BASIN-WIDE DEBRIS FLOW MONITORING – DEVELOPMENT OF PORTABLE UNITS AND DEPLOYMENT STUDY

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ABSTRACT: Because of the global climate change, the extreme weather becomes more common and has brought flooding, debris flow, landslide disasters that usually occur as compound hazards with large scale and serious threat to the public. The Soil and Water Conservation Bureau (SWCB) has developed and established on-site and mobile stations to observe debris flows in Taiwan. However, due to the limited time and budget, the debris flow monitoring system cannot be widely established to cover every potential area. To achieve the goal of monitoring a whole watershed, the concept of basin-wide monitoring network has been considered and a new type of monitoring equipment had been developed and applied at Laonong and Qishan Rivers. The newly developed monitoring equipment, called portable unit, integrates sensors, data transmission, power sets, and control system into a weather-resistant box, and fulfills the design requirements of light-weight and easy-to-carry. The deployment plan for portable units also had been studied. Approaches of integer programming and genetic algorithm (GA) were applied and evaluated using the cases of Laonong and Qishan River watersheds. Different combinations of portable units and monitoring stations were taken into consideration. The results had shown that the portable units can effectively support the monitoring network and the deployment study indicates the flexibility of portable units, which can enhance the monitoring network.

1. INTRODUCTION

The debris flow has become a common hazard in Taiwan in the last decade. In order to monitor the debris flows and prevent hazards, the Soil and Water Conservation Bureau (SWCB), a central government unit responsible for slope safety in mountain area, began to establish monitoring stations in 2002. Currently there are 17 debris flow monitoring stations (Figure 1) and 3 mobile stations in Taiwan. Instruments of rain gauge, water level meter, wire sensor, soil water moisture sensor, and CCD camera are used for monitoring debris flows. Each station has a data center to receive and transmit debris flow information from the site to the emergency operation center. The debris flow monitoring system has successfully assisted the SWCB and the public in response to the debris flow hazards in the past years.

Considering the annual budgets and the time to construct a monitoring station, SWCB has kept seeking monitoring alternatives that can be transported into remote mountain areas. Working with the research team of Feng Chia University, a newly developed monitoring device had been produced. The new equipment, called portable unit, carries sensors to collect debris flow-related data at remote areas. The portable unit was designed to work with current monitoring stations and mobile stations. There are 14 portable units ready to work.

The main goal of developing portable unit is to set up the monitoring network for the whole basin. The concept of basin-wide monitoring network comes from the fact that current natural hazards usually occur in multiple manner, and the need of widely distributed monitoring spots is urgent. Therefore, the basin-wide monitoring for debris flow indicates the interoperation and applications of on-site monitoring stations (for long-term data collection, usually at mid- and downstream), mobile stations (for event monitoring, usually at mid- and upstream), and the portable units (for event monitoring, usually at upstream and remote sites). All types of monitoring stations construct the basin-wide monitoring network for debris flow. Figure 2 shows the concept of basin-wide monitoring.

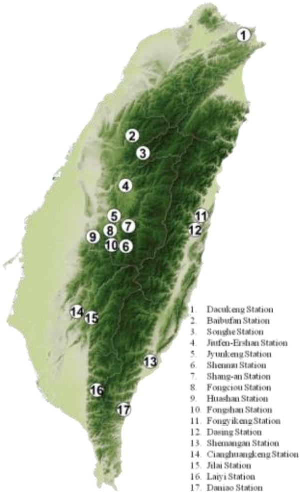

Figure 1 Debris flow monitoring staions in Taiwan

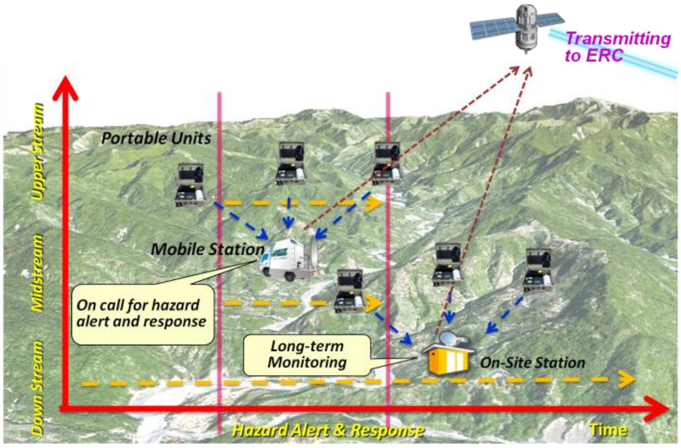

Figure 2 Basin-wide monitoring network.

