ISSN: 0975-833X

Available online at http://www.journalcra.com

International Journal of Current Research
Vol. 9, Issue, 01, pp.45207-45212, January, 2017

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

RESEARCH ARTICLE

AN INFORMATION SYSTEM FOR WARNING AND FORECASTING OF FLOODS IN THE VALE DO ITAJAÍ BASIN

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ARTICLE INFO

Article History:
Received 09th October, 2016
Received in revised form
11th November, 2016
Accepted 24th December, 2016
Published online 31st January, 2017

Key words:
Mobile application,
System for forecasting.

ABSTRACT

The software product shown in this article is a system solution aimed at civil defense and municipalities that are located in regions suffering from steadily floods. There is great interested in programs to manage such disasters, particularly with the aid of information technology. The web system SIAH has a joint solution for the civil defense and cities suffering from river flooding. It includes technical analysis and monitoring of the river basin, full real-time forecasting, and several other technical information for the civil defense and hydrologists. In addition to technical information, the developed software will allow managing of the data that will be delivered to the population. Real-time notifications and monitoring of river and rainfall can be done via smartphones and other mobile devices. The application of the developed system will centralize the information in a single system and safe environment, reducing maintenance costs.

Citation: Aluizio Haendchen Filho, Wagner Correia, Pedro Zanchett and Hércules Antonio do Prado, 2017. "An information system for warning and forecasting of floods in the vale do itajaí basin", *International Journal of Current Research*, 9, (01), 45207-45212.

INTRODUCTION

Since the beginning of its occupation, the mesoregion of the Itajaí valley, in the state of Santa Catarina, south of Brazil, has regularly suffered from flooding of the rivers Itajaí Mirim and Itajaí Açú. There are historical records of major floods in 1880, 1957, 1961, 1984 in the cities of Brusque and Blumenau, as well as in many other regions of the valley. In 2008 a severe flood along with a big amount of mud caused huge losses and 136 deaths in the region. At present, the civil defense of the cities in the valley do not have a tool for sending flood warning messages and information to the population in real time. Once the population has access to information in real time, it will be possible to prevent large property damages, as well as provide appropriate shelter, avoiding loss of lives. Hence, it is necessary to develop a software for these units in order to speed up the work of civil defense and city employees, avoiding empirical procedures to achieve the expected results. In addition, such system can be useful to other cities and communities around the country affected by the same problem. It is evident that there is a general failure in information management during natural disasters in the cities of Brusque, Blumenau and other regions of the Itajaí valley. Several agencies, including the civil defense, do not have sufficient structure to avoid natural disasters in critical situations affecting the population living in risk areas. There is a lack of scientific and technical skills within these agencies, and many decisions are based on empirical knowledge. Much of the information delivered to the public by official agencies have no scientific basis. There are no records to support more precise technical decisions. In the city of Brusque, the civil defense has a number of telemetry stations for data collection. These data are automatically released to the public on their website and anyone may have access to information regarding river levels and warning of danger. These systems are considered critical and should be available in emergency situations. During the floods of October 2015, instability and frequent drops on the civil defense website occurred. This was a major drawback, considering that this is the main information system offered to the population. Besides, river level predictions are performed manually and based on onsite measurements. However, extracting information from hydrological data such as average and accumulated rain is a task that requires a lot of work from professionals working in the civil defense, and these routines are not the core activity of this institution.

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Related works

There are some related works concerning mobile applications for rain disaster. An example is the AlertaRio application of the Municipality of Rio de Janeiro, which is distributed as AlertaRio on Google Play (2016) and AlertaRio on iTunes

