Reverse RTK Data Streaming for Low-Cost Landslide Monitoring

Etim E. Eyo, Tajul A. Musa, Khairulnizam M. Idris and Yusuf D. Opaluwa

Abstract This chapter describes the preliminary study of real-time data streaming in support of the proposed low-cost landslide monitoring system using the Reverse Real-Time Kinematic (RRTK) technique. The RRTK algorithm was implemented by streaming raw Global Positioning System (GPS) data of both the reference and roving station(s) to the control centre for processing, and transmission of the position solution to the roving station. The main purpose of the data streaming was to investigate the quality of the measurements, for utilization in landslide modelling and analysis in near real-time. A novel methodology using a high pass filtering technique was implemented, to detect outliers in the observations. Also, the autocorrelation of GPS time series was investigated.

Keywords Data streaming · Landslide · Monitoring · Low-cost · GPS · High pass filter · Autocorrelation

1 Introduction

Landslide is defined as "the movement of a mass of rock, debris, or earth down a slope" (Cruden 1991). Globally, there is an upsurge in landslide occurrence, which could be attributed to the increasing human activities on the environment (Glade 2003; Sidle et al. 2004) and the impact of climate change (Geertsema et al. 2006). The consequences of landslides are enormous. Recent landslide disasters in Brazil, Philippines, China, Indonesia, Pakistan, etc. have destroyed infrastructure, killed thousands of people, and resulted in heavy economic losses (USGS 2013). The

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continuous occurrence of disastrous landslide events has increased the demand for new and improved techniques for landslide monitoring and analysis.

The Global Navigation Satellite Systems (GNSS), namely—GPS, GLONASS, Galileo, Compass, QZSS and IRNSS are now being utilized as global infrastructure for a wide range of applications. The Global Positioning System (GPS), in particular, has been widely used in monitoring the dynamics of landslide. GPS has been employed in landslide monitoring based on the type of monitoring campaigns, namely, periodic (Rawat et al. 2011; Wang 2012; Yalçinkaya and Bayrak 2002) and continuous (Wang and Soler 2012; Xiao et al. 2012). These studies highlight the critical factors in the choice of a particular monitoring campaign, which include accuracy, cost, and safety of equipment. Some studies in landslide monitoring have used GPS to compare results from conventional surveying or geotechnical methods, such as theodolite, Electronic Distance Measurement, levels, total station, inclinometers, and wire extensometers (Bertachini et al. 2009; Calcaterra et al. 2012; Coe et al. 2003; Gili et al. 2000; Malet et al. 2002; Moss 2000; Rizzo 2002; Tagliavini et al. 2007).

Other studies have integrated GPS and other surveying techniques, namely, terrestrial laser scanning, SAR interferometry, and photogrammetry, to investigate the landslide phenomenon (Mora et al. 2003; Peyret et al. 2008; Rott and Nagler 2006; Wang et al. 2011). This combination provides valuable information on the magnitude and direction of the displacements, total volume of the moving mass, and the evolution of the landslide process. Some studies have investigated the accuracy of low-cost single-frequency GPS receivers for landslide monitoring (Janssen and Rizos 2003; Squarzoni et al. 2005). Finally, GPS has been employed in landslide monitoring based on different GPS techniques, namely, static (Brunner et al. 2007), rapid-static (Hastaoglu and Sanli 2011), real-time kinematic, RTK (Wang 2011), and based on the comparisons of these techniques (Othman et al. 2011a, b).

The main goal of our ongoing research is to design a low-cost monitoring system for landslide investigation using the RRTK technique. Some of the advantages of RTK GPS which can be utilized for landslide monitoring application include (Mekik and Arslanoglu 2009): (1) post-processing is not required, (2) acquired coordinates of points can be easily transformed to local coordinate system in real-time, and (3) it is a reliable tool for monitoring multiple number of points—increasing productivity and saving cost. For a standard RTK-GPS operation, dual-frequency geodetic-grade receivers with the supporting firmware are usually required. However, the high cost of these receivers and the supporting software is one of the reasons limiting the use of RTK GPS for several monitoring applications (Takasu and Yasuda 2009). Due to the harsh operational environment frequently faced during landslide monitoring, coupled with security concern and the prospect of losing the equipment during landslide event, the needs for low-cost monitoring equipment are imperative.

