Chapter 3
People as Sensors: Towards a Human–Machine Cooperation Approach in Monitoring Landslides in the Three Gorges Reservoir Region, China

Zhenhua Li, Guoxuan Cheng, Wenming Cheng, and Hongbo Mei

Abstract Landslides are serious geologic hazards which have occurred in most countries and can cause significant loss of life and damage to property. The loss and damage may be avoided to some extent by monitoring and early warning systems for landslides. Currently, the most popular method to detect landslides is the wireless sensor network. In this paper, a human–machine cooperation system is proposed, which not only employs 500 sensor sets to collect data in the conventional way but also mobilizes over 6000 people to inspect landslides and gather data by simple tools daily, to take advantage of human wisdom and mobility to remedy the weakness of fixed sensors, which could not move, observe, think, and make decisions. For its 12 years of application in the Three Gorges Reservoir Region, China, the system has successfully predicted most threats which take place nearly 100 times each year.

3.1 Introduction

Landslides are common geologic hazards worldwide which heavily threat human life and property. On October 9, 1963, a huge landslide caused approximately 270 million cubic meters of rock and debris to fall into the Vajont reservoir, Italy, as a result a wave overtopped the dam and destroyed many villages in the Piave valley, with the loss of over 2000 lives.

For the detecting landslides, there are two types of observation method: remote sensing and ground-based monitoring. The former uses satellite, unmanned aerial vehicle (UAV), and even balloon to actively or passively monitor the surface

Z. Li (✉) · G. Cheng · H. Mei
China University of Geosciences, Wuhan, China
e-mail: zhli@cug.edu.cn

W. Cheng
The Headquarters of Prevention and Control for Geo-Hazard in the Three Gorges Reservoir Area, Yichang, China

S. Guo, D. Zeng (eds.), *Cyber-Physical Systems: Architecture, Security and Application*, EAI/Springer Innovations in Communication and Computing,
https://doi.org/10.1007/978-3-319-92564-6_3

displacement through optical, radar, and LiDAR technologies [2–4, 8]; the latter utilizes sensor networks to detect the whole status of landslide, on both surface and underground, such as surface deformation [1, 11], deep displacement [7], groundwater level [12], rainfall [10], reservoir level (if there is a reservoir around) [6], etc., or some or all of them [5, 9].

To take advantages of the above modern technologies, the government in the Three Gorges Reservoir area constructs a multilevel, three-dimensional, and full-time monitoring system to integrate Remote Sensing Monitoring System, Global Positioning Satellite Monitoring System, and Comprehensive Monitoring System, including over 500 sensor sets to collect data of absolute displacement, relative displacement, groundwater level, pore water pressure, soil pressure, meteorology, earthquake, earth sound, and human activities, and, in addition, mobilizes over 6000 persons to collect data by simple tools and inspect landslides daily, in an economic way, to take advantage of human wisdom and mobility to remedy the weakness of fixed sensors, which could not move, observe, think, and make decisions.

3.2 Project Description

The Three Gorges Reservoir region has been vulnerable to landslides, because of its complicated terrain and climate. More than 70 geological disasters had taken place in this area from 1982 to 2000, killing over 400 persons. Landslides have seriously damaged the social and economic life in the reservoir area (Fig. 3.1).

However, the Three Gorges Dam Project, the largest hydroelectric dam in the world, though it brings huge benefits such as flood control, power generation, and navigation, etc., exacerbates the scale and frequency of the geological disasters, as the water is pushed to its maximum level periodically. On July 13, 2003, just 1 month after it first impounded up to the 135 m, Qianjiangping landslide occurred in Zigui County, which was responsible for the deaths of 24 people, and destruction of 129 houses and 4 factories. To prevent and respond to risks of the geological disasters, the Chinese government has so far invested over 250 million yuan in monitoring nearly 4000 landslides in this area.

3.3 The Sensor-Based Monitor System

The Monitor System is composed of three subsystems: the Remote Sensing Monitoring System, the Global Positioning Satellite (GPS) Monitoring System, and the Comprehensive Monitoring System, to build a multilevel, three-dimensional, and full-time monitoring and early warning platform.

