuously. Surveying is obviously much faster and more efficiently conducted when using this kind of receivers. However, while there are several receivers of this kind on the market, their price is quite high for the Vietnamese contest, and this fact has been preventing their wide adoption.

Noting these facts and recognizing the interest in the Vietnamese society for the development of technological solutions in line with the demands of the local society, the NAVIS Centre started to work on a project for the development of a low cost GNSS receiver providing centimeter level accuracy using up-to-date technological solutions but standard components available on the market. This activity has also been partly supported by some Vietnamese national research funding.

With GNSS technology, the position on earth of a GNSS receiver is obtained first computing its distance from different GNSS satellites, whose position in sky is known, and then deriving its position by trilateration. The final accuracy and precision of the computed position depends on whether the distance from satellites is derived using only the code transmitted to the receiver or also the phase of the carrier signal. Furthermore, it is affected by different error components related to the satellite orbits, the clocks on board the satellites, the effect of the ionosphere and of the troposphere on the signals traveling through them.

To achieve high positioning accuracy, it is required on the one side to use carrier phase measurements, on the other side to reduce to the largest possible extent the measurement errors (Subirana et al. 2013).

Two main approaches have been developed in GNSS technology to perform this last task: Real Time Kinematics (RTK) and Precise Point Positioning (PPP).

2.1 Real Time Kinematics

Real Time Kinematics (RTK) is the most commonly used precise positioning method providing decimeter (or even centimeter) level precision in real-time. Besides using carrier phase measurements, in this approach most of the error components in the distance determination between receiver and satellites are eliminated implementing a differential measurement strategy. It consists in using two receivers: one in a fixed position (the so-called base station) while the second (the so-called rover) is moving around to take measurements in different points. Assuming that the errors in the determination of the distance between satellites and receivers are almost the same for the rover and the base station (which is true if the distance between the two does not exceed 20 km), the differential measurement allows deleting most of the error components providing a very accurate determination of the relative position between rover and base station. If the position of the base station is precisely known, which can be the case if the base station is in a known reference point or if it has been in position for a sufficiently long time allowing a very accurate determination of its position, then also the absolute position of the rover is very accurately known.

Indeed, the main disadvantage of RTK is the need of a reference station closed by. The requirement can be overcome if a CORS network of reference stations is available. This infrastructure consists in a network of reference stations interconnected through NTRIP servers to a NTRIP Caster that can broadcast corrections through the internet to any connected rover operating within the area covered by the RTK network. Indeed, the cost of such infrastructure is related to its extension, and to the number of connected reference stations but in general is quite large. Interested readers can refer to (Mekik and Arslanoglu 2009) and (Gakstatter 2013) for more details on RTK.

2.2 Precise Point Positioning

Precise Point Positioning (PPP) is a different approach to precise position determination. Using dual frequency receivers, the important error component connected with the ionospheric delay, which is frequency dependent, can be removed using a linear combination of measurements at the two frequencies. In addition, accurate corrections provided through the internet are used for orbits and clocks. These corrections are derived with different models and solutions by the International GNSS Service (IGS) which makes use of the data collected by a global network of receivers covering the whole world. Since 2010, IGS is running a pilot project in which registered users can access free of charge its real-time correction data. Interested readers can refer to Grinter and Roberts (2013) and Rizos et al. (2012) for more details on PPP.

3 The NavisA Receiver

At the NAVIS Centre keen attention has been devoted in past years to the development of a low cost GNSS receiver, the NavisA, that provides good accuracy and can be customized to the needs of the Vietnamese users. Different prototype versions of it have been developed, constantly improving the characteristics and the features of the equipment. All the versions have been designed using off-the-shelf components and chipsets. At the beginning in 2013 a very simple single-frequency receiver was built as training prototype used for familiarizing with all practical problems related to the construction of this kind of equipment. Following versions were dual-frequency receivers in which both technical performances and friendliness of use were constantly improved. With these receivers both the RTK and the PPP solutions have been implemented. The latest version of this receiver is shown in Fig. 2 and is described in more detail hereafter. It should be noted that in this version the RTK solution is implemented relying on the corrections provided by the CORS network recently setup in Vietnam by the Department of Survey and Mapping while the PPP solution is derived using IGS NTRIP streams available at the following link https://

Fig. 2 NavisA presented to Prime Minister of Vietnam Mr. Nguyen Tan Dung

Fig. 3 GNSS receiver module of NavisA: it can be connected to an android tablet through Bluetooth or with a cable to a PC

www.igs.org/rts/products. However, the receiver can also work together with a base station that has also been developed at the NAVIS Centre and was commonly used with previous prototype versions.

