Monitoring of Flexible Barrier for Slope Safety Against Potential Rockfall using IoT Sensors

Dr. Tim CHUK T. Y[1*], Ringo SZE W. H[1], Mike FUNG S. H[2], Simon NG P. H[3],
Frankie YEUNG H. W[3]

[1]Amain Engineering Development Ltd., Hong Kong
[2]Hong Kong RFID Limited, Hong Kong
[3]Mannings (Asia) Consultants Ltd., Hong Kong

*Corresponding author

doi: https://doi.org/10.21467/proceedings.159.19

ABSTRACT

Flexible barrier is one of the widely used geotechnical features to mitigate/minimize open hillslope landslide (OHL) hazards affecting roads/existing development for natural terrain. While routine maintenance of flexible barrier may identify early signs of minor rockfall/landslide through visual inspection of any accumulation of rock/soil at toe, the actual happening of such event and/or the duration cannot be assessed/determined which may cause time lag for any necessary follow-up actions. This can be overcome through the fixing of IoT sensors to flexible barrier posts with a non-destructive metal "mounting clamp" to measure the movement with data then transfer to a cloud platform for analytical process. Data is presented in an easy-to-understand heat map format showing the movement patterns of the entire flexible barrier system. This method helps to detect any large movements of the barriers. In time, through learning the movement patterns especially during adverse weather conditions, can provide valuable reference to Geotechnical/Civil engineers. The use of smart technology in this manner represents a significant advancement in supervision and monitoring techniques for flexible barrier.

Keywords: Flexible Barrier, IoT sensor, Monitoring

1 Introduction

1.1 Attributes of Flexible Barrier

Flexible barrier is one of the defense measures adopted in Hong Kong in recent years against landslide debris or boulder fall from natural hillside terrain with the aim to strike a balance between risk mitigation, cost effectiveness and disturbance to the natural environment. A flexible barrier typically consists of components such as chain wire meshes, steel ring nets, longitudinal steel wire ropes, steel posts, bracing steel wire ropes and energy dissipation devices (Figure 1 and Figure 2). The interval of steel posts is typically at 10.0m c/c.

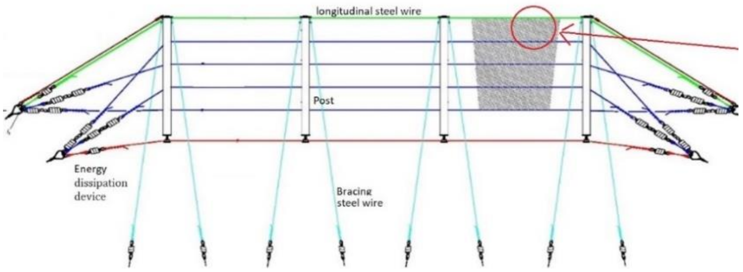


Figure 1: *Schematic arrangement of flexible barrier*

Proceedings DOI: 10.21467/proceedings.159; Series: AIJR Proceedings; ISSN: 2582-3922; ISBN: 978-81-965621-6-8

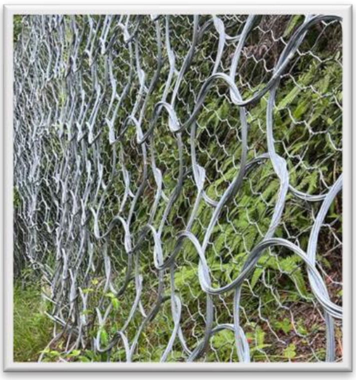


Figure 2: *Photo of chain wire meshes and teel ring nets.*

With Reference to Geotechnical Engineering Office Technical Guidance Note 37 (TGN37), empirical approach can be adopted for the selection of flexible barriers based on the relationship between the open hillside catchment and downhill facilities. The flexible barrier types for selection:

R1: 3,000 kJ flexible rock fall barrier with minimum height of 4 m
R2: 2,000 kJ flexible rock fall barrier with minimum height of 3 m.
R3: 1,000 kJ flexible rock fall barrier with minimum height of 3 m.

For a 3,000 kJ flexible barrier, it is typically assumed that the flexible barrier to have a ceiling velocity of 9.0 m/s under a landslide volume of approx. 200m3. with reference to GEO Report 333, debris from landslide reaches the flexible barrier at different phases leading to variations in debris velocity and thickness at different time. Hence, a continuous monitoring of flexible barrier with the aim to capture the fluctuation of flexible barrier can be useful.