Fig. 3.1 Damages caused by landslides in the Three Gorges area

3.3.1 The Remote Sensing Monitoring System

As the Three Gorges Dam was built, the storage water level went up from 135 to 175 m. To explore the environment influence of reservoir impoundments, remote sensing data in three stages: before filling, filling to 135 m level, and filling to 175 m level are compared to investigate the changes. And, the remote sensing maps, along with geographic information system and GPS system, became the foundation of the Monitor System (Fig. 3.2).

3.3.2 The GPS System

The GPS Monitoring System adopts a three-layer hierarchical network architecture (see Fig. 3.3). The first layer, A-level, is the GPS control network with 15 control points; the second one, B-level, is the GPS base network with 210 base points; and the last one, C-level, is the GPS monitoring networks with 1070 monitoring points on 127 landslides [13].

Fig. 3.2 Identify a landslide from remote sensing images

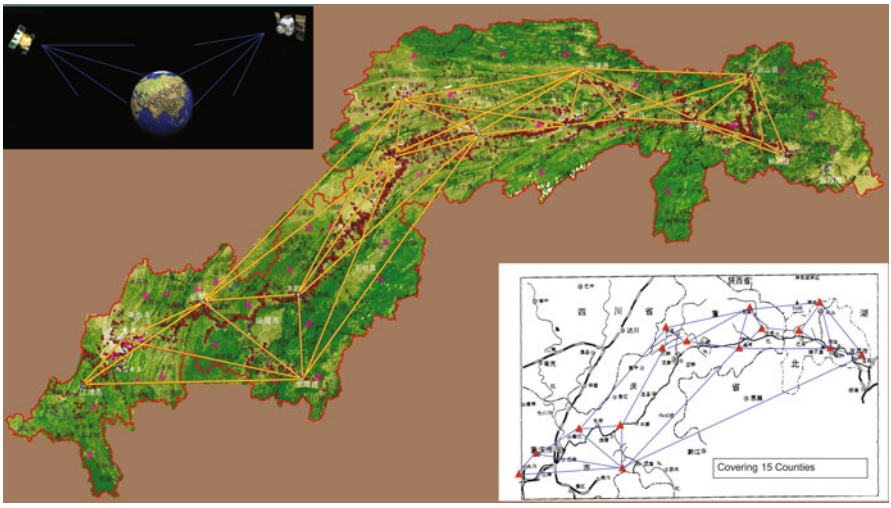

Fig. 3.3 The GPS monitoring network

GPS monitoring points were built as can be seen in Fig. 3.4. For surface displacement monitoring, GPS technology yields 3D measurements with a high accuracy (in the range of a few millimeters) and high frequency (hours to days).

