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Application of Low-Cost Tools and Techniques for Landslide Monitoring

Abstract This paper proposes a low-cost landslide monitoring system using the Reverse Real-Time Kinematic (RRTK) technique. First, the server-based processing technique, which utilizes the two-way communication channel for the computation and transmission of the user's accurate position, is discussed. Second, the basic infrastructure requirements for RRTK in low-cost landslide monitoring application are described. In order to implement the proposed RRTK algorithm, real-time data streaming of raw Global Positioning System (GPS) data of both the reference and roving station(s) to the control centre, are performed. A high pass filtering technique was employed to detect outliers in the observations. Finally, the autocorrelation of GPS time series was investigated to validate the presence of white and coloured noises in the GPS observations.

Keywords: Landslide monitoring, Low-cost, GPS, Reverse Real-Time Kinematic, Data streaming

1. Introduction

The main goal of our ongoing research is to design a low-cost monitoring system for landslide investigation using the Reverse Real-Time Kinematic (RRTK) technique. 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). 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.

In this paper, a new landslide deformation monitoring concept that uses RRTK principle is being proposed. In order to support this proposed technique, real-time data streaming of raw GPS data of reference and rover stations was carried out using the ISKANDARnet infrastructure and Ntrip protocol.

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).

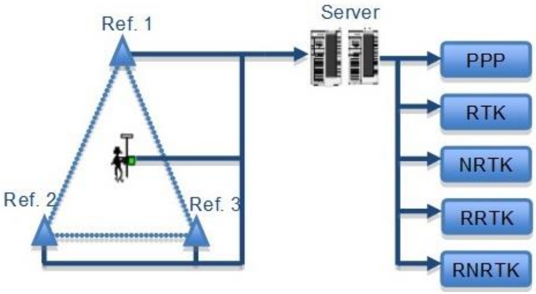

Fig. 1: Server-based RTK concept (Feng et al., 2009)

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.

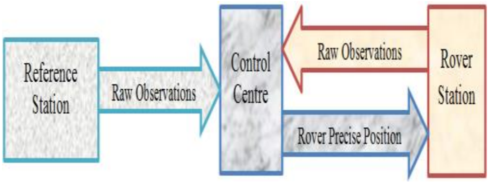

Fig. 2: Two-way communication channel

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 (Rizos, 2007; Zinas et al. 2012).

3. Infrastructure for Reverse RTK

The infrastructure requirements for RRTK technique (see Fig. 3) include the following: receivers, software, power management, communication, continuously operating reference stations (CORS), and data handling and processing.

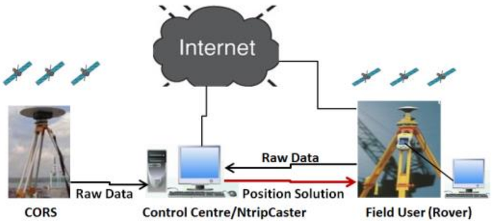

Fig. 3: The architecture of RRTK technique

In this study, a low-cost positioning system using Magellan Professional AC12 GPS OEM receiver which cost a few hundreds of US dollars is being designed. This receiver provides precise carrier phase outputs and has the capability for employment in high accuracy applications such as land and marine navigation, deformation monitoring, asset and personnel tracking and relative navigation (Alkan and Saka, 2009).

The software requirements to operate the reverse RTK algorithms could be quite expensive. To avoid the inherent costs in software development, this study employs the RTKLIB software. The unique advantages of RTKLIB are that it supports low-cost receivers to stream raw measurement data of GPS signals, and enables users to design and operate original low-cost RTK GPS systems (Takasu and Yasuda, 2009).

Secure energy supply is of paramount importance in landslide monitoring which is often carried out in remote locations with little or no access to electricity network. The main facilities with energy demand include sensor equipment, communication and data processing (control centre) infrastructure. The main concern here is to choose facilities with the capacity to minimise power usage in order to extend battery life.

There are many options available for supporting the data transmission component of the RRTK system. These include: radio-based communications, Internet communications, and wireless communications. A technique using Internet for streaming GNSS data between different user equipment for precise positioning and navigation known as “Networked Transport of RTCM via Internet Protocol (NTRIP)” is used for the real-time GPS data streaming in this study.

The server-based processing technique usually utilises 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). At the time of writing this paper, 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. 4.

