Adaptive Video Streaming in Hybrid Landslide Detection System with D-S Theory

Zhi Liu, Kenji Kanai, Masaru Takeuchi, Toshitaka Tsuda, Hiroshi Watanabe
Waseda University, Tokyo, Japan 169-8555
Email: {liuzhi@aoni.waseda.jp, {kanai,takeuchi}@katto.comm.waseda.ac.jp
tsuda-toshitaka@aoni.waseda.jp, hiroshi.watanabe@waseda.jp}

***Abstract*—Disaster detection is an important research topic and draws great attentions from both industry and academia. In this paper, we study the hybrid landslide detection system, which utilizes the video surveillance camera and multiple kinds of sensors and can detect the landslide automatically. Edge processing is adopted in this hybrid system to fuse the sensor data based on the *Dempster-Shafer (D-S)* theory, i.e. utilizing multiple sensors' information to calculate the possibility of the landslide. Edge processing can make faster decisions than the control center, the results of the edge processing are then used to schedule the sensor's transmission frequency and video transmission under the network constraints in this system. The simulation results show that the proposed scheme outperforms the competing schemes in typical network scenarios.**

***Index Terms*—landslide, disaster, Dempster-Shafer (DS), WSN, video streaming**

I. Introduction

Disaster detection becomes a hot research topic recently. Japan is one of the countries most affected by natural disasters, such as the earthquakes, tsunami and landslide. How to monitor the scene of interest and detect the emergency (i.e. unusual) in time to avoid unnecessary losses becomes a very important and emergent research issue. The emergency detection covers a wide range of research areas including wireless communication, multimedia transmission and analysis, localization [1].

Wireless sensor networks (WSNs) [2–4] have been widely used in many industrial and consumer applications (e.g. industrial processing monitoring and control, machine and building health monitoring) due to WSNs' efficiency, low-cost, 24-hour sensing ability. Scene monitoring and unusual event detection [5, 6] are typical applications of WSNs, and there are WSNs, which have already been deployed to monitor the scene of interest and detect the unusual events automatically and continuously with relatively low cost.

The state-of-the-art WSNs usually adopt multiple types of sensors to provide good and reliable performances. Given different types of sensors are used in the sensor system, how to combine the different information captured by these different sensors draws many attentions. There are many sensor fusion methods in literature and D-S theory [7, 8] is one among these methods. D-S theory is a general framework for reasoning with uncertainty, with understood connections to other frameworks such as probability, possibility and imprecise probability theories [7]. D-S is reported to be able to provide good performance in terms of sensor fusion.

This paper studies such WSN system to detect the landslide automatically. This system uses multiple kinds of sensors to capture the scene of interest including the incline meter sensor, weather sensor, humidity sensor, etc. The sensor data is transmitted to the control center via Wi-SUN transmission[1] (i.e. IEEE 802.15.4g). Wi-SUN transmission supports multi-hop transmission and is with low energy consumption. IEEE 802.15.4g is to create a Physical layer (PHY) amendment to 802.15.4 with the goal to provide a global standard that facilitates very large scale control applications. Then the control center can obtain the knowledge of the monitored scene by reading and analyzing the sensor data. Edge processing [9] is enabled at the intermediate node along the path from sensor node to control center, with the aim to help make the decisions faster and further improve the performance of the sensor system. In this system, edge processing is enabled at the router.

Given the sensors are not always 100% reliable, video surveillance cameras are also installed in this system to capture the scene of interest. The video data will be directly sent to the control center via the commercial wireless networks and this network only has limited high speed wireless data volume within each month. If the used data volume is larger than this usage constraint, the network speed will be limited to a very low data rate. By checking the video, the control center can better understand what is happening in the monitored scene.