The big challenge, therefore, in GNSS monitoring is how to reduce the cost of the monitoring scheme. The cost of monitoring includes the costs of RTK GPS receivers, power supply, communication, logistics, and personnel. Several authors have proposed the use of low cost GPS L1-only monitoring receivers (Chen 2001; Roberts 2002). The shortcoming of this approach is the fact that, unlike the dual-frequency data, the single-frequency GNSS receivers' data cannot be corrected for ionospheric delay (Rizos et al. 2010). Research on the development of low-cost RTK GPS deformation monitoring systems for landslide monitoring application are ongoing (e.g. Aguado et al. 2006; Brown et al. 2006; Glabsch et al. 2009; Verhagen et al. 2010; Yu 2011).

In this chapter, a new landslide deformation monitoring concept that uses RRTK principle is being proposed. The unique advantage of the RRTK approach is that low-cost receiver hardware can be deployed for field data streaming since the responsibility of complex computations is shifted from the roving receivers to the control centre.

This chapter is organized as follows. In Sect. 2, the server-based processing technique is discussed. In Sect. 3, an overview of GPS/GNSS Continuously Operating Reference Stations (CORS) is presented. In Sect. 4, the real-time GPS data streaming using Networked Transport of RTCM via Internet Protocol (Ntrip) is described. Section 5 presents the experimental data collection and processing. The results and analyses are presented in Sect. 6. Finally, the summary, outlook and field challenges are presented in Sect. 7.

2 The Server-Based Processing Technique

The conceptual framework of this study is based on the server-based RTK processing concept. According to Feng et al. (2009), the server-based RTK processing concept can be used in various RTK techniques (see Fig. 1)—precise point positioning (PPP), standard single-baseline RTK, network-RTK (NRTK), reverse single-baseline RTK (RRTK), and reverse network RTK (RNRTK).

The last two techniques (RRTK and RNRTK) combine the server-based processing concept and two-way communication for the computation and transmission of the user's accurate position. The reverse technique, which technically alters the one-way communication flow in the conventional RTK technique, involves a two-way communication (see Fig. 2) which requires the field users to transmit their raw observations to a control centre for the computation of the position solution, after which the computed solution along with the quality control indicators are transmitted back to the field users.

The reverse approach based on combining the server-based processing concept and two-way communication has evolved for over 5 years now. But research opportunities offered by this approach is still not adequately exploited. The first practical implementation of RNRTK was made by Nippon GPS Solution in Japan (Kanzaki 2006). Rizos (2007) proposed the development of new business model using the RNRTK approach, with the main goals of placing the control of the products with the service providers and enhancement of commercial value on the service. A new framework for RNRTK using distributed-computing technique was

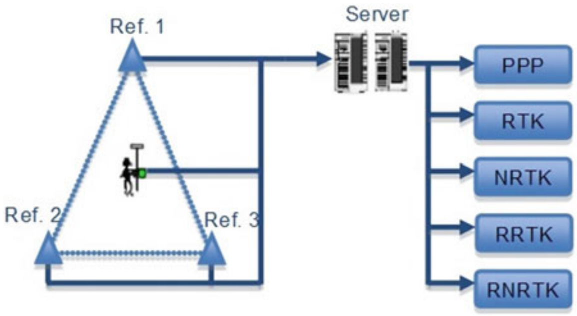

Fig. 1 Server-based RTK concept (Feng et al. 2009)

Fig. 2 Two-way communication channel

proposed by Lim and Rizos (2008). The main goal of the framework was to integrate information and communication technologies, database and web technologies, and GPS CORS network infrastructure, to upgrade the capability of the server to real-time data processing. These augmentations enable the servers to carry out data management and spatial analysis, and at the same time creating a platform for the users to efficiently utilize the results. Zinas et al. (2012) present an enhanced processing strategy by combining a single-baseline and a multiple rover network solution in a centralized (server-based) GNSS architecture. The main goal of this study was to use the shorter inter-receiver baselines to improve the results of single-epoch ambiguity resolution.

