Reasoning and Progression Prediction in Context Awareness Using Multi-Sensors

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Abstract. The scope of context awareness needs to be extended to reasoning of current context and prediction of future progression from being limited to recognizing the current context. This study uses a case of deformation of the landslide protection wall and risk of collapse to propose the measures to infer the cause of the dangerous situation and to predict the future progression. Measures of reasoning and situation progression prediction applicable to different environments will help coping with various emergency cases. The Dempster-Shafer theory can provide the clue for inferring the change factor. This paper proposed the measures to calculate BPA based on the values reported by sensors using the theory. After inferring the cause, the equation of state to apply the factors to Kalman filter is obtained to predict how these risk factors will behave in the future.

Key Words: Context inference, protection wall, Kalman filter

1. Introduction

There have been active studies of inferring the context. Most of them focus on recognizing what is happening currently. However, there is the need to understand the cause of the situation and predict how the situation will develop in the future. In the real word, there are many cases that should not occur. Accidents or crimes should never occur. It is important to grasp the signs of the accident before the accident occurs and to understand how the dangerous situation will develop by which cause when the sign of the accident is grasped.

This paper describes the ration measures to infer the cause when the sign of dangerous situation is detected and to predict how the situation will develop when the cause is not eliminated. We will use the risk of collapse of the landslide protection wall in a construction site to estimate the cause when the tilting or deformation of the landslide protection wall is detected and to predict how the risk will increase when the cause is not eliminated or problem is corrected. Collapse of the landslide protection wall is an accident that can cause great damage as it will cause not only the significant property damage but also the loss of manpower in the site. When the problem of the

landslide protection wall in a large construction site is detected, it is difficult to disassemble the wall to find the cause and it may take a long time to eliminate the cause and solve the problem even after the cause is discovered. Therefore, there must be a way to predict how the landslide protection wall problem will develop during the delay until the cause is eliminated.

To solve such problems, this study infers the cause using the data fusion of heterogeneous values. The correlation between the earth pressure, water pressure, content load, and wall deformation, all of which are estimated to be the factors of deformation of the landslide protection wall, is studied and used to obtain the equation of state. Based on the measured values, the basic probability assignment is determined and the deformation factors are estimated based on it. After the causes are inferred, how the situation will develop in the future by each cause is estimated. For that, the Markov chain and Kalman filtering are needed. We can use the Kalman equation to predict the risk increase trend of the landslide protection wall.

We propose the measures of determining the basic probability assignment to infer the cause of the dangerous situation and obtaining the equation of state to predict the progression of the dangerous situation. This paper is organized as follows: Chapter 2 describes the related studies and Chapter 3 presents the proposed measures of cause inference and progression prediction. Chapter 4 describes the test and evaluation and Chapter 5 presents the conclusion.

2. Related Works

2.1 Data Fusion and Context Inference

There have been many attempts to obtain better context data by data fusion of heterogeneous data in order to achieve the goal of obtaining the highly accurate information. As there are many factors and elements affecting the situation in the real world, the use of multi-sensors having different functions have been studied in various fields. It began with the study of using the multi-sensors to estimate the position of the launched missile. The study has been extended since then to position estimation of unmanned aircraft as well as the moving vehicles on the ground. In robot control, the studies of using the multi-sensors to obtain the information needed for robot control or to recognizing the robot status have been ongoing. Sensors were attached to various areas of the robot to acquire the data needed to monitor the robot status and control the robot, and data fusion was used to increase the accuracy of robot information. Data fusion of multi-sensors is also used for inferring the cause of the specific context. Rakowsky proposed the measures to estimate the system error using the Dempster-Shafer theory[1]. The factors of the cause of the context were inferred by calculating the *belief* and *plausibility* of each significant element from BPA and then calculating the *uncertainty*.

