Smart Risk Assessment Systems using Belief-rule-based DSS and WSN Technologies

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Abstract—Smart risk assessment systems are becoming more and more important in the society. If the chances of reducing and managing certain risks are increased, the impacts can be controlled and reduced significantly. This article surveys different belief-rule-based decision support systems and various wireless sensor network technologies that can be used in collaboration to build interesting risk assessment applications. We propose a model for building such an environment and describe a potential application of our proposed model for assessing flood risks in a case study.

Keywords—Smart risk assessment systems; Belief-rule-based DSS; WSN; Flood risk assessment

I. INTRODUCTION

Risk assessment of flooding is important because flooding is considered to be one of the most catastrophic forms of natural disaster, responsible for the highest number of fatalities and greater economic damage in comparison to other natural disasters [1][2]. Flooding involves complex, interrelated and multi-dimensional geophysical processes and has a wide range of impact on human lives, activities and properties. Furthermore, the risks of flooding on a specific object may force a series of further objects to suffer the consequences of flood disasters in a ripple fashion. In general, assessment of flood risk, like other risks, comprises different stages including identification, modeling and evaluation [2][3][4]. The identification stage is concerned with characterizing factors that cause a flood and the physical and the socio-economic objects exposed to flooding. The modeling stage is associated with the estimation of likelihood of a flood and its consequences to obtain a calculated view of risk. The evaluation stage determines the acceptance or aversion limit of flood risk, based on which decisions should be taken to reduce the consequences of flooding. Each decision should be analyzed against environmental, social and economic criteria, to make it a balanced one. Wireless sensor networks (WSNs) are used to collect and distribute sensor data, often processed by data mining techniques, which can be used to collect various data necessary to assess the risks of flooding.

This article surveys different belief-rule-based decision support systems and various wireless sensor network technologies that can be used in collaboration to build

interesting risk assessment applications. We propose a model for building such an environment and describe a potential application of our proposed model for assessing flood risks in a case study.

The remainder of this article is structured the following way: Section II surveys the area of smart risk assessment systems, while Section III describes impacts from belief-rule-based decision support system (DSS). Section IV describes impacts from WSN technologies, while Section V presents a case study where our model is applied to flood risk assessment. Finally, Section VI concludes the article and indicates future work.

II. SMART RISK ASSESSMENT SYSTEMS

Existing methods of flood risk assessment are focused on the analysis of exposure units to flooding, probability of flood occurrence, flood damage assessment or a combination of both [19][20][21]. Some methods calculate the likelihood of occurrence of flooding by taking the flood depth dimension into account [8][22]. In other methods, depth and areal dimensions are considered along with flood causing and intensifying factors such as rainfall, topography and river characteristics. All the above-mentioned methods have relied upon quantitative measures. However, in most situations where places are identified as at risk of flooding, there is little data available with which to estimate either the probability of exceedence of a given discharge or to predict the depths and velocities resulting from such a discharge. Flood frequency estimates, whether estimated by fitting statistical distributions, by regionalization from gauged sites, or by continuous simulation [23][24] are known to be highly uncertain. The predictions of flood inundation models, even when conditioned on observed depth or flooded area information, are also known to be uncertain (and in some cases cannot match the observations throughout the flow domain) [25]. In the past, these quantitative uncertainties have often been ignored in flood risk assessments but should be taken into account in the future. This recognition has been a major driver for the UK FRMRC program and the science program of the international Prediction of Ungauged Basins (PUB) initiative. In addition, some of the factors contributing to flood likelihood are qualitative in nature and difficult to quantify, in part because of

the ill-defined nature of the problem. Hence, expert judgments are needed for identification of the values of some variables [5][9]. Many of the ‘softer’ social dimensions, which influence flood risk, are also difficult to quantify, for example the effects of public behavior and policy. Whilst it has been common practice to use contingent valuation to quantify economic impacts, such techniques are controversial when applied as ‘willingness to pay’ measures to attempt to quantify other social impacts such as disruption, stress and wider community impacts. Meanwhile, more inclusive social science concepts such as social vulnerability and adaptive capacity have been developed by social scientists, but these concepts have largely remained as qualitative concepts and rarely been used by the flood risk modelers [6][7][8]. Hence, there is a lack of a consistent and unified framework for bringing together the ‘hard’ physical and economic dimensions with the ‘softer’ social dimensions, and of aggregating both qualitative and quantitative data with uncertainty.

