A Web Based Belief Rule Based Expert System for Assessing Flood Risk

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ABSTRACT

Natural calamities such as flooding, volcanic eruption, tornado hampers our daily life and causes many sufferings. Flood is one of the most catastrophic among the natural calamities. Assessing flood risk helps us to take necessary steps and save human lives. Several heterogeneous factors are used to assess flood risk on the livelihood of an area. Moreover, several types of uncertainties can be associated with each factor. In this paper, we propose a web based flood risk assessment expert system by combining belief rule base with the capability of reading data and generating web-based output. This paper also introduces a generic RESTful API which can be used without writing the belief rule based expert system from scratch. This expert system will facilitate the monitoring of the various flood risk factors, contributing in increasing the flood risk on livelihood of an area. Eventually, the decision makers should be able to take measures to control those factors and to reduce the risk of flooding in an area. Data for the expert system has been collected from a case study area by conducting interviews.

KEYWORDS

Belief Rule Based Expert System, Uncertainty, Flood Risk Assessment, RESTful API, Web Based Application

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1 INTRODUCTION

Even in this twenty first century, in the era of significant innovations and technological enhancements, humans are helpless in the hand of natural disasters such as floods, earthquakes, volcanic eruptions etc. Flooding is one of the most devastating catastrophic disasters among all and it causes significant socio-economic losses every year all over the world. It has been noticed that floods are responsible for one-third of all deaths, one-third of all damages and one-third of all injuries from natural disasters [1].

For example, one of the most devastating floods occurred in China during 1941 caused by overflowing of water from Huang He River (Yellow River). It caused the complete inundation of eighty-eight thousand square km of land, four million loss of life and eighty million people were homeless [2]. Since 1990, floods have caused more than 10,000 deaths, and economic losses are greater than US 70 billion in the United States alone. In Europe, during 1971-1995, there were 157 major floods, and the cost of damages in the period of 1991-1995 was estimated as Euro 99 billion by European Environment Agency [3]. In Bangladesh, floods caused serious threat to lives in 1954, 1955, 1974, 1984, 1987, 1988 and 2004 [4].

Since flood is devastating and causes enormous damage, assessing the risk of flooding is very important. It will help to take necessary steps, enabling to save millions of life and hence, losses can be reduced significantly. Several factors such as transportation, agriculture, road network and mental health should be taken into consideration while assessing the risk of flooding. Some of these factors are quantitative in nature while others are qualitative. For example, financial loss can be measured in a quantitative way while health condition should be expressed in a qualitative way. Therefore, various types of uncertainty such as vagueness, imprecision, ambiguity, ignorance and incompleteness can be noticed while measuring these factors. A belief rule based expert system (BRBES) methodology can be employed which has the capability to process heterogeneous as well as data with various types of uncertainties in a single integrated framework to assess the consequences or damages of flooding in an area.

This research is significant as it helps to build a unified framework considering heterogeneous data for flood risk assessment and their associated uncertainties. Establishing a web based BRB expert

system also enables the widespread use of the system for different domains. Eventually, the expert system is also implemented in real case study area and performance analysis is conducted. The procreation of such expert system enables companies and academia to come up with several interesting real time systems such as disease diagnosis, disaster recovery system like assessment of risk of flooding, which is the use case for this research.

Knowledge base, inference engine and user interface are the most essential components of an expert system. Moreover, different types of uncertainties such as ignorance, vagueness, ambiguity, incompleteness and imprecision can be associated with the data as pointed out before. There are several reasons for causing these uncertainties such as lack of human knowledge, insufficient data or faulty sensors. Therefore, it is necessary to consider uncertainty along with heterogeneity while designing an expert system. Belief Rule base knowledge representation schema captures all the above type of uncertainty. BRBESs methodology use belief rule base to represent uncertain knowledge, while Evidential Reasoning works as the inference engine with the capability of handling both heterogeneous and uncertain data [5]. This paper describes the BRBES which is build up and tested with data taken from survey. A dynamic BRB tree traversal algorithm is introduced which can traverse any Belief Rule Base tree as well as a RESTful API is built by which researchers, who want to use the BRB algorithm without writing it from scratch, can evaluate the expert system result from their data.