The inherent issues then become how to combine the different sensors' data to judge the situation in the monitored scene, i.e. sensor fusion for this landslide detection system, and how to schedule the video transmission in different situations with the total usage constraints. In this paper, we propose to use D-S theory to perform the sensor fusion, where the different incline meter sensors' data at different time instances are considered. The weather sensor, humidity sensor, etc. are also considered by giving different weights to the probabilities of each state (such as emergency and normal as defined in the system). Then the video transmission is scheduled considering the total monthly data usage constraint and the status of the scene indicated by the sensor fusion. The simulation results show that the proposed scheme can outperform the competing scheme in typical scenarios.

The rest of this paper is organized as follows: related works in the field of the WSNs, sensor fusion and video streaming

[1] https://www.wi-sun.org/index.php/en/

are introduced in Section II. Section III introduces the hybrid landslide detection system using sensors and video cameras. We then show how we perform the sensor fusion and schedule the video transmission in Section IV. We show the simulation results in Section V. Section VI concludes this paper and shows some future directions.

II. Related Work

This section overviews the related works in literature and shows the difference between this paper and the existing work at the end of this section.

A. *Wireless sensor network*

WSN [3, 4] is a mature research topic, and WSNs are used in many scenarios. They are also good options for detecting the unusual events in the scene of interest by analyzing the data samples collected from the networked sensor nodes. The network transmission that helps connect the sensors can be ZigBee [10], Wi-Fi, Wi-SUN, etc. The WSN can be used in many areas and there are many researches made for the WSNs, e.g. authors in [6] study the sensor system for usual detection in railway system and propose a method to help reduce the data transmission (energy consumption) without sacrificing the detection performance. Local sensor data processing or decision making is also feasible if the sensor nodes have certain level computational capabilities, and this could help reduce the network traffic.

Given different types of sensors are used in the sensor system, how to combine the different information captured by these different sensors draws many attention [7, 8]. D-S theory is a general framework for reasoning with uncertainty, with understood connections to other frameworks such as probability, possibility and imprecise probability theories [7]. Note that different sensor systems may have different specific situations when applying the sensor fusion and the sensor fusion method in the landslide detection system needs to be designed carefully.

B. *Video transmission*

Video streaming mainly studies the video coding, video transmission optimization at different layers (such as MAC, and application layer), loss recovery, emerging video services, video over different kinds of networks [11–15]. This is an interdisciplinary topic and basically covers the research contents in the communication society, signal processing society, etc.

Different from these works, this paper studies a real system used for disaster detection and schedules the video transmission under the total monthly cellular usage constraint in this system. This distinguishes this paper from the existing schemes.

III. System

The hybrid landslide detection [16] system is shown in Fig. 1 and designed as follows: There are different kinds of sensors used in this system including multiple incline meter sensors, weather sensors such as humidity sensors, temperature sensors. The sensor data is sent to the control center via Wi-SUN. After reading and analyzing the received sensor data, the control center can obtain the knowledge of what is happening in the scene. Edge processing in this system is enabled to help reduce the response time of the disaster detection, where the edge processing is making the decisions at the intermediate node before the data arrives at the control center. The edge processing results can be directly sent to the sensors to change the sensor' transmission frequency if needed, the results can also be acquired by the control center.

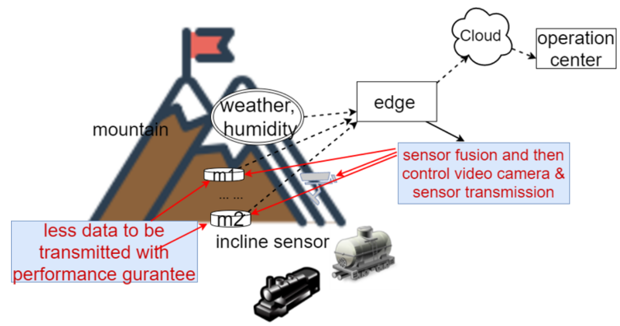


Fig. 1. Illustration of the hybrid landslide detection system.

There are multiple kinds of sensors used and the sensors are not synchronized. The sensors keep capturing the data from the environment but only transmit part of the captured sensor data periodically instead of all the time and all the data, in order to save power. During each transmission, couple of consecutive data samples are transmitted. Weather sensor and humidity sensor will tell the information about the weather and humidity of the soil, which is important information for landslide detection.

