FLOREON - SYSTEM FOR FLOOD PREDICTION

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ABSTRACT

The main goal of our system is to provide the end user with information about an approaching disaster. The concept is to ensure information access to adequate data for all potential users, including citizens, local mayors, governments, and specialists, within one system. It is obvious that there is a knowledge gap between the lay user and specialist. Therefore, the system must be able to provide this information in a simple format for the less informed user while providing more complete information with computation adjustment and parameterization options to more qualified users.

One system feature in high demand is the ability to display reliable and understandable graphical and textual information. Information for various types of users must be adapted to a desired format which is understandable to a particular group of people. For example, a specialist can ask for all available results from different simulation models in text format. This type of information may be useless, however, to the user who only wants to find out whether or not his house will be flooded.

Another important feature is the open structure and modular architecture that enables the usage of different modules. Modules can contain different functions, alternative simulations or additional features. Since the architectural structure is open, modules can be combined in any way to achieve any desired function in the system.

INTRODUCTION

There are many types of natural disasters in the world. Many of which depend specifically upon geography. The flood is one of the worst and most recurrent types of natural disasters in our region [3, 4, 18]. Local governments require reliable models for flood simulations and predictions to save on ample funding that must be otherwise invested in post-flood repairs for impacted regions [4]. Therefore, the issue of flood prediction and simulation has been selected as a case choice for experimental development. This sophisticated system should combine all knowledge from existing models and systems while providing results to a wide range of people that are not experts in this particular field. The name of the system that is being developed is FLOREON (**FLO**ods **RE**cognition on the **N**et).

A wide range of professionals in various fields are already familiar with this system concept. Systems that are able to model floods and present them to qualified system users already exist. The concept of using single, preferred and utilized software (or the combination of several types) plays a major role regarding the limited experience and viewpoints of some specialists [3, 18]. Furthermore, strict deadlines, resulting from the demand for promptly obtained modeling results to support timely decision making, present another significant issue [3]. In addition, the individual, qualified user is not able to operate more models and assemble predictions at the same time. For these reasons, the goal of this system is to combine the results of all prediction and simulation systems and provide simulation results to people who are less informed concerning the complexity of this issue. These results should be accessible to a wide range of users including professionals from various fields. Inhabitants of flood plains should be able to view the results directly in a simple way while more complex information should be accessible to local representatives and rescue teams. Legal bodies responsible for entire regions (i.e. local governments) should be able to view as much information as possible. Thus, the front end of the entire system must be able to satisfy all types of users. A logical solution, and genuinely efficient method of achieving this goal, would be to combine several visualization tools and equipment in the system. All users would be able to access the system from one website. Local representatives and rescue teams can also use other types of thin equipment such as local visualization applications. Governments will be able to use more sophisticated thin or fat equipment that will enable access and visualization of all types of information, based on their needs.

The main concern of our project is to prove that a combination of the latest information technology, along with results from fields that are in some way connected to creating flood simulations and predictions, would be very useful. Fields of interest considered detrimental to supplying theses results include hydrology, meteorology, geoinformatics, remote sensing, integration of prediction models, development of new models, and others [3, 18]. The information system itself is focused on the development of a reliable architecture and a graphic user interface (2D, 3D) that should satisfy the needs of all types of users expected to eventually interact with the system.

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The technological integration of the necessary system module is provided by means of internet technology which enables dynamic configuration and the construction of an open architecture [4]. We base the communication of modules within the system and communication with the other systems on Web Services [19].
Although, the primary goal of this system is flood prediction, simulation and presentation, it is possible to expand this system to include modules that can represent a wide range of other disasters. Examples of some modules that may be added to the system include modules that simulate and predict air and water pollution, advective-dispersion processes, forest fire spreading, and etc…
The addition and removal of system modules (including alternative models for simulations and predictions) is based on the plug and play principle. All of these system futures should establish the base for a complex and unique system that enables users to tap into its potential for observing and controlling various types of disasters. Every type of model (rainfall-runoff, hydrodynamic etc…) can be replaced by other models. Reasons for considering such substations include the dropout of hydrometeorological data input for a particular model method (i.e. snowmelt module) and the added issue of method limitations during specific rainfall-runoff episodes – i.e SCS CN method performance differs from SMA method performance during rainfall-runoff events of varying duration and rainfall intensity.

