An Approach for Flood Prediction Visualization based on Atmospheric Transmission Measurements and Spatial Interpolation Methods

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***Abstract*—This paper presents a proposal for calculating and visualizing flood prediction on the basis of rainfall prediction within given area in surface. Rainfall prediction and visualization is performed in multiple subsequent steps. As a basic, this approach uses quantified ground-level precipitation from the measured attenuation of microwave signals of cellular networks. Quantified precipitation along signal lines is used as an input into GIS module which performs spatial interpolation of precipitation for the area intersected by microwave signals. Interpolated values are used to calculate the estimated total amount of rainfall. Further, in combination with DEM model for the selected area, estimated rainfall is used to perform a flood prediction and visualization within the same GIS module.**

I. Introduction

Flooding has proven to be one of the most destructive disasters in the world [1, 2, 3, 4, 5]. Floods can affect different regions, usually surrounding river basins. However, due to unpredictable climate change, flood risk is likely to increase so floods gain possibility of affecting large regions [6]. As stated in [6], "in a 28-year span from 1982-2011, there were about 3,000 floods worldwide that affected close to three billion people and caused approximately $70 billion in damage". More recent studies indicate that a part of world's population expected to be subject of flooding is likely to increase due to increased economic activities on river and coastal plains resulting from socioeconomic growth. Also, climate change directly increase flood because of increases in intense precipitation[13, 14]. Researchers worldwide have reported 0.8 billion people are exposed to a 1-in-100-years river flood disasters resulting in $50 trillion damage [14, 15], whereas coastal floods in the world's main port cities are endangering 40 million people and may cause $3 trillion damage [17]. In the past three decades, nations suffered $1 trillion direct economic losses and over 220 000 fatalities as a result of river floods [18].

As a response, research community is working on developing means for simulating flood risks using various data sources and models. The variety of strategies used to model flood risk is a consequence of fact that floods can be of many different types and scales. Thus, flood type directly influences differences in the architecture and implementation of flood prediction systems. Reference [19] distinguishes between five different types of landscapes with separate flooding behavior:

1. High mountain ranges - subject to flash floods and geophysical flows
2. Foothill areas - intense rainfalls and snowmelt, and inundation is widespread
3. Large floodplains -low velocities; floods caused by the landscape being unable to quickly pass all the incoming flows
4. Urban areas - inadequate sewer capacity and numerous barriers to flow
5. Coastal areas - flooding is typically caused by cyclones and storm surges

These different flood types require different architecture and implementation of flood prediction and visualization systems. Authors of this paper are focused on using rainfall data to simulate and visualize flood risks. Research presented in this paper as inspired with previous development in this domain. Previous research and development has proven accurate detection of rainfall is of great importance for the warning of possible flooding. In previous decades, different numerical methods for detection of precipitation using information about the received signal level (RSL) of commercial microwave links are developed. These approaches implement complex calculations that may require a lot of time, so the implementation of numerical methods can expose some limitations for real-time information systems. One of possible approaches would be to use artificial neural networks for precipitation detection based on the received signal level of microwave links. Such detection could significantly reduce the time required to process the data obtained at the link, which results in increasing the efficiency of the entire system. Thus, it becomes possible to acquire precipitation data estimation and combine it with digital elevation models (DEM) to perform food risk evaluation for a particular area of interest. Having DEM and raster images both combined within Geo-Information Systems (GIS), it is our opinion that appropriate GIS extension tool can be developed for performing and visualizing flood risk evaluations.

II. Related Work

Nowadays, we are witnessing many flood incidents worldwide every year. This led to the development of many flood estimation and alerting systems. In many cases, approaches used to simulate flooding and estimate flood risks are usually based on rainfall data. These mechanisms are not a novelty in research community but still occupy significant attention. In order to perform adequate and precise flooding estimation, information systems should be capable of using complex models, like one-dimensional Saint-Venant equation, in real-time. Also, expected output should be accompanied with spatial information [7][8]. Due to high complexity of used models, these proposals are hardly to be used in near real-time information systems. As a consequence, many alternatives with less complex computational models have been proposed [9][10][11]. This significant effort of research community aided development of global flood alerting and weather forecasting systems.

GloFAS is the global system that provides information regarding flood alerts. It uses global forecast and ERA-Interim precipitation dataset as inputs and HTESSEL and Lisflood for flood forecasting. HTESSEL computes the land surface response to atmospheric forcing, and estimates the surface water and energy fluxes and the temporal evolution of soil temperature, moisture content and snowpack conditions. Lisflood is a GIS-based spatially distributed hydrological model, which includes a one-dimensional channel routing model.