Some of the advantages of combining the server-based processing concept and two-way communication in the reverse approach include (Rizos 2007; Zinas et al. 2012):

- Control of the products is vested with the service providers.
- Quality of service is guaranteed.
- Increased value on product, and enhancement of commercial value on the service.
- The user is relieved from the burden of complex computations.
- Low-cost receiver hardware can be deployed for field data streaming.
- Multiple users can be supported simultaneously.

- The streaming of raw observations data from both the reference and roving stations to the control centre implies that all available information can be effectively utilized.

The main advantages that the server-based processing technique can provide for landslide monitoring application are that the costs and tasks of the monitoring scheme will be drastically reduced, as low-cost receiver hardware will be utilized for real-time streaming of raw GPS measurements and complex algorithms and computations at the user end will be eliminated.

3 Continuously Operating Reference Stations (CORS)

Networks of GNSS are being established in many regions of the world to provide valuable infrastructure for real-time kinematic positioning and applications in areas such as surveying, mapping, navigation and environmental monitoring. The server-based processing technique usually utilizes existing GPS/GNSS CORS infrastructure. The CORS facilities utilized for this study is the ISKANDARnet. The control centre of ISKANDARnet is located in the Faculty of Geoinformation and Real Estate, Universiti Teknologi Malaysia (Shariff et al. 2009). ISKANDARnet was developed to provide infrastructure for strategic research in areas such as atmosphere, meteorology, and precise positioning in the Iskandar region of Johor, Southern Malaysia. At the time of writing this chapter, ISKANDARnet consists of four reference stations (ISK1, ISK2, ISK3, and ISK4), while more reference stations are being planned for the future. The distribution of the current ISKANDARnet reference stations is given in Fig. 3.

The conventional RTK method employs radio links to transmit reference receiver data (or observation corrections) to the rover receiver. The rover unit utilizes this data together with its own raw measurements to resolve the ambiguity of the differenced carrier phase data and to estimate the rover's position. The main problem of the single-base RTK technique is the restriction of the baseline length to 10–20 km, due to distance-related errors (e.g. orbit errors, and atmospheric signal refraction) (Rizos et al. 2010). The network RTK technique, on the other hand, uses a network of CORS to acquire a large amount of data, over a wide geographical scale, for the determination of the position solutions. The NRTK allows the separation between the reference stations at significantly longer baseline lengths, and has been able to address the baseline length restriction of the single-base RTK technique. In this study, the reverse approach is being implemented based on the standard single-base RTK technique (i.e. RRTK).

Fig. 3 Distribution of ISKANDARnet reference stations (as modified in Google Maps)

4 Real-Time GPS Data Streaming Using NTRIP Protocol

Ntrip protocol is used for the real-time GPS data streaming in this study. Ntrip (see Fig. 4) basically consists of the following components (Weber et al. 2006):

(a) *NtripSources* generate continuous raw GPS data streams. Each GPS data sources are recognized by a unique identifier called mount-point.
(b) *NtripServers* transfer raw GPS data stream of an NtripSource to the Ntrip-Caster or control centre.
(c) *NtripCaster* provides security for the service providers and facilitates the accessibility of data to multiple users. The administrator of the NtripCaster organizes all available NtripSources and defines all source identifiers (mountpoints), port number, and user passwords. Source-table containing information on stations and data streams is also managed by NtripCaster. The control centre and NtripCaster used for this study are located at GNSS and Geodynamics Laboratory, Universiti Teknologi Malaysia.
(d) *NtripClient* receives final position solution from the NtripCaster or control centre.