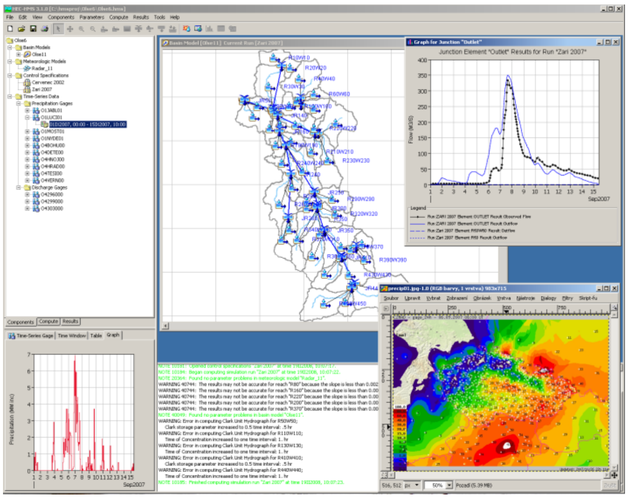

Fig. 1: Rainfall-runoff calibration episode 9/2007 and the result of the rainfall-runoff HEC-HMS simulation model

MATHEMATICAL MODELING

The input data for such a system is subdivided into two groups. The first type of data is the spatial data required for model development (catchment schematization, river channels schematization, etc...). This type of input data is mainly obtained via GIS preprocessing. Time series (Hydrometeorological data) is the second type of data. Both types have their own spatial and temporal variations. The basic character of the modeled domain (catchment size, geometry and topology) is constant during the modeled rainfall-runoff episode. Another type of spatial data with a higher level of variability is the antecedent precipitation index (API). Time series and hydrometeorological data vary both spatially and temporarily (i.e. measured and predicted precipitation and temperatures). The general computation scheme of the rainfall-runoff and hydrodynamic modeling task is as follows [3, 18]:

1. input data pre-processing and storage
2. rainfall-runoff modeling (discharge hydrograph forecast)
3. hydrodynamic modeling (water level forecast)
4. post-processing of the results (hydrographs, floodplain delineation, etc...).

Precipitation, both measured and predicted, represents the most significant time series data input for such basic computation schemes and cases. There is also a radar data utilization option in the FLOREON system.

Motivation Scenarios

At the beginning of the development of all information systems, interaction scenarios between the system and user must be defined. In our case, two main scenarios were selected at the beginning of our project. These two scenarios are:

- Simple communication between the system and user – users can see the actual situation, simulated prediction, or historical data about floods.
- Coordination of the result generation – for example, if the data about rainfall intensity and prediction represent the system input, the result of the flood simulation must be generated by a computation chain.

These two scenarios, as well as other derived or future scenarios, must be supported by the system's architecture.

Two basic scenarios have been implemented. The first first scenario presents a computation of hydrographs in the rainfall-runoff model and flood areas (floodlake) in the hydrodynamic model (Fig. 2). A computation chain is started as soon as the hydrometeorology data is available – precipitations, temperatures and measured discharge volumes in our case. Data frequency is dependant upon the provider and is available every 6 hours in an FTP service provider. Our module downloads it into our data store and starts the computation chain. This data is then processed by a software module that performs the computation – the hydrologic module. After the module finishes the computation, obtained results - discharge volumes and floodlakes - are uploaded back to the data store. An

hydrologic module provides a simulation for up to 2 days.
The second scenario involves user interaction with a Floreon graphic user interface (GUI) accessible with a web browser (Fig. 3). The user can define areas, layers – ortophotomaps, growth, buildings, motorways, rivers, foodlakes, etc... – and the necessary timeframe for the construction of a result picture. These attributes can also be changed, interactively, by the user.