Incline sensors detect the movement of the ground, and the sensor has three different transmission frequencies: green (i.e. once per day), yellow (i.e. once per hour) and red (once per thirty minutes). Higher transmission rate will give better understanding of the scene, but high transmission rate consumes higher energy. Hence it is better to apply the low data transmission rate during normal and high transmission rate during emergency, which can save energy consumption during normal states and give control center enough data to analyze the situation during emergency. Each sensor has two threshold values and can automatically change to the corresponding different frequencies according to the comparison of the captured data and threshold values. For example, if the sensor is using 'green' transmission and the newly captured value is larger than the pre-defined threshold for the 'yellow', the sensor will send the data using the 'yellow' transmission frequency.

These transmission frequency and threshold values can not change after the sensors are made due to the limit of manufacturing technologies used. But there are patterns we can set up for each sensor. In this system, each incline sensor has 3 patterns: model-self, model-yellow and model-red. Model-self has three different transmission frequencies and two threshold values, which are explained above. Model-yellow and model-red only has one special transmission frequency, i.e. once per hour and once per thirty minutes, respectively. These two models are not triggered by the sensor itself, instead, it is enabled by the 'edge processing'. In another word, when there is unusual detected by the 'edge processing', these two models will be triggered by the edge processing and these instructions will be sent to the sensors. Then the specific model will be applied by the sensor. Note that if the current sensor is operating at 'red' frequency but the 'edge processing' suggests using 'yellow', the sensor will continue using 'red' frequency for safety.

Edge processing makes the decision based on the data captured by other neighboring sensors. i.e. sensor fusion. Note that the sensors far from the target sensor will not be considered in the sensor fusion. Fig.2 illustrates the general picture of the edge processing, and the sensor fusion method is explained in Section IV in details.

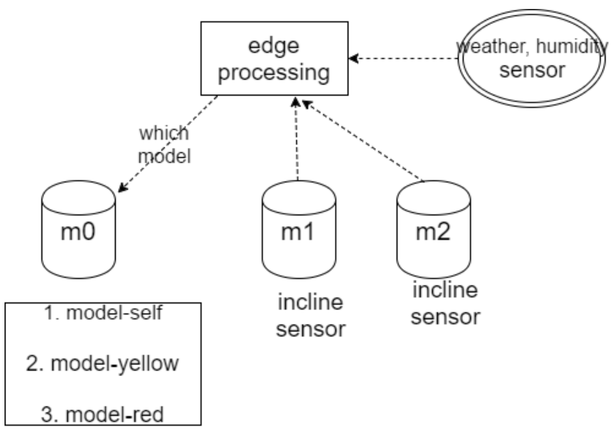


Fig. 2. Illustration of the edge processing.

Video surveillance cameras are also used in this landslide detection system since the sensors are not always available. The captured video frames are sent back to the control center using wireless networks. The the control center can use these information to judge what is happening in the monitored scene and help redefine the results got from the sensor data and modify the decision rules of the control center. The usage of wireless network has the following constraint: if the total data volume used is less than C GB within one month, high speed LTE network is supported. The channel bandwidth will be limited to a very small number after the data usage is beyond C GB. The specific numbers may vary in different countries and areas, and may also vary due to the data plan chosen.

Since the high speed data volume is limited, we need to schedule the video transmission properly to guarantee that there is bandwidth left. These left bandwidth is mainly for the video transmission during emergency, although the emergency may not happen at all. The inherent issue is how to make the decision based on the captured sensor data and schedule the video transmission jointly considering the sensor fusion results.

IV. SENSOR FUSION AND ADAPTIVE TRANSMISSION

This section introduces how we use the D-S theory to perform the sensor fusion and schedule the video transmission accordingly.

