USING AUTHOR'S GNSS RTK MEASURMENT SYSTEM FOR INVESTIGATION OF DISPLACEMENT PARAMETERS OF STRUCTURE

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INTRODUCTION

For almost two decades scientists from couple of world famous universities have been working on using satellite navigation data to detect deformations and movement parameters of big structures like tall buildings, long bridges or dams (Bond et al., 2007). Evaluation of software and hardware solutions dramatically increases spectrum of construction parameters which can be investigate using GNSS technology. This process is changing very dynamically and brings a lots of possibilities for construction specialist who investigates buildings structures (Breuer et al., 2007). Today many Structural Monitoring Systems includes high-rate GNSS receivers and software able to calculate phase measurements to sub centimeter level (Nickitopoulou et al., 2006; NI et al., 2009; Chmielewski et al., 2009). This paper introduce first test of measurement system based on Global Navigation Satellite System technique and Real Time Kinematic method.

SYSTEM DESCRIPTION

The main purpose of the system is to provide the real-time measurements from high frequency GNSS receivers deployed on the test object. They can be used for direct analysis of the behavior of the structure, for further processing or integration with other measuring devices. Today there are many similar applications, which implement the above problem. They are mainly designed for manufacturers of GPS/GNSS receivers, and for those intended. Computational procedure in these systems is to receive raw satellite observations from base receivers and connecting themwith rover data to obtain the position of a particular receiver. Main disadvantage of this solution is using producer raw data format only what obligates user to use sensor from only one producer. The developed system has been designed to use multiple types of GNSS receivers independently from manufacturer restrictions and the whole procedure of position calculating was shifted to the receiver side. Thanks to this system is entirely flexible and ensures obtaining high-frequency observations with calculations carried out at the hardware level, rather than programmatic. Example diagram of the system is shown in figure 1.

The developed measurement system based on GNSS receivers uses the RTK (Real Time Kinematic) method that allows to obtain the accuracy of 2-3 cm horizontally and vertically in nearly real-time. Base receivers located outside the area of constructions movements influence observe GNSS signal permanently and generate correction data for rover receivers located on the construction.Those mobile receivers that are already

directly on the object are able to compute precise position in real-time with frequency up to 50Hz.

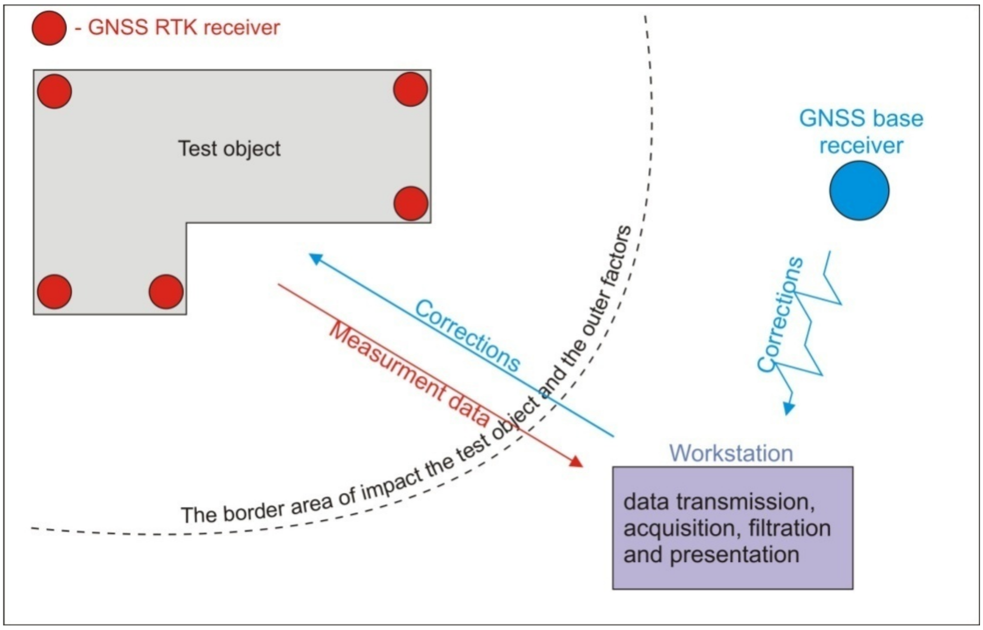

Fig. 1. Sample scheme of the systems data flow.

