Fuzzy Flash Flood Forecasting and Telemetric System for the Daguitan Watershed

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Abstract. This paper presents a fuzzy logic-driven forecasting agent along with a telemetric service for the Daguitan River, the main natural drainage of the Daguitan Watershed, situated in the central eastern part of the Philippines. Its sensing nodes are custom-tailored to continuously measure water level, average rate of river water level rise/fall over time, ambient temperature and relative humidity in selected points. Collected in 24x7 fashion, these metrics are utilized as linguistic variables in layered fuzzy forecasting and are submitted via SMS to the Telemetric Service Center for further data analyses and database storage. Upon sensing of any potential alarming river condition, the same center will auto-notify local civil authorities as well as broadcast media via SMS for immediate announcement of an imminent flash flood.

Keywords: Flash flood, telemetric, watershed, fuzzy logic, forecasting

1 Introduction

One of the identified critical and flood-prone watershed areas in the central eastern region of the Philippines, is the Daguitan Watershed. It covers a land area of about 294 square kilometers which is as well the home for about 80,000 people in eighty three (83) villages. The major waterway of the watershed, the Daguitan River, runs about 34 kilometers downstream to its mouth connecting an adjacent gulf [1].

Be that as it may, rain storms cannot be prevented, however, with the right tools at the right time, flash floods can be sensed and foretold, thereby allowing authorities to manage and implement risk reduction mechanisms and eventually minimize if not eliminate fatalities. It is therefore in this problem space that motivated the researchers to initiate the conceptualization and development of a telemetric system as well as the formulation of a layered flash flood forecasting algorithm tailored-fit for the conditions of the watershed basin.

2 Related Works

Different works of this sort have been made. The Indian real-time flood forecasting case uses statistical and deterministic approaches [2], while the Ayalon, Israel flash flood forecasting model performs auto-regression of forecast errors, minimizing them, and yielding corrections [3], and the Czech Republic flash flood forecasting situation presents precipitation estimate and nowcasting approach [4].

3 Flash Flood Forecasting and Watershed Telemetry

Daguitan watershed basin is situated between N10°45'04” and N11°01'07” latitude as well as E 124°44'45” and E 125°02'26” longitude. Characterized by rugged and mountainous terrain, the basin has its highest elevation of 1,125 meters above sea level and lowest at 10 meters near the mouth of the river. The basin's steep slope is about 8 km from the topmost part of the river, which is technically susceptible to erosion and landslide [1].

The locality has two distinct climatic regions based on the Modified Corona Climate Classification. Daguitan watershed area falls under Type II climate with average monthly temperature of 27°C and relative humidity of 71% in May as well as 25°C and 85% in January. Atmospheric temperature swings between 21°C to 34°C. It exhibits no dry season with very pronounced maximum rainfall, usually occurring from November to January [5].

3.1 Telemetric Engineering

The architectural organization of the system comprises of data collecting agents installed at the flood water path. Collected facts are cyclically delivered and relayed in a fixed time interval of 15 minutes to the telemetric service center via SMS in almost real-time for analyses and repository.

The command post of the entire distributed system is the Telemetric Service Center, which fetches data in the form *n-mmddyyyy-hhmm-nnnn-nnnn-nnnn-nnnn-n*. This eight-field datum is fragmented into; NodeID, 1 byte; Date, 8 bytes; Time, 4 bytes; WaterLevel, 4 bytes; RateOfWaterRise, 4 bytes, AmbientTemperature, 4 bytes; AmbientRelativeHumidity, 4 bytes; and AccelerometerStatus, 1 byte; and eventually stored into its dedicated database as a transactional record.

3.2 Fuzzy Forecasting Framework and Algorithm

Fuzzy logic as the prime mover of the flash flood forecasting operation in this study, courtesy of Lotfi Zadeh (1965), is a mechanism that direct the ability of the system to make assessment primarily of flood water level and rate of water level rise/fall in arriving at a reliable conclusion. Shown in Figure 1(a) is the general picture of the forecasting framework adopted in this study.