The latest NavisA is split in two parts and the one with the GNSS receiver (see Fig. 3) is quite compact, light with limited power consumption. It is implemented with the dual-frequency Hemisphere (P306) chipset integrated with a Bluetooth transceiver module that ensures the connection with an android-based tablet to which it provides the raw pseudorange and phase measurement data. On the tablet, all the software programs that implement RTK or PPP solutions are allocated and run. These programs elaborate the raw pseudorange measurements together with relevant information retrieved through internet using the GPRS connection of the tablet. When implementing the RTK solution, the information retrieved through internet typically consists in the corrections received from the CORS network setup and managed by the Department of Survey and Mapping and Geo-Information of Viet Nam. Of course, it is possible to use also other networks, or the data provided by a base station. When implementing the PPP solution, IGS corrections are retrieved from internet. The Graphic User Interface (GUI) presents all relevant information on the tablet screen in a user-friendly way. Obviously, still an antenna must be connected to the receiver. With this solution, the whole equipment results to be of quite easy use and turns out to be very portable.

To test the performances of this equipment, different pilot experiments have been conducted and are described in Sect. 5.

4 NaviNet: A Small CORS Network of NavisA Receivers

In 2015, when the Department of Surveying, Mapping and Geo-Information of Viet Nam had not yet deployed its CORS network, the NAVIS Centre has been running for some months a small research-oriented CORS network, named NaviNet, covering a limited area in the Hanoi city. The stations of this network were equipped with NavisA receiver modules (like the one shown in Fig. 3) each one connected to a PC and through internet to the server at the NAVIS Centre. The locations of the stations together with some information about each one of them are shown on in Fig. 4.

The server at the NAVIS Centre, besides storing the data from all the stations, made them available to registered users for research purposes. An experimental service providing post processing corrections was also operational for some time.

Since the CORS network managed by the Department of Surveying, Mapping and Geo-Information of Viet Nam has become operational, this network was dismounted and only data from the receiver at the NAVIS Centre can still be accessed by registered users for research purposes.

The experience gained with this experimental CORS network has been very valuable. It has supported research and demonstration activities allowing also to show to different authorities the advantages of this kind of solution. It has also facilitated some demonstration activities conducted in the framework of the European funded project BELS (Povero, et al. 2015).

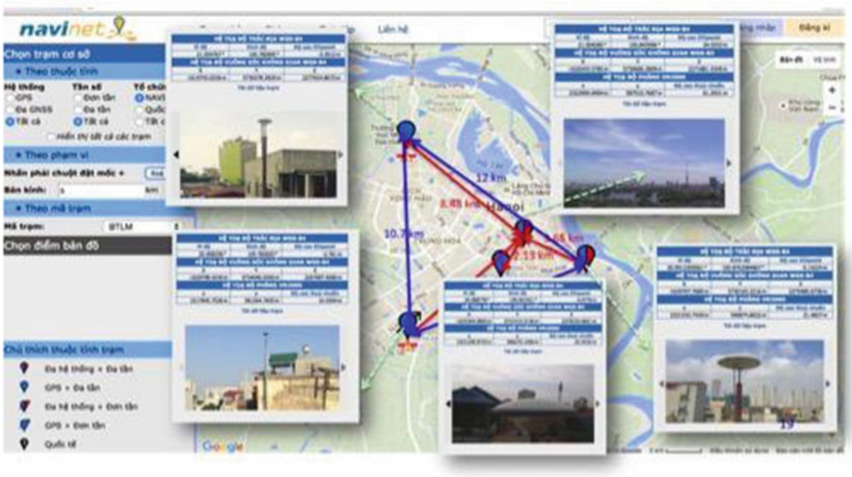

Fig. 4 NaviNet, a small-scale network of NavisA receivers to provide differential correction for precise positioning

5 Experiments and Pilot Testing of NavisA Receiver

Several experiments and tests were conducted to assess the performances of the NavisA receiver and to compare them with those provided by traditional methods employing total stations, the conventional equipment still widely used for this kind of task in Vietnam. This comparison had also the scope to allow potential users of the NavisA receiver to verify that its performance is as good as that of traditional methods but much less effort and time is required to acquire measurements and results.

5.1 Experiment at the Hanoi University of Science and Technology

A first test to evaluate the performances of the NavisA was conducted in the premises of the Hanoi University of Science and Technology where the NAVIS Centre is located. A pattern, to be followed by the receiver antenna, was drawn on the floor of the court of the university and then it was carefully followed with the NavisA antenna.

The positions provided by the NavisA were reported on a grid with centimeter-resolution and are shown in Fig. 5 both for the RTK solution (green points) and for the PPP solution (orange points).

From this experiment it can be noticed that in both cases a centimeter-level precision is continuously obtained.