The main function of the measurement system is developing software solution which enables the implementation of the above-described process with high frequency and acquisition of measurements into a database for additional filtration (using KalmanFilter) (Kalman, 1960). The main functionality of the system is presentation of the measurements in graphical form on a computer screen. The entire exchange of data between the receiver and the workstation can be in any way adapted to the test object, for example, through a network of fiber optics or radio broadcast. Designed interface enables to take full control of the measurement process like creating new projects, multi-format data export, receiver and transmission management. Additional functionality of the system is also possibility of generating alarm states which enable sending information to the user (by GSM or e-mail) about construction geometry changes.

FUNCTIONAL TEST

1. STATIC TEST

Static test was one of three which has been made using this measuring system. It consisted of long-term measurements with 1Hz frequency at well stabilized points to determine the precision of obtain coordinates. Results of this session are presented on figure 2.

For horizontal coordinates standard deviation did not exceed 0.6 cm, while for the component to height, this value was little more than 1 cm. These results were further improved through the use Kalman Filter (for the variance of R = 1 and Q = 10^{-5}). As shown in the charts, there is no multiple points of proving the absence of accurate and reliable solutions, called "No. Fix".

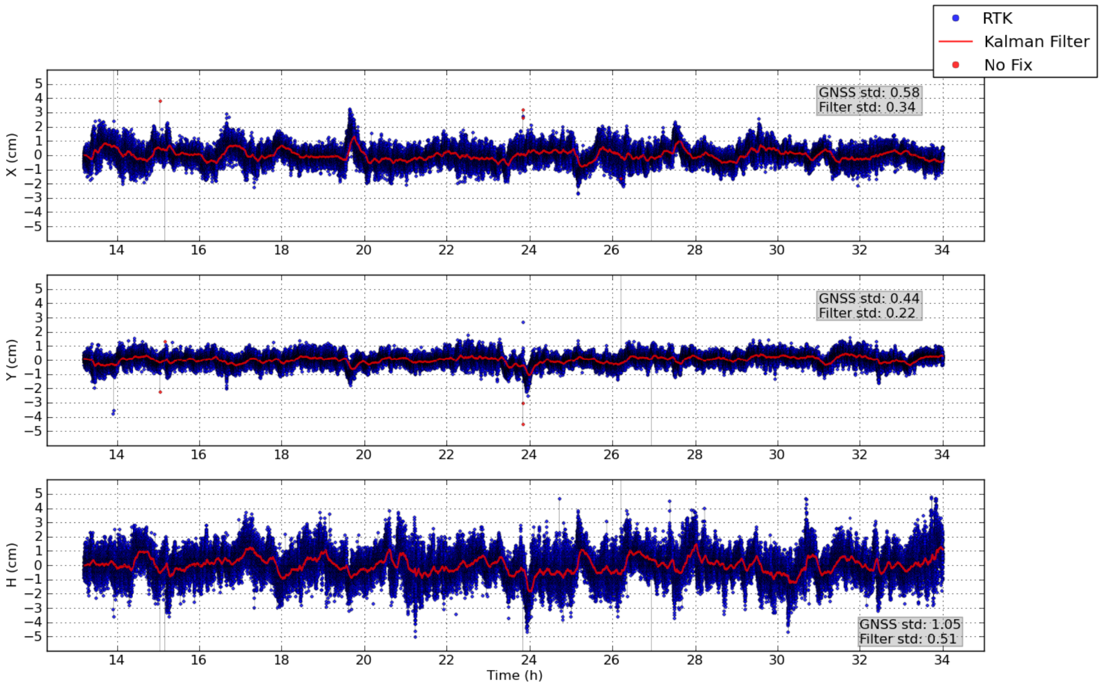

Fig. 2. Results of the static test.