2.2 Context Progression Prediction

Kalman equation was first used to estimate the position of the missile. Since then it

was extended to position estimation of unmanned aircraft as well as the moving vehicle on the ground[3][4][5]. It is mostly used for fusion of electronic data on the ground. By repeating the steps of checking the gap between the theoretical value and actual measurement, calculating the estimated position by considering it, and then comparing it with the actual measurement to calculate the gap again, the position can be estimated even when it is not measured[6][7]. Since then, its application has been expanded to extended Kalman equation to be used in various fields[8].

Existing context awareness focuses on recognizing the current situation. It is to understand which events are occurring. In many cases, we are interested in knowing what caused the current situation. Moreover, we are also interested how the current situation will develop in the future. Existing studies did not describe the cause and progression of the result in details. Although the method of using the Kalman equation enables estimation of the past, present, and future, its recognition scope is limited to the position. Therefore, investigating the relation of the past, present, and future in various contexts in addition to position estimation is needed.

3. Progression Prediction

Context awareness must be able to recognize not only the current situation but also infer the past cause and predict the future if the current situation is continued. Current situation can be considered as the result of past causes. Recognizing the current situation and finding the cause of the current happening is the important issue of context awareness. Then how the current situation will develop? That is also an important issue.

Progression Prediction: Although the current emergency situation must be immediately dealt with, there may be the cases in which the prompt countermeasures are difficult. There can be the cases of having to predict how the current dangerous situation will develop when it will take some time to prepare the countermeasures or when high cost of the emergency measurement may delay the countermeasures. To predict such progression, the equation of state representing the relation between the dangerous situation and the inferred cause of the situation is needed. When the equation of state is obtained, we can predict future progression using the Kalman equation.

The relation between the factors of the force applied to the landslide protection wall and tilting of the landslide protection wall in a construction site can be described as follows:
F is the restitution force by elasticity of the landslide protection wall so that the wall will not collapse. This force is applied perpendicularly to the landslide protection wall.

where θ is the inclination angle of the protection wall while, k is the coefficient of the material of the wall material.

The factors of the force applied to the landslide protection wall includes the earth pressure, water pressure from the raised underground water level, and content load pressure applied to the soil of the landslide protection wall. The figures below show these factors.

First, the earth pressure is the area of the triangle in the figure. Its pressure and load increase as the height decreases. The earth pressure can be expressed by

$$P_a = (q + \gamma_z) \tan\left(\frac{\pi}{4} - \frac{\emptyset}{2}\right) - 2c \tan\left(\frac{\pi}{4} - \frac{\emptyset}{2}\right)$$

The earth pressure in the opposite side of the landslide protection wall can be expressed by

$$P_p = \gamma_z \tan^2\left(\frac{\pi}{4} + \frac{\emptyset}{2}\right) + 2c \tan\left(\frac{\pi}{4} + \frac{\emptyset}{2}\right)$$
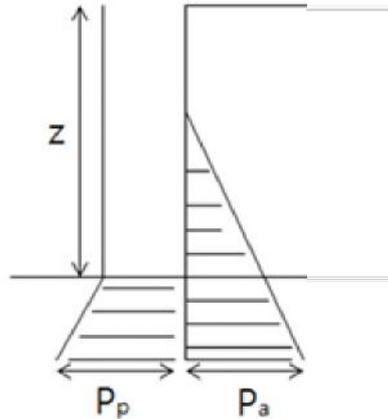

Fig. 1. Earth pressure

Water pressure increase by the underground water penetrating into the soil as the underground water level increases is another pressure factor applied to the landslide protection wall. The pressure by increasing underground water level is defined as follows.

$$P_2 = \frac{1}{2} k_0 \gamma H_1^2 + k_0 \gamma H_1 H_2 + \frac{1}{2}(k_0 \gamma^2 + \gamma_0)H_2^2$$

where $\frac{1}{2} k_0 \gamma H_1^2$ is the earth pressure to the depth H.