2016). This tool displays the city weather in real time with variables such as rainfall, and air humidity measured by pluviometric and meteorological stations around the city. The tool also provides information on the probability of occurrence of landslides in the four macro drainage basins that are part of the municipality. Cristofolini (2016) describes an application that brings data visualization of the National Water Agency (ANA in Brazil). The main objective is to monitor the level of rivers, based on 3757 stations in Brazil, and details about increasing or decreasing levels. The Application FLOOD ALERT Mustachio (2016) allows you to track in a simple manner the level of the Itajai-Açu River in each season. In case of precipitation alert and flood alerts, it has a link to the Civil Defense site. The ALERTABLU System (2016) offers the population a website with information on the situation of rainfall, river levels and related functions. This alert system was built by the company Squitter and tailored to the city of Blumenau in disaster prevention issues, rainfall, meteorological and hydrological monitoring. The system is operated by multidisciplinary and highly trained technical teams of meteorologists, to perform daily activities in a central environmental monitoring site. The ALERTABLU provides an interface for smartphones where you can see the river level and the situation in real time, facilitating alertness and readiness. The application allows registering of local citizens for monitoring of quota near their homes, or workplace. Among its main features, the ALERTABLU application provides information on river levels, shelters, streets and flood quotas, alerts and notifications. A series of studies carried out in a Scientific Initiation Research Project (FUMDES) held in UNIFEBE (University Center of Brusque), found out that in the Itajaí valley region there are agencies such as the civil defense and environmental department in need of tools for processing hydrological data. In this scenario the Information System for Hydrological Analysis (SIAH) application was developed at UNIFEBE, which provides information collected from the Civil Defense database to support decision- making.

Technologies

The Alerta Brusque is an application for smartphones that provides public information in real time about the river levels and volume of rainfall in the Itajaí Mirim river basin. The system was developed in partnership with the Civil Defense and with support of the Brusque Prefecture. The application is well known and used in the region. Since its release in November 2015, there have been many reports in newspapers, TV, radio and magazines, including a broadcast on most popular RBS TV. The application was built for Android and iOS using the CASE (Computer-Aided Software Engineering) tool Apache Cordova. It is a framework for mobile development of universal applications based on web-oriented technologies HTML5, CSS3, and JavaScript. As in the development of native applications, Apache Cordova allows integration between software and hardware. Thus, the application can access various features of the device, such as camera, GPS, file system, etc. In addition, it has an integrated security system and an application generator for Android BlackBerry, iOS and Windows 8 mobile devices. It is necessary to use an Apple computer with OSX El Capitan operating system to generate the iOS version. This application runs as a WebView within the native container, which is distributed to app stores. For the application business layer the AngularJS framework was applied, which focused on the development of applications in HTML5 on the client side. According to Balasubramanian *et al*. (2013) the framework to implement the MVC (Model-View-Controller) is different from the traditional MVC architecture, such as SpringMVC where the website is processed on the server side. On the other hand, in AngularJS the browser works in the Model layer with all the necessary data, and the control layer handles the interaction between the HTML page and the Model. The advantage here is that there is no call on the server side involved in these operations. Everything is done from the client side with the cached data. The AngularJS works with the SPA (Single Page Application) concept. According Pereira (2014) SPA are web applications that carry a single page, which is considered the application entry point. This page, in turn, will be responsible for loading the necessary resources on demand, such as JavaScript or CSS files, for example, without redirection or page reload (...). The Alerta Brusque application has an administrative module integrated to the SIAH for Civil Defense manage their information. This module allows configuring the mobile application, send notifications and also registering streets and quotas, shelters, phone numbers, links and news. The module was built with Zend Framework. The Zend Framework is an open source framework for PHP applications focused on the development of enterprise applications based on the MVC (Model View Controller) pattern. Its use was only possible from version 5 of PHP, since from this version PHP offers full support to object orientation.
Perhaps the main advantage of using Zend Framework is able to be supported by a specialized company. It makes no great difference to developers accustomed to the use of free software, but for the business world this is important. Zend is formed by major developers of the PHP language, as Zeev Suraski and Andi Gutmans, two of those responsible for large amounts of source codes in the early versions of the language. It has important partnerships such as IBM and Oracle, which strengthens the use of PHP in large companies. The development of this framework for companies and other institutions, makes the use of PHP increasingly secure in their projects (MINETTO 2007).

