Context Inference for Predicting Cause of Protection Wall Deformation

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Abstract

Measures for inferring context through multiple sensor data fusion are being actively used in various fields. The landslide protection wall refers to the structure/engineering method that prevents the collapse of soil during ground excavation. To prevent safety accidents of the landslide protection wall, it is necessary to devise measures for detecting the deformation of the landslide protection wall and for inferring the cause of the deformation. Context inference through multiple sensor data fusion can be used to analyze the influential factors of the problem among safety-threatening factors during generation of anomalous events in the landslide protection wall. This study presents the method for inferring decisive factors through multiple sensor data fusion based on the Dempster-Shafer evidence theory in an environment in which the deformation of the landslide protection wall is affected by earth pressure, water pressure and surcharge effect. Based on the Basic Probability Assignment (BPA) function of factors, this study calculated the belief and plausibility of factors through Dempster's Rule of Combination. Uncertainty intervals can be calculated and compared with one another based on the belief and plausibility of factors to achieve inference of decisive factors

Keywords: *Dempster-Shafer Evidence Theory, Multi-sensor data fusion, Context inference*

1. Introduction

Context inference through multiple sensor data fusion is being used in various fields. Recently, problems in various fields have been solved through the inference of enhanced information achieved by integrating information reported from different sensors.

The landslide protection wall refers to the structure/engineering method that prevents the collapse of soil during ground excavation. The landslide protection engineering method is composed of timber sheeting and soldier pile. As a temporary structure built for temporary use, the landslide protection wall is commonly recognized as a temporary structure that will be removed once the purpose of establishment is accomplished. Thus, it is often handled carelessly to cause safety accidents. As the collapse of the landslide protection wall incurs fatal risk on human safety, it is crucial to provide careful measures for safety inspection and accident prevention. To prevent accidents, landslide protection wall is measured to analyze the deformation of the landslide protection wall, analyze the cause of the deformation and establish relevant measures. However, the most important task is to discover the cause of accidents as soon as possible. It is often difficult to analyze the cause of deformation among the various factors that threaten the safety of the landslide protection wall. Also, wrong prescription measures are often used when the cause is inaccurately analyzed.

To measure the deformation of the landslide protection wall, the degree of risk is analyzed through sensors. A sensor for confronting the content of the particular risk is required to fully understand the cause of the risk. However, there are limitations in analyzing the cause of the context only by using a sensor with a particular function. Thus, it is necessary to apply the multiple sensor data fusion-based context inference method in landslide protection wall construction. This study proposes the context inference method based on the Dempster-Shafer evidence theory that can be used to prevent accidents generated in landslide protection wall construction.

This study is composed as the following. Chapter 1 provides the introduction and Chapter 2 gives a summary of related studies. Chapter 3 presents the multiple sensor data fusion-based context inference method for predicting the cause of landslide protection wall deformation. Chapter 4 evaluates the proposed context inference method. Lastly, Chapter 5 presents the conclusion of this study.

2. Related Work

2.1 Multi-sensor Data Fusion and Context Inference Using Dempster-Shafer Theory(DST).

DST is a probability theory to express uncertainty[8,9,10,11]. Each sensor, S_i will contribute its observation by assigning its beliefs over Θ. This is called the "basic probability assignment (BPA)" of the sensor S_i, denoted by m_i. According to sensor S_i's observation, the probability that is indicated by a "confidence interval" is

$$[belief_i(\mathrm{A}), plausibility_i(\mathrm{A})]$$

The difference $plausibility_i(\mathrm{A})$-$belief_i(\mathrm{A})$ represents the *uncertainty* [4, 9].

DST can be applied to context inference in the wireless sensor network. With the use of DST, the *belief* and *uncertainty* interval of each focal element that consists of an entire set mathematically can be computed. By comparing the *belief* and *uncertainty* of each focal element, it is possible to reach context inference. As the computation process is applied to context inference in the wireless sensor network, focal elements can be replaced with 'estimations' detected by sensors. The estimations can be considered factors that affected special context.

2.2 Landslide Protection Wall Construction

The landslide protection wall refers to the structure/engineering method that prevents the collapse of soil during ground excavation.