1.2 Routine Inspection Practices for Flexible Barrier

In Hong Kong, large majority of flexible barriers were constructed under Landslip Prevention and Mitigation Programme (LPMitP) by the Civil Engineering and Development Department (CEDD). The number of flexible barriers constructed is continuously increasing and CEDD detailed the minimum requirement for inspection and maintenance of flexible barrier in Guide to Slope Maintenance (Geoguide 5).

Under Geoguide 5, the routine maintenance inspection frequency for flexible barrier is governed by the Consequence-to-life (CTL). For CTL Category 1 and Category 2 slopes, the routine inspection frequency is once every year while it is once every two years for Category 3 slopes. It is noted that Geoguide 5 does not require the routine maintenance inspection of flexible barrier be conducted by professional grade personnel with geotechnical knowledge.

For Government Departments, the inspection officer to conduct the routine maintenance inspection for flexible barrier is typically a supervising level staff such as work supervisor or technical officer.

In conducting the routing maintenance inspection, the inspection officer is required to complete the record sheet in Geoguide 5 and identify the need for maintenance works including:

- trim/remove undesirable vegetation from the barrier
- remove accumulated debris from the barrier,
- and other general maintenance actions such as drainage channel clearance.

In addition, the inspection officer is also required to identify, if applicable, whether the barrier has been affected by landslide/rockfill/hill fire with estimation of the volume of debris generated. This would then trigger a special follow-up review by professional engineers and/or barrier manufacturers. Nevertheless, an Engineer's Inspection (EI) by professional engineer is required in 5 years or 10 years intervals depending on the CTL Category of the slope.

Given the routine maintenance inspection covers mainly general maintenance and conducted by non-professional staffs but the flexible barrier is aimed to be, in some circumstance, the last line of defense to facilities against openhill landslide hazard (OHL), therefore the use of internet of thing (IoT) sensors to enhance the monitoring of flexible barrier can provide a solution in an innovative and creative ways.

1.3 This Project

This paper presents the development of tailor-made remote sensor for long term monitoring of flexible barriers in Hong Kong. The sensors are fixed to the flexible barrier steel post(s) near the based supports and measure the acceleration in g (m/s^2) and transfer the measured data directly to a cloud server.

Measured data is then processed to give the movement of steel post in velocity (m/s) to produce a real-time graph at the online cloud platform. The movement of steel posts at the pinned-joint base can be recorded and then be statistically analyzed individually and/or as a whole to "learn" the movement trends with the aim to produce a baseline movement data during normal and adverse weather condition. In time, with sufficient measured data, this baseline can be used as on-going reference with the aim give alert signal when abnormal movement against baseline is recorded which may indicate the likelihood of a potential landslide/rockfall events that enable relevant parties to trigger a proactive inspection and necessary follow-up action.

2 Use of IoT Sensors for Monitoring of Flexible Barrier

2.1 Information of IoT Sensors

Development of tailor-made IoT sensor was required with the following conditions:

- accurate measurement of movement/motion and its directions
- ability to transmit measured data wirelessly to cloud platform
- ability to remotely monitor and amend the sensor settings
- minimize power consumption to run minimum 3 months
- not easily notifiable by public and small in size

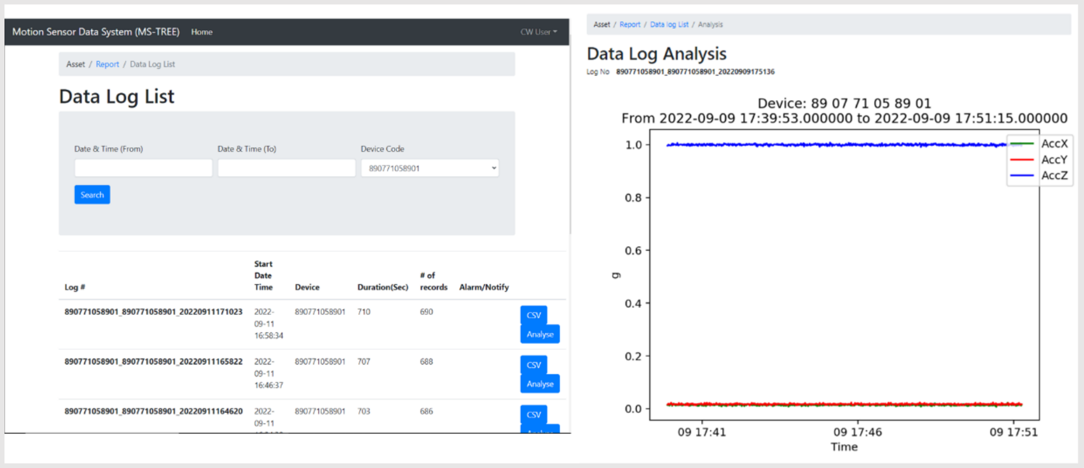
The team was able to deliver a IoT sensor with Wireless Sensor Network (WSN) that can fulfill the technological difficulties with reliability and productivity (see Figure 3).