Methodology

The research used for application development is mainly applied research, where the main objective is to generate knowledge directed to the solution of specific problems for social interest. In the approach, quantitative and qualitative research methods were used. Quantitative research translates into collected data from the database for classification, analysis, generation of information, and knowledge. During the requirement specification phase, we use exploratory research involving examples of analysis, information provided by the authorities, and interviews with people that had practical experience with the problems. We also used explanatory research, seeking to deepen the knowledge of reality from the collected data. Factors that determined or contributed to the occurrence of phenomena were identified.

Population and Universe of Research

The research included data from eleven telemetry stations, all with capabilities for rain level measurement. Three of these stations measured the level of the Itajaí Mirim river, four measure the level of smaller rivers in the city, and the others measured rainfall. All the information is automatically updated in the application screen. According to Tude (2013), telemetry is the transfer (via fixed or wireless network) and use of data

coming from multiple remote machines distributed in a geographical area. The Itajaí Mirim river nascent is located in the city of Vidal Ramos and then the river crosses the cities of Botuverá, Brusque and Itajaí before reaching the Atlantic sea The total length of the river this nascent to the mouth is 177 km.

Table I shows the main stations that perform the river level monitoring and rainfall in the city. It presents information regarding the collection, sampling interval and the interval between collections. The other stations installed in the city do not play an importance role in flooding.

Table I. Main stations for data collection

Station 1	- Collection: only the river level.
Vidal Ramos	- 06/2005 – 12/2011: one hour' interval.
	- After 2011: fifteen minutes' interval.
Station 2	- Collection: rainfall and river level.
Botuverá	- From 08/2012: teen minutes' interval.
Station 3	- Collection: rainfall and river level.
Guarani:	- From 08/2012: teen minutes' interval.
Station 4	- Collection: only the river level.
Centro	- From 06/2005: one hour' interval.
Station 5	- Collection: rainfall and river level.
Dom Joaquim	- Data from 07/2015: teen minutes' interval.

Figure 1. A map with the location of the main telemetry stations in the region

Fig.1. Main telemetry stations location

Data Collection Instruments

The Alerta Brusque application is integrated to SIAH coming from the research project "Development of a system for generating statistics based on data from rain levels and the river in Brusque and region" through an API (Application Programming Interface) with data output in JSON format. Through this API, the application can check for SIAH telemetric data on river levels and rainfall. With the use of systems based on API's, it is possible to have the integration of multiple data sources in a single application. Currently, the data sources used by both systems (SIAH and Alerta Brusque) come from the Civil Defense of Brusque, CEOPS (Alert System Operation Center - FURB) and ANA (National Water Agency).

Alerta brusque architecture

One important advance in the context of software development that can help in easing the creation of distributed information systems is SOA, a service-oriented architecture. SOA defines an architectural style to build loosely coupled software applications that need services available in the Web. A Web Service (Lewis *et al*., 2010) is an instance of SOA, whose interfaces and bindings are described in XML and can be discovered by looking-up a services catalog. SOA offers the fastest way available to create powerful and reusable business services from existing applications, supporting direct interactions with heterogeneous software applications. Figure 2 shows a Components Diagram divided into three layers, which represent applications (Alerta Brusque, SIAH, Telemetry System) and the communication flow between the layers.