$k_0 \gamma H_1 H_2 + \frac{1}{2} k_0 \gamma_0 H_2^2$ is the earth pressure from H_1 to H_2, and   is the earth pressure when the water is full.
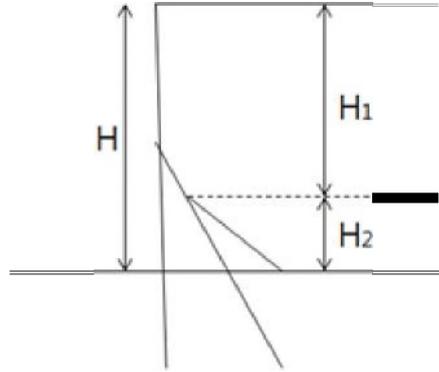
Fig. 2. Water pressure

When the concentrated load is applied as shown in the figure below,   represents the size of the concentrated load. Assuming X to be the distance between the landslide protection wall and the point of concentrated load and H to be the depth of the landslide protection wall, X=mH. The depth z is expressed by multiplication of H and variable n as z=nH.

Since the pressure changes according to the depth as shown in the figure, the micro pressure can be obtained by definite integral as follows:

Since the pressure is 0 and the concentrated load has the maximum value on the earth surface, it can be expressed by following function.

$$P_2 = Q_p \int_0^H z \cdot X^{-2} \, dz = Q_p \int_0^H nH^2 \cdot (mH)^{-nH} \, dn$$
$$= Q_p \int_0^H H^2 \cdot (mH)^{-nH} n \, dn$$
$$= Q_p \cdot H^2 \cdot \left[(mH)^{-nH} - n(mH)^{-nH} \cdot \frac{1}{\ln(mH)} \right]_0^H$$
$$= Q_p \cdot H^2 \cdot \left[(mH)^{-H^2} - H(mH)^{-H^2} \cdot \frac{1}{\ln H^2} \right]$$
$$= Q_p \left(H^2 - \frac{H}{2\ln H} \right) (mH)^{-H^2} \left(\frac{t}{m^2} \right)$$
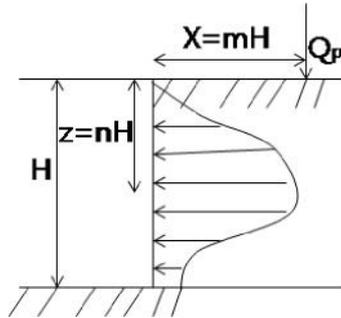
Fig. 3. Concentrated load

In other words, the pressure is directly proportional to the applied load and has the negative correlation with the distance from the landslide protection wall.

If the landslide protection wall is inclined, the weight of the soil and wall is applied as the load according to the inclination angle.
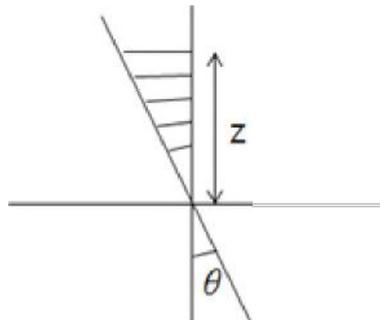
Fig. 4. Protection wall cline angle

The volume of the soil is   .

Since the unit weight is , the load can be expressed as   (where is the weight of the landslide protection wall and A is the cross sectional area).
The force applied to the soil load is

(where g is the gravitational acceleration).
Decomposing with forces applied perpendicularly to the landslide protection wall, the pressure can take cosθ and soil load can take sinθ. Thus, it can be defined as

$$k\theta = \left(\omega + \frac{1}{2}z^2\gamma\tan\theta \cdot A\right)g \cdot \sin\theta + (P_a + P_2 - P_p)\cos\theta \cdot A$$

.

A can be converted to force by multiplying the pressure by the area. Assuming that the landslide protection wall is completely flat without deformation, all applied forces can be expressed in terms of 0. Since it the flat surface without curvature, the pressure and load can be converted to the vectors perpendicular to the surface.