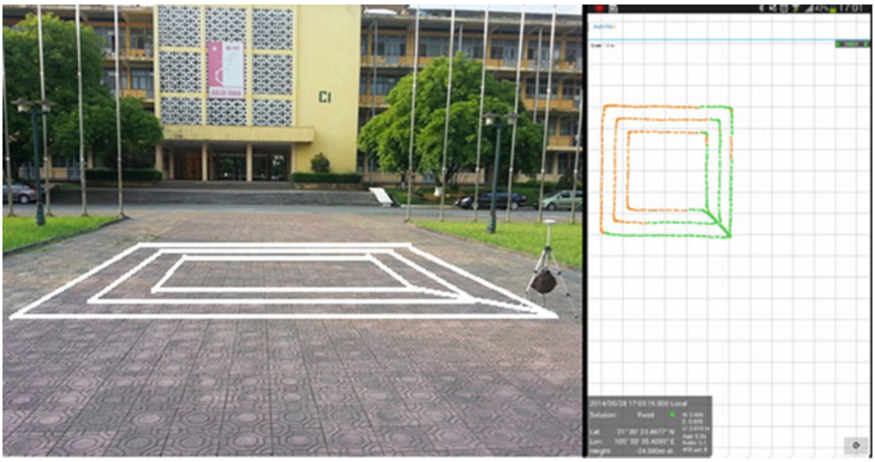

Fig. 5 Experiment for testing the NavisA receiver at HUST campus

5.2 Surveying Angular and Distance Framework Measurement

In this experiment, a set of seven points placed on the perimeter of a construction site had to be accurately located to be used as reference points for the construction surveying. The position of each of these points was determined with the NavisA receiver as well as with the traditional total station method. The two methods provided almost the same outputs. The differences in the distances between adjacent points evaluated with the two methods were all under 1.5 cm.

5.3 Measurements of Earth Crust Movements

The NavisA receiver has been used by officers of the Surveying, Mapping and Geo-Information Department to test whether it could be used for monitoring slow land movements like the ones occurring in landslides (Quang 2018). In this study, investigators evaluated the height retrieved with the NavisA receiver in a set of points for which the official height was also available from the database of the Surveying, Mapping and Geo-Information Department. One of the points was then chosen as reference and the differences in height between all the tested points and the reference one have been computed using the NavisA measurements as well as using the official data. The difference in the obtained results with the two data sets was typically in the range of 1 cm and in any case not larger than 2.5 cm. Thus, the surveyors, considering usual practices in Vietnam for landslide monitoring, found the results satisfactory and concluded that the NavisA could be used for monitoring landslide movements.

5.4 Topographical Survey for Construction Site

Another test was autonomously performed by a construction company that borrowed the NavisA equipment and tested it. In the test, 3D positions of some test points were derived with the NavisA and with the traditional total station method. The results of their comparison were provided to the NAVIS and are reported in Table 1.

It can be noted that the differences between the measurements performed with the two methods are rather limited, in the range of some centimeters, with maximum values of 9.8 cm for X direction, 5.1 cm for Y direction and 5.0 cm for the height. It should be noted that the measurements were obtained with two independent methods, thus their individual errors can add up when computing their difference.

Being satisfied with the performances of the NavisA, the construction company used it together with a laser scanner in order to derive a high-resolution topographic mapping to be used in official documents related to the construction of a highway near Chu Lai airport in Quang Nam Province, Vietnam.

Table 1 Point measurement with NavisA and total station equipment

Point	Difference NavisA-Total Station		
	X(m)	Y(m)	H(m)
DC5-11	0.000	0.000	0.000
DC5-12	-0.052	0.051	0.050
DH1	-0.098	-0.042	0.011
DH2	-0.057	-0.012	0.018
DH3	-0.064	-0.010	0.007
DH4	-0.064	-0.016	0.022
DH5	-0.058	0.006	0.016
DH6	-0.069	-0.020	0.024
DH7	-0.065	-0.021	0.004
DH8	-0.083	-0.003	0.014
DH9	-0.007	-0.004	0.010
DH10	-0.048	-0.001	0.024
DH11	-0.067	-0.003	0.022
DH12	-0.040	-0.012	0.017

6 Conclusions

In this work, some of the RTD activities conducted at the NAVIS Centre in collaboration with the NavSAS Group of Politecnico di Torino and Fondazione LINKS (former ISMB) have been presented. Specifically, the GNSS based solutions oriented to fulfill needs of the Vietnamese society in the field of surveying, mapping and land monitoring have been presented. The main product produced at the NAVIS Centre for these activities is the NavisA GNSS receiver, a prototype that presents good performance as proved with several experiments but has the advantage of being less expensive than other receivers available on the market. On top of this, the equipment can be easily customized to the needs of Vietnamese users.

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