Web-based applications allow users to easily access and use the system without any additional software to install on users machine. Web-based applications are deployed and maintained in one location, namely web server, which can be accessed via specific Internet Protocol Address (IP address) and URL. They provide a standardized way of communication between different applications. Internet Protocols such as XML, Simple Object Access Protocol (SOAP), Hypertext Transfer Protocol (HTTP), Web Service Definition Language (WSDL) and Universal Description, Discovery, and Integration (UDDI) can be used for the communication [6]. Web services can be of two types namely Simple Object Access Protocol (SOAP) based and Representational State Transfer (REST)-compliant [7]. Both of these service types provide the flexibility of communication in cross platforms via simple service endpoints. It allows other applications to communicate with the system using the aforementioned protocols. Therefore, developing a web-based expert system will provide easy development, deployment and maintenance of applications as well as better user accessibility whereas the RESTful API will give a better and secure way of communication between users and the system.

Previously, BRBES was developed using PHP and MySQL which runs on a server [8]. This system was built for static data and due to the concreteness of the system it could have been used for a specific BRB. For these reasons, it was essential to develop a dynamic web based expert system application which will allow to run the expert system on a web server with more computational power and memory as well as will provide easy access for multiple users providing more user friendly interface. This paper describes an RESTful API which will allow other applications or users to run their own BRB framework without reinventing the wheel. This

system will provide easy access to the system for researchers who want to work with BRB system.

The remaining article is structured as follows. Section 2 covers related work on different expert Systems for flood risk assessment, Section 3 provides a brief overview on Belief Rule Base Expert System; Section 4 describes the Web-based Belief Rule Base Expert System and the RESTful API. Section 5 presents the results and discussion, while Section 6 concludes the paper and indicates future work.

2 RELATED WORK

There are different existing web based flood risk assessment systems which are used by various research groups and organizations throughout the world. The National Flood Insurance Program (NFIP) uses a web based system which is built using hydrological method developed in the 1960 's by U.S Department of Housing and Urban Development(HUD) of USA to asses flood risk for insurance purposes [9]. This method derives a water surface elevation probabilistic function to evaluate the flood risk in a geographical area. It transforms the probabilistic function as a function of depth inundation using a model of damage. This probability function is then integrated to compute the average annual loss. NFIP also has a more comprehensive model for risk analysis that can evaluate site specific probabilities to represent risk. It takes the performance and reliability of flood protection as well as the effect of their failure on flooding into consideration [10].

U.S. Army Corps of Engineers (USACE) follows the analysis procedures from Engineering Manual 1110-2-1619 to assess flood risk [11]. Methods from the engineering manual are used in flood damage reduction analysis software. It generates the results of economic analyses to assess flood risk. Compared to the approach of NFIP, this approach provides additional features such as site-specific flood hazard result and levee fragility.

Many organizations and insurance companies assess the risk of flood including other catastrophic disasters such as earthquake, cyclone using catastrophe models [12]. These models are generally developed for large or geographically diverse areas. It is possible to assess individual or combined risk using these models. In general, catastrophic models include the following risk assessment components: 1) A probabilistic scenario of flood hazard; 2) How hazard is modified by mitigation and management measures which represents the likelihood of success or failure of the results; 3) A mathematical approach of exposed elements and 4) A model of the vulnerability caused by those elements to the hazard.

North Carolina Floodplain Risk Information System is another system which is used by North Carolina state authority to assess certain components of flood risk [13]. They have developed site-specific water surface elevation probability functions using hydrological and hydraulic studies to assess flood risk. This system can compute the annual probability of flood using the information collected from building footprints from the state. It provides a dynamic and accurate statewide mapping of floods.

As European floods are different in nature compared to the floods in North America and Asia, different approach is used in Europe for flood risk assessment. A flood risk assessment method, created by Gillard and Givone in late 90s [14], which creates land use map

and price map to assess the vulnerability based on those maps is used for assessing flood risk, mainly in Europe. This method was used to assess the flood risk for different rivers across Europe for example the Turiec River, Slovakia [15]. It assess the vulnerability as a product of weight and price of the land.

Another flood risk assessment framework was used for assessing flood risk in different parts of Europe which was originally originated from Federal Office for Water Management (FOWM), Bern, Switzerland [16]. This framework is based on a risk matrix in combination with principles based on expressing the maximum acceptable risk. For example, flood risk in Rafina sub-urban area in Greece has been evaluated using FOWM method.