Sensitivity	1mg/digit
Measurement range	±2.0 g
Sensitivity change vs temperature	0.01 %/°C
Typical zero-g level offset accuracy	±40 mg
Zero-g level change vs temperature	±0.5 mg/°C
Acceleration noise density	µg/√Hz

Figure 3: *Tailor-made IoT Sensor*

2.2 Sensors Components

Within this, there are the sensor, power source and micro-controller all connected to the main board. Another core element is the transceiver which is a chip of Nordic nRF905 to handle data processing in each node. It has an inbuilt proprietary media access control that supports data packets up to 32B and required only an SPI-bus connection to the sensor. This transceiver does not provide radio function but used to control modulation scheme making it compatible with NB-IoT and battery control. The sensor just one small part of a complex system that includes internet links from the sensor to a cloud platform that enables real-time access of measured data (see Figure 4).



Motion Sensor Data System (MS-TREE) Home

Asset / Report / Data Log List

Data Log List

Date & Time (From):
Date & Time (To):
Device Code: 890771058901

Log #	Start Date Time	Device	Duration(Sec)	# of records	Alarm/Notify	
890771058901_890771058901_20220911171023	2022-09-11 16:58:34	890771058901	710	690		CSV Analyse
890771058901_890771058901_20220911165822	2022-09-11 16:46:37	890771058901	707	688		CSV Analyse
890771058901_890771058901_20220911164620	2022-09-11	890771058901	703	686		CSV

Asset / Report / Data log List / Analysis

Data Log Analysis

Log No 890771058901_890771058901_20220909175136

Figure 4: *Remote access of real-time measured data from cloud platform*

Each of these components is critical for successful environmental monitoring. The internet link from a sensor network to the server assumes that an internet endpoint exists but this is not always the case. Communication of NB-IoT is ideal in principle but sometimes problematic in practice. It is common to naively presuppose that servers are always connected, but the truth is that network connectivity infrastructure is unable to guarantee always up. During the connectivity down moment, those servers are inaccessible from the outside world and its live environmental data.

Accuracy and calibration are critically important which must reflect accurate data of environment state. Sensor calibration and detecting stuck values from broken transducers are critical too.

2.3 Information of Selected Flexible Barrier for this Project

Selected flexible barrier is located near the downhill side of Sai Wan Shan at Pamela Youde Nethersole Eastern Hospital Staff Quarters was selected for this project (see Figure 5).

Figure 5: *Map of Selected Flexible Barrier*

At crest of Sai Wan Shan (~ at 190mPD), it is the transposer station that can be accessed through Lei Yue Mun Park. It is estimated the Sai Wan Shan has a gradient of 35° and since the uphill was excavated/distributed, there is a possibility of landslide/rockfill in time after adverse weather condition and therefore flexible barriers were provided at downhill (Figure 6).