A. Sensor fusion

The sensor is running on three different patterns: model-self, model-yellow and model-red. The model-self is controlled by the sensor itself. Model-yellow and model-red are controlled by the 'edge processing', where the 'edge processing' will use all the sensor data it has to calculate the possibility of the happening of the landslide. According to this calculated possibility, the instruction of whether using model-yellow or model-red will be sent to each sensor. The video transmission frequency is also decided based on the possibility.

We adopt the D-S theory as the basic method in the 'edge processing' to help decide whether to use the model-yellow or model-red for each sensor, i.e. D-S theory is used for the sensor fusion. During the calculation, the sensor data across time is considered and different weight values are added for the sensor data at different time instances. We mainly use the neighboring incline sensors' data as the input of the sensor fusion and the weather sensors are used to weight the initial judgement of each incline meter sensor. Fig. 3 shows the data used in the sensor fusion and the decision flow.

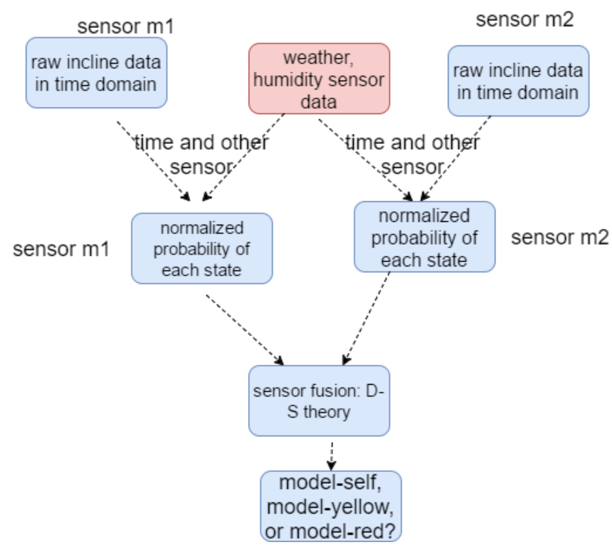


Fig. 3. Illustration of the sensor fusion and decision flow.

B. Initial judgement

Each incline meter sensor has a captured value and we can use p_i^t to represent how likely there is a disaster happening by looking at the sensor value v_i^t alone, where i is the sensor indicator and t is the time instance. Theoretically, p_i^t can be any function and step function is widely used. One setup of the initial judgement could be: when v_i^t is larger than a predefined threshold, p_i^t=0.95 (0.95 is used here as an example, it can be changed accordingly), which means the captured value is larger than the predefined threshold and there is a high probability (i.e. 0.95) that emergency may happen. If v_i^t is very small, p_i^t will be assigned with a very low value or even zero. The threshold values are decided by considering the adopted environment, historical data samples, etc.

There are also another two states named 'normal' and 'unknown' in this paper, which can be defined similarly as the state 'emergency'. The state 'normal' and 'unknown' means the state of the scene is as normal as usual and unknown, respectively. The sum of the probabilities of all the possible states is 1. Note that other state definitions (e.g. we can only use 'normal' and 'emergency') are also possible, we use these defined states in this paper.

C. Weather sensor and other sensors.

We do not directly use the data captured by the weather sensor, etc. including the humidity sensor in the landslide detection in the D-S theory. Instead, we use these data to weight the probability of each state. Specifically, when the weather condition at a particular time instance is easy to trigger the landslide, larger weight will be assigned to the happening probability of the landslide (state 'emergency'), and smaller weight will be assigned to the probability of state 'normal', vice versa. Then the probability will be normalized so that the sum of the probability at each state equals to 1.

This means the weather sensor, etc. helps adjust the probability. If the weather condition at a particular time instance is easier to trigger the landslide, the probability of happening of the 'emergency' will be adjusted to be higher accordingly, vice versa. How to change the probability will be decided based on the historical data and the specific environment where the sensors are deployed, which is out of the scope of this paper.

