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Research Article

Public Alerts on Landslide Natural Disaster Using Vehicular Communications

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Landslide is a serious geological disaster that has severe impact on road safety, traffic flow efficiency, and environment preservation. It is important to develop a landslide warning system to recognize the sharpness of the landslide. However, there are several problems (e.g., the quality of the collected sensor data) to reduce the performance of the system (e.g., false alarms). Thereby, this study aims to design a landslide detection technique based on (i) motion detection and (ii) cross movement methods. They are applied in a detection phase, in order to identify the degree of landslide influence on road capacity by considering vehicles dimensions. Roadway landslide information dissemination (RLID) detects the landslide based on several image processing techniques, and determines the current condition by considering landslide level of road safety. As a result, landslide information can be disseminated to vehicles encountering the target area by using infrastructure-to-vehicle (I2V) and vehicle-to-vehicle (V2V) communications, in order to reduce crash likelihood and to increase traffic flow efficiency. Experimental results have shown that the proposed method in the detection phase can identify the degree of landslide influence on road capacity and monitor the level of effect on road safety.

1. Introduction

Geological disasters around the world cause extensive destruction of properties, physical injuries, and deaths. Landslide is a serious geological phenomenon that has severe impact on transportation construction and roadway traffic. These events usually occurred by the loss in equilibrium of the solid mass in a particular area. Such changes can be from various parameters, for example, rainfall, solid wetness, snowmelt, vegetation, and so on. However, rainfall has been regarded as the most common cause of roadway landslides [1, 2]. Road hazards caused by landslide can decrease the driving safety in roadways where the vehicle encounters unexpected obstacles. Occurrence of such a disaster in roadways not only is counted as a major threat for travelers, but also affects the traffic flow. Several literatures provide important insights related to the landslide risk assessment [3, 4].

Despite the potential effectiveness of roadway engineering on road safety, landslide hazards are generally overlooked during route planning [5]. Another promising way to reduce the landslide impacts is to increase awareness through landslide warning systems. Effective and timely monitoring landslide disaster can reduce the casualties, traffic jam, and economic loss in roadways [6]. But it is found that effectiveness of landslide monitoring systems is highly sensitive to detection and monitoring methods used. In other words, employing inaccurate monitoring system leads to high level of false alarms in warning messages. This paper is aiming to reduce the loss of human lives and assets by using a roadway landslide information dissemination (RLID) that detects the landslides based on series of image processing features performed on the periodic images that are captured by high resolution camera which is mounted in the specific part of the road that is subjected to landslide. We take advantage of vehicular communications to disseminate landslide information based on four levels of messages (no risk, slight risk, moderate risk, and high risk) to immediate response.

The rest of this paper is organized as follows. In Section 2, we overview the landslide monitoring systems. In Section 3, we illustrate our methodology which introduces a novel method for detecting landslide along roadway. In Section 4,

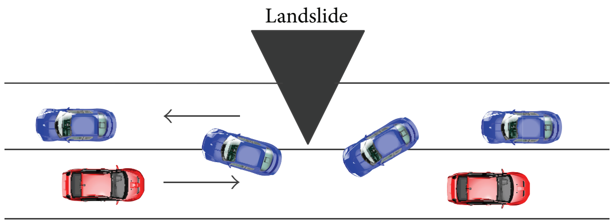


Figure 1: Top view of landslide impact on road safety and traffic flow.

we concentrate on evaluation of our approach under different scenarios. Results and discussion are described in the same section. In Section 5, we demonstrate propagation of the warning messages by taking advantage of vehicular technology. Finally, in Section 6, we draw a conclusion of this paper.

2. Overview of Landslide Monitoring System

Road safety and traffic flow efficiency give an impact on a roadway landslide. Since landslide affects the normal operation of the road, traffic conditions and potential risks increase. This phenomenon sometimes requires traffic to be detoured to adjacent lane which causes varying degrees of influence on traffic safety and may also decrease the bearing pressure of partial sections of the road. Figure 1 depicts two-way road, in which landslide blocks one lane and requires traffic to detour to adjacent lane. The disruption caused by trespassing vehicles not only increases crash likelihood but also decreases traffic flow efficiency for the opposite direction vehicles in another lane of the road.