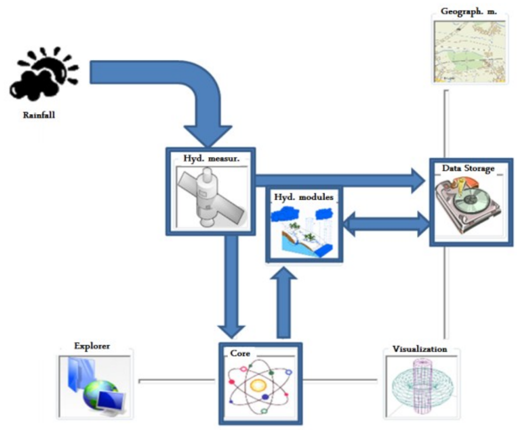

Fig. 2: First scenario – hydrograph computation in the rainfall-runoff model and flood areas in a hydrodynamic model.

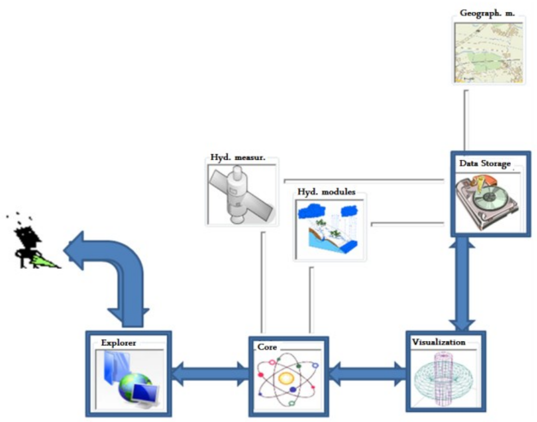

Fig. 3: Second scenario – user interaction with graphic user interface.

ARCHITECTURE

The system architecture that has been developed for this project fulfills all desired features and enables any extension that might be added in the future. Moreover, our architecture includes an option for changing the technology that implements the architecture because the structure of the architecture itself is completely independent and does not rely on implementation.
The main modules of the present system are the core, data warehouse, meteorological data module, hydrology module, geographic module, alternate numeric method module, visualization module, and web server module. The system is mainly based on a Microsoft .NET framework and written in C#. Other languages, such as C++ for special functions, are used when necessary.
All these modules must be connected and communicate in some way. Web Services seem to be the best technology currently available. Web Service technology ensures implementation independence, simple maintenance of connections, standardized communication, and simple module exchange. This technology enables the construction of a flexible and independent system.

Coordinator

A core module is responsible for the coordination of system scenarios and controls all modules that are plugged into the system.

Database Storage

A data warehouse stores all necessary data provided by a wide range of sources (geological data, meteorological data, etc…) or serves as a proxy to remote resources. The following technology is being used:

- PostgreSql database and its spatial extension PostGis
- Microsoft SQL Server
- Raster Provider - proprietary solution that will be soon published as an open source project [8].

Hydrometeorology

A meteorological module is a provider of meteorological data and weather predictions. We use a variety of sources:

- CHMU – Czech Hydrometeorological Institute provides measurement of hydrometeorological data (precipitation, temperature, water level stages, discharges, snow cover) obtained both from the station net and remote sensing methods (e.g. radar estimations of precipitation rates) [3]
- ALADIN – numerical weather forecasting system engaged by CHMU [1]
- Povodi Odry - company established by the government to provide measured discharge volumes in rivers and information about reservoir water levels and operations [15].

The hydrology module is mainly responsible for the computation of floods. More independent applications are used in our computation chain. These programs are connected to provide fully automated options. They involve the following applications:

- HEC-HMS (USACE) –Rainfall-runoff model
- MIKE 11 (DHI) – 1D hydrodynamic model
- MIKE 11 GIS (DHI) – GIS post-processing software, which inspects and provides measures of the flood occurrence and extent in the terrain

- ArcGIS (ESRI) – another platform for the post-processing of results

Additional information about the involved models is available on the internet or in [3].