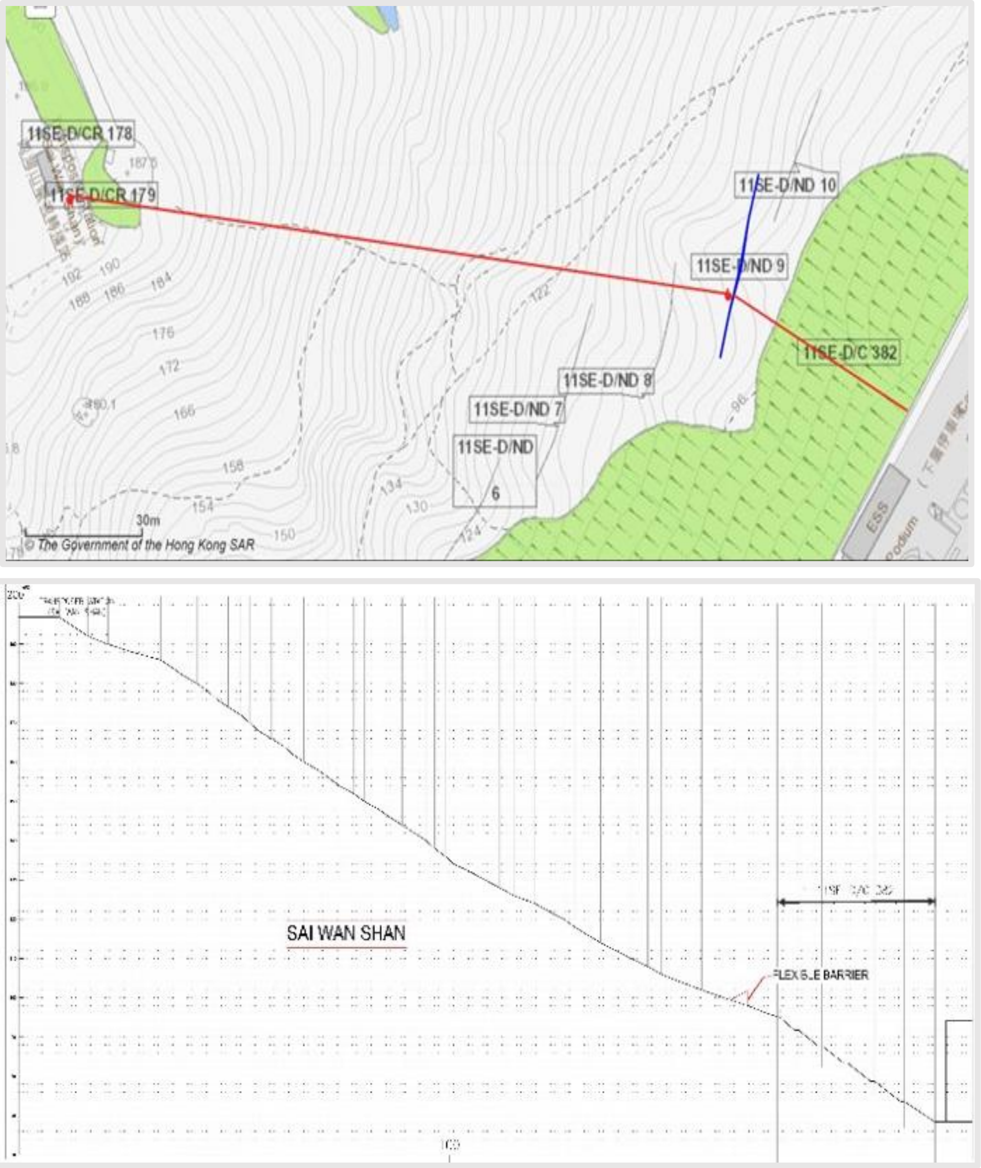


Figure 6: *Site Plan and Section*

This flexible barrier (slope number: 11SE-D/ND9) is one of flexible barriers located at downhill of Sai Wan Shan along the hospital facilities with a man-made slope in-between. The concerned barrier is located about 50m from hospital facilities at +90mPD with 40m in length and 4.0m in height, consisting of 5nos steel posts at 10m intervals. Based on the information available, this flexible barrier has absorbing capacity of 3000 kJ.

2.4 IoT Sensors Installation to Flexible Barrier

To securely fix the IoT sensor onto the flexible barrier without affecting its structural integrity, a tailor-made steel "clamp" was designed to fix the sensor onto the steel post without the need to form any drillhole /weld Figure 7. Then the sensor together with its mounting can be fixed onto the steel clamp and facing the downhill side of the steel post Figure 8.

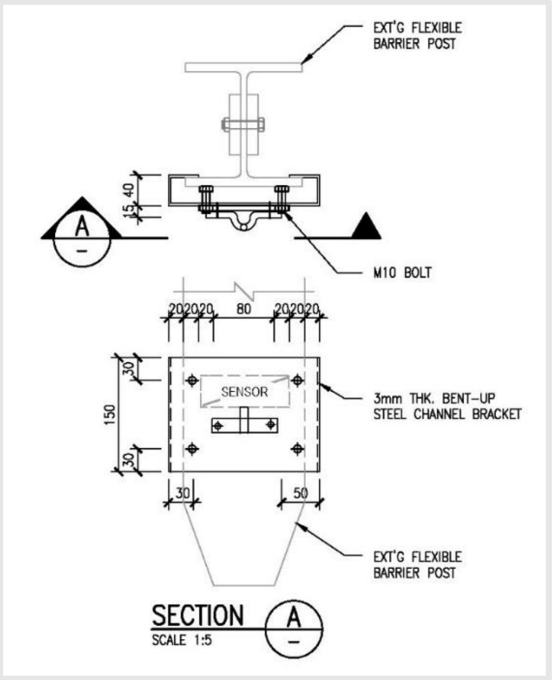


Figure 7: *Schematic Details of Steel Clamp for Sensor Fixing*

Figure 8: *Photo of Sensor Fixing to Steel Post*

In addition, an external weatherproof USB cable is prefixed to the sensor for recharging of battery without the need to direct-in-touch the sensor body (see Figure 9).