In this study, the Ntrip protocol was utilized to test the RRTK algorithm (see Fig. 5) by streaming raw GPS data from both the reference and roving stations to the control centre for processing, and transmission of the position solution to the

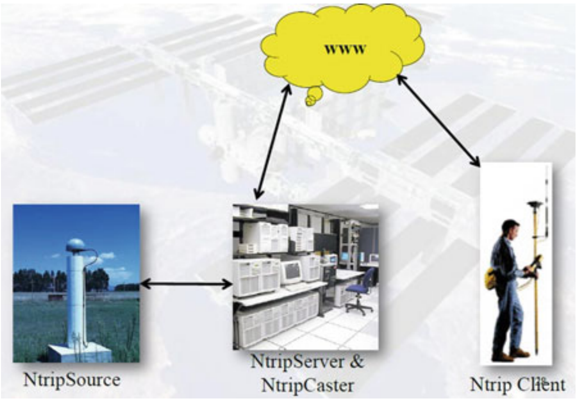

Fig. 4 Ntrip system components

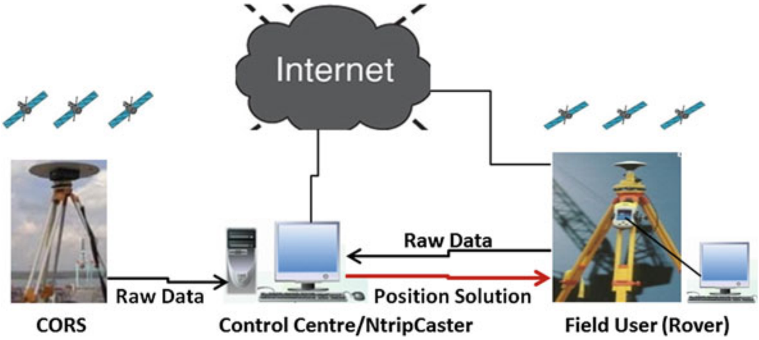

Fig. 5 The architecture of RRTK technique

roving station (user). The transmission of both data and results were performed over the Internet. The real time GPS measurement stream provided a new measurement every second for each GPS data sources. The emphasis of this preliminary study was to investigate the quality of the measurements.

5 Experimental Data Collection and Processing

The proposed landslide deformation monitoring technique using RRTK principle and the server-based processing methodology was tested using data from test sites located at the Universiti Teknologi Malaysia. A 388-s dataset acquired at 1 s interval on March 18, 2013, was processed to test the performance of the developed methodology. The reference station and rover configuration is shown in Fig. 6.

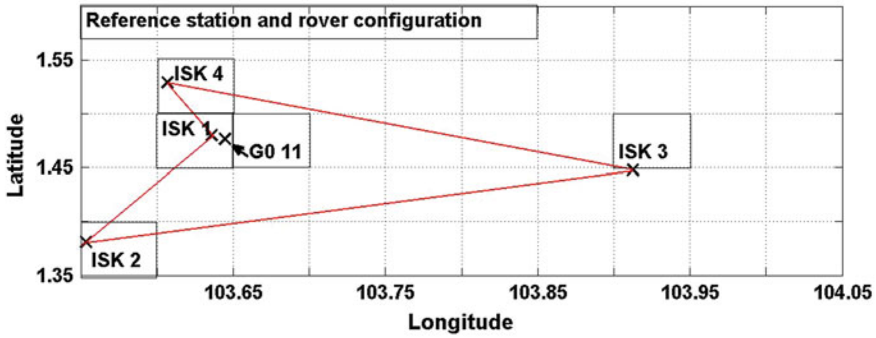

Fig. 6 Test network consisting of four reference stations (ISK1, ISK2, ISK3 and ISK4) and one rover (GO11)

The processing of the real-time GPS data was performed using the modified RTKLIB software package, based on server-based processing methodology. In this approach, the rover station was processed using the single-base RTK technique from the closest reference station. The reference station used for the data streaming at G011 was ISK 3, a distance of about 23 km apart. In the next test campaign, all the reference stations will be utilized in processing the rover position. The results of the baselines solutions are presented in the local cartesian coordinates.

The baseline of about 23 km may have introduced distance-related errors into the observations. Also, the high latency rate caused by fluctuations in Internet service in the streaming of data to the control centre, may have contributed to delay in ambiguity resolution for the determination of the position solution. In order to detect outliers in the observations, a high pass filter was implemented. In this study, a weighted mean value is calculated from the coordinates and sigma according to Eq. (1) (Sundström 2009):

$$X_f = X - \hat{X}, \tag{1}$$

where X_f is the filtered position, X is the observed value and $\hat{X}$ is the weighted mean value obtained from:

$$\hat{X} = \sum\nolimits_{i=1}^{N} X_i.w_i, \tag{2}$$

where N is the total number of observations for the filter and w is the weight obtained from Eq. (3):

$$w_i = \frac{\frac{1}{\sigma^3}}{\sum\nolimits_{j=1}^{N} \frac{1}{\sigma^3}}, \tag{3}$$

where σ is sigma (the standard deviation values of Easting, Northing and Height).