In this paper, the authors will briefly describe the development of portable unit, and its deployment method in application. A practical testing was conducted during the event of Typhoon Fanapi in 2010. Testing results indicate the success of portable units and the potential to construct the monitoring network at events.

2. DEVELOPMENT OF PORTABLE UNIT

2.1 Design Concepts

The portable unit needs to match the requirements of easy-to-carry and basic monitoring functions. Thus, the development of portable unit adopts the light-weight, compact size, and self-operation design. In addition, to fulfill the requirement of mobility during an event, the monitoring function of a portable unit needs to start automatically when on site. The one-switch design was included to enable monitoring functions, such that anyone can use it and the operation becomes as easy as three steps: carry on, turn it on, and leave it. Communication and power are another two key design points for portable unit. Three communication methods were used and high efficiency batteries were installed to power the system for three days.

The portable unit was also designed in three types: basic, advanced, and premium types. The basic model includes a rain gauge and a soil moisture sensor. The advanced one has an additional geophone sensor, and the premium type includes a set of CCD camera. Different types of portable units will be used depending on the site condition and the requirement of data collection. These models of portable units provide flexibility in deployment during debris flow monitoring.

Overall, the portable unit features basic monitoring functions, compact size, light weight, self-operation, and flexible deployment. More description about the portable unit will be addressed in the following sections.

2.2 Instruments, Hardware, and Software

A portable unit can equip 3 monitoring sensors and one CCD camera. The sensors include rain gauge, soil moisture sensor, and geophone. Rain gauge and soil moisture senor are basic monitoring instruments in all three portable models. Geophone is only available in advanced and premium model. The CCD camera is only for premium model, in which extra battery sets are added to make up the additional power consumption from the camera. All these instruments are light-weighted and considerably small in size. Each portable unit can record and transmit data of rainfall and soil moisture, the two most important factors about the debris flow. Additional information is available when using advanced and premium models.

The hardware of a portable unit includes the case, the computer, batteries, and a radio transmitter. The case of potable unit is strong, tough, water proof, and weather-resistant. A touch-screen portable PC is installed running control system to receive and transmit monitoring data. Two high efficiency batteries of 50 Ah are used to power the unit. The last key hardware is a radio transmitter (FM) which is responsible for data communication between the portable units and monitoring stations. The communication methods are summarized in Table 1. Figure 3 shows the outlook of an advanced portable unit, and Figure 4 illustrates the transmission options.

Table 1 Communication options of portable unit.

Condition	Option	Priority
within the range of ISP service	Use GPRS/3G/3.5G to transmit images and data	1
within 1-2km distance of mobile to monitoring stations	Use 2.4GHz for images, FM for data	2
within 3-5km distance of mobile to monitoring stations	Use FM for data	3

Figure 3 The outlook of an advanced unit.

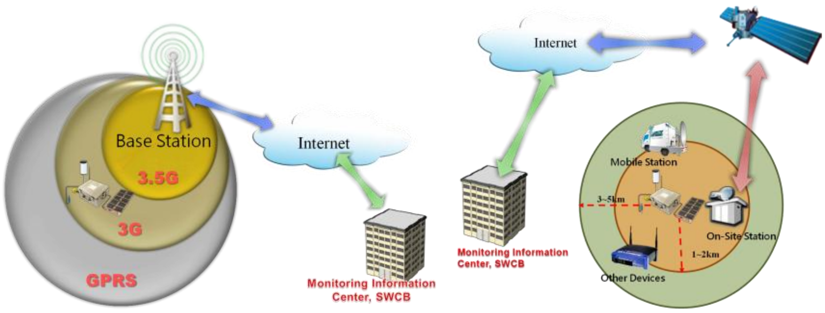

Figure 4 Illustration of communication options

In each unit, system modules of data receiving, data transmission, and data display are implemented to control the monitoring functions. A portable unit captures data per minute, and saves a data set per day, which contains 1440 entries. Each entry of data records rainfall, soil moisture, and geophone data. The transmission module works to send data to the nearby monitoring stations with predefined frequency and communication option. The data can also be displayed on screen at the site through the portable PC. Figure 5 shows the data check screen.

Figure 5 Screen of checking data

3. DEPLOYMENT OF PORTABLE UNITS

Another focus in this paper is the deployment of portable units. Potable units need to work with mobile and on-site monitoring stations during a typhoon event. To understand the combination of different types of monitoring stations, the deployment method of portable unit had been studied. Discussion about the deployment method is described in below.