In addition to the landslide drawbacks, congested traffic caused by landslide increases fuel consumption and environmental pollution owing to the number of vehicle stops [7, 8]. Since a proper and timely landslide warning system increases traffic flow efficiency due to immediate response from transportation manager, fuel consumption and environmental pollution caused by number of vehicle stops are reduced. Landslide monitoring system is another potential way to reduce the landslide impacts on roadways. In this section phases that are involved in landslide monitoring systems are discussed.

Landslide warning approaches are based either on detailed site-specific investigations and movement monitoring programs [9] or on statistical threshold models [10, 11], in which minimum or maximum level of some quantity is defined for a process to occur [12]. For instance, a threshold defines the rainfall, solid moisture, or hydrological conditions that, when reached or exceeded, are expected to trigger landslides. These thresholds might be defined on conceptual or empirical bases [13–15].

Although statistical analysis performed by Baum and Godt [16] shows that both the rainfall threshold and the intensity-duration threshold have the power to detect rainfall conditions that can trigger landslides, a number of factors (e.g., storm, ground vibration, etc.) decrease that reliance and cause poor quality of data [17]. In addition, lack of homogeneity and completeness, landslide timing, rainfall data resolution, and rain gauge location significantly have effects on quality of data and lead to false alarm [18].

Appropriate response to landslide phenomena is the main key for a disaster management program. To do so, timely data monitoring from reliable source is an urgent need. Therefore, the traditional monitoring methods by manual operation could not be efficient due to lack of real-time information. For instance, radio, television, and internet are utilized to broadcast the warning messages in Seattle, Southern California, and Western Oregon [16], which could not be effective in situations where immediate response is required.

3. Methodology

Roadway landslide information dissemination (RLID) aims at reducing the crash likelihood and increasing traffic flow efficiency in situation of roadway landslide by improving the detection and monitoring phases. To accomplish this goal, landslide is detected by using series of image processing techniques that are performed on the 60 frames acquired from high resolution camera that is installed in roadway area subjected to landslide. In order to detect the landslide, a program is written in MATLAB that analyzes the frames and monitors the road condition to the control center based on the landslide degree of influence on roadway. The information is also disseminated to vehicles using I2V and V2V communications. Therefore, drivers are able to operate their vehicles in a way that enhances road safety since they are updated on the road condition ahead. Figure 2 illustrates the flowchart of the RLID architecture, which is described in the following subsections.

RLID consists of two main areas: (1) landslide detection that is involved in detecting and identifying the roadway landslide impacts on road traffic safety and (2) information dissemination that delivers the landslide information to vehicles that encounter obstacle caused by landslide.

Landslide Detection. Area that was subjected to landslide in a roadway was determined for this experiment. A highway camera is mounted at the distance of 25 feet from the monitored zone. Note that, the wider the road width is, the more the distance is required. In other words, Distance between camera and monitored zone depends on the camera lenses.

Therefore, by considering the road width which is 6.6 meters (3.3 meters in each lane) in this case, distance between camera and monitored zone was selected, as shown in Figure 3. Several image processing methods including motion detection and cross movement were applied to extract changes in the frames that were acquired using the camera in order to detect the landslide. Detection phase depends on environmental characteristics which can be either dynamic or static. In cases where detection needs to be performed in static environment, one frame is used as the reference which will be subtracted from other captured frames. A new frame is resulted from this subtraction which demonstrates the difference between the two frames. However, this method cannot be applied in dynamic environment like roadway