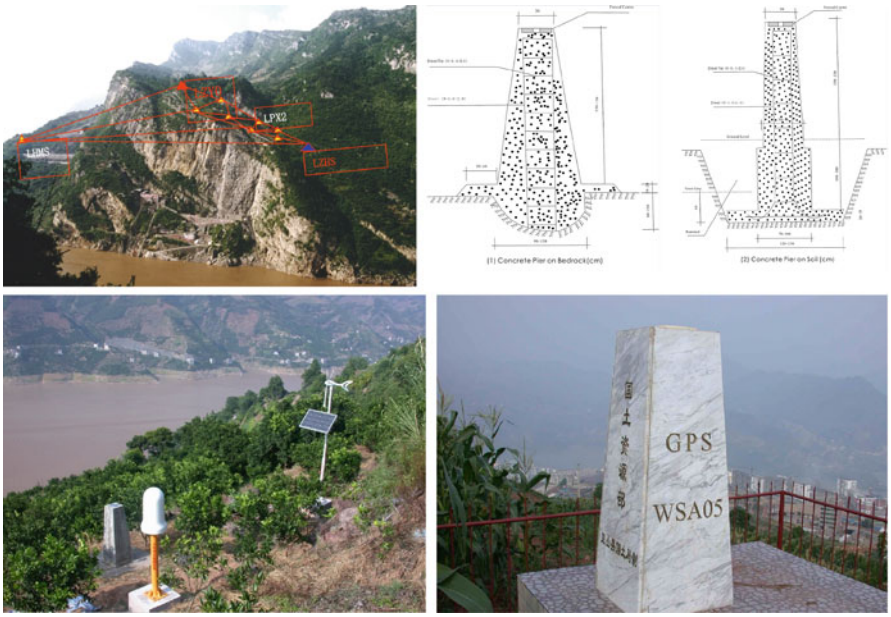

Fig. 3.4 The GPS monitoring points

3.3.3 The Comprehensive Monitoring System

The above two systems aim to detect surface displacement, the most important measurement. However, there are other factors also significant to landslide monitoring. According to geological conditions in study area, the Comprehensive Monitoring System is developed to monitor the rain gauge, deep deformation (see Fig. 3.5), landslide thrust, and groundwater level (see Fig. 3.6). The first measurement, rain fall, is an important factor to trigger landslide movement, and the latter three are meaningful kinematic parameters of landslide process.

There is still another trigger of geological disaster in this area, the reservoir water level, whose data comes from Changjiang Water Resources Committee.

3.4 The Human-Based Monitoring System: People as Sensors

The project employs over 6000 part-time local people to observe landslides and upload results daily through mobile phone. To use people as sensors, there are two obvious advantages in the Mass Monitoring System (Figs. 3.7 and 3.8):

Fig. 3.5 Detecting rain gauge and deep deformation

Fig. 3.6 Detecting landslide thrust and groundwater level

Fig. 3.7 Information bulletin of a landslide observer (the upper figures), mobile APP for reporting observations (the lower-left figure), and warning devices, a gong & a loudspeaker (the lower-right figure)

1. Machines are programmed to follow certain rules, while wise people can adapt to new environments. In fact, there are no sensor networks that can replace people to investigate landslides so far.
2. Besides the investigation of landslides, some measurements can be done more flexibly and cheaply by people. In Fig. 3.9, a scrap of paper, or a tape can be used to detect the movement of landslides.

3.5 The Monitoring and Early Warning Platform

To combine the Sensor-based Monitor System and the Human-based Monitoring System and improve the efficiency of disaster response and preparedness, the Monitoring and Early Warning Platform is built as follows (see Fig. 3.10).

The Platform is composed of 4 subsystems and 27 modules, as shown in Fig. 3.11. The subsystems are information system, early warning system, data center, and administration system.

Fig. 3.8 Penetration at the trailing edge of the landslide (the upper-left figure), crack at the trailing edge of the landslide (the upper-right figure), the steep surface between the failed body and the terrain (the lower-left figure), and road deformation in the front edge of the landslide (the lower-right figure)

3.6 Conclusions

The monitoring and early warning system, combined the Sensor-based Monitor System with over 500 sensor sets and the Human-based Monitoring System with 6000 people to monitor nearly 4000 landslides in 26 counties, has been run in the Three Gorges Reservoir Region for nearly 12 years and it has successfully predicted most threats which occur nearly 100 times each year, with no life loss.

The human–machine monitoring system, essentially a combination of Internet of Things and Crowdsourcing, with Chinese characteristics, offers an economical and flexible alternative to monitoring and prediction of geo-hazards, especially for developing countries.

Fig. 3.9 Scraps of paper to monitor wall crack (the upper figures) and a tape to measure the length of landslide rapture (the lower figures)