3.1 Study Area

The area chosen for study is at the basins of Laonong and Qishan Rivers in Kaohsiung. There were 58 potential debris flows in this area before 2009, including 37 high potential debris flows. Additional 18 debris flows were marked after Typhoon Morakot in 2009, making the current total of 76 debris flows in this area. In this study, only the 58 debris flows were considered when conducting the deployment method. The locations of debris flows in this area can found at SWCB website. (http://246.swcb.gov.tw/)

3.2 Deployment Analysis

The deployment study for portable units mainly considered the distance to the mobile or monitoring stations, the range of communication, the severity of potential debris flows, and the portable models. These factors influence the number and locations of portable units in the deployment analysis. To simplify the procedure, two conditions were considered.

C1. With one on-site monitoring station, but no mobile station available.

C2. With one on-site monitoring station and certain mobile stations.

The above conditions indicate that the portable unit must transmit data through mobile or on-site monitoring stations. The target of monitoring is the debris flow. Therefore, the location to set portable units is at a debris flow without exception. Methods used in this study for deployment analysis were linear programming (LP) and genetic algorithm (GA). Tools of Excel® and Matlab® were used to generate the results.

3.2.1 Linear Programming

Linear programming uses a mathematical model to achieve the best outcome for some list of requirement represented as linear relationships. For portable unit deployment, the higher scores estimated for each accessible debris flow and unit models indicate the better deployment. During the analysis, the rainfall was included as a factor to determine if a debris flow had been triggered. Table 2 shows the results of condition C1, where DF* means the serial number of debris flow.

Table 2 Deployment results for condition C1.

Rainfall		Premium Unit	Advanced Unit	Basic Unit
Daily rainfall (mm)	200	DF013	DF045,DF016,DF014	DF020,DF015,DF019,DF018,DF012
	350	DF013	DF045,DF020,DF016	DF019,DF018,DF014,DF015,DF012
Accumulated rainfall (mm)	400, 600	DF013	DF045,DF016,DF014	DF020,DF015,DF019,DF018,DF012
	800, 1000	DF013	DF045,DF016,DF014	DF020,DF019,DF018,DF015,DF012
	> 1200	DF013	DF045,DF020,DF016	DF018,DF014,DF015,DF012

3.2.2 Genetic Algorithm

Genetic algorithm is another mathematical computation in which useful solutions are routinely used to optimize the results. Factors used in the linear programming were repeated in the GA analysis. The analysis of GA had shown same deployment results as linear programming for condition C1. For condition C2, Table 3 shows the deployment results when one on-site and one mobile station are available.

Table 3 Deployment results for condition C2 (one mobile station).

Rainfall		Mobile Station	Premium Unit	Advanced Unit	Basic Unit
Daily rainfall (mm)	200	DF058	DF059	DF060,DF013,DF045	DF056,DF016,DF014,DF020,DF015,DF019,DF018,DF057
	350	DF043	DF061	DF013,DF044,DF045	DF020,DF019,DF016,DF018,DF014,DF052,DF015,DF012
Accumulated rainfall (mm)	400	DF061	DF013	DF044,DF043,DF045	DF016,DF014,DF020,DF052,DF019,DF018,DF042,DF012
	600	DF052	DF061	DF013,DF044,DF043	DF045,DF016,DF014,DF020,DF015,DF042,DF019,DF018
	800	DF052	DF061	DF013,DF044,DF045	DF043,DF016,DF014,DF020,DF019,DF018,DF015,DF042
	1000	DF044	DF061	DF013,DF045,DF043	DF016,DF014,DF020,DF019,DF052,DF018,DF015,DF042
	1200	DF044	DF061	DF013,DF043,DF045	DF020,DF019,DF016,DF018,DF014,DF052,DF015,DF042
	1400	DF039	DF038	DF013,DF033,DF029	DF045,DF020,DF019,DF016,DF034,DF018,DF014,DF015

3.2.3 Deployment for Protected Villages

The deployment results described in the previous sections were generated mainly for a specific on-site monitoring station or mobile stations. The locations of deployment were not necessarily correlated in space, meaning distributed as a network from the upstream to downstream of a basin. Besides, the main goal of debris flow monitoring is to protect people from hazards. Therefore, a village-specific deployment procedure was conducted to include the protected target (the village in this study) as a restriction, and the previous analysis results (from LP or GA) were considered as well. Take the Qishan River Basin as an example. There are 4 villages can be chosen as protected targets: Minsheng, Minquan, Minzu, and Jiaxian villages. The potential debris flows threatened to these villages can be marked in advance (see Table 4). Thus, the deployment based on the protected villages can be generated. Table 5 shows the analysis results, where PU-B, PU-A, and PU-P are basic, advanced, and premium models, respectively; Mobile means the mobile station.