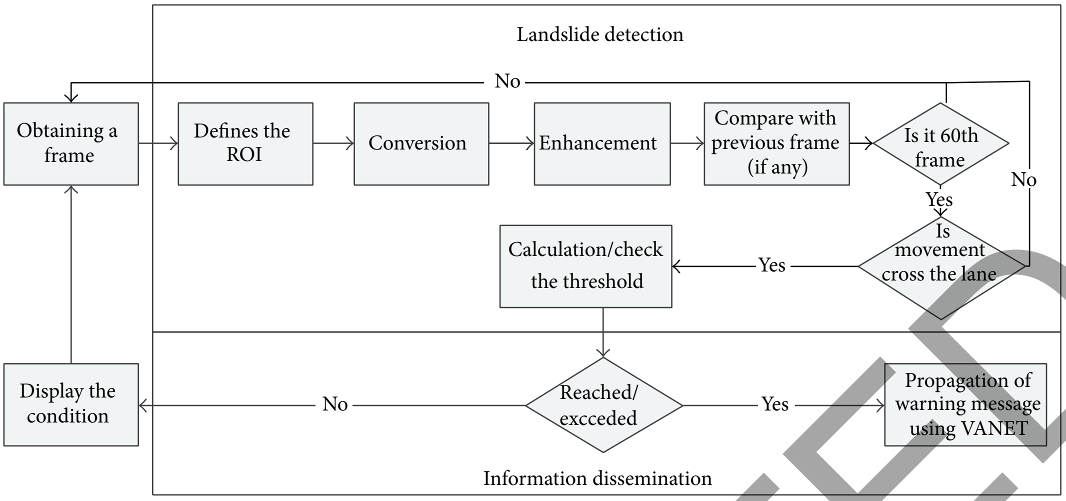


Figure 2: The procedure of RLID method.

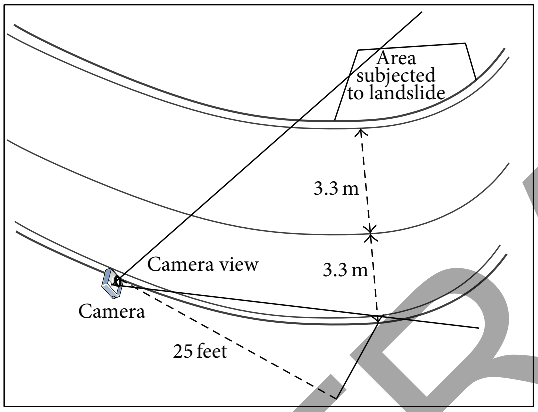


Figure 3: Top view of roadway coordinate and camera location.

since several factors such as vehicles can affect the resultant frame. Therefore, in the proposed method, one frame is captured every 2 seconds and subtracted from its next frame until the 60th frame is captured. After the subtractions of last two frames (59th and 60th), one frame is created that included changes in all frames (if any). The created frame shows the changes that were observed in all 60 frames. Since dimension of vehicles and their coordination are different at the time of capturing each frame, a vehicle cannot be captured in all 60 frames. The number of frames is determined as 0.5 per second to ensure that vehicles cannot affect the detection phase in different traffic conditions. Therefore, by applying this method, the system will not detect the vehicles as a landslide.

Second method which is applied in the proposed landslide detection phase is the direction of movement. Although the mentioned method removes the need of direction of movement, in case of traffic in the roadway, vehicles can be observed in most of the captured frames. This problem can be solved by implementing a classical optical flow method called Horn and Schunck [19]. Therefore, direction of movement can be defined by using optical flow which is formulated as follows:

$$E = \iint \left[\left[\left(I_x u + I_y v + I_t \right)^2 \right] + a^2 \left(\|\Delta u\|^2 + \|\nabla u\|^2 \right) \right] dx dy, \quad (1)$$

where I_x, I_y, and I_t are the derivatives of the image intensity values along the x, y, and time dimensions, respectively. $\vec{V} = [u(x, y), v(x, y)]^T$ is the optical flow vector, and the parameter α is a regularization constant. Note that larger values of α lead to a smoother flow:

$$\frac{\partial L}{\partial u} - \frac{\partial}{\partial x}\frac{\partial L}{\partial u_x} - \frac{\partial}{\partial y}\frac{\partial L}{\partial u_y} = 0, \quad (2)$$