Meteoalarm is the most popular system for extreme weather forecasting and alerting in Europe. It offers rain and flood alert for the whole Europe. This system calculates four risk levels for countries and regions in European countries. Meteoalarm uses information from meteorological services from participating countries. Further, SCHAPI coordinates flood forecasting in France based on observation collected from 500 real time rain gauges, 24 meteorological radars and 1500 real time water level stations, soil properties and various types of hydrological models.

GIS have proven to be reliable platforms for the development of flood forecasting systems worldwide. Their usage can provide for a system that is easier to handle and maintain. There is a significant number of flood forecasting and warning solutions using GIS components for visualization and decision-making support. Also, GIS can be integrated with remote sensing techniques for early warning systems [20]. In [21], GIS is used for flood prediction in different regions in Malaysia. The results show that the combination of hydrological models and water balance model in GIS is very suitable to be used as a tool to obtain preliminary flood possibility information. Reference [22] reports usage of GIS with purpose of developing decision support system for flood prediction and monitoring. This solution integrates GIS and hydrological modelling with additional bridge sensors and users' observation. This solution predicts water levels for the next 24 to 48 hours and displays them via dynamic web pages. Water level prediction is overlaid with maps of the transportation network, property boundaries, municipal infrastructure and water depth contour lines. Authors of this solution claim they can provide good flood prediction precision and strong support to the public evacuation if flood events happen.GIS-Amur [23] is monitoring, forecasting, and early warning system. It uses observational data from weather and gaging stations, data from hydrological forecasts, and satellite data.Due to its web-based GIS component, this solution provides near-real time access to all available hydrometeorological data in the Amur River basin of Russia thus supporting timely decision-making for flood risk reduction. There are also examples of mobile GIS applications supporting flood warnings, such as the architecture described in [24].

III. Flood Prediction Visualization Process

In order to be able to estimate possible flooding, some sort of predicting or gaging of the rainfall is required. Usually, such value is received from ground level gauges that are measuring rainfall rate. Such input is then used to make proper estimations of the rainfall across the area that is assessed. But such approach requires gauging stations to be deployed along the area that is being monitored. The process is expensive and requires regular maintenance of such stations. Additionally, the stations need to be connected to the central system that is collecting measurements in order to provide accurate estimations of the possible flooding danger.

As a contrast to rainfall gauges whose sole purpose is measuring rainfall, there are various technical equipment that is deployed into the field. Incentives for deploying such equipment are other commercial reasons. The possibility of using side effects of such equipment to measure rain fall might provide cheap sources of ground level rainfall measurements. Namely, in order to acquire quantified spatial and temporal distributions of ground-level precipitation, the attenuation of microwave signals of cellular networks can be used. Microwave links can be observed as a type of sensor that can be used for the areas not covered by other types of meteorological sensors. The network based on this type of sensor can cover large areas with good spatial and temporal resolution. Such approach has already been developed and initial algorithms relating to the attenuation rate of cellular network signals to rainfall intensity along signal lines were previously provided as a result of the "Regional Precipitation Observation by Cellular Network Microwave Attenuation and Application to Water Resources Management" (PROCEMA) project [12].

The rainfall rate calculated in the described approach applies to the line of sight between two mobile cell stations whose signal attenuation is measured. Commercial cell stations can provide signal attenuation data in near real time which can provide rain detection and rainfall rate estimation. Compared to the network of rainfall rate gauges, this approach lacks covering strategic locations which are the most appropriate for measuring but provides increased coverage of the observed region. In addition, the main difference to the network of gauges is that gauges provide rainfall in distinct locations while the approach with signal attenuation measurements provides rainfall rates along the lines between pairs of stations.

Ground level rainfall rate data are obtained in North Western Bavaria in Germany. Digital Elevation Model data and GIS flood estimation modules were developed for Serbia. In order to make initial research proof of concept, locations of base stations from Germany were first translated to cover the area in Serbia, and the location of therefore, the cell stations were treated as imaginary stations deployed to translated locations. The research goal was to first estimate the possibility of using such data, once those are provided by the Serbian telecom operators. The overall rainfall prediction process is shown in Fig. 1.

In order to be able to make spatial interpolation of the ground level precipitation on the whole area that is being monitored, the first step was to sample distinct points along the lines. Because the lines are of different length, in case of sampling predefined constant number of dots on each line, shorter lines would be having higher influence on the spatial interpolation because of the higher points density. Therefore, we have used equal distance sampling such that a dot is sampled on each kilometer of the link length.

