Debris-flow Hazard Forecast and Alert System Based on Real-Time Wireless Communications

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Summary
This paper developed a Real-time Mobile debris-flow Disaster Prevention and Alert system (RMD2PA), which is the three-tier architecture composed of the mobile node, the multimedia server, and the decision support system based on the wireless/mobile and Internet communications. Mobile clients use handheld devices, e.g., PDA combining a cellular phone, to transmit and receive multimedia debris-flow information via the GSM/GPRS network. The case-based reasoning mechanism is embedded in the handheld device to achieve the simple debris-flow prevention and decision when the mobile communication fails. The multimedia server provides the customized information for mobile users and effectively reduces the bandwidth consumption of the mobile network. Based on the database of the pre-analyzed 181 potential debris-flows in Taiwan, we build the accurate prediction models to achieve the effective debris-flow prevention by case-based reasoning scheme in the decision support server.

Key words:
Decision and Support Mechanisms, Embedded Multimedia Communication System, Reasoning Engines, Debris-flow, Wireless and Mobile Communications

Introduction

In the past several years, many researches developed feasible mechanisms and systems to predict the occurrence of debris flows and provide effective alerting methods for significantly reducing the damage of debris-flow disaster [4, 17]. The information technologies, including the Internet communications and decision support system, are widely used on the prediction and alerting of debris-flows [6, 10]. Recently, with the rapid progresses on handheld devices and wireless/mobile communication technologies, pervasive services with provision of Internet and ubiquitous connections, e.g., PDAs combining smart cellular phones, are popularly applied on the alerting of debris-flow disaster. [7, 9, 13, 15].

In this paper, we proposed and designed a Real-time Mobile debris-flow Disaster Prevention and Alert system (RMD^2PA) to provide real-time and effective information for the prevention and alter of debris flows in Taiwan. The proposed RMD^2PA system is the three-tier architecture, which is composed of the mobile node, the multimedia server, and the decision support system. The communication networks include Internet and GPRS/GSM mobile networks. We especially focus on determining the occurrence probability of debris flows. In decision support system, the modeling base of debris-flow prediction is designed by case-based reasoning (CBR) scheme to predict the probability and make alarms for mobile users when the occurrence probability of debris-flow exceeds a threshold.

The rest of this paper is organized as follows. Section 2 describes the fundamental control policy of the Case-based reasoning scheme. Section 3 describes the infrastructure and components of the RMD^2PA system. Section 4 describes the system analysis of CBR. Section 5 finally concludes this work and provides the future improvement directions.

2. The Case-based Reasoning Scheme

Case-based reasoning (CBR) is successful implement in many specific areas, e.g., speech recognition, medical diagnosis, and legal arguments [1, 8, 11, 18]. CBR uses the explicit and experienced cases to address and reasons the new solutions of un-deterministic problems based on heuristic rules and theoretical models. Case-based approaches enable the core of reasoning engine to learn from the experienced and historical data. After reaching a search-based solution for a specific problem, the CBR mechanism saves the solution and related information to reasons in next time. Figure 1 depicts the flow chart of case-based reasoning [8, 10, 12] and the control steps are described as follows.

(1) Step 1
Retrieve appropriate cases from the experienced database by sequence searching to find the most similar case. The searching scheme is based on the Euclidean Distance (ED) method. The formula of ED is as follows.

$$ED_i = \sqrt{({}_iC_1^{old} - {}_iC^{new})^2 + ({}_iC_2^{old} - {}_iC^{new})^2 + ({}_iC_3^{old} - {}_iC^{new})^2 + \cdots} \quad \forall i \in case_{\{1..i\}} \qquad (1)$$

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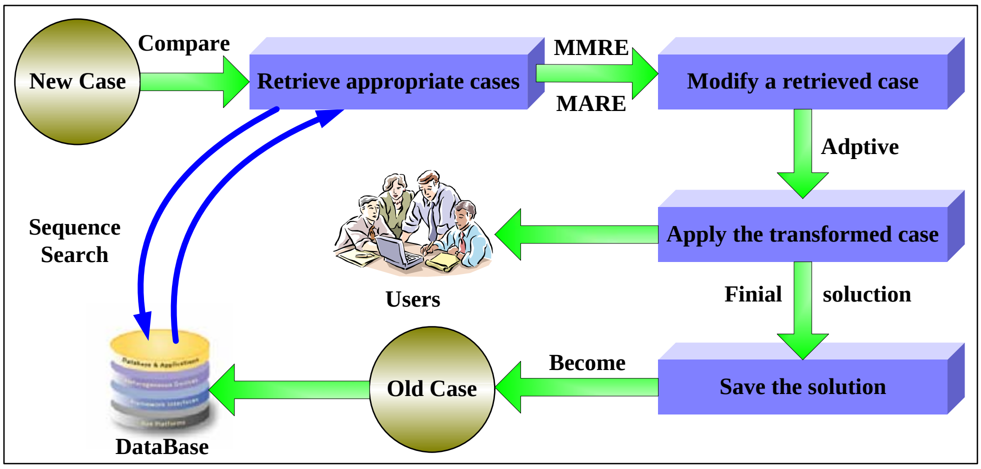

Fig. 1 The flow chart of case-based reasoning

ED_i: The Euclidean Distance between new case and old Case_i.