where L is the integration of the energy expression; consider

$$\begin{aligned} I_x \left(I_{x^u} + I_{y^v} + I_t \right) - \alpha^2 \Delta u &= 0, \\ I_y \left(I_{x^u} + I_{y^v} + I_t \right) - \alpha^2 \Delta u &= 0, \end{aligned} \quad (3)$$

where the subscripts again denote partial differentiation and $\Delta = \partial^2/\partial x^2 + \partial^2/\partial y^2$ denotes the Laplace operator. Since the solution is sensitive to the neighbouring values of flow field, it will be repeated once the neighbours have been updated. Figure 4 shows area of mountain roadway that is subjected to landslide. By applying cross movement method, direction of movement can be detected in order to increase the accuracy.

Region of interest (ROI) allows the calculation to be performed on an interest portion of the frames only. By defining ROI only changes in the road are considered in the calculation, and remaining changes are ignored. Figure 5 shows two-way road that is used as the reference image for the simulation test. The lane widths are determined based on the Federal Highway Administration policy [20].

Once the binary mask is created to define the ROI, series of sequential operations are utilized as preprocessing landslide detection system (e.g., gray conversion, normalization, etc.) to reduce noises and processing complexity.

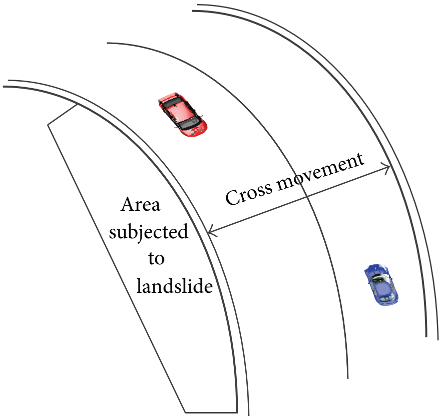


Figure 4: Top view of cross movement.

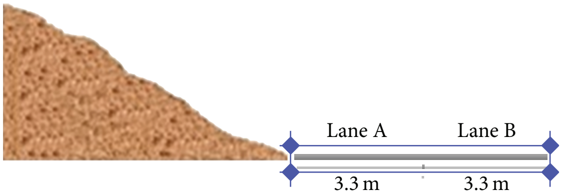


Figure 5: Frontal view of two-way mountain road.

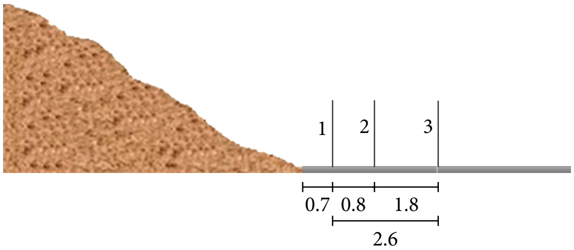


Figure 6: Determination of thresholds based on lane width capacity.

Table 1: Definition of landslide impacts under different segments.

Segment	Lane width capacity	Definition
1	3.3 m	Full availability of a lane
2	>2.6 m	Landslide affects the road capacity but cannot hinder the traffic
3	>1.8 m	Only passenger vehicles are able to cross
4	<1.8 m	Neither passenger vehicles nor heavy vehicles are able to cross

The gray scale image is then converted into binary in order to be processed further. Predefined functions in MATLAB workplace are used to calculate the differences between the reference and taken images.

Once the total changes exceeded the predefined thresholds, warning messages will be sent. Note that these thresholds are determined on the basis of engineering principle, in which consideration is on the landslide effect on lane width capacity. Many studies were carried out to identify the effect of lane width on the capacity of road under different conditions [20, 21].

The novelty of this study is to identify the degree of landslide influence on road capacity by consideration of vehicles dimensions. To this end, vehicles are divided into two main categories including heavy and passenger vehicles. Maximum dimensions of each category of vehicles are measured based upon the dimensions of vehicles regulations [22]. According to the collected data, lane width is divided into 3 segments, each of which describes different degrees of impacts. Figure 6 depicts this layout while Table 1 describes the condition of lane capacity where landslide hits different segments.