Fig. 3.10 Diagram of the monitoring and early warning platform

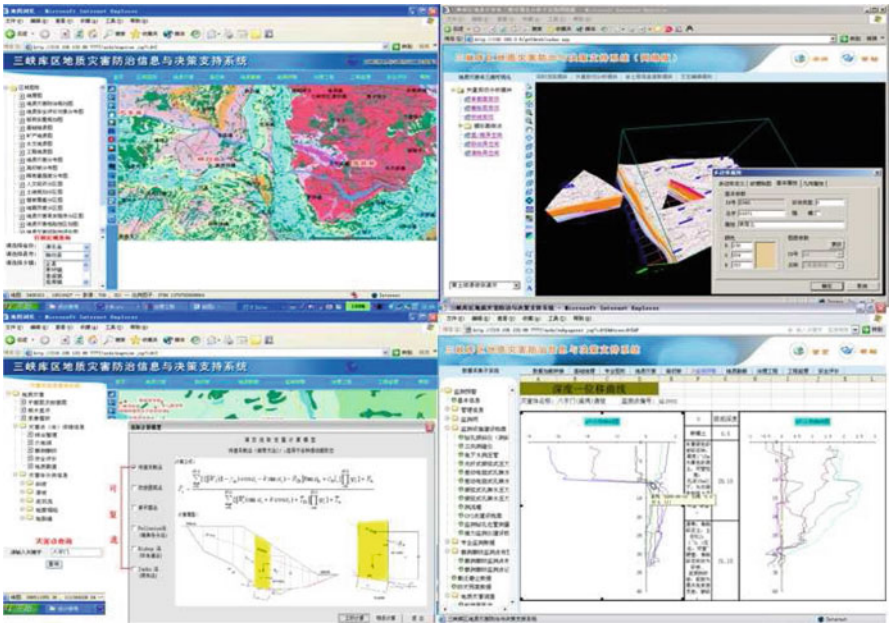

Fig. 3.11 Snapshots of system UI

References

1. Benoit L, Briole P, Martin O, Thom C, Malet JP, Ulrich P (2015) Monitoring landslide displacements with the geocube wireless network of low-cost gps. Eng Geol 195:111–121
2. Colesanti C, Wasowski J (2006) Investigating landslides with space-borne synthetic aperture radar (SAR) interferometry. Eng Geol 88(3–4):173–199
3. Dingfa H, Jun Q (1998) GPS-based target monitoring and navigation system for remote sensing-equipped flying balloon. In: Proc. SPIE 3504, Optical remote sensing for industry and environmental monitoring, pp. 131–135. https://doi.org/10.1117/12.319526
4. Jaboyedoff M, Oppikofer T, Abellan A, Derron MH, Loye A, Metzger R, Pedrazzini A (2012) Use of LIDAR in landslide investigations: a review. Nat Hazards 61(1):5–28
5. Ju Np, Huang J, Huang Rq, He Cy, Li Yr (2015) A real-time monitoring and early warning system for landslides in southwest china. J Mt Sci 12(5):1219–1228
6. Kaczmarek H, Mazaeva OA, Kozyreva EA, Babicheva VA, Tyszkowski S, Rybchenko AA, Brykala D, Bartczak A, Skowinski M (2016) Impact of large water level fluctuations on geomorphological processes and their interactions in the shore zone of a dam reservoir. J Great Lakes Res 42(5):926–941. https://doi.org/10.1016/j.jglr.2016.07.024
7. Lami Y, Nocera G, Genon-Catalot D, Lagreze A, Fourty N (2016) Landslide prevention using a buried sensor network. In: 2016 IEEE radio and antenna days of the Indian Ocean (Radio)
8. Maria Mateos R, Azanon JM, Roldan FJ, Notti D, Perez-Pena V, Galve JP, Luis Perez-Garcia J, Colomo CM, Gomez-Lopez JM, Montserrat O, Devantery N, Lamas-Fernandez F, Fernandez-Chacon F (2017) The combined use of PSInSAR and UAV photogrammetry techniques for the analysis of the kinematics of a coastal landslide affecting an urban area (SE Spain). Landslides 14(2):743–754

9. Palis E, Lebourg T, Tric E, Malet JP, Vidal M (2017) Long-term monitoring of a large deep-seated landslide (La Clapiere, South-East French Alps): initial study. Landslides 14(1):155–170. https://doi.org/10.1007/s10346-016-0705-7
10. Ramesh MV (2009) Real-time wireless sensor network for landslide detection. In: 2009 3rd international conference on sensor technologies and applications (Sensorcomm 2009) pp 405–409
11. Vera JE, Mora SF, Cervantes RA (2016) Design and testing of a network of sensors on land surfaces to prevent landslides. In: 2016 IEEE biennial congress of Argentina (Argencon)
12. Xu Q, Liu H, Ran J, Li W, Sun X (2016) Field monitoring of groundwater responses to heavy rainfalls and the early warning of the Kualiangzi landslide in Sichuan Basin, Southwestern China. Landslides 13(6):1555–1570. https://doi.org/10.1007/s10346-016-0717-3
13. Yue W, Xuebin H, Shaoquan X, Wenming C, Yingbing L (2006) Application of GPS technique for geological hazard professional monitoring in TGR area. J Geomatics 31(5):16-17