Figure 9: *Photo of Sensor Charging using power bank*

3 Processing of Measured Data from IoT Sensor

3.1 Data Collection and Pre-processing

Over two months continuously measured data starting from 26 Nov 2022 to 18 Feb 2023 on the movement of flexible barrier posts was collected by the IoT motion sensors. The primary data used for analysis was the maximum level of displacement in gravity (m/s^2) unit each day. Pre-processing steps were conducted to ensure that the data was in a suitable format for time series analysis. The pre-processing steps included removing any missing or invalid data points through data cleaning, and scaling the data to ensure it had a mean of zero and a standard deviation of one through data normalization.

Next, the data was plotted as a heatmap, with the sensors displayed on the Y-axis and time on the X-axis. The heatmap showed the maximum velocity (m/s) recorded for the sensor on each day (Figure 10).

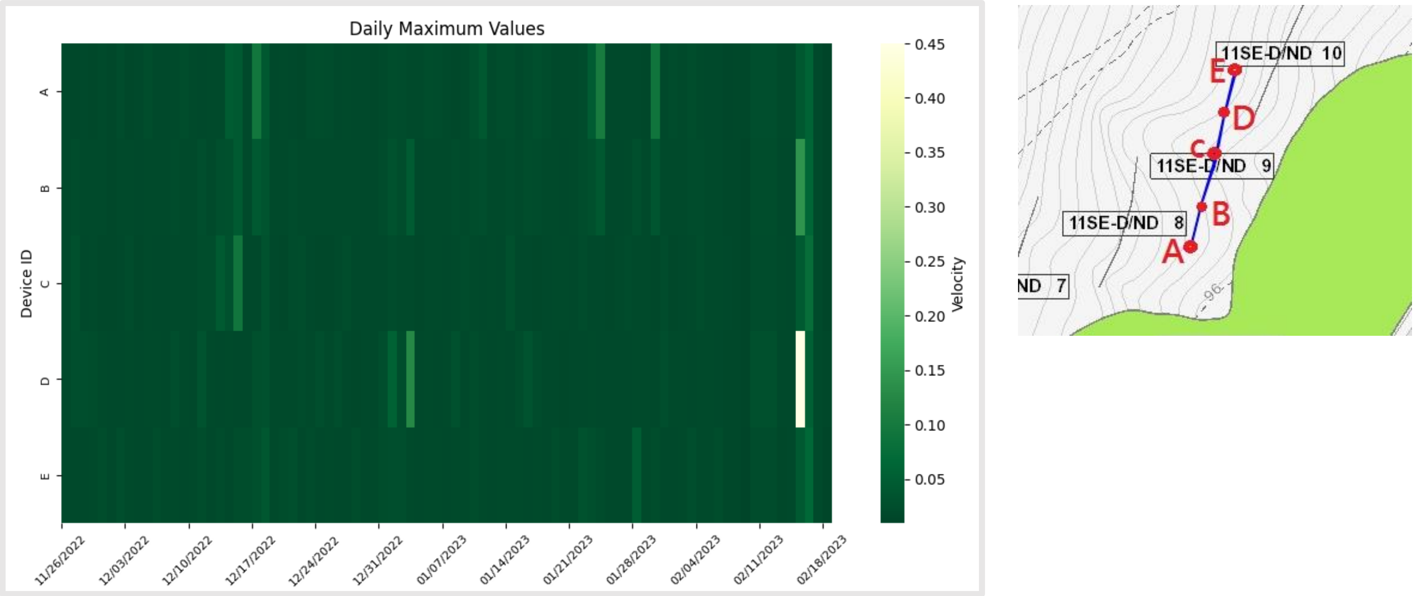
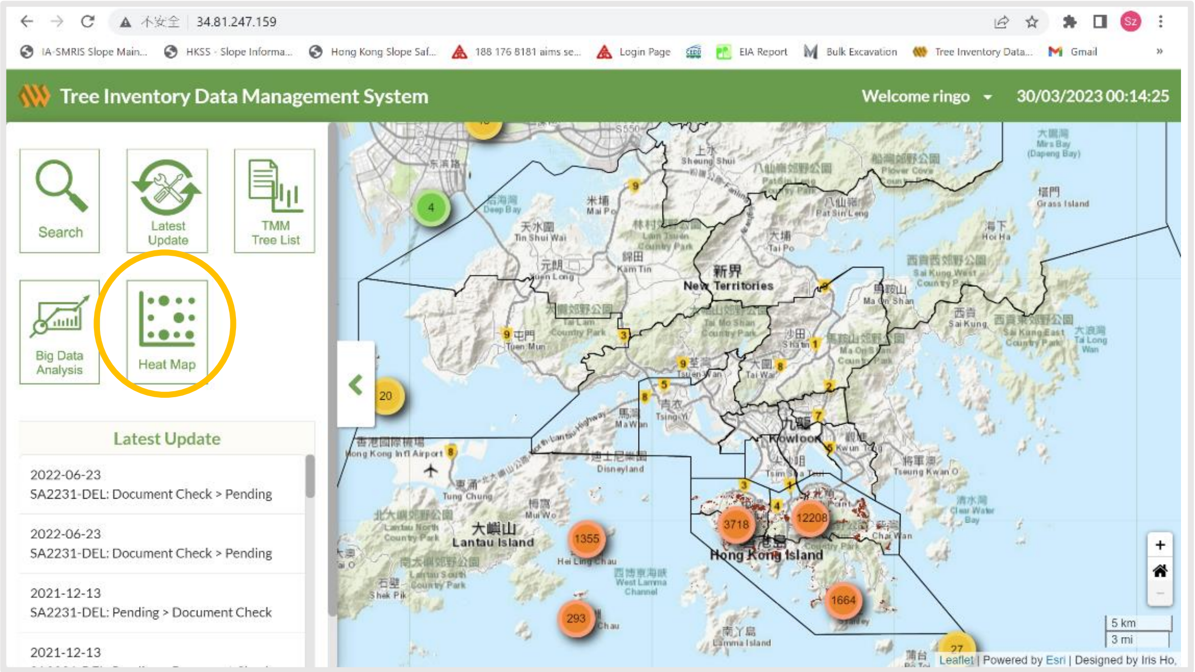