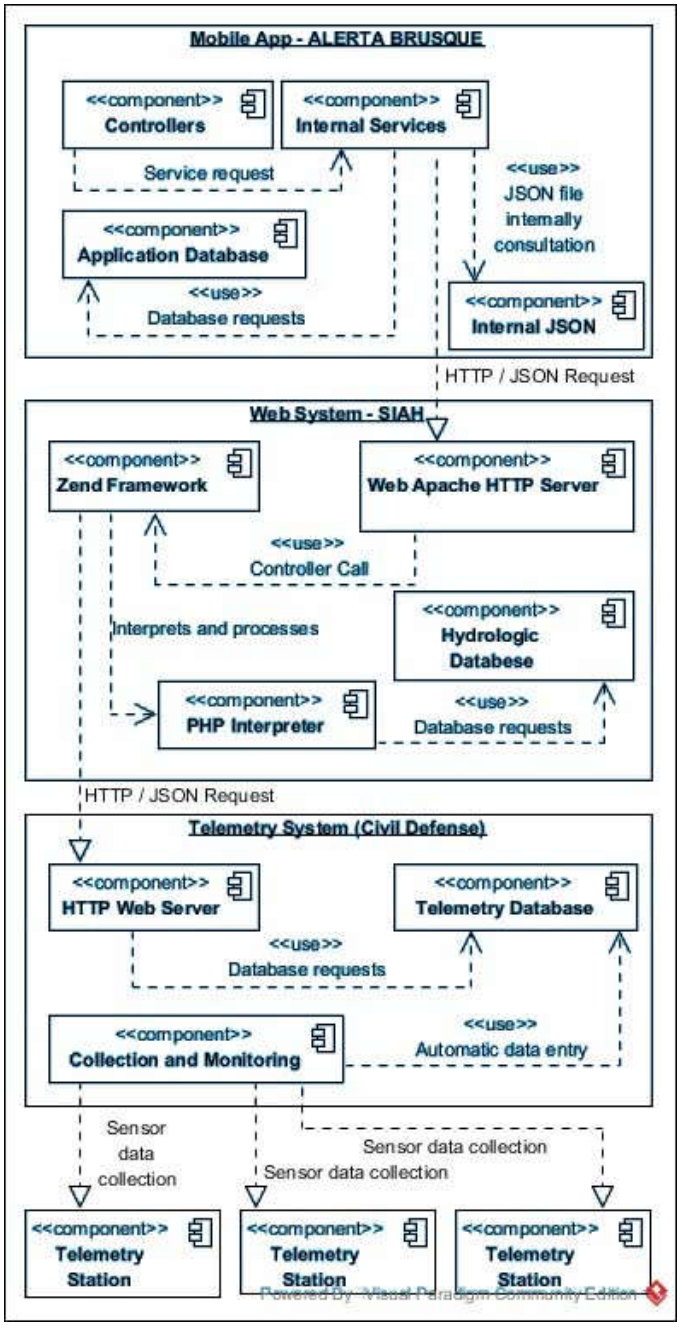

Fig. 2. Component diagram exemplifying integration between Alerta Brusque and SIAH

The mobile application Alerta Brusque and SIAH application are developed using the MVC pattern. The Alerta Brusque system was developed based upon AngularJS framework for Javascript. All model layers, represented by the Internal Services component are based on services. The controller

component executes the call service regardless of whether it comes from local or Web database. Local databases are represented by application database components and internal JSON. The service requests are forwarded from the controller to the internal services component. Static lower volume data is stored in internal files in JSON format, whereas larger amounts of information that suffer few modifications are stored in SQLITE database device itself. The information from external sources is obtained from SIAH system, which manages the hydrological data, represented by the Hydrologic Database component. This database contains data obtained from measurements by sensors, which have a very fast update period. The Alerta Brusque application gets the SIAH data via HTTP requests, with output in JSON format. The Zend Framework component represents the framework of SIAH application. It receives the controller calls from the requests sent to the Apache HTTP web server. All information handled by SIAH is interpreted by PHP Interpreter, which handles the connection with the hydrological database.