All these risk assessment methods for flooding described above address the different components of flood risk using methods tailored to their needs. Some methods such as the USACE and the comprehensive risk assessment methods explicitly consider uncertainty occurred due to levee performance but not all the uncertainties mentioned earlier while the NFIP method, Gillard method and FOWM method do not take any uncertainty of data in concern [9] [10] [11] [12] [13] [14] [15]. Moreover, all these methods mainly relies upon quantitative measures but do not consider qualitative data which also have influence on the likelihood of flood occurrence.

3 BELIEF RULE BASED EXPERT SYSTEM

There are two main parts in Belief Rule Based Expert System (BRBES) named as knowledge base and inference engine. Belief Rule Base (BRB) is used to build the initial knowledge base while evidential reasoning is used as inference engine. Evidential Reasoning (ER) is a decision analysis procedure which can handle heterogeneous data [17]. ER can handle different types of uncertainty such as incompleteness, ignorance, imprecision, vagueness exist in data [18] [19].

BRB is an extension of traditional IF-THEN rule base. A belief rule has two parts, namely the antecedent part and the consequent part. The antecedent attributes take the referential values while the consequent of a belief rule is associated with belief degrees. To capture uncertainty in data, several knowledge representation parameters such as rule weight, antecedent attribute weight and belief degrees are used. A belief rule can be defined as:

IF Financial Condition is High AND Mental Condition is Low
THEN Indirect Intangible factor is
{(High, 0.9), (Medium, 0.1), (Low, 0)}

(1)

In this example, "Financial Condition" and "Mental Condition" are the antecedent attributes, while "High" and "Low" are their corresponding referential values. "Indirect Intangible" is the consequent attribute with referential values such as "High", "Medium", and "Low" where (High, 0.9), (Medium, 0.1) and (Low, 0) are the belief distribution of the consequent "Indirect Intangible" mentioned above. As the summation of belief degrees associated with referential values of the consequent attribute is one, the rule can be said complete. In traditional IF-THEN rule, the relationship between antecedents and the consequent attribute is linear, whereas it is non-linear in case of belief rule. Moreover, data collected from the

surveys or interviews are non-linear in nature [8] and hence, it is possible to use belief rules to represent the data efficiently.

The inference procedures using Evidential Reasoning approach consist of various steps including input transformation, rule activation, belief update, and rule aggregation. The goal of input transformation is to distribute the input data over the referential values of the attribute of a rule, which is called matching degree. After calculating the matching degree, the rules are called packet antecedent and they become active and are kept in the short-term memory. This matching degree is used to calculate the activation weight of each rule. It is interesting to note that each rule has different weight while calculating the referential values of the consequent attribute. The summation of the rule activation weight of a rule base should be one.

The belief degree associated with each rule in the rule base should be updated when an input data for any of the antecedent is ignored or missing. This is done by the procedures mentioned in [17]. The output of the BRB system is fuzzy, meaning that qualitative values can be transformed into crisp values, i.e. quantitative data, by assigning utility scores to each referential value of the consequent attributes.

4 SYSTEM ARCHITECTURE

This section describes the system architecture for the web based flood risk assessment system. The BRB expert system developed here adopt a four-layer architecture model, including data management layer, application layer, Application Programming Interface (API) layer and interface layer as shown in Figure 1.

Figure 1: Architecture of the web base BRB Expert System

4.1 Data Management Layer

Data management layer is responsible for the initial rule base creation using the data collected from the case study area during survey. The initial BRB is generated in the data management layer which is the knowledge base of the system. A BRB framework was developed to construct the knowledge base for this expert system as shown in Figure 2.