2.2.1 Deformation and accidents of landslide protection wall

A) Deformation of landslide protection wall

These deformations can be gradually presented according to increased external force on the landslide protection wall or can lead to an abrupt collapse due to the sudden force.

B) Accidents

Accidents can be classified into 1) problems influenced by ground conditions, 2) structural problems of the landslide protection wall and 3) construction problems. The disasters that can be generated by such accidents are as follows.

① Movement and settlement of rear side ground

② Transform and collapse of landslide protection wall

③ Partial or whole collapse of rear side ground

④ Differential settlement of surrounding building or collapse

⑤ Demolition of streets and infrastructure (cables, gas pipes, water supply pipes)

3. Multiple Sensor Data Fusion-based Context Inference for Predicting the Cause of Landslide Protection Wall Deformation

The measurement of the landslide protection wall is important in preventing major, irrevocable accidents. Thus, it is crucial to construct a system in which various sensors can be installed on the landslide protection wall structure, rear ground and surrounding structures to infer safety-threatening causes for deformation and to implement immediate countermeasures. To achieve this, this study applies the Dempster Shafer theory to achieve fusion of data measured by multiple sensors and to find the decisive cause of landslide protection wall deformation.

Currently, specific sensors are used to measure landslide protection walls. The data read from these sensors are collected by experts and used to deduct the cause of the problem. However, this study proposes the method for automatically analyzing the leading cause by fusing the data read from multiple sensors.

3.1 Inference of Risk Factors

The external forces that influence timber sheeting in ground excavation may include earth pressure according to the backfill load, pressure according to groundwater and surcharge of surrounding ground. This study selects the following 3 factors as the subjects for multiple sensor data fusion.

1) At-Rest Lateral Earth Pressure

2) Earth Pressure At-Rest for Partially Submerged Soil

3) Backfill-Partially Submerged Cohesionless Soil Supporting a Surcharge

Three types of sensors were used to detect changes in At-Rest Lateral Earth Pressure, Earth Pressure At-Rest for Partially Submerged Soil and Backfill-Partially Submerged Cohesionless Soil. Event reports from these sensors were estimated and adopted as h_1, h_2, h_3 to detect changes related with risk factors.
Warnings that notify danger situations detect deformations of the landslide protection wall. These sensors detect the cause of deformations after analyzing the risk symptoms of the landslide protection wall.

For all evidence E_k: $\text{Belief}_i(\text{A}) = \sum_{E_k \subseteq A} m_i(E_k)$ (1), $\text{Plausibility}_i(\text{A}) = 1 - \sum_{E_k \cap A = \phi} m_i(E_k)$ (2)

Combining sensor S_i's observation m_i and sensor S_j's observation m_j:

$$(m_i \oplus m_j)(A) = \frac{\sum_{E_k \cap E_{k'} = A} m_i(E_k) m_j(E_{k'})}{1 - \sum_{E_k \cap E_{k'} = \phi} m_i(E_k) m_j(E_{k'})} \quad (3)$$

Table 3.1 Based on the BPA Functions

$m(A_k)$	$bel(A_k)$	$pl(A_k)$	2^Ω	$m(B_k)$	$bel(B_k)$	$pl(B_k)$
0.15	0.15	0.7	h_1	0.15	0.15	0.85
0.3	0.3	0.85	h_2	0	0	0.3
0	0	0.2	h_3	0.15	0.15	0.85
0.35	0.8	1	$h_1 \cup h_2$	0	0.15	0.85
0	0.15	0.7	$h_1 \cup h_3$	0.4	0.7	1
0	0.3	0.85	$h_2 \cup h_3$	0	0.15	0.85
0.2	1	1	Ω	0.3	1	1

Based on the BPA functions presented in Table 3.1, this study calculated the belief, doubt, commonality, plausibility and disbelief for the estimation of the two time zones.