(where k is elastic coefficient)

Since   (where A is the cross sectional area) at the critical angle , it can be defined as

$$k\theta = \frac{1}{2}\gamma gz^2\tan\theta\sin\theta \cdot A + \sum PA\cos\theta$$

where is the force applied the wall, $\frac{1}{2}\gamma gz^2\tan\theta\sin\theta \cdot A$ is the force pressed by the soil in the inclined area, and $\sum PA\cos\theta$ is the sum of the force by the water pressure and earth pressure.

is unit mass and is content load meaning the pressure from the force pressed by the construction material or large trucks. Therefore,

$$\sum PA\cos\theta = A\cos\theta\,(P_1 + P_2 + P_3)$$
$$= A\cos\theta\left(P_a - P_p + \frac{1}{2}k_0\gamma H_1^2\right) + k_0\gamma H_1 H_2 + \frac{1}{2}(k_0\gamma^2 + \gamma_0)H_2^2 + P_3$$

where z is the depth from the earth surface and constant not varying even when the wall is inclined and the wall is assumed to be completely flat with inclination of 0.

The obtained equation of state can be substituted in the Kalman equation to estimate how the current situation will develop. It can predict how the landslide protection wall that began tilting will incline more as well as the time when the wall collapses after continuing tilting. By predicting the time left before the wall collapses, the landslide protection wall can be supplemented or people can be evacuated by the estimated time.

4. Experiment and evaluation

Context inference with measurement of inclination of the landslide protection wall and signals detected by multi-sensors indicated that the cause was the increase of the earth pressure caused by increasing underground water level. After analyzing the relation between the level of inclination of the landslide protection wall and increase of earth pressure due to increasing underground water level, the relation between the level of inclination of the landslide protection wall and underground water level increase after some time later was again calculated. Such relation was substituted in the Kalman equation to estimate how the landslide protection wall tilting will

progress.

We have to adopt the extended Kalman filter because of the state equation of 0 is non-linear.

$$X_k = \begin{cases} P_1 \\ P_2 \\ \theta \end{cases}$$

P_1:earth pressure, P_2: water pressure, 0:cline of the protection

wall Non-linear function F(X) can express as follows.

$$f(x) = \begin{bmatrix} P_1 \\ P_2 \\ \frac{1}{K}\left[(\omega + \frac{1}{2}z^2 \tan\theta \cdot A)g\sin\theta + (P_1 + P_2)\cos\theta \cdot A\right] \end{bmatrix}$$

$$X_{k+1} = Ax_k + \omega_k$$
$$z_k = Hx_k + v_k$$

Transfer matrix A is

$$A = \begin{bmatrix} \frac{\partial f_1}{\partial P_1} & \frac{\partial f_1}{\partial P_2} & \frac{\partial f_1}{\partial\theta} \\ \frac{\partial f_2}{\partial P_1} & \frac{\partial f_2}{\partial P_2} & \frac{\partial f_2}{\partial\theta} \\ \frac{\partial f_3}{\partial P_1} & \frac{\partial f_3}{\partial P_2} & \frac{\partial f_3}{\partial\theta} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ \frac{A\cos\theta}{k} & \frac{A\cos\theta}{k} & \dot{\theta} \end{bmatrix}$$

$$\dot{\theta} = \frac{1}{k}\left[\omega g\cos\theta + \frac{gz^2 A}{2}\cdot\frac{(2\cos\theta+\sin\theta)\sin\theta}{\cos\theta} - (P_1 + P_2)A\sin\theta\right]$$