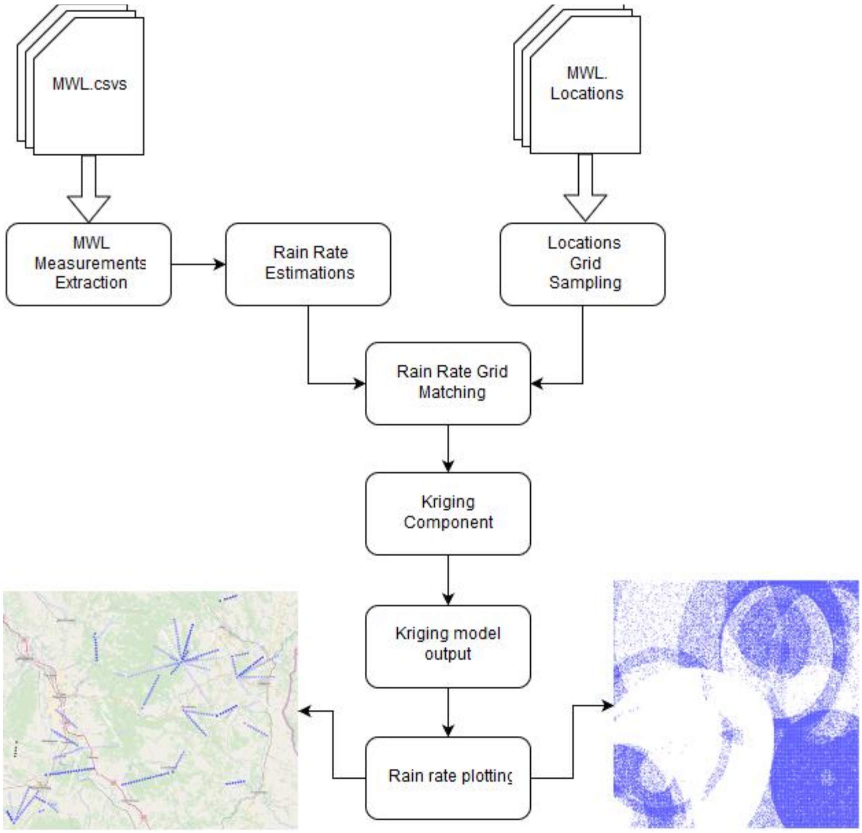

Figure 1. Rainfall prediction algorithm

Having obtained a scattered set of points with predicted precipitation values, they are feed into the Kriging module. Kriging module has been developed using the kriging.js library, a JavaScript library that is capable of calculating the spatially interpolated model from a distinct set of spatial locations with rainfall rate values. After the data has been fed into this module, it performs kriging, an advanced geostatistical procedure, to generate an estimated precipitation surface which covers the whole space under analysis. Once the kriging model is generated, it is possible to acquire a precipitation estimation value for each distinct location of the given area.

Once the kriging model is generated, it is possible to draw a proper heatmap that will show precipitation estimation. Along with the heatmap that can visualize the level of precipitation in certain area, it is also possible to calculate the volume of the rainfall for the given timeframe on the given area.

The core of flood prediction visualization process is the usage of estimated spatial distributions of ground-level precipitation within GIS-based technical platform for flood analysis and risk management. Technical platform is based on a custom developed GIS application capable of providing support for diverse data types, data conversion, visualization and analysis. The data obtained as the Kriging output is used to calculate the overall rainfall amount. This value is used as the input needed for flood analysis to be possible. GIS application integrates DEM model of the observed area and uses it to determine the point with lowest elevation in observed area.

Figure 2. Example of flood prediction output

All rainfall is expected to interflow towards the point with lowest altitude so this point is used as a starting point for flood fill algorithm implemented within GIS application. GIS application simulates flooding in iterations by increasing the reached water level at the point with lowest elevation while population the rest of the area according to flood fill algorithm. After each iteration, the amount of water used for filling the area is checked against the total amount of rainfall estimated by kriging algorithm. Once the total amount of rainfall is reached, the simulation ends and GIS application visualizes the area expected to be flooded. An example of area expected to be flooded is shown in Fig. 2.

IV. Conclusion and Future Work

This paper presents a first research and development step towards developing an integrated GIS solution capable of calculating and visualizing flood prediction. Our proposal is based on the usage of rainfall prediction which is performed in multiple subsequent steps. The approach presented in this paper can obtain quantified ground-level precipitation which is the result of measured attenuation of microwave signals of cellular networks. This data is supplied to GIS solution which uses it for precipitation prediction through spatial interpolation methods. Area covered by prediction is the area intersected by microwave signals. The sum of predicted precipitation represents estimated total amount of rainfall which is used for flood fill algorithm starting at the point with lowest elevation of the observed area. Presented solution will be upgraded by modeling the impact of soil structure upon predicted total amount of rainfall. Further, we plan to investigate appropriateness of the methodology in cases of river basins intersecting the area of interest and compare interpolated values to actual measurements in areas covered with real time rain gauges.

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