2. FIRST DYNAMIC TEST

The first dynamic test was made to determine the suitability of the system to study slow deformation of the structures. It was made on the designed steel frame with 20 liter water tank, from which water flowed with rate about 7 liters per hour. For loadable in this way the structure have been placed two receivers - one performing GNSS observations (Trimble SPS 881), and second only GPS (Trimble 5700). In addition LeicaDisto sensor was use to provide distance measurements, which were carried out for comparison with GNSS and GPS results. Satellite observations were conducted at a frequency of 1Hz.

Figure 3 shows a comparison of level changes between the results obtained in real-time measurement system (GPS RTK), calculated after completed measurements (Postprocessing), readings from the electronic rangefinder (Disto) and KalmanFiltering is also carried out in real time (for the slow deformation mode: variance of R = 0.08 and Q = 10^{-5}). Displacement of the steel structure after 3 hours with a range finder measurements was 6.8 cm. Similar value was obtained after filtering the results of RTK (6.9 cm). Weakest results came out of the post-processing measurement results, which showed 5.6 cm of displacement. However, data from the real-time system shows 6.2 cm. It must be remembered that the nominal vertical accuracy of the GPS observations is more than 1 cm, so the results can be regarded as valid. In addition, as shown in the charts the GPS signal is characterized by a loud noise, and read value are temporary. Quality of collected data can be rise by up by quasi-dynamic Kalman Filter. In Figure 3, it is clearly seen the points marked in red ("No. fix"). They mean that in a given period of time was not reliable and accurate measurement. For data postprocessing, there are several such moments that affect the final information. For the measuring system can also be seen many points of "No. Fix", but unlike the data

obtained after completed measurements, they are not clustered in groups, and only occur in the individual periods of time. This has much less impact on the falsification of information provided to the user of such a system.

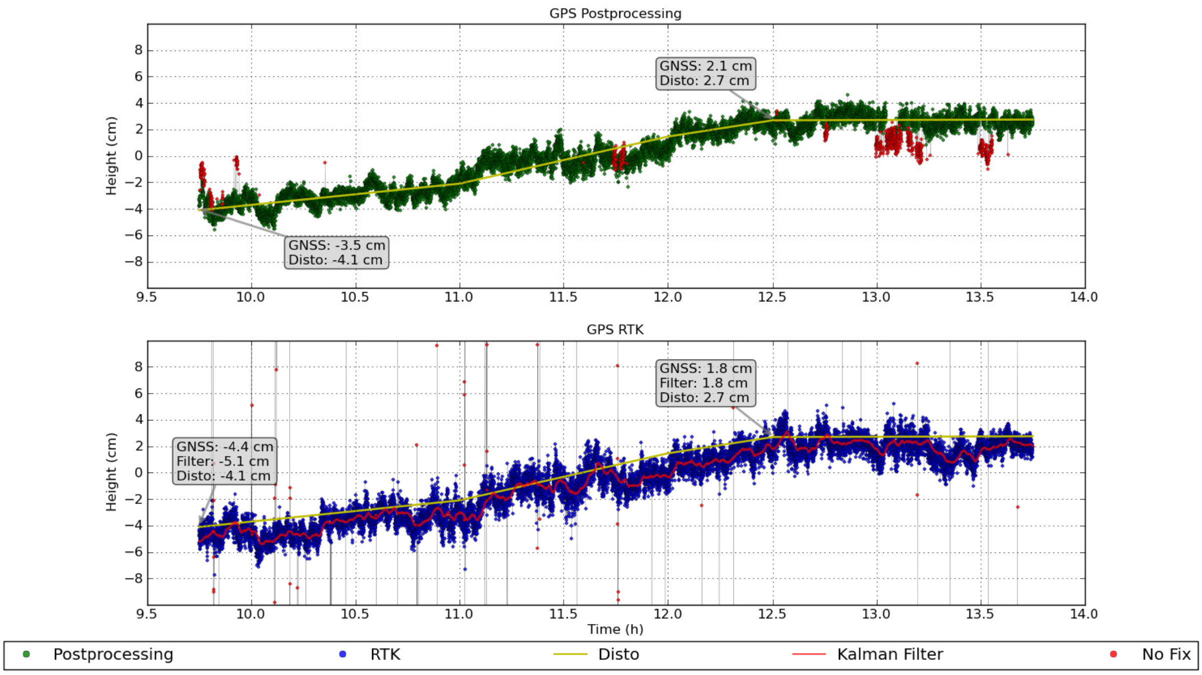

Fig. 3. First dynamic test results for GPS receiver.