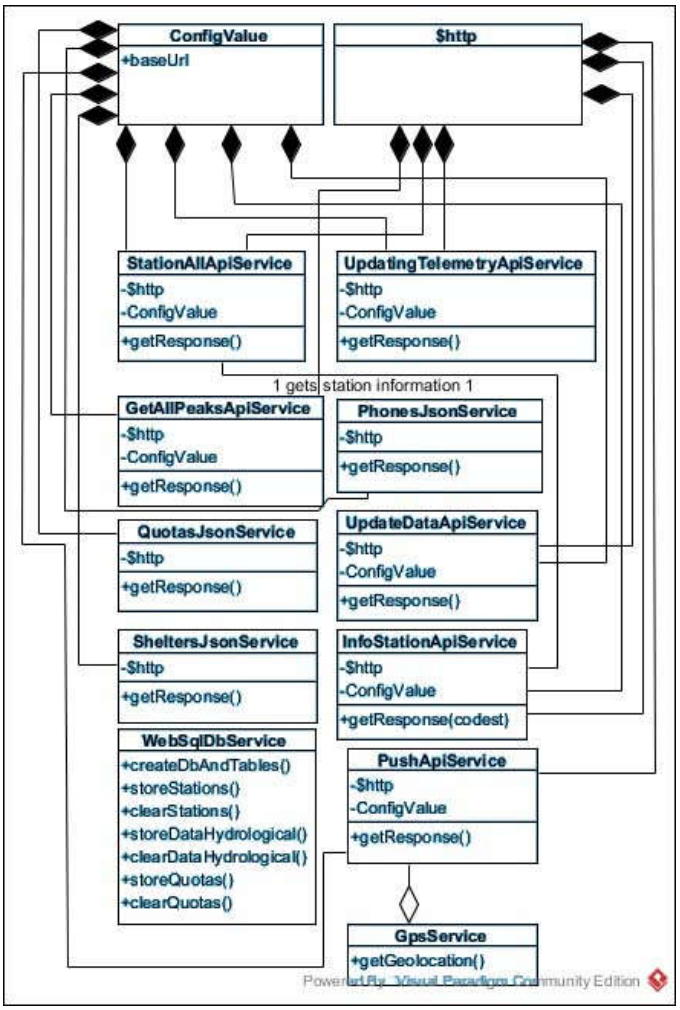

Fig. 3. Class Diagram of the Alerta Brusque application

The Telemetry System performs the collection of telemetry data for civil defense and feeds the hydrologic database. It provides data collected by sensors that perform the measurement of the river and rain quota level. The data is transmitted by radio signal to the Collection and Monitoring components that stores the data in the Telemetry Database. The information is provided by the SIAH via an API available by the component HTTP Web Server. Figure 3 shows the Class Diagram of the application Alerta Brusque. The highest level class ConfigValue and $http have a set of subclasses with aggregate composition relationship. This means that the classes participating in the composition depend on the existence of the two higher-level classes. The Config Value class provides the parameter configuration for the other class services. The $http class is a core Angular service that facilitates communication with the remote HTTP servers via the browser's XMLHttpRequest object or via JSONP. The subclasses of the composition containing the $http and Config Value objects represent instances of these classes. Most of the services inserted in the classes depend on the "injection" of higher dependencies.

The Station AllApiService, InfoStation ApiService, Update Telemetry ApiServic, GetAllPeaks ApiService and PushApiService classes perform remote queries. They use the *getResponse()* method for remote communication via XMLHttpRequest. The StationAllApiService class receives the list of telemetry stations available for data query via *getResponse()* method. The InfoStationApiService class collects individually data for each station as quota of river and rainfall level ones receiving the code as a parameter. The UpdateTelemetryApiService class provides the timestamp of the last update of data on the server to be used as an indicator for application data update routine. River data and rainfall of all telemetry stations present on the server are provided by GetAllPeaksApiService class. The PushApiService class is responsible for receiving notifications sent to the application. It possesses communication with the web system API to receive complete messages, in addition to the GCM (Google Cloud Messaging) and APN (Apple Push Notification) service notifications. The PushApiService class has the GpsService aggregate, which performs the collection of the user's geolocation data. Thus, it may send that information to the web system so that the notifications are issued in a segmented way based on user location. The application includes a local database represented in WebSqlDbService class that provides the procedures for working with relational database. The database stores street quota information, which enables the user to know exactly when its property will be reached by a flood. The database is also used to carry out temporary storage of river levels and rainfall. The ShelterJsonService, PhonesJsonService and QuotasJsonService classes provide methods to consult the javascript objects notations. These classes are used for simpler operations and to manipulate data that need to stay offline in the scope of application. They also provide methods for the registered shelters, a list of useful telephone numbers and street quotas in order to load the database at the first launch of the application. In general, all internal services return their data in a standardized way, with no importance of the origin of the data in the highest levels of application. If there is a need for future change in the access way to external data, it is no need to change the main scope of the application. The service continues to return data in the current standard regardless of the way this data is obtained.