Fig. 4: Distribution of ISKANDARnet Reference Stations (as modified in Google Maps)

Data handling consists of storing, processing, and presenting data in a format useful for the required application. In the RRTK technique, a greater proportion of positioning computation is shifted from the user end to the control centre. RRTK positioning requires transmission (typically every second) of reference and rover stations to the control centre. The volume of data involved can be very huge and efficient processing can be challenging.

4. Experimental Data Collection and Processing

The proposed new 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-second dataset acquired at one second interval on March 18, 2013, was processed to test the performance of the developed methodology. The reference station and rover configuration are shown in Fig. 5.

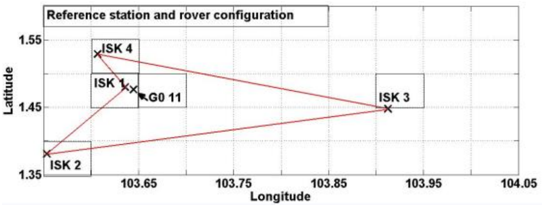

Fig. 5: Test network consisting of four reference stations (ISK1, ISK2, ISK3 and ISK4) and one rover (GO11)

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 Go11 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 Equation [1] (Sundström, 2009):

$$X_f = X - \hat{X}, \qquad [1]$$

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

$$\hat{X} = \sum_{i=1}^{N} X_i . w_i, \qquad [2]$$

where N is the total number of observations for the filter and w is the weight obtained from Equation [3]:

$$w_i = \frac{\frac{1}{\sigma^3}}{\sum_{j=1}^{N} \frac{1}{\sigma^3}}, \qquad [3]$$

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:

$$R_h = {C_h}/{C_o}, \qquad [4]$$

where C_h is the autocovariance function:

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

and C_o is the variance function:

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

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

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.

5. Results and Analysis

The plots of both filtered and unfiltered observations for the first 25 seconds are given in Figs. 6 to 8. 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 seconds and 16 second are outliers. The noises were due to the fact that the position solutions of first 5 seconds were in float solution as the system was still in the initialization stage. The fixed solution commenced from the sixth second observation.

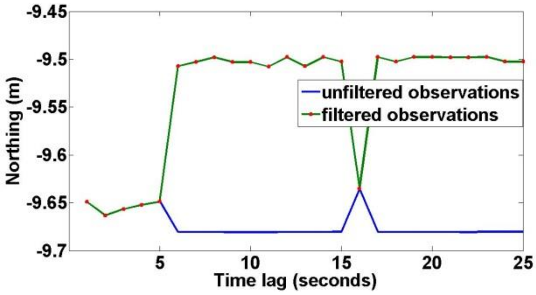

Fig. 6: Filtered and unfiltered observations for Northing components

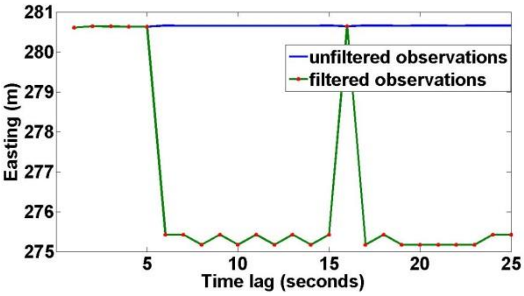

Fig. 7: Filtered and unfiltered observations for Easting components

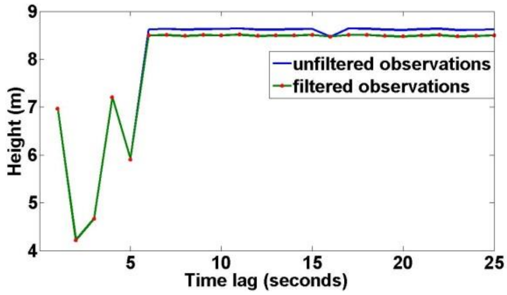

Fig. 8: Filtered and unfiltered observations for Height components

The plot of the standard deviation values for the first 25 seconds is given in Fig. 9. The standard deviation values for the three components were generally high in observations of first 5 seconds and 16 second; Northing and Easting having the highest values of about 1 m, and height of 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.