III. IMPACTS OF BELIEF-RULE-BASED EXPERT SYSTEMS

A Belief Rule Base (BRB) is a knowledge representation schema, which allows the capturing of various types of uncertain information. Evidential Reasoning (ER) is used as the inference methodology in the Belief Rule Based Expert System [11][12][13][14][15][16][17]. ER is mainly used to aggregate the rules in the BRB either in recursive or analytical way. This approach is widely known as RIMER methodology. A BRB can capture nonlinear causal relationships under uncertainty between antecedent attributes and the consequent, which is not possible in traditional IF-THEN rules.

Other knowledge representation languages such as Propositional Logic (PL), First-order Logic (FOL), and Fuzzy Logic (FL) are used to develop the knowledge-base [18][19] and reasoning mechanisms such as forward-chaining (FC) and backward chaining (BC) are used to develop inference engines [20]. However, neither PL nor FOL are equipped with schemas that can capture uncertainties. On the other hand, although FL handles some uncertainties due to ambiguity, vagueness or imprecision, it can’t handle other types of uncertainties such as ignorance, incompleteness, and ignorance in fuzziness that may exist with different categories of variables associated with e-government. However, RIMER methodology as mentioned can handle different types of uncertainties that exist either in knowledge representation or in inference mechanism [21][22]. Fig.1 shows the architecture of the Belief Rule Based System, consisting of its input, inference procedures and output components. Inference procedures consist of input transformation, rule activation weight calculation, rule update mechanisms, followed by the aggregation of the rules of a BRB by using ER. This aggregation allows obtaining the distribution of belief degrees for the consequent (C) attribute for the given values of antecedent attributes (input data) of a BRB (P_i) as illustrated in Fig. 1. The RIMER methodology has been employed to develop expert systems in the area of risk assessment, medical domain, meditation [21][22][23][24]. However, the capturing of input data on a real time basis will allow the estimation or prediction of an event either in risk assessment or medical

domain more accurately. This will eventually enable the development of appropriate preparedness plan to tackle an event in advance. Therefore, the employment of the state of the art wireless sensors to collect the input data with an objective to feed the BRB system is necessary.

Fig. 1. Single-layer BRB inference architecture with RIMER Methodology

IV. IMPACTS OF WSN TECHNOLOGIES

WSNs have been studied the past 15 years. Akyildiz et al. [26] provided a comprehensive overview and identified a few grand challenges including integration of sensor networks with the Internet as well as real-time and multimedia communication. A number of MAC protocols for wireless sensor networks have been proposed. Ye et al. [27] proposed S-MAC while Jamieson et al. [28] proposed Sift. Demirkol et al. [29] surveyed the field of MAC protocols for wireless sensor networks. Also, a number of routing protocols for wireless sensor networks have been proposed. Manjeshwar et al. [30] proposed TEEN, while Schurgers et al. [31] proposed an energy efficient routing scheme. Al-Karaki et al. [32] and Akkaya et al. [33] surveyed the field of routing in wireless sensor networks. Perrig et al. [34] covered security in wireless sensor networks. The most common wireless technology used in wireless sensor networks is the IEEE 802.15.4 standard [35] while the 6LOWPAN architecture [36][37] was designed in order to allow for IPv6 packets to be carried on top of low-power wireless networks, specifically IEEE 802.15.4. The most important standard for services is the Open Services Gateway initiative (OSGi) framework [38]. Kächele et al. [39] described a POSIX compliant implementation while Schmidt et al. [40] described a cloud-enabled implementation. The Session Initiation Protocol (SIP) [41] is an application layer protocol that was originally designed for establishing, maintaining, and closing multimedia sessions on the Internet. Rosenberg [42] and Lonnfors et al. [43] extended SIP for conveying presence information, also described by Schulzrinne in [44]. The use of SIP in wireless sensor networks was proposed by Roychowdhury et al. [45]. The Application Protocol for Constrained Networks/Nodes (CoAP) [46][47] is yet another application layer protocol that is intended for use in resource-constrained Internet devices, such as nodes in wireless sensor networks. It was designed to easily translate to HTTP (Hypertext Transmission Protocol) for simplified integration with the web, while also meeting specialized requirements such as multicast support, very low overhead, and simplicity. CoAP can run on most devices that support UDP (User Datagram Protocol).