D. Weight in the time domain

The incline sensor data captured at different time instances are considered and we put smaller weight to the data captured further from the calculation time. Assume the current calculation time is t_j, the possibility of the decision made by the sensor data captured at time t_i is calculated as $w_{t_i} = e^{t_i - t_j}$. We the normalized all the w_{t_i} so that sum of the weight values is 1. This weight function means the decision made based on the recent captured data will be considered more, and w_{t_i} is same to all the states (i.e. emergency, normal and unknown). Note that other decreasing function can also be applied, we use $w_{t_i} = e^{t_i - t_j}$ in this paper. Different sensors may have different working time periods, we consider N groups of data or all the possible data samples (if less than N groups) in the edge processing to help make the decisions.

Then the weight will be multiplied by the probability of each state after initial judgement and taking the weight of the weather sensors, etc into consideration. The calculated probability will be used as the input of the D-S theory.

E. Calculation using D-S Theory

D-S theory is a general framework for reasoning with uncertainty, with understood connections to other frameworks such as probability, possibility and imprecise probability theories. D-S theory has standard calculation methods and there are many references and textbooks for this and its advanced versions. Here one example is used to show how D-S works, where we assume there are two neighboring sensors and the probabilities calculated based on the two sensors are assumed to be as follows:

TABLE I
PROBABILITY OF THE EACH STATE.

probability:	sensor m_1	sensor m_2
normal:	0.2	0.3
emergency:	0.7	0.6
unknown:	0.1	0.1

Note that the probabilities shown in Table I are after adjustment based on the weight in time domain and weather conditions, etc. From the table, we can observe that from the information of sensor m_1, the probability of emergency, normal and unknown are 0.7, 0.2 and 0.1, respectively. From the sensor m_2's data, the probability of emergency, normal and unknown are 0.6, 0.3 and 0.1, respectively.

Then we can calculate the a intermediate parameter K=0.7*0.6+0.2*0.3+0.1*0.1=0.49, and this K is quite useful in the calculation of the probability of each state based on the D-S theory. Then, by using the D-S theory, the probability of emergency, normal and unknown becomes 0.7*0.6/0.49=0.857, 0.2*0.3/0.49=0.122, and 0.1*0.1/0.49=0.021, respectively. The (0.857,0.122, 0.021) will be the new probability of the emergency, normal and unknown, respectively.

These values calculated using D-S theory will be compared with two threshold values, and model-yellow and model-red may be triggered if the probability of emergency is larger than the pre-assigned threshold value. These threshold values are also adjusted based on the environment information and historical data.

F. Adaptive video streaming

Video transmission rate is defined to be of three classes: high, middle and low. Each class corresponds to one sensor data transmission frequency and state (i.e. emergency, unknown and normal). When the video will be transmitted is fixed and we will transmit the video at higher quality when there is emergency, vice versa. Given the total data volume is limited by the C GB, we use the following scheduling methods, where the probability of each state is calculated based on the D-S theory.

We first divide one month into X slots, with the length of each slot to be $td * 60 * 24/X$ minutes, where td is the total days within the month. At the starting of each slot, the video will be transmitted. X is decided by the system, then we set the data unit size at the normal, unknown and emergency state to be a_1C/X , a_2C/X and a_3C/X. Note that a_1, a_2 and a_3 can be changed according to the system requirements, but a_1 must be smaller than 1. One typical example can be a_1=0.5, a_2=1 and a_3=2.

Everything goes normal during most of the time, then the available C GB high-transmission-rate data volume will be left, which is mainly to guarantee there is high speed network available when emergency happens. We can increase the data rate as the time goes by and the following data rate increasing method can be adopted to avoid the waste of the high speed data transmission capability. And the transmitting more data can help improve the results and modify the rules of decision making. The method is designed as follows: First, we calculate how much data volume is left if all the slots use the lowest data rate transmission, i.e. $a_1 C/X$. Then we can know the data volume left is $(1 - a_1)C$ at the end of this month, and we propose to allocate these data volumes into the X slots following a linear function (note that other distribution is also possible such as exponential distribution), i.e. we send $a_1 C/X + (1 - a_1)C\beta$, where β is increasing linear function with t, i.e. $\beta = f(t)$, a typical β can be $f(t) = t/(X * X)$. One concern is that this increases the complexity of the encoding, since it needs to change its parameter as the time changes.