Figure 2: BRB framework to assess the flood risk on livelihood

Data can be collected in different formats such as Comma Separated Values (CSV), eXtensible Markup Language (XML) and JavaScript Object Notation (JSON). JSON has been considered as the data format in this research. The reason behind choosing JSON over CSV or XML is that it is a text format which is completely language independent, lightweight and easy to read and write. Figure 3 represents the data for the node 'Financial Condition' in JSON format.

```

1- {
2-   "x8": {
3-     "antecedent_id": "x8",
4-     "antecedent_name": "Financial Condition",
5-     "attribute_weight": "1",
6-     "rule_weight": "1",
7-     "ref_val": [
8-       "1",
9-       "0.5",
10-      "0"
11-     ],
12-     "ref_title": [
13-       "High",
14-       "Medium",
15-       "Low"
16-     ],
17-     "consequent_values": [
18-       "[]"
19-     ],
20-     "crisp_val": "",
21-     "parent": "x3",
22-     "input_val": "",
23-     "is_input": "true"
24-   }
25- }

```

Figure 3: JSON data format for a node in BRB framework

4.2 Application Layer

Application layer consists of inference engine with procedures including input transformation, rule activation, rule update and rule aggregation which are the parts of ER based expert system as mentioned in previous chapter.

Based on the referential values, input of each antecedent is transformed into a distribution from the belief rule base. This distribution denotes the degree which has been activated for each antecedent. The activation weight of a rule is calculated by aggregating the degrees to which all antecedents are activated. Then, the output of consequent of the rule is obtained with a certain degree of belief. Finally, the inference mechanism is implemented for rule-based system using the ER approach. Figure 4 illustrates the architecture of BRBES inference procedures.

Figure 4: BRBES inference procedures

Application layer takes the initial BRB as input from data management layer and run the inference mechanism on it. As the initial BRB tree can be of more than one level, a dynamic tree traversal algorithm has been developed. This algorithm uses a bottom-up approach for BRB tree traversal. It is a modified implementation of traditional Breadth First Search (BFS) algorithm which traverses the tree in top-down approach. Both the space and time complexity of this algorithm is linear i.e. $O(n)$, where n is the number of nodes in the tree. It means that the algorithm is as efficient as BFS for bigger trees regardless the space and time complexity. The algorithm is illustrated in Algorithm 1.

The beauty of the above described tree traversal algorithm is that it is generic and can be applicable for any BRB tree from any domain. No matter for which domain the BRB tree is created for, this algorithm can traverse the whole tree from bottom to top and can generate the result of the top node by calculating the subtrees step by step.

4.3 API Layer

API Layer is a layer of abstraction of the underlying system for users which gives a simple programming interface for generating

Algorithm 1 Dynamic BRB Tree traversal algorithm

```

procedure BRBTREE TRAVERSAL
   $Nodes \leftarrow \{x_i, x_{i+1}, \dots, x_N\}$ 
  top:
   $begin \leftarrow \{Nodes_0\}$ 
   $parent = Parent_{begin}$ 
   $siblings = \{begin\}$ 
   $j \leftarrow i + 1$ 
  loop:
  if  $parent = Parent_{Nodes[j]}$  then
     $siblings \leftarrow Nodes[j]$ 
    goto loop.
   $isAllInput = False$ 
  loop:
  if  $isInput_{siblings[k]} = True$  then
     $isAllInput = True$ 
    goto loop.
  if  $isAllInput = True$  then
    Run ER on the subtree to find out Parent referential values
     $isInput_{parent} = True$ 
     $Nodes = Nodes - siblings$ 
    goto top
  if  $len(Nodes) = len(siblings)$  then
    Run ER on the subtree
    break

```

output of different levels of the BRBES using Uniform Resource Locator (URL), named as API endpoints. This API can communicate with the data management layer, application layer and provides a communication channel for the users using high level of abstraction.

RESTful API's communicate with HTTP verbs such as POST, GET, PUT, and DELETE [20]. The API initializes the BRB algorithm with a POST request which takes the JSON data file as input with the URL "/v1/initiate_brb". This URL will return an access key which is a "sha1" based hash represented in hexadecimal format [22]. A sample initialization of the RESTful API with JSON data is illustrated in Figure 5.

Figure 5: Initialization of BRB algorithm with JSON data for the RESTful API

The output of the API call is shown in the lower part of the Figure 5 and there is an "access_key". After initialization, the API can be accessed via different API endpoints, using the access key. For example, to generate the initial rule base for the BRB algorithm, an API call with a GET request can be triggered using the URL "/v1/<access_key>/get_initial_rule_base" where "access_key" is the key received from the output of "/v1/initiate_brb". This sample API call and the output is shown in Figure 6.