Alerta brusque functionalities

The Alerta Brusque system provides population access to the information generated by automated stations in real time for the most critical locations of Brusque city and surrounding towns. With this application, available for mobile platforms Android and IOS, it is possible to see the level of the Itajaí Mirim river, as well as smaller rivers of the basin, and even check the amount of rainfall in various neighborhoods.

Table II. Principais estações para coleta de dados

	AlertaBlu	Alerta Brusque	AlertaRio	Cristofolini (2016)	Mustachio (2016)
River level	Yes	Yes	No	Yes	Yes
Streets and Quotas	Yes	Yes	No	No	No
Shelters	Yes	Yes	No	No	No
Rain conditions	Yes	Yes	Yes	No	No
Conditions Slip	Yes	Yes	Yes	No	No
Push Notifications	Yes	Yes	Yes	No	No
Notifications Segmented by Geolocation	No	Yes	No	No	No
River level forecast	No	Yes	No	No	No
River Level History	Yes	Yes	No	Yes	No
Weather forecast	Yes	Yes	Yes	No	No
Weather warning	Yes	Yes	No	No	No
Profile Registration	Yes	Yes	No	No	No
Adaptive resources	No	Yes	No	No	No
Traffic analysis and roadmaps	No	Yes	No	No	Yes
Weather Radar Map	No	Yes	Yes	No	No

The data arrives to the system automatically without the action of people. Each city telemetry station performs transmission of data at regular of 10 minute intervals. A very useful information contained in the application are the streets quotas. This information, available without the need for internet connection, enable citizens to have knowledge about the situation of their house or commercial establishments in relation to the river floods. This information is available for consultation in 1878 streets quotas in the Alerta Brusque application. In order to know the dimension of it street, the user must enter the street name in the use case of the search field of this feature. All streets quotas are recorded in the SQLITE relational database within the application. In the same database, for each street quota record, there is latitude and longitude site data. Based on this information, we intend to perform an application update allowing the user to know the exact elevation of its current location via a GPS device. Besides the information on rivers and rainfall, the application allows access to useful telephone number in emergency times. Citizens can make phone calls directly from the application and consult public utility sites and news published by the Civil Defense of the municipality of Brusque. During states of emergency, it is possible to consult the location of shelters, and find out about houses in danger due to a landslide, flood, etc. The Brusque Alert application receives push notifications type of APN and GCMS. A use case is the "Registry of My Places" where citizens can register a place (home or business). When river levels have flood forecast in the coming hours a notification is send to their smartphone. Besides the registration of places, the application has the geolocation information for emitting segmented notifications based on user location. The application also receives the following notifications: the weather forecast for the next hours, weather warnings, unexpected situations and information coming from the meteorologist team and news about the civil defense. The citizen has the option of configuring the application to receive notifications or disable this feature.

There are other application-specific features which are in the testing phase and have related ongoing research. These features depend exclusively on Internet access for their operation because they require data processing on the server side, such as the river level forecast. Through this feature, the user may know the river behavior for the following 6 to 8 hours. Another feature is the traffic analysis roadmaps which are based on the quota information of streets, allowing reports of streets that could be affected by floods. The application also provides the weather radar map, where users can view the information radar installed in the state of Santa Catarina. In addition to the resources that depend on Web access, there are adaptive features that do not depend on Internet access. Through a knowledge base, the application will learn how the user makes use of it, and present content based on user's preferences.