If the emergency happens in the middle of the month and the high speed data volume is used up, we will keep sending the video at the constant data rate, which is limited by the network operator.

V. Simulation Results

This section introduces the simulation setup and the simulation results.

A. Simulation setup

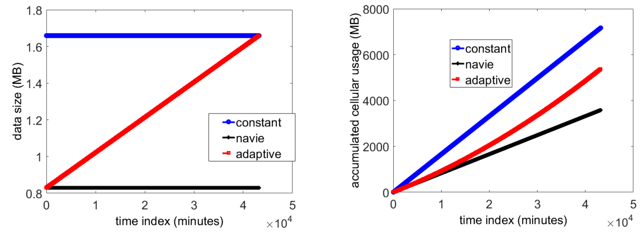
In this simulation, we use a_1=0.5, a_2=1 and a_3=2. The total data usage limit is 7GB and the bandwidth will be limited to 128Kbps when the accumulated data usage is beyond 7GB. Note that these data values are the actual numbers in Japan and used in this system. These numbers can be changed to the corresponding values in different countries and areas, and the data plan.

We test the case when there are three video frame rates (in terms of data size transmitted at specific time instance), this is also consistent with the state assumptions in Section IV. The 'unknown' can correspond to *yellow* since we want to make sure the emergency can be detected. *emergency* uses the highest data sending rate.

B. Simulation results

To show the performance of the proposed scheme, we use two comparison scheme *constant* and *naive*. The *constant* uses the same data rate for all the time and 7GB will be used up. *naive* sends the data with size $a_1 * 7GB/X$, $a_2 * 7GB/X$ and $a_3 * 7GB/X$ at each time instance (this is similar to the data rate). The proposed *adaptive* is an extended version of *naive*, and increases the data size at each time instance as time goes.

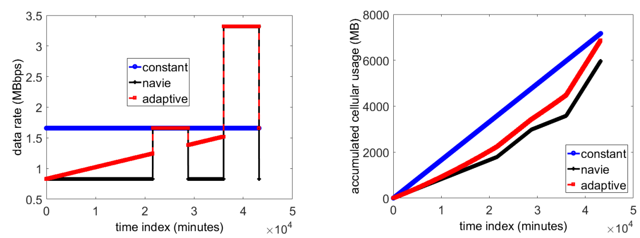
The data rate when no emergency happens is shown in Fig. 4, and we can find that the *constant* actually provides the best performance but this does not give any benefit when emergency happens. *adaptive* increase the data size as the time goes by, and the total data usage is larger than *naive*. All the three schemes use no more than 7GB.



(a) data rate. (b) data usage within one month

Fig. 4. Comparison of the performance when emergency does not happen.

We also simulate the case when emergency and case when unknown happens. The emergency happens 3600∼4320 minutes and the unknown happens during 2160∼ 2880 minutes. The results are shown in Fig.5, where we can find that the *constant* can not provide high data rate transmission when emergency happens while the *adaptive* can. Comparing with *naive*, *adaptive* can better utilize the 7GB cellular network.



(a) data rate. (b) data usage within one month

Fig. 5. Comparison of the performance when emergency happens.

VI. Conclusion and Future Work

In this paper, we study the hybrid landslide detection system, which utilizes the video surveillance camera and multiple kinds of sensors. Edge processing is adopted to make the decisions based on the D-S theory for the sensor fusion, i.e. utilizing the multiple sensor information to calculate the possibility of the happening of the landslide. Then the video transmission is scheduled based on the results of the sensor fusion. The simulation results show the advantage over the competing schemes.

In the future, we plan to verify the performance in the field test and design a scheme to automatically update the parameters used in this system to help better detect the landslide. More advanced video transmission with performance guarantee will be provided as well.

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