The autocorrelation of GPS time series was also investigated. The observation time series is described as (Y_1, Y_2, Y_3, …, Y_k, …Y_n), which are made at equidistant time intervals Δt. N is the total number of the observations. The mean value of all observations is computed as $\bar{Y}$; then the autocorrelation coefficient (R_h) of the observation series is computed as follows:

$$R_h = {}^{C_h}\!/_{C_o}, \tag{4}$$

where C_h is the autocovariance function:

$$C_h = \sum_{t=1}^{N-h} (Y_t - \bar{Y})(Y_{t+h} - \bar{Y})/N, \tag{5}$$

and C_o is the variance function:

$$C_o = \sum_{t=1}^{N} (Y_t - \bar{Y})^2 \Big/ N, \tag{6}$$

h is time lag ($h = 1, 2, 3, \ldots$).

The plot of R_h for varying h is called the correlogram for the random process Y_k. The correlogram is used to check for serial dependency in an observed time series.

6 Results and Analysis

The plots of both filtered and unfiltered observations for the first 25 s are given in Figs. 7, 8, 9. It is shown that the implementation of the high pass filter has been able to detect outliers in the observations. The observations of first 5 and 16 s are outliers. The noises were due to the fact that the position solutions of first 5 s were in float solution as the system was still in the initialization stage. The fixed solution commenced from the sixth second observation.

The plot of the standard deviation values for the first 25 s is given in Fig. 10. The standard deviation values for the three components were generally high in observations of first 5 and 16 s; Northing and Easting having the highest values of about 1 m, and height more than 3 m. The standard deviation values for the subsequent observations were about 1 mm for Northing and Easting and about 3 mm for Height.

The plot of the displacement vectors for Northing, Easting and Height components, for the first 25 s is given in Fig. 11. It is shown that the displacements are affected by high standard deviation values. That is, large displacements have high standard deviation values.

The autocorrelation functions of the GPS time series for Northing, Easting, and Height, respectively are shown in Figs. 12, 13, 14.

In the correlogram of Northing (Fig. 12), the autocorrelation functions take the value Ro = 0.003 and decrease exponentially until at time lag 300 s when the autocorrelation of the observations is not so obvious. In the correlogram of Easting