Figure 10: *Heat Map of Sensor Movement*

This heatmap showing the velocity of each IoT sensors at the flexible barrier is accessible through the cloud platform (see Figure 11).



Latest Update

2022-06-23
SA2231-DEL: Document Check > Pending

2022-06-23
SA2231-DEL: Document Check > Pending

2021-12-13
SA2231-DEL: Pending > Document Check

2021-12-13

Figure 11: *Heat Map at the Cloud Platform*

3.2 Methodology of Data Analysis using Time Series Analysis

To analyze the daily maximum displacement recordings, data was segmented in weeks and two time series models were utilized. The first model was based on the Singular Spectrum Analysis (SSA) approach which is a decompositional approach that involves transforming data into a series of principal components (Golyandina & Zhigljavsky, 2018). SSA is particularly useful for time series that exhibit complex patterns, such as nonlinear, trends or cyclical variations. The second model was based on the Vector Autoregression (VAR) approach, which helps to analyze the relationships between multiple time series. VAR was used to investigate the relationships between the weekly time series of daily maximum displacement data.

The stationarity of the time series was evaluated using both methods. With SSA, the trend component was extracted from the time series and tested for stationarity using the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test. VAR was also applied to model the relationship between multiple time series, with the data segmented into weeks to create a time series for each week. Both SSA and VAR were employed to provide a comprehensive approach to analyze for stationarity.

SSA is able to better capture complex trend patterns, while VAR can identify correlations among trends over different time periods. Alert signal will be generated when stationarity is likely violated.

3.3 Further Analysis on Alert Signal with Stochastic Processes

To analyze alert signals generated in the previous step, the Hidden Semi-Markov Model (HSMM) approach was employed (Lütkepohl, 2005). The likelihood of instability was estimated for each post, and the likelihoods were subsequently normalized into probabilities using HSMM. By providing a precise assessment of potential instability based on the observed patterns in the time series data, this approach enables effective identification of safety risks and guidance of targeted interventions to mitigate those risks.

3.4 Data Analysis for This Study

The graphs below show the moving average of the five sensors (see Figure 12 to 16 for Sensor A to E respectively) over the measured period.