H matix for the z_k,

$$H = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & \dfrac{0}{1} & \dfrac{0}{-1} \\ 0 & 0 & \dfrac{}{(20°-\theta)k\Delta t} & \dfrac{}{(20°-\theta)k\Delta t} \end{bmatrix}$$

$$z_k = \frac{1}{T},$$

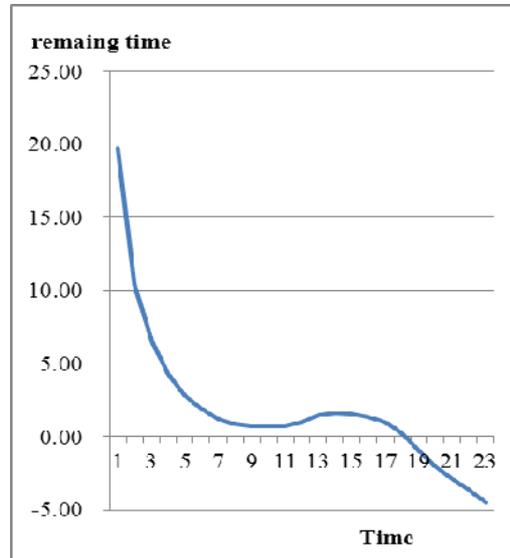So, T= $\frac{1}{z_k}$, T is the remaining time to collapse.

We can get the left time from the Kalman filter with the state equation that addressed in former chapter. Following Table 1. shows the result of prediction.

Table 1. Result of prediction

P1(N/m2)	P2(N/m2)	Theta(dgrees)	remaing time
10	5	0.00	_
11	7	10.06	19.77
12	9	14.83	10.46
13	13	17.19	6.53
14	15	18.43	4.25
15	17	19.10	2.83
16	19	19.47	1.90
17	18	19.70	1.24
18	15	19.81	0.85
19	13	19.86	0.73
20	12	19.87	0.73
21	7	19.88	0.75
22	2	19.84	1.04
23	4	19.78	1.52
24	5	19.78	1.64
25	7	19.80	1.60
26	9	19.84	1.37
27	14	19.89	1.00
28	21	19.97	0.27
29	24	20.09	-0.91
30	25	20.19	-2.00
31	26	20.26	-2.87
32	28	20.32	-3.63
33	30	20.38	-4.47
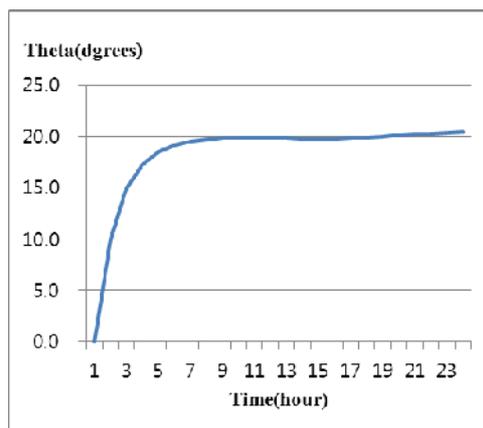
Fig. 5. Prediction of protection wall cline

Fig. 6. Remaining time to collapse of the wall

We can predict 19.77 hours remained until the protection wall breaking. In this experiment, P_3 refers to the truck up to top of the wall is pressed. P_3 is not working in this case. The active pressures are earth pressure and water pressure that were main cause of the wall cline.

The test confirmed that the method proposed in this paper can be useful in real world situations.

5. Conclusion and Further Study

The scope of context awareness should not be limited just to which situation is currently occurring. This study proposed the measures of not only recognizing the current situation but also inferring the cause of the current situation and evaluating the impact of the cause to the current situation to predict how the situation will develop. It inferred the cause of tilting of the landslide protection wall applying the multi-sensor data fusion using DST. It then analyzed the relation between the estimated cause and the landslide protection wall and used it to Kalman equation to predict future situation. When the current situation has significant risk, the cause can be estimated and used to eliminate the cause. If the dangerous situation cannot be immediately dealt with, it can predict the future progression to estimate how much time can be given for countermeasures. Although the scope of the context inference could be extended, it was based on measuring and evaluating the signal changes. Therefore, studies of linking the model with the information obtained in advance would be needed.

Acknowledgement

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