DISCUSSION

The application Alert Brusque was released by the end of 2015, offering quick information from the Civil Defense to smartphones and tablets (Brusque Prefecture, 2016). The software had great repercussion in the media. It acceptance was very positive and as it has been helpful to keep the population informed about details of rainfall in the region. Google Play users got a score of 4.8 out of a maximum of 5.0. A new version of the application is being launched this semester. Among the innovate features are Notifications Segmented by Geolocation, River Level Forecast, Adaptive Resources and Traffic Analysis. Table II shows a comparison between application functionality for the monitoring and flood warning. In this comparative table it can be seen that the AlertaBlu and Alerta Brusque applications are those with the largest number of features and available platforms (iOS and Android). The works of Cristofolini and Mustachio provide information on the level of the river in several cities in Brazil, but do not present different features compared to the other research works. One of the biggest concerns of the general population during a flood is the velocity of the increase of river water levels. Any misinformation regarding river levels may result in damage to the population. Inaccurate information may result in loss of property or even loss of lives. The prediction of river levels is a feature that is being improved using Artificial Intelligence and mathematical models. It consists in finding the correlation between different stations along the basin, and applying an algorithm that "learns" as river's behavior changes. From these techniques, the algorithm must be able to predict changes in river levels. Considering the current mathematical model, the algorithm receives input data and then returns as output on river levels for the following 6 to 8 hours, according to the article ARMAX model (Cordero *et al*., 2012). Another important feature that does not exist in the available applications is the ability to create alternative traffic routes. Thus, even during frequent city floods drivers can be aware of the pathways that are blocked due to flooding, and alternate routes can be offered. The Adaptive Resource enables that the users particularities to be represented by models. The system adapts to the content, navigation and presentation,

according to the user's profile. In our application we have implemented Notifications Segmented by Geolocation because not all information disclosed by the civil defense is important to everyone. This information is sent in real time by the civil defense only to people living in selected locations. The user profile is identified according to user behavior in the application, with the aid of a knowledge base. According to Koch (2000) the adaptation of content and presentation avoid cognitive overload, presenting the right information to the user employing the appropriate layout. The adaptation of navigation solves the problem of disorientation in the hypermedia, limiting the navigation space, providing additional information links, hiding contents and irrelevant links, or suggesting the best links to follow. With increasing application functionality in this new version, we provide a software capable of meeting the needs of a larger number of users. The new features fill a gap existing in the previous version. They significantly differentiate other existing application in the market, both for additional functionality as well as usability provided by the embedded adaptive resources.

Ongoing work

In the current research, we are giving enphasis on data reability. Is an essential feature that we are taking into account in the work in progress. Even though the telemetry station in town are relatively new and operate with the latest technologies, problems such as sensor sand accumulation are relatively frequent and cannot be diagnosed with accuracy. This situation has recently occurred in Botuverá city. To avoid such errors, data correction models can be used to analyse cross sectional data coming from several stations regarding variables such as rainfall, weather forecast and river levels. Data correction models for this purpose analyze cross-sectional data like the rainfall, Considering the research done so far, it is possible to for see the use of mathematical models with "double mass curve" and coefficients. Artificial Intelligence can possibly be used for this purpose. With this model it may be possible to telemetry a number of stations, indicating whether they are in full operation or not. An example of a problematic telemetry station is the one currently used in Vidal Ramos, which is has a misreading of one meter above normal river levels. Variables such as precipitation of rain, relief, climate and river time flow, are captured by telemetry stations. Data obtained from the Civil Defense database can be used to carry out data mining of hydrological data, identifying patterns and extracting knowledge. Based on our understanding of the problem, we consider the application of descriptive methods such as cluster analysis, predictive techniques, and identification of environmental and climatic preconditions that allow anticipation of events. Thus, it is expected that the characterization parts of a geographical area can be extract from climate and demographic variables in a grouping scheme according to the degree of risk. On the other hand, the combination of variables for generating association rules can also be considered (Srikant *et al*., 1997). In addition, increased knowledge acquired from cluster analysis and association rules facilitates buildup of classifiers which enables mapping of variables considered relevant to the treated events (Witten *et al*., 2005).

Conclusion

This paper presents improvements in the Information System for Hydrologic analysis (SIAH) and Alerta Brusque software systems for rainfall and flood forecasting, featuring relevant technological innovation and contributions of public interest. We have not identified application systems in the literature with all the features described for flood forecasting such as the one presented in our paper. The main scientific contributions are related to the Artificial Intelligence and data mining techniques applied to identify patterns and gain knowledge from hydrologic databases.

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