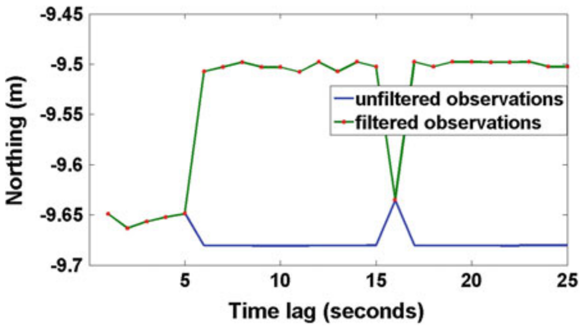

Fig. 7 Filtered and unfiltered observations for Northing components

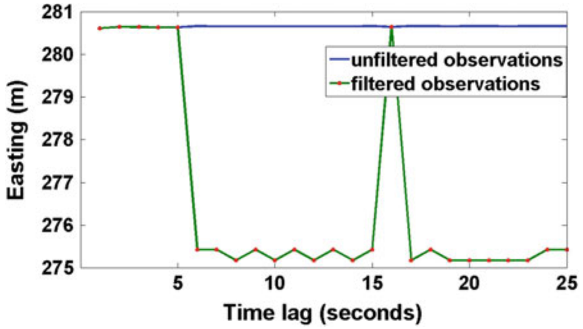

Fig. 8 Filtered and unfiltered observations for Easting components

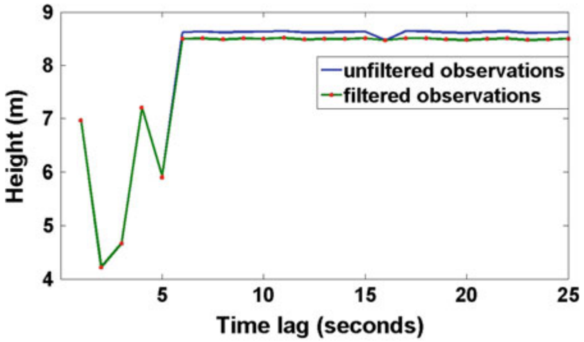

Fig. 9 Filtered and unfiltered observations for Height components

(Fig. 13), the autocorrelation functions take the value Ro = 0.003 and decrease exponentially until at time lag 300 s when the autocorrelation of the observations is not so obvious. In the correlogram of Height (Fig. 14), the autocorrelation functions take the value Ro = 0.003 and decrease exponentially until at time lag 200 s when the autocorrelation of the observations is not so obvious. These deviations show that the GPS measurements contain white and coloured noises. The coloured noises in the GPS measurements follow the exponential distribution. When the time lag is larger, for example 200 s, the autocorrelation of the

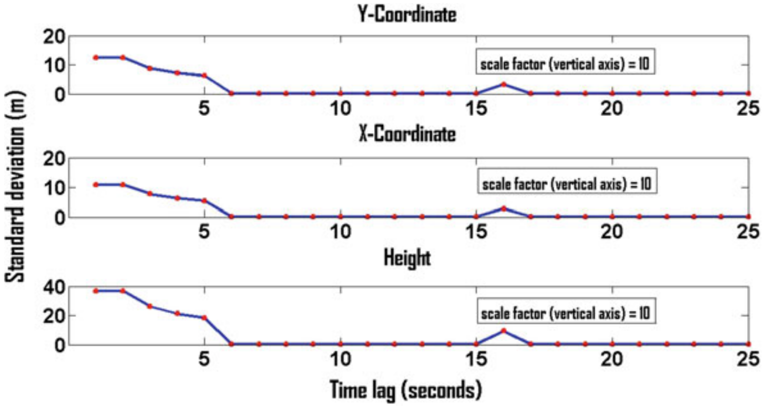

Fig. 10 Standard deviation values for Northing, Easting, and Height components

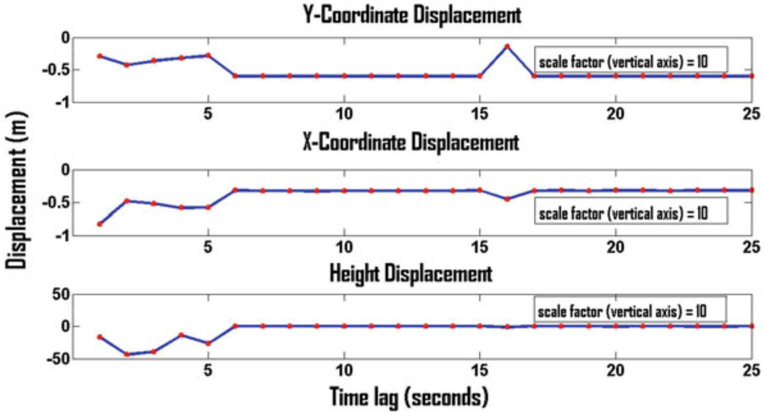

Fig. 11 Displacement vectors for Northing, Easting, and Height components

observations is not so obvious. But when the time lag is smaller, for example 1 s, the autocorrelation coefficient between two observations becomes larger.

7 Summary and Outlook

We have discussed the concept, principles and advantages of a proposed low-cost landslide monitoring system using RRTK technique. In order to implement the RRTK algorithm, a real-time data streaming of raw GPS data of both the reference and roving stations was carried out by utilizing the Ntrip protocol. The main purpose of the data streaming was to investigate the quality of the measurements.