Case_i: The ith case.

${}_iC^{new}$: The attributes of the new case.

${}_iC_k^{old}$: The attributes of the experienced (old) case, for $k = 1..n$.

The formula (2) illustrates the normalization process for the values of the attributes.

$$Attribute_{i.new} = \frac{Attribute_{i.old}}{Attribute_{MAX}} \quad \forall i \in case_{\{1..i\}} \qquad (2)$$

The CBR mechanism searches a new case and compares it with experienced cases in the database. Every experienced case generates an ED value. The case has the smallest value of the ED is the most similar case and then CBR mechanism uses the most similar case as the modification reference of the next reasoning step.

(2) Step 2

The purpose of modifying a retrieved case tries to apply the retrieved case on the current situation. The retrieved experienced case usually isn't suitable for the new situation. The modification controls are based on the Mean Magnitude Relative Error (MMRE) and Mean Absolute Relative Error (MARE), which are the measure estimation errors using in CBR engine. The formula of MMRE and MARE are as follows.

$$MMRE = \left(\sum_{i=1}^{n} \frac{A_i - E_i}{E_i} \right) \times \left(\frac{1}{TC} \right)$$

(3)

$$MARE = \left(\sum_{i=1}^{n} \frac{|A_i - E_i|}{E_i} \right) \times \left(\frac{1}{TC} \right) \qquad (4)$$

A_i: actual value of the estimated case.

E_i: estimative value for the estimated case.

TC: total numbers of the estimated cases.

$i=1,2,3,\ldots, N$: N is total number of the estimated cases.

(3) Step 3

When CBR mechanism finishes the step (1) and (2) finished, the CBR mechanism applied the transformed case to the new problem. Based on the reasoning results, the CBR mechanism would determine the conclusion and give the suggestion for users.

(4) Step 4

The CBR mechanism stores the final reasoning case need into the experienced database. As the volume of the experienced cases increases, the CBR mechanism is capable of having more accurate reasoning determination.

3. The Infrastructure of the RMD^{2}PA System

Effective information transmission via robust communications is very important and critical on the prevention and alert of the debris flow disaster. For the debris-flow disaster, the real-time information is very helpful for making decision. To achieve effective ad real-time prediction and alert of debris-flow, we developed a Real-time Mobile debris-flow Disaster Prevention and Alert system (RMD^{2}PA). RMD^{2}PA system is three-tier architecture includes mobile node, multimedia sever and decision support server. Figure 2 illustrates the RMD^{2}PA system architecture and related components.