By considering the lane width capacity of each segment, different thresholds are defined to monitor current condition based on four levels of messages (no risk, slight risk, moderate risk, and high risk).

4. Evaluation

The evaluations were performed on four landslide scenarios of varying levels of impacts. The scenarios were termed no risk, slight risk, moderate risk, and high risk, respectively, in Figure 7. In the first scenario (condition (1)), there is no sign of landslide existing in the road, and therefore both lanes have the available width of 3.3 m. In this case, all types of vehicles are able to cross without any difficulties. Condition (2) depicts landslide that reduced the lane width availability to 2.6 m from the default 3.3 m. In such situations, heavy vehicles may have trouble to cross the affected area which causes reduction of traffic flow efficiency. Once the availability of the lane width reached a value of less than 2.6 m "condition (3)," passenger vehicles could be the only vehicles that are able to cross the affected area. Condition (4) shows the fourth scenario in which landslide hinders traffic completely by reducing the lane width availability up to 0.6 m. Therefore, neither heavy vehicles nor passenger vehicles can cross which bring the main problem, in which vehicles need to detour to adjacent lane and crash likelihood is increased. To solve this issue, the proposed approach used aforementioned methods to provide accurate detection system.

Utilizing predefined functions in MATLAB workplace difference between frames is calculated and the resultant image is achieved to find the changes. Note that when there is any change, the resultant image will have cupric portion in the motion area and remaining area will be blank. This means that if there is no change then image will be fully blank; see Figure 8 (condition (1)).

The area of cupric portion shown in Figure 8 (conditions (2)–(4)) is calculated by summing 1s in the overall image. All 1s are found and summed up by using number of nonzero (NZZ) pixels to find if the sum crosses the predefined threshold. Different thresholds are defined for each of the scenarios. Once the changes reached or exceeded the predefined thresholds, a warning message related to that threshold is displayed. In other words, warning messages depend on conditions that have different meaning.

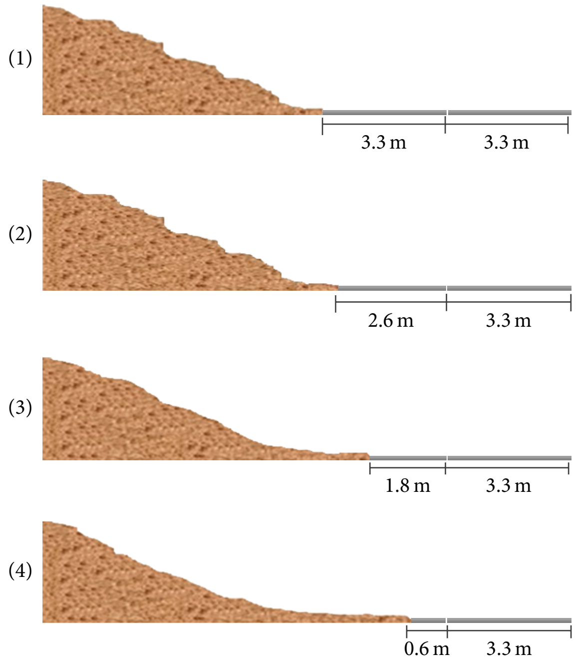


Figure 7: Images under different conditions.