Studies with WSNs being used to feed DSSs with input are described in [48][49]. However, these studies do not take into account belief-rule-based DSSs and the use of heterogeneous wireless sensor networking technologies to the potential being possible today. Furthermore, Hughes et al. [50][51] proposed grid-based flood prediction, while De Roure et al. [52] proposed flood warning times being improved by using pervasive and grid computing. Our proposed project uses cost efficient and open source-based software which is easier to maintain and easier to deploy. Furthermore, our proposed project takes more factors into account such as climatological (rainfall and rain fall duration), topographical (slope and aspect), geology (soil type, soil infiltration rate) river characteristics (river flow, river depth, river width, river bed slope) and human activities (land use, deforestation, embankment failure and many others). Also, our proposed project will develop procedures for transforming raw data received from sensors using advanced data mining techniques in a way that can be fed in the rule based expert DSS. This will address the issues of various types of uncertainties associated with the above-mentioned data.

V. PROPOSED SYSTEM ARCHITECTURE TO ASSESS RISK OF FLOODING

Highly complex systems are faced with increasing inability to cope with high impact events such as natural or man-made disasters and market disruptions. The assessment of risk for complex systems has become increasingly important. Risk is defined as a function of the probability of occurrence of an event and its consequences, which can be material, environmental or cultural damages. Risk assessment of flooding is important because flooding is considered to be one of the most catastrophic forms of natural disaster, responsible for the highest number of fatalities and greater economic damage in comparison to other natural disasters. Flooding involves complex, interrelated and multi-dimensional geophysical processes and has a wide range of impact on human lives, activities and properties. Furthermore, the risks of flooding on a specific object may force a series of further objects to suffer the consequences of flood disasters in a ripple fashion. In general, assessment of flood risk, like other risks, comprises different stages including identification, modeling and evaluation [1][2][3][4][5][6]. The identification stage is concerned with characterizing factors that cause a flood and the physical and the socio-economic objects exposed to flooding. The modeling stage is associated with the estimation of likelihood of a flood and its consequences to obtain a calculated view of risk. The evaluation stage determines the acceptance or aversion limit of flood risk, based on which decisions should be taken to reduce the consequences of flooding [7][8][9][10]. However, this paper presents the belief rule base framework to estimate the flood water level of an area as shown in Fig. 2. The framework considers meteorological, geological, river characteristics, topographical and human activities. 17 input data are required to feed the system, which are both quantitative and qualitative. Examples of quantitative data are rainfall, velocity, soil infiltration rate, etc. and the examples of qualitative data are settlement on the

flood prone area as shown in Fig. 2. Various types of wireless sensors can be employed to collect the quantitative data and WSN architecture to collect rainfall data and feeding the BRB system is illustrated in Fig. 3.

Fig. 2. BRB framework to assess flooding in an area

Fig. 3. WSN Architecture to collect rainfall data

VI. CASE STUDY FLOOD RISK ASSESSMENT SYSTEM

Fig. 4a depicts the location of the case study area, which is located in the southern part of the Chittagong district of Bangladesh and covering an area of approximately five square miles. The area consists of plain land and also with a number of canals, facilitating the drainage of rainwater. Flash flood is a regular phenomenon in this area especially during rainy season. The livelihood of the people depends upon the production of various crops in the soil of this land. Therefore, the regular prediction of flood water level or the generation flood scenarios taking different input variables into account is very essential. Table 1 shows the input data of the 17 variables for the case study area. Fig. 4b illustrates the interface of the BRBES (Belief Rule Based Expert System) to predict flood water level of an area.

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