An alternative, numeric method module is an experimental module that encapsulates new flood prediction methods developed by the group of mathematicians that we are cooperating on this project with. There is a 1D numerical approach as well as a more sophisticated 2D approach. The 2D numerical approach is based on the Finite volume method [2].

Geography and Visualization

The geographical module is responsible for the provision of all actual terrain data, maps, etc... It is a group of standalone tools used for data pre and post-processing:

- SharpMap for shapefile parsing [11]
- Quantum GIS [9] for data import and management

This module also combines all the information stored and created by the system and prepares this information for user presentation. This module uses 2D and 3D techniques to display results.

Web User Interface

A web server module communicates with users and transfers the visualization data to the user. The user can be equipped with any type of device. This module adapts the information to the user's device type.

RESULTS

We have already implemented the two scenarios described above. The system fully computes and predicts floods automatically and periodically. Results are accessible on the Internet with any modern browser. The user only needs to select a specific area and input the date of a given situation. The date can be set from the past or for the future. The system returns pre-computed and stored results.

A GUI demonstration, as well as a computed floodlake, is displayed in Fig. 5. Other layers such as buildings, roads, river channels or orthophoto maps, are displayed behind the floodlake. The additional layers are important for fast and precise orientation during a flood situation (i.e. damaged buildings visible in the picture).

This view represents a rather small area with high zoom. The application also provides a less detailed overview of an inspected area. The view also contains an expressively smaller amount of information, because it could be quite messy to draw a larger scale of information with a lower grade zoom.

Created Applications and Modules

- Web client based on Web 2.0 technology. Average size of transferred data between server and client is 50 KB.
- 3D client also for stereo projection
- Mobile client which identifies location with GPS and actual situations downloaded from FLOREON
- Desktop client based on vector graphics
- Application of import model schematization to FLOREON

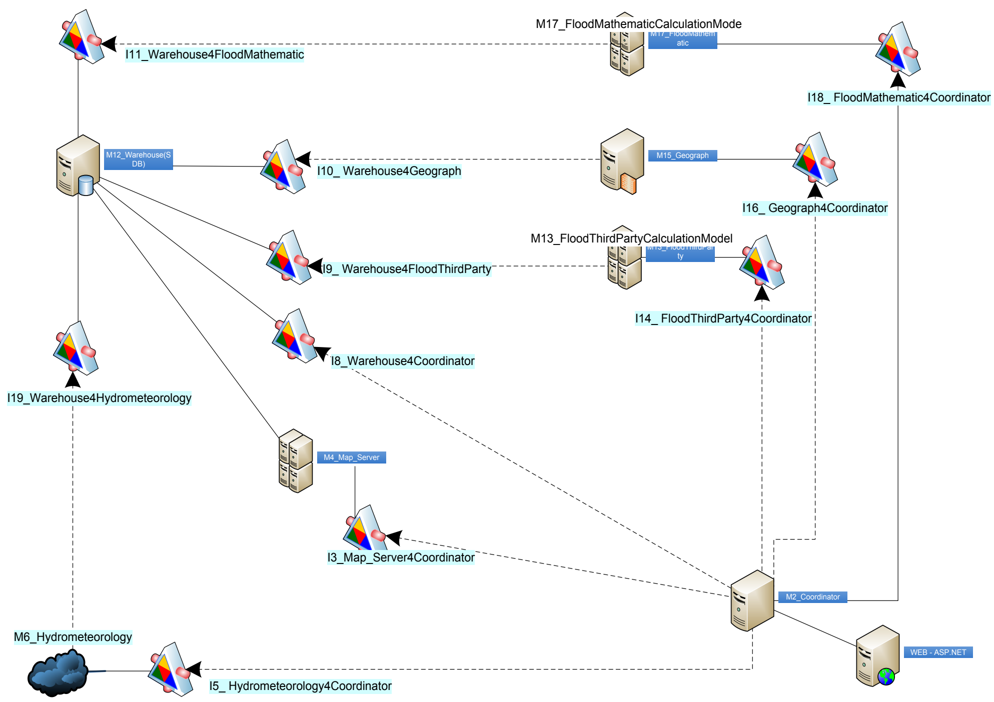

Fig. 4: System architecture

- 3D library for generation 3D maps as images
- RasterProvider for work with raster data and for storing terrain data
- Interface to FLOREON based on Web Services
- MATLAB libraries for model computation
- others