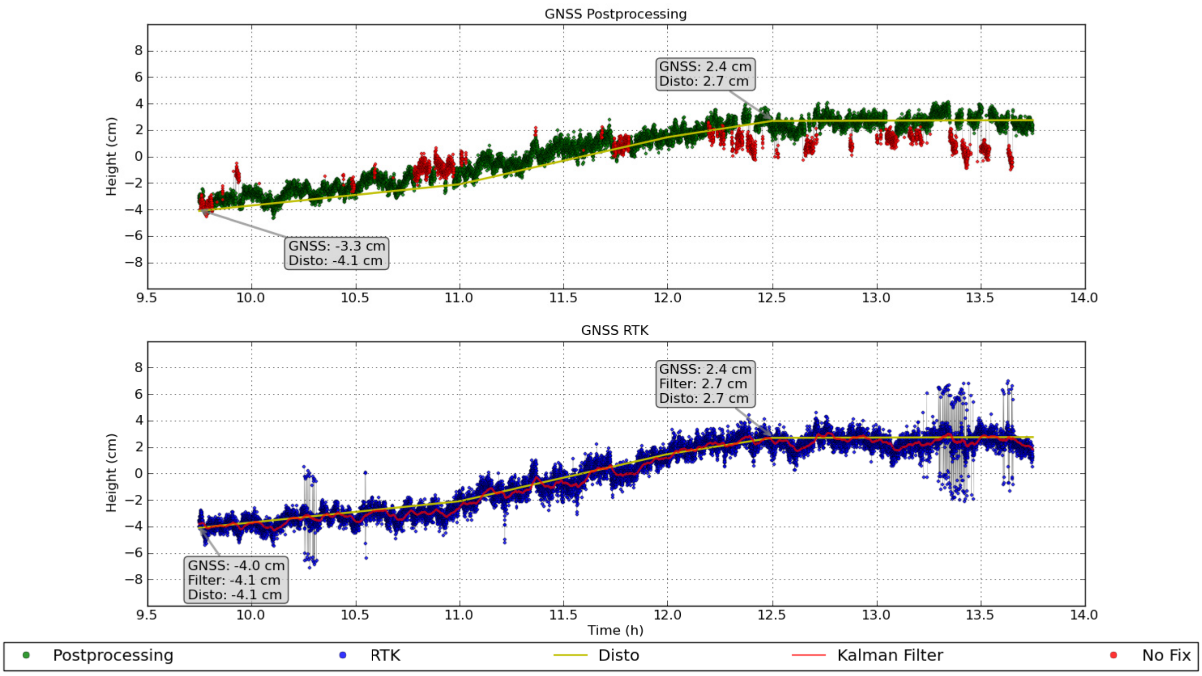

Fig. 4. First dynamic test results for GNSS receiver.

In the case of GNSS measurements clear improvement of results was observed (compared to GPS measurements) for RTK data. Displacement of the steel frame was 6.4 cm for the raw data and 6.8 cm for the filtered data (displacement designated rangefinder - 6.8 cm). Fared worse and observations calculated in postprocessing. The resulting displacement value was 5.7 cm and observed a number of time periods for which there was no credible position. In the case of the measurement system, there is no point of "No. Fix". Favorable results obtained in measurements performed in real time, you may be caused by better algorithms used in receivers to calculate position. It validates to transfer part of computing to system hardware page.