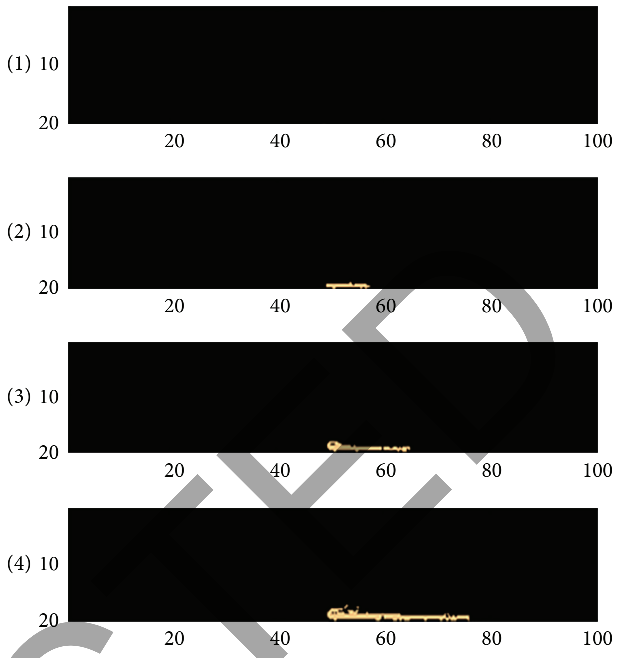


Figure 8: Plot of differences between the reference and taken images under different circumstances.

4.1. Scenarios Results. Calculations were made to find any differences between two images. Figure 8 highlights plot results of differences between images taken from each scenario mentioned in the previous section and the reference image. As pointed out earlier, the more the changes in the plot, the higher the level of landslide impact. Condition (1) of Figure 8 demonstrates no difference between the reference and the images taken from the first scenario. Hence, the plot is fully blank. On the other side, Figure 8 (conditions (2)–(4)) demonstrates different degrees of differences were observed among last three scenarios.

Based on the thresholds that were defined for each scenario, different types of messages were received that explained the level of the landslide impacts. The numbers of pixel changes exceeded the predefined thresholds in last three scenarios. Condition (2) depicts negligible changes in number of pixel unlike conditions (3) and (4) that showed high level of influence of lane width. According to the predefined segments in Table 1, heavy vehicles and passenger vehicles are not able to cross from affected area in conditions (3) and (4), respectively.

4.2. Experimental Results. Figures 9(a) and 9(b) show that camera was installed in a place of mountain roadway that was subjected to landslide. Each frame was captured every 2 seconds and compared with its next frames until the 60th frame was captured. After the comparison of last two frames (59th and 60th), one image was created that included changes in all frames (if any). As pointed out earlier, the changes are shown in the resultant frame that was observed in all 60 frames.

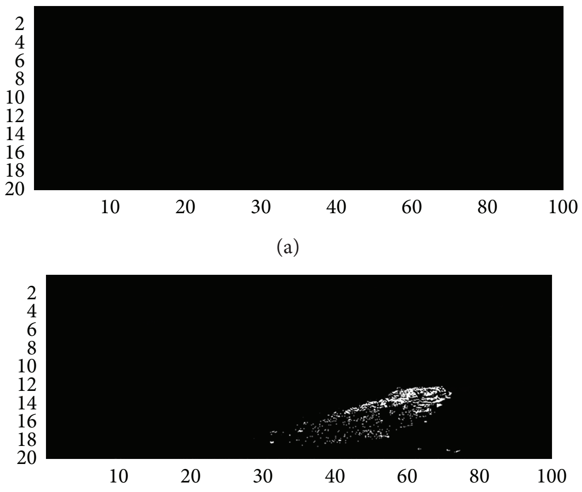
Figure 9(a) shows normal road condition with no trace of landslide. Thereby, the selected road has full capacity which is 3.3 m. On the other side, Figure 9(b) depicts landslide occurrence results of high risk condition that hinders traffic from entire lane.

(a)

(b)

Figure 9: Camera view of landslide in order to detect the cross movement.

Figures 10(a) and 10(b) depict resultant images that were obtained during this experiment. As there was no change in the total frames, Figure 10(a) is fully blank, unlike Figure 10(b) which shows that the resultant image was created from the static changes in all captured frames. In this image NNZ pixels exceeded the predefined thresholds and showed the high level of risk, in which obstacle caused by landslide hinders traffic in one lane entirely. Accordingly, vehicles require detouring to adjacent lane which results in varying degrees of influence on road safety. The results have shown that combination of motion detection and cross movement methods that were applied in the detection phase removes the



(a)

(b)

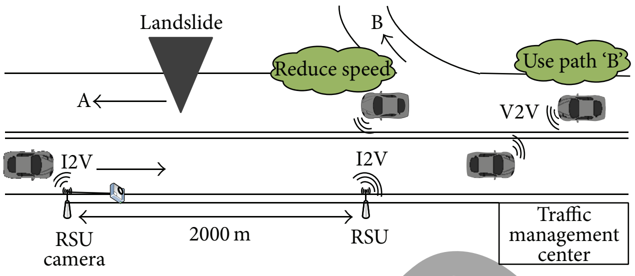
Figure 10: Resultant images from observed changes in the frames.

false alarm that was caused by detection of stopped vehicles on the road and any static objects.