Table 3.2 Calculated *belief, commonality* and *plausibility*

	m	bel	cmn	pl
Ω	0.0839	1	0.0839	1
$h_1 \cup h_2$	0.1469	0.7622	0.2308	0.9580
$h_1 \cup h_3$	0.1119	0.6434	0.1958	0.8741
h_1	0.4895	0.4895	0.8322	0.8322
h_2	0.1259	0.1259	0.3566	0.3566
h_3	0.0420	0.0420	0.2378	0.2378

By observing the calculation results of Table 3.2, it can be verified that the estimations h_2 and h_3 have significantly lower *belief* when compared with other estimations. This presents that it is difficult for these two estimations to be established independently. Estimation h_1 presented a relatively wide uncertainty interval ($pl\text{-}bel$ = 0.34). On the other hand, it can be known that the uncertainty interval ($pl\text{-}bel$ = 0.23) calculated from the combination of estimations h_1 and h_3 is narrower than the interval presented in the independent occurrence of estimation h_1. As h_1 and h_2 present a narrower uncertainty interval ($pl\text{-}bel$ = 0.19) than h_1 and h_3, it can be concluded that the estimation achieved by the combination of h_1 and h_2 becomes the cause of the danger situation. Thus, the causes for the deformation of landslide protection wall can be deducted as Lateral Earth Pressure and Earth Pressure At-Rest for Partially Submerged Soil.

4. Experiment

This experiment verifies that the cause of a context can be discovered through the multiple sensor data fusion-based context inference method proposed in this study. The BPA for each estimation was calculated by experts as the following. The *belief* and *uncertainty* of the estimated values calculated through Dempster-Shafer theory-based data fusion were verified to be effective in finding the cause of the deformation of the landslide protection wall.

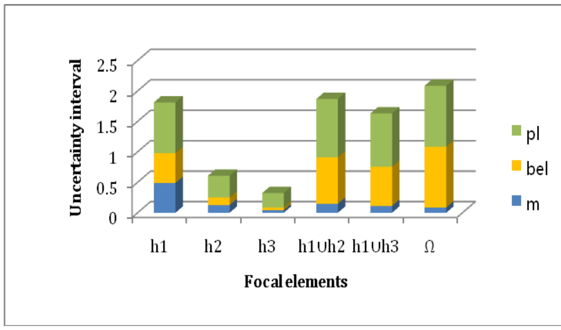

Figure 1. BPA, *belief* and *plausibility*

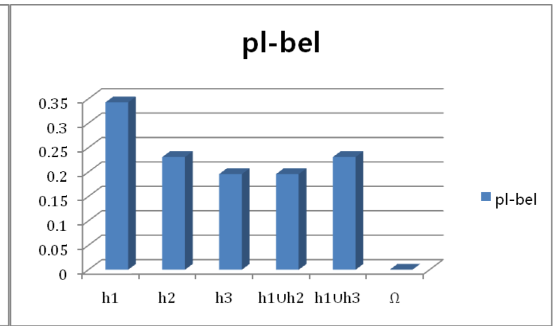

Figure 2. Calculated *uncertainty*

Figure 1 shows the BPA, belief and plausibility of each estimation. Figure 2 shows the uncertainty of each estimation. We could perceive the estimation "$h_1 \cup h_2$" is the crucial one.

5. Conclusion

The landslide protection wall refers to the structure/engineering method that prevents the collapse of soil during ground excavation. To prevent accidents, landslide protection wall is measured to analyze the cause of the deformation and establish relevant measures. It is often difficult to analyze the cause of deformation among the various factors that threaten the safety of the landslide protection wall. Therefore, it is necessary to apply the multiple sensor data fusion-based context inference method in landslide protection wall construction. This study proposed the context inference method that can be used to prevent accidents in landslide protection wall construction. We introduced the data fusion method based on the Dempster-Shafer evidence theory. We selected factors that influence the context and calculated the BPA function based on factor assessment to implement multiple sensor data fusion. We calculated the *belief* and *plausibility* values of the factors that were expected to affect contexts by implementing multiple sensor data fusion based on Dempster-Shafer theory. Ultimately, we compared the *belief* and *uncertainty* intervals to deduct the cause of the context.

Acknowledgements

Funding for this paper was provided by Namseoul University.

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