Table 4 Potential debris flows around villages

Basin	Village	Potential Debris Flow at Upstream
Qishan River	Minsheng	DF001,DF002
	Minquan	DF062,DF063,DF064,DF065,DF003
	Minzu	DF066,DF067,DF004
	Jiaxian	DF005,DF006,DF007,DF008,DF009,DF010,DF011,DF017,DF016,DF015

Table 5 Deployment results for Qishan River.

Debris Flow	Protected Villages			
	Minsheng	Minquan	Minzu	Jiaxian
DF001	PU-P	PU-B	PU-B	
DF002	Mobile	PU-P	PU-A	PU-A
DF062		PU-A	PU-A	PU-B
DF063		PU-A	PU-B	
DF064		PU-A	PU-B	PU-B
DF065		Mobile	Mobile	Mobile
DF003		PU-B	PU-A	
DF066			PU-B	
DF067			PU-B	PU-B
DF004			PU-P	PU-A
Control Pt. 2				Mobile
DF008				PU-B
DF009				PU-B
DF010				PU-A
DF011				PU-B
DF017				PU-P
DF016				PU-B
DF015				PU-B

4. PRACTICAL TESTING

The portable units were tested during the Typhoon Vanapi in 2010 at Qishan River. A mobile station was sent to the Minquan village, and two basic portable units were carried to Minsheng and Minzu villages. According to Table 4, the portable units can be placed at debris flows of DF001 and DF002 for Minsheng village, and DF066 and DF067 for Minzu village. In the testing, the #1 basic model was placed at DF002 and #2 unit was at DF067, as shown in Figure 6. The monitoring results (see Figure 7) from the event indicates that the portable units functioned well as expected during the typhoon, and supported the monitoring network to provide additional data. The testing results also indicate that the deployment plan suggested suitable locations to place the portable units. The village-specific deployment procedure, therefore, is useful for portable units on event monitoring. Same deployment procedure can be applied to other protected villages in different areas.

Figure 6 Locations of the tested portable units.

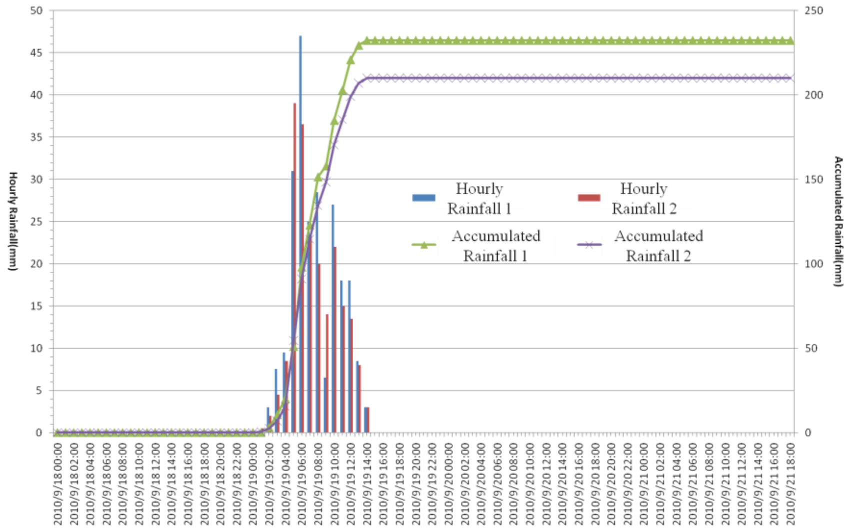

Figure 7 Rainfall data from portable units during Typhoon Vanapi (2010).

5. CONCLUSION

In response to the climate change and the more common debris flow hazards in Taiwan, the basin-wide monitoring network has been introduced and the application of portable units has been described. The development and the deployment study of portable units are presented. The practical testing and the studies in the paper lead to the following conclusions.

a. The design of portable units matches the requirement of easy-to-carry and self-operation resulting, a successful monitoring unit which can support the existing monitoring network and system.
b. The methods of linear programming and genetic algorithm are suitable for deployment analysis for portable units.
c. From the practical testing, the village-specific deployment analysis procedure is reasonable and practical for real event monitoring.
d. Portable units provide great potential for debris flow monitoring in terms of network flexibility and prompt response to hazards.

Overall, the development of portable unit reveals the possibility of basin-wide monitoring network, and the portable unit potentially demonstrates as a versatile carrier in which various sensors can be equipped for different hazard monitoring purposes.

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