5. Landslide Information Dissemination

Nowadays a large number of proposed applications and approaches in ITS [23] area have focused on employing the VANET as a technology for dissemination of information to the vehicles passing through the specific ROI. The capabilities of VANET have led it to become a suitable network due to multipurposes characteristics for superfluity of applications [24]. The proposed applications for ITS may commonly be classified into two main clusters on the basis of their provisioning services: providing either the safety related services or entertainment services [25]. The entertainment services include traffic information, advertisement, video streaming, and internet services, while safety related services include lane closure information and commonly urgent information systems. Therefore in RLID the warning message dissemination places in the second cluster. In this work, we are not going to deeply concentrate on propagation of warning messages as our focus is mostly on detection phase.

Information dissemination is performed by using I2V for the vehicles that are in range of the road side units (RSUs) coverage which is 1000 m and V2V communication for the vehicles that are placed out of the RSU's coverage. To do so, two RSUs are installed in the selected area that is subjected to landslide, spaced 2000 m apart. These RSUs are connected through a cable which is connected to the closest traffic management centre. Once landslide is detected, alert has been sent to the vehicles encountering the target area by using vehicular communication to reduce their speed or use alternate paths (if any) in order to reduce crash likelihood and increase traffic flow efficiency. Besides, landslide information is disseminated to the traffic management center for further actions. This information is based on four levels of messages (no risk, slight risk, moderate risk, and high risk) to immediate response. Figure 11 depicts the basic layout of our approach.



RSU: road side unit
I2V: infrastructure-to-vehicle
V2V: vehicle-to-vehicle

Figure 11: Basic layout of the proposed monitoring framework.

Message type	Packet ID	Area coordination

Figure 12: Structure of broadcast warning messages.

Broadcast packet delivery is utilized for this communication since all vehicles can be affected by the landslide hazards and should be aware of the warning messages [26]. The procedure of warning message propagation starts by detecting landslide in target area. Same packet structure is defined for both V2V and I2V communications which comprise "Message type," "Packet ID," and "Area coordination." This structure is depicted in Figure 12.

The "Message type" specifies the purpose of broadcasting this warning message in order to avoid any conflict with other messages broadcasted using VANET. The "Packet ID" is a numeric value that is incrementally increased. Onboard unit (OBU) of the vehicle checks the packet's ID and discards it if the value is less than the packet previously received by the vehicle. The "Area coordination" specifies the 2D coordination (latitude-longitude) of start point and end point of the targeted area where landslide occurred.

6. Conclusions

This study highlighted the impact of roadway landslide disaster on road safety, traffic flow efficiency, and friendly environment. Although landslide monitoring system is one of the potential ways to reduce the landslide impacts, it is found that the success of such systems is highly sensitive to the methods applied in detection and monitoring phases. It is also found that the reliability of traditional detection methods relies upon various factors and could be reduced under different circumstance (e.g., storm and ground vibration).

This paper proposed roadway landslide information dissemination (RLID) approach which aims to provide an accurate detection technique by applying motion detection and cross movement method in detection phase in order to identify the degree of landslide influence on road capacity by considering vehicles' dimensions. Experimental results showed that developed MATLAB program is successfully recognized and monitors the road conditions based on four levels of messages (no risk, slight risk, moderate risk, and high risk). Landslide information achieved by RLID was disseminated to vehicles by using I2V and V2V communications in order to reduce crash likelihood while increasing traffic flow efficiency.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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