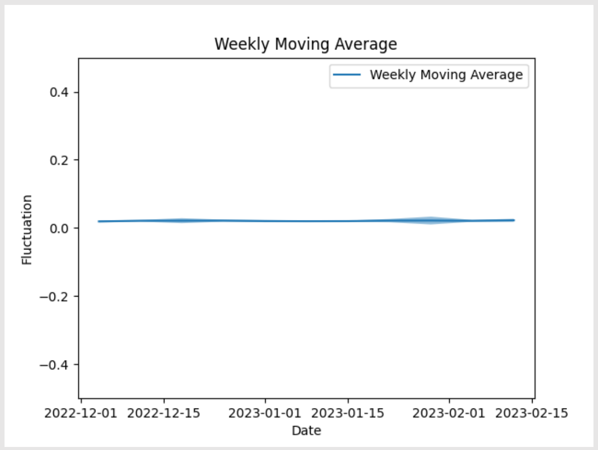


Figure 12: *Sensor A*

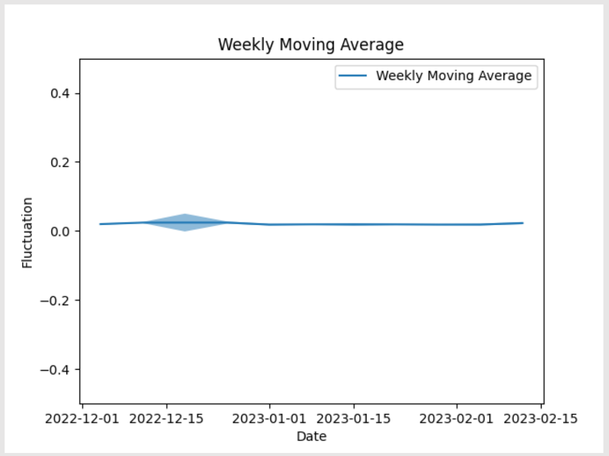


Figure 13: *Sensor B*

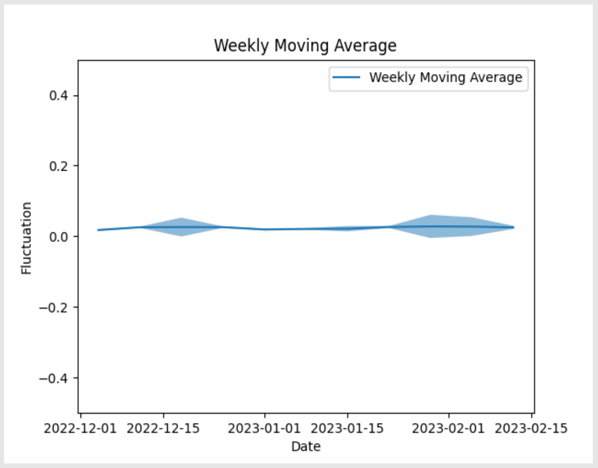


Figure 14: *Sensor C*

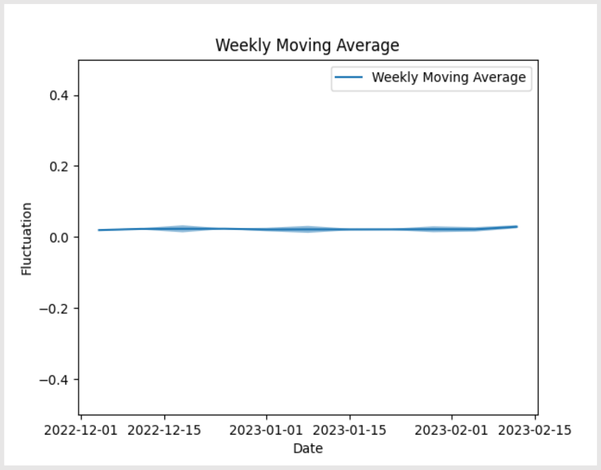


Figure 15: *Sensor D*

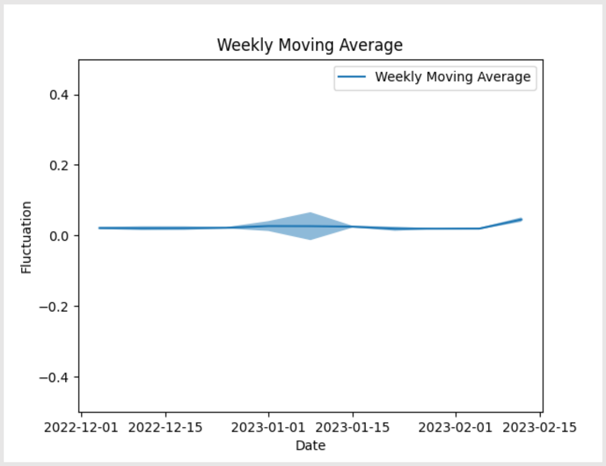


Figure 16: *Sensor E*

The moving average of the sensors seem smooth, but the analysis of the maximum displacement gave a different finding.