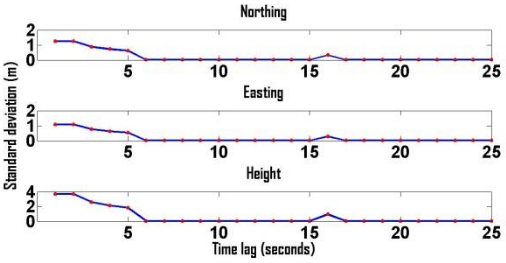

Fig. 9: Standard deviation values for Northing, Easting, and Height components

The plot of the displacement vectors for Northing, Easting and Height components, for the first 25 seconds is given in Fig. 10. It is shown that the displacements are affected by high standard deviation values. That is, large displacements have high standard deviation values.

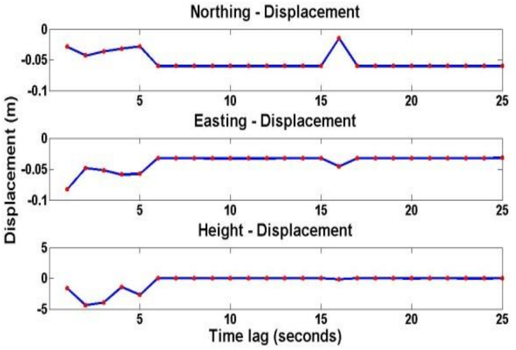

Fig. 10: Displacement vectors for Northing, Easting, and Height components

The autocorrelation functions of the GPS time series for Northing, Easting, and Height, respectively are shown in Figs. 11-13.

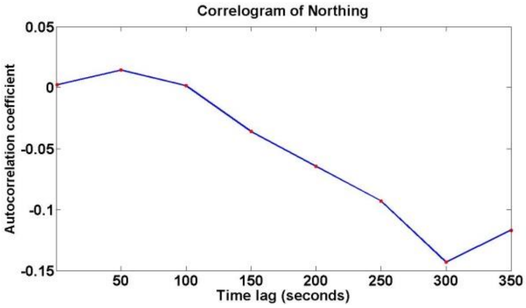

Fig. 11: Correlogram of Northing components for time lag 0 to 350 seconds

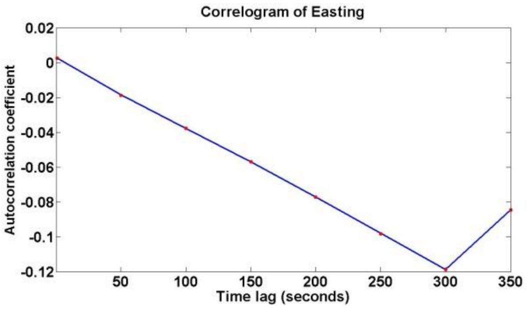

Fig. 12: Correlogram of Easting components for time lag 0 to 350 seconds

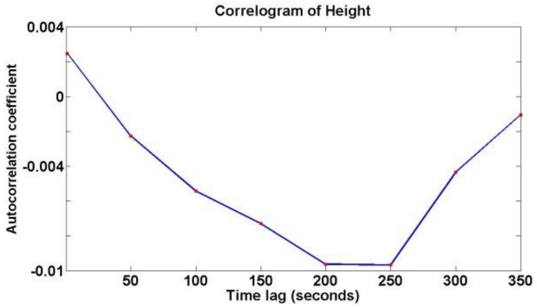

Fig. 13: Correlogram of Height components for time lag 0 to 350 seconds

In the correlogram of Northing (Fig. 11), the autocorrelation functions take the value R_0 = 0.003 and decrease exponentially until at time lag 300 seconds when the autocorrelation of the observations is not so obvious. In the correlogram of Easting (Fig. 12), the autocorrelation functions take the value R_0 = 0.003 and decrease exponentially until at time lag 300 seconds when the autocorrelation of the observations is not so obvious. In the correlogram of Height (Fig. 13), the autocorrelation functions take the value R_0 = 0.003 and decrease exponentially until at time lag 200 seconds 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 seconds, the autocorrelation of the observations is not so obvious. But when the time lag is smaller, for example 1 second, the autocorrelation coefficient between two observations becomes larger.

6. Summary and Outlook

We have discussed the concept, principles, and infrastructure requirements 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 the reference and rover stations was performed by utilizing the ISKANDARnet infrastructure and Ntrip protocol. The main purpose of the data streaming was to investigate the quality of the measurements. A high pass filter was implemented to detect outliers in the measurements. Autocorrelation analysis of GPS time series was also carried out 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.

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

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