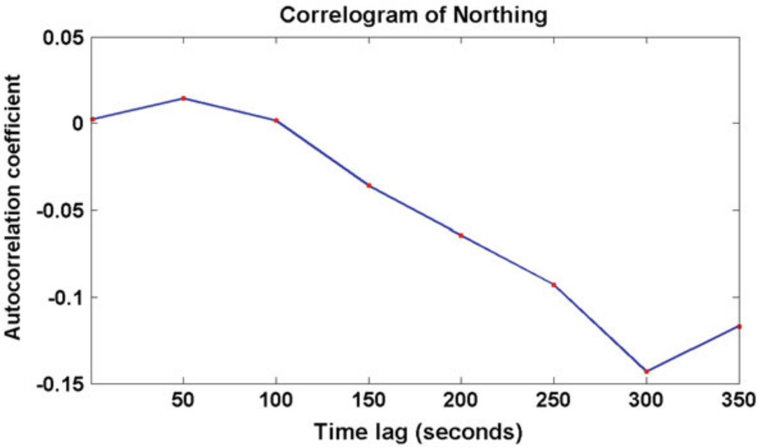

Fig. 12 Correlogram of Northing components for time lag 0–350 s

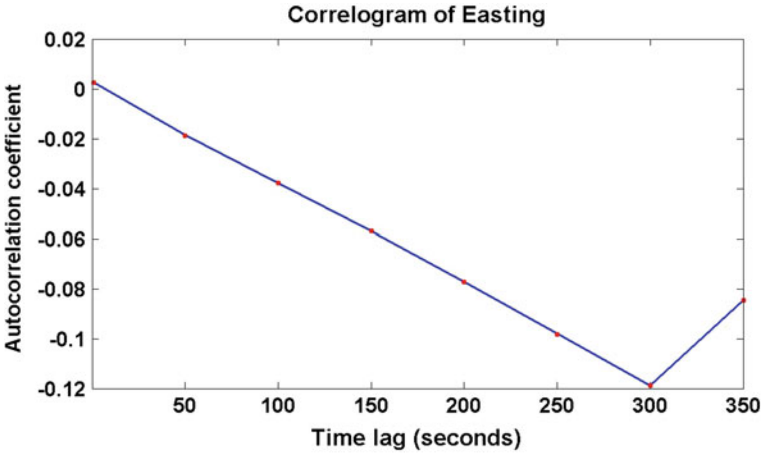

Fig. 13 Correlogram of Easting components for time lag 0–350 s

In order to detect outliers in the measurements, a high pass filter was implemented. Autocorrelation analysis of GPS time series was also performed to validate the presence of white and coloured noises in the GPS measurements.

The main problems encountered during field work include: power supply problems and fluctuation in Internet services. There is a great concern for power supply because a typical landslide site may be located in remote areas where access to the electric network is not readily available. The fluctuation in Internet services was a big concern as this may have contributed to a high latency rate in the streaming of the data.

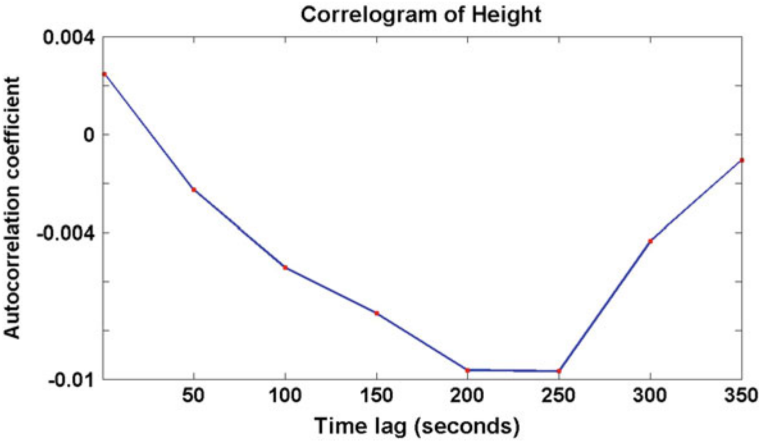

Fig. 14 Correlogram of Height components for time lag 0–350 s

The next phase of the study will involve the implementation of RRTK GPS technique on real-world landslide sites.

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