SSA and VAR were used to analyze the daily maximum displacement recordings by weekly segment. To examine the stationarity of the time series, the trend component was extracted from the time series using SSA, and the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test was used to evaluate the extracted trend component. Then the data was segmented into weeks so that each week became a time series, and VAR was applied to model the relationships between multiple time series.

The analysis of the weekly time series of daily maximum displacement data revealed that, on average, 9 trends were noted for Post “A” using both SSA and VAR approaches. No trend was noted for Post “B”, while 4 trends were noted for Post “C”, and 5 trends were noted for both Post “D” and Post “E”. These trends signals spanned over a total of 12 weeks.

Then, Stochastic Processes based on the Hidden Semi-Markov Model (HSMM) approach was used to analyze the occurrence of these trends yielded from the previous step analysis. Based on the transition pattern for each post, the estimated likelihood of the post being potentially unstable and normalized the likelihoods into probabilities using HSMM is presented (Table 1)

Table 1: *Result of probabilities on alert occurrence using* HSMM

Post Mark	Probabilities p
A	0.03
B	0.01
C	0.18
D	0.17
E	0.17

The analysis indicated Post "A" had a significantly longer duration being in a trendy state, indicating that Post "A" was at higher risk of being potentially recording higher movement. Yet no trend was observed for Post "B" could indicate that notifiable object(s) causing these movements between Post "A" and Post "B" occurred more towards Post "A". Site inspection conducted in 2 March 2023 and no abnormality was observed from to the flexible barrier. The measured data will be compared again after Typhoon Season from June to October 2023 so as to get a more comprehensive benchmark data on the movement of flexible barrier during normal and adverse weather condition. This benchmark data will continuously be enhanced with the aim to improve the effectiveness in using IoT sensors for monitoring the movement flexible barrier.

4 Conclusion

In this study, through the installation of IoT sensors onto the flexible barrier steel posts, and present the measured data real-time on a cloud platform, with a two-step time series to further analyze the data. While the accuracy on monitoring of movement or deformation of flexible barrier under actual situation is not available, the monitoring of flexible barrier is enhanced and, in time when making reference with the benchmark data under normal and adverse weather condition, if any large movement to the flexible barrier in comparison to the benchmark data, then this finding can be a valuable reference to the Geotechnical/Civil engineers in considering a proactive inspection and any follow-up actions if necessary.

5 Declarations

5.1 Acknowledgements

The authors would like to express our gratitude to Mr. Liu Lam Fung, Xavier and Mr. Wong Hoi Hong, both graduates from Thei for their supports in IoT sensors management and Mr. Hui Ka Chun for his expertise in building the Cloud Platform.

5.2 Publisher's Note

How to Cite

Tim *et al.* (2023). Monitoring of Flexible Barrier for Slope Safety Against Potential Rockfall using IoT Sensors. *AIJR Proceedings*, 243-253. https://doi.org/10.21467/proceedings.159.19

References

GEO. (2021). *Guide to Slope Maintenance, Geoguide 5*. https://www.cedd.gov.hk/filemanager/eng/content_113/eg5.pdf

Geotechnical Engineering Office. (2014). *Guidelines on Empirical Design of Flexible Barriers for Mitigating Natural Terrain Open Hillslope Landslide Hazards*. The Government of the Hong Kong Special Administrative Region. https://www.cedd.gov.hk/filemanager/eng/content_427/TGN37.pdf

Golyandina, Nina., & Zhigljavsky, A. A. (Anatoliĭ A. (2018). *Singular spectrum analysis for time series*. Springer Berlin, Heidelberg. https://link.springer.com/book/10.1007/978-3-642-34913-3

Kwan, J. S. H., & Koo, R. C. H. (2018). *Enhanced Technical Guidelines for Design of Debris-resisting Barriers*. https://www.cedd.gov.hk/filemanager/eng/content_581/er333link.pdf

Kwiatkowski, D., Phillips, P. C. B., Schmidt, P., & Shin, Y. (1992). Testing the null hypothesis of stationarity against the alternative of a unit root: How sure are we that economic time series have a unit root? *Journal of Econometrics*, *54*(1–3), 159–178. https://doi.org/10.1016/0304-4076(92)90104-Y

Lütkepohl, H. (2005). New introduction to multiple time series analysis. In *New introduction to Multiple Time Series Analysis*. Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-27752-1

Peng, Y., & Dong, M. (2011). A prognosis method using age-dependent hidden semi-Markov model for equipment health prediction. *Mechanical Systems and Signal Processing*, *25*(1), 237–252. https://doi.org/10.1016/J.YMSSP.2010.04.002