3. SECOND DYNAMIC TEST

The second test dynamic test was intended to answer the question of how measuring system for high vibration of construction and whether it is possible to determine its natural frequencies. For this purpose, also uses a steel frame, which contains two receivers, one GPS and GNSS (acquisition frequency of 10Hz) and 100Hz accelerometer, which was used to compare results. Frame was also ordered to 13kg weights, and then was subjected to frequent vibrations.

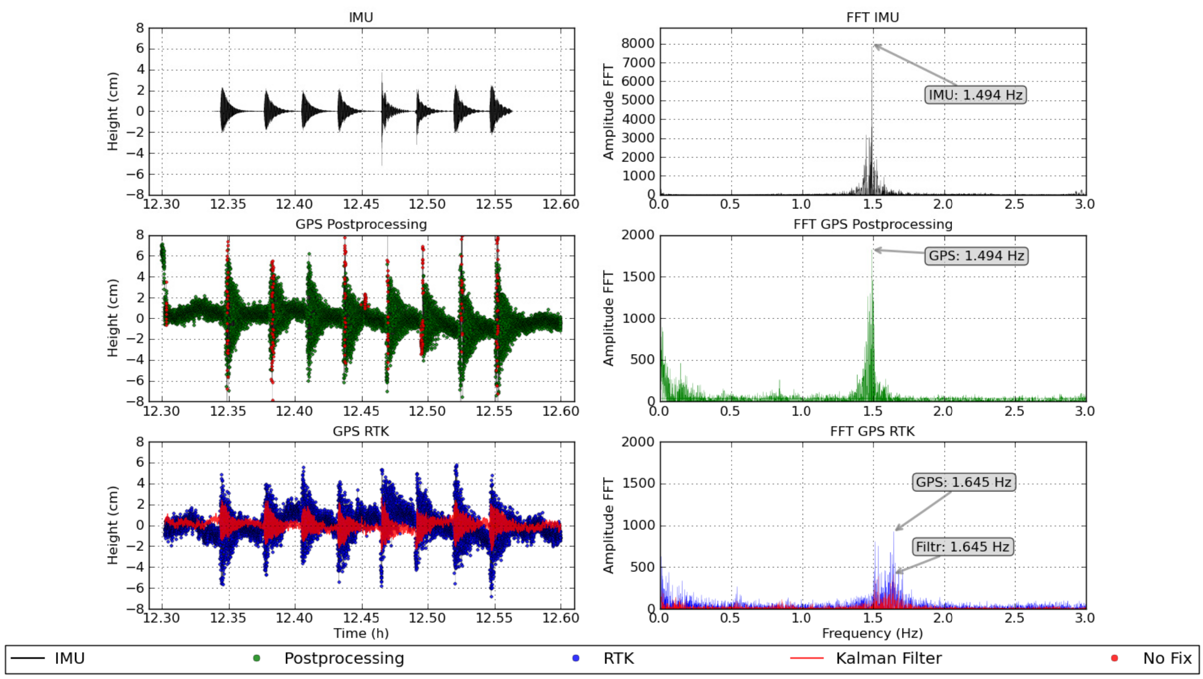

Fig. 5. Second dynamic test results for GPS receiver.

In the case of measurements made using only the GPS system (Fig. 5) the best results were obtained for post-processed data. Despite the many points of "No Fix" (not in the case of data from RTK) the same result as the natural frequency design using 100Hz accelerometer (IMU), and it amounted to 1.494Hz were obtain. The spectrum of RTK before and after filtration was shifted to higher frequencies and was 1.645Hz. It should be noted that the values of displacement data after filtering (for variance R = 0.01 and Q = 10^{-1}) were similar to those obtained from the accelerometer.