Mobile Node means the high mobility handheld devices,

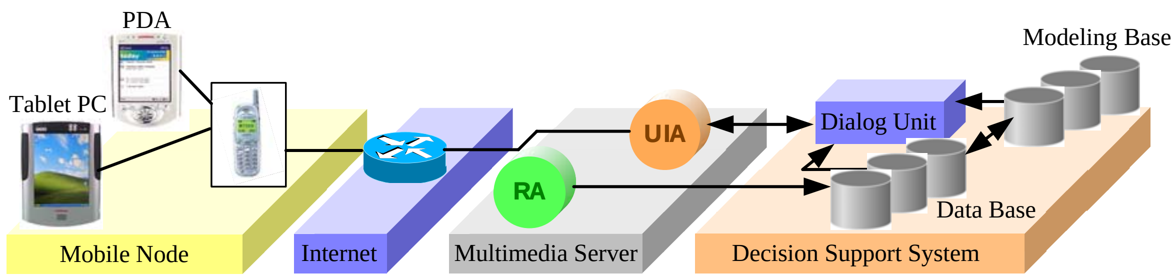

Fig. 2 RMD^{2}PA system infrastructure

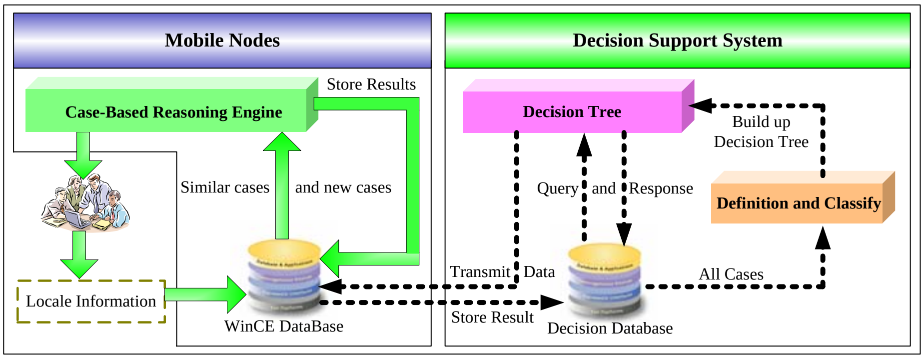

Fig. 3 The system architecture of the case-based reasoning mechanism

e.g. PDA, or Tablet PC. Users could use PDA combine the cell-phone to transmit the real-time information. Multimedia server provides multimedia information between the mobile nodes and the decision support system. The rainfall agent (RA) of the multimedia server, which monitors the rainfall website of weather station in Taiwan, provides rains information to help predict the occurrence probability of debris-flow disaster [3, 14]. The user interface agent (UIA) also provides the suitable user-friendly interface and customized information depending on the computing capability of mobile devices.

The decision support system is composed of the dialog unit, the database, and the modeling base [2, 5, 16]. Dialog Unit communicates with the UIA) of the multimedia server. The experienced of debris-flow database provides eight debris-flow related parameters, which are the effective IR average, the effective NDVI average, the effective accumulation of rainfall for 24 hours, the effective accumulation of rainfall for 1 hour, the effective length of the river, the effective gradient of the rive, the measurement of gathering water, and the characters of rocks. The primary component of the modeling is the case-based reasoning (CBR) engine, which determines the occurrence probability of debris flows.

The case-based reasoning mechanism is embedded in the mobile nodes and the decision support system. The mobile client using the handheld devices downloads the new information from the decision support system based on the mobile communication links and stores the received data into its own database. Due to the light computing and memory capabilities of handheld devices, RMD^{2}PA system provides a decision tree of debris-flow occurrence to reduce the volume of data transmission and required bandwidth. Figure 3 depicts the system architecture and the control workflow of the CBR mechanism.

4. System Analysis

The experienced data is based on the 181 potential debris-flows rivers of Taiwan to reason the occurrence probability of debris flows. There are 100 records used for train model and the remaining 81 records to proof the correctness. Figure 4 depicts the reasoning rule of the CBR mechanism. (i) The mobile user inputs the related eight debris-flow related parameters. (ii) The RMD^{2}PA system normalizes the eight parameters. (iii) The CBR mechanism uses100 records to build reasoning model and uses 81 records to prove the correctness of the reasoning results. (iv) CBR mechanism revises the reasoning record revise by the MMRE and MARE. (v) CBR mechanism displays the related results and saves into the database to build the reasoning model.

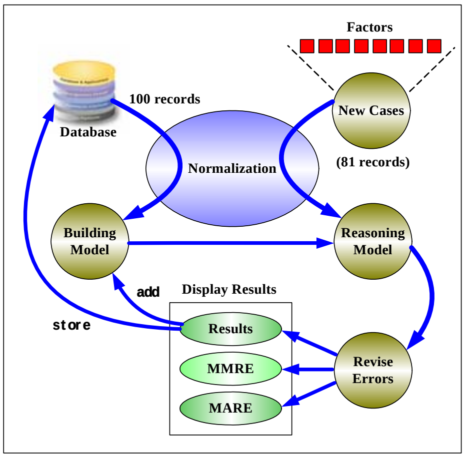

Fig. 4 The reasoning rules of CBR in DSS

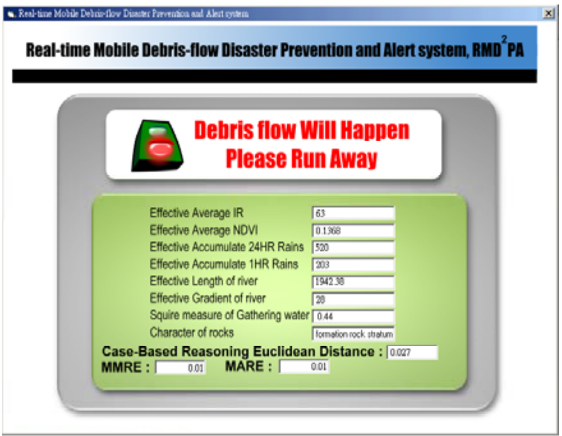

Fig. 5 The implementation result of DSS

Fig. 6 The implementation result of PDA

The emulation results of CBR reveal that 65 records are corrected and 16 records are error. It means that 80.246% are corrected and 19.753% are error. Figure 5 and figure 6 illustrate the implementation results of the RMD^{2}PA system.

5. Conclusion

In this paper, we developed a Real-time Mobile Debris-flow Disaster Prevention and Alert system (RMD^{2}PA), which provides the occurrence probabilities of debris flows in Taiwan and the real-time multimedia communications based on mobile environments. Mobile node could use all kinds of handheld devices to transmit and receive the multimedia information between the disaster area and the rescue-control center. We proposed a prediction models based on the case-based reasoning scheme to achieve accurate prediction probability. The emulation results reveal the high prediction probability of the proposed CBR model.

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