Modeled Regions

The western Carpathian catchment of the Olse/Olza river (2-03-03) was selected as the pilot area. The upper part of this catchment has a mountainous character and the lower parts have been significantly affected by human activity (e.g. coal mining). The Olse catchment has been damaged by significant flooding twice within the past two years. Both floods were identified as the flash flood type. The confluence of Olse, and its tributary Stonavka, is the pilot area for hydrodynamic modeling. Thalwegs, a cross-section and detailed LIDAR digital terrain model was accessible and was further developed and reconstructed for FLOREON modeling cascade requirements.

Team Participants

Our development team is composed of professionals from several fields and divided into various departments based on individual modules. The Web, visualization, coordination, data storage and metrological modules are made up of a group of employees and Ph.D. students from our "Department of Computer Science" [12]. The group also realizes the integration of applications in the hydrology module.

Data gathering and pre-processing in the geographical module is carried out by the "Institute of Geoinformatics" [13].

Employees of "The Institute of Geological Engineering" [14] are responsible for the hydrological model construction.

The mathematical models are developed by the "Department of Applied Mathematics" [15] in cooperation with University of West Bohemia in Pilsen [16].

Fig. 5: Flood demonstration

Future Work

The main goal of the informatics group of this project is the systematic development of the system's architecture. The continual enhancement of 2D and 3D visualization to provide optimal visualized information to the user, based on an open source and commercial technology, is another significant goal for this group.

Of further relevance is the issue of system coordination and communication with external subjects. The main concern is the usage of a standardized interface and security.

An information system is practically useless without current data. Therefore, the data for the simulations and predictions must be systematically and periodically updated. Some of this data is stored in a data warehouse – schematizations of river basins, terrains etc… Data source coordination, data selection and updating are long term tasks that must be carefully planned.

Ensemble simulations and predictions based mainly on the assumption of the input meteorological data uncertainty and fuzziness is another advance planned in our system. Information about the "optimistic" and more "catastrophic" variant of predictions for qualified users can be provided as a sequence of hydrographs or buffered zones with a statistical assessment. The offer of ensembles based on various methods of rainfall-runoff and hydrodynamic solutions implemented in various types of models is yet the another important point of view.

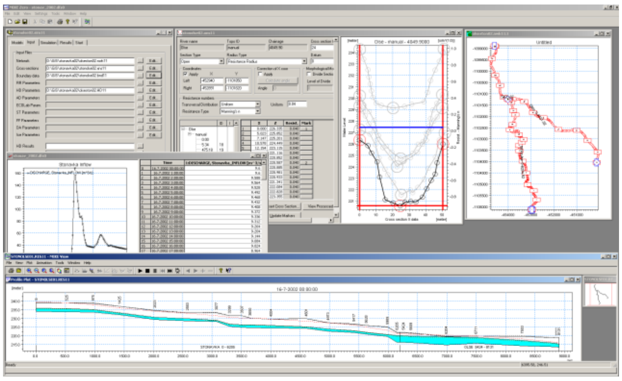

Fig. 6: Hydrodynamic model MIKE 11 GUI and the result of the model simulation (water levels in thalweg)

Conclusion

In our opinion, and based on the response of external subjects specializing in the field of flood prediction or the coordination of emergency units, this project is thoroughly useful. This system can be easily extended or connected to other systems and establish a portal for disaster control, management, and presentation. This project seems to be innovative in its unique connection and coordination of many results from many different disciplines.

The architecture of this system is completely open and general. Therefore, all future features can be easily added to this system without negatively affecting its present functionality. Even the implementation of the architecture itself can be rebuilt without significant malfunctions in the entire system.

ACKNOWLEDGEMENT

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