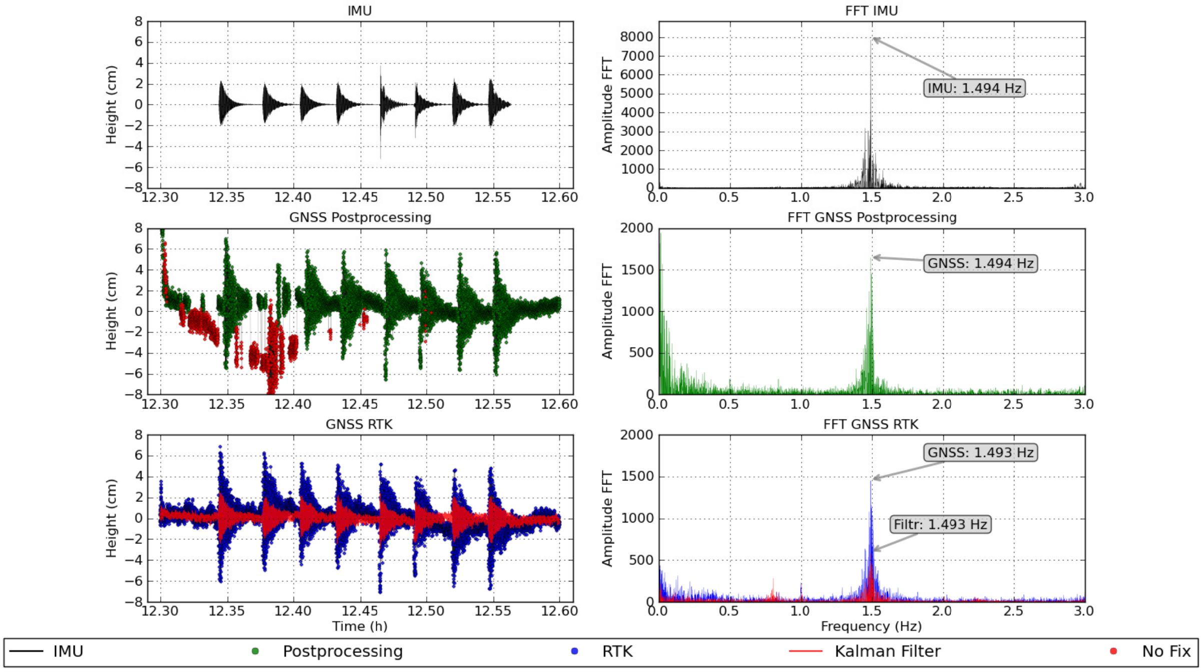

Fig. 6. Second dynamic test results for GNSS receiver.

Fared much better are measurements performed by the GNSS receiver (Fig. 6). In both case of the post-processing and real-time measuring system such as the frequency obtained using the accelerometer. However, the results the postprocessing contain a large number of measurements "No. Fix", which do not occur for RTK. Also fared very well the data after filtering, the amplitude of displacement and vibration frequency were similar to measurements from the IMU. Performed tests have shown that the measuring system developed using RTK GNSS method can be used to study the dynamics of the structure better than traditional GPS measurements and the results developed in postprocessing mode. An additional advantage is possibility of achieving high frequency performance in real time.

OTHER CAPABILITIES OF THE SYSTEM

The developed measurement system provides full communication with the user through a graphical application created that allows such create a new design of the measuring receiver and traffic management, data export to text files and graphics, as well as drawing graphs (defined by the user) in real time, such as the height difference between two receivers. In addition, the system can be defined so. Emergency rule for derived data, beyond which a particular procedure is triggered alarm. You may be informed about exceeding the limit established in the form of information on the screen, an audible alarm and e-mail or text message sent directly to the persons concerned. This module can be successfully used for monitoring of landslides, geotechnical or other big structures in real-time.

SUMMARY

The experiments carried out at Center of Applied Geomatics indicate that the developed measurement system GNSS RTK can be successfully used to study the dynamics of engineering structures to ensure reliable and high frequency information about the behavior of the object in nearly real time. The advantage of such a solution is the position calculating by every rover receiver so system do not need high-powered workstation and it also makes the system more flexible through the possibility of using different manufacturers sensors. The main limitation of the GNSS RTK solution is still low accuracy, especially for the vertical component. This situation is changing, however, for the benefit through the introduction of new GNSS systems (EuropeanGalileo and Chinese COMPASS) and the development of algorithms for data processing.

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