Figure 6: Output of the RESTful API for the initial rule base in JSON format

4.4 Interface Layer

Interface layer is responsible for showing the system output in more human readable way which can be accessible by the users via a web interface. A graphical user interface (GUI) has been created for the BRBES as a part of this research which provides a visual platform to enable the interaction between the user and the system. The GUI for the BRBES for flood risk assessment is illustrated in Figure 7.

Figure 7: GUI of BRBES for flood risk assessment

This GUI displays the data for the antecedent attributes (leaf nodes) of the BRB framework shown in Figure 2. These data are collected from the case study area by interviewing people. This interface enables the displaying of the evaluation result of the top node, x5 which is "livelihood" as well as the result for the sub rule bases. There are two parts of the result for each node namely consequence values and crisp value. The consequent value is obtained from the ER module and then converted into a crisp value.

Table 1: Comparison of features between the proposed system and Raihan et al. [8]

Features	Proposed web based BRBES	Raihan et al. [8]
Ease of access	Excellent	Good
Deployment	Easy	Hard
Modularity	Yes	No
Scalability	High	Low
Database	Flat file (JSON)	MySQL
Accessibility	High	Low
Creation of BRB	Dynamic	Static
RESTful API	Yes	No
Performance	High	Low
Programming tools	Python, Flask, HTML, AJAX	PHP, MySQL, AJAX

Using this system, we can generate and access the risk of flooding on livelihood of a particular area. Our system is built using layered and modular architecture consisting of four layers namely data management layer, application layer, API layer and the interface layer. We have used the Model-View-Controller (MVC) design pattern for our web back-end and the API is built as a RESTful API.

5 RESULT AND DISCUSSION

The Web-BRBES provides better user interface with more readable format of data compared to the previous web-based application. The new system can also get input from JSON file rather than using the static data. It provides a clean and user friendly access of the system than the previous version as users do not need to install any additional software at their end. It can be simple accessed via a web browser which is available in any operating system. Moreover, previous web-based BRBES works only for flood prediction in a concrete manner while the new web-based one works with any BRB tree for which the JSON file is provided to the system. Furthermore, using open source technology ensures the interoperability of the system. Users also need not to be worried about the software version update as it will be done automatically in the server.

RESTful API is a modern way of accessing data which provides an interface to the users by which users can communicate with the system without any prior knowledge of the system. The RESTful API is a new addition to the system along with the updated, modern and more accessible user interface which allows user to run the expert system on a web server with more computational power and memory as well as will provide easy access for multiple users instead of running on local machine. This API also allows other applications or users to run their own BRB framework without reinventing the wheel. Some students from Bangladesh, who are working with BRB in different domains, have used the RESTful API to get the results in stead of writing the BRB algorithm from scratch. A comparison of features between the new and old web-based BRBES is presented in Table 1.

Raihan et al. [8] developed a prototype using layered architecture. His prototype is divided into presentation, application and data management layers. Our system also introduces a modular architecture and adds the feature of more accessible and user friendly interface as well as the RESTful API. In summary, our system is modular, scalable, maintainable and more user friendly than his system.

6 CONCLUSION

In this paper, an implementation of the Web-based Belief Rule Based Expert System has been presented. This experts system ensures usability, portability and more computational power to handle larger rule bases. The RESTful API gives a layer of abstraction for the users who want to use the expert system without knowing much about the underlying algorithm. This RESTful API also makes the system more robust and highly accessible. The dynamic tree traversal algorithm provides the flexibility of developing and testing BRBES from different domains. Nevertheless, we used open source tools so the system is cost effective. The next step will be to check the performance of the system by doing stress testing. As this system does not take sensor data, we have a plan to incorporate sensor data interacting with the system. As sensors provide huge amounts of data, there is always a possibility of storing data directly on the web server's hard disk. However, since this is not a scalable solution, our future plans include using big data technologies such as Hadoop and MapReduce to process large scale data coming from IoT devices. Security is also an important aspect of the web based system so we have plans to enrich the security of the system.

Figure 8: Location of case study area

The location of the case study area from where the data is collected by conducting interviews, is named Bakkhali river, located in Cox 's bazar district of Bangladesh, which is the southern part of Bangladesh. Bakkhali experiences flooding in regular intervals. Due to the severity of the flooding each year in the adjacent area of Bakkhali river, it has been chosen to study the consequence of flooding by applying the web based BRBES.

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