The general framework of this system uses a layered fuzzy networks intended to satisfy interdependence of two major metrics in the forecasting process as shown in Figure 1(b); namely, the level of flooding and category of downpour. The *degree of membership, μ*, measures the level of belongingness of each set in the fuzzification given an input value. With such an input value on the x-axis, the μ for a particular variable and specific pair of fuzzy sets can be easily calculated using triangular similarities as illustrated in the algorithm shown in Figure 2. By employing

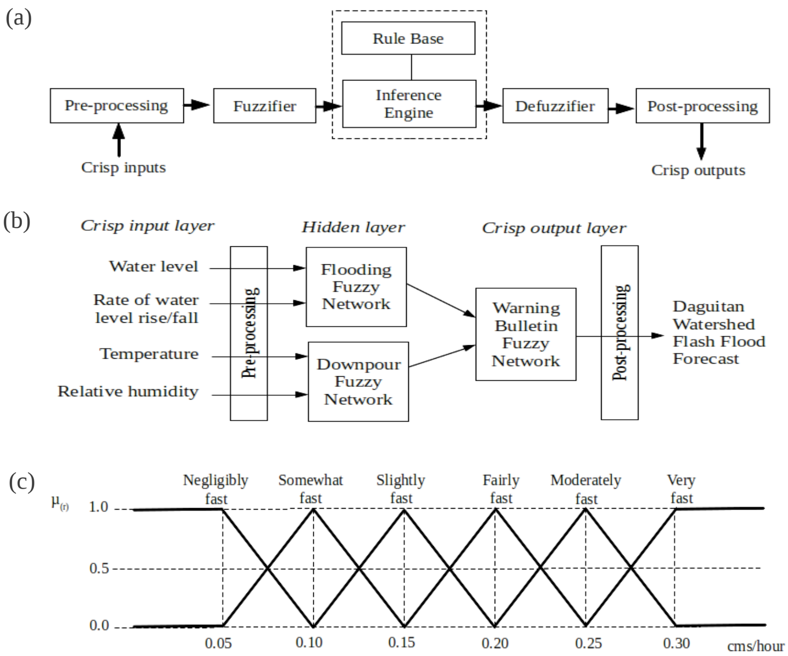

Figure 1. Fuzzy forecasting processing overview. (a) General perspective of fuzzy inferencing system; (b) Proposed layered fuzzy network; and (c) membership function for rate of water level rise/fall over time

parameters such as *vertex references a* (upper diagonal) and *b* (lower diagonal), *i* (crisp input value), the value for $\mu_{(i)}$ can be anywhere between 0 and 1.0, inclusive.

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INPUT: vertex references of the diagonals, crisp input
value
OUTPUT: degree of membership
Function degreeOfMembership(a, b, i, diagonal)
Loop across membership function
       if i is peak then return 1.0
       else
              if diagonal is upper then return (i-a)/(b-a)
              else return (b-i)/(b-a)
```

Figure 2. Algorithm for the calculation of degree of membership

As a result, the numeric values of the consequence taken from the numeric designations of each element in the fuzzy rules table itself, are then aggregated into a new set of values. One of the popular procedures employed for this operation is the Mamdani (1977) inferencing or implication method [6], which the researchers had used in this paper. Mamdani's rule of conclusion is a fuzzy set, which states that

IF $input_1$ is A_1 AND $input_2$ is A_2 THEN $output_1$ is C_3
where A_x and C_x are fuzzy sets defining the input space and the output space partitioning, respectively.

Table 1 shows the partial rows of consequent vis-a-vis the rules that fire (bold) during the inferencing operation with their corresponding results. Take note that rules that fail to fire (normal) are designated with zero values.

Table 1. Implication form based on Mamdani method

Rule	Antecedent		Consequent by Mamdani implication		
	a	b	Output fuzzy set	Value	$Value^2$ (RSS)
1	If level is negligibly rising AND rate is negligibly fast		Negligibly deep	0	0
2	**If level is slightly rising AND rate is negligibly fast**		**Negligibly deep**	**min(a, b)**	**$\min(a, b)^2$**
3	If level is moderately rising AND rate is negligibly fast		Slightly deep	0	0
. . .					
29	**If level is quickly rising AND rate is very fast**		**Extremely deep**	**min(a, b)**	**$\min(a, b)^2$**
30	If level is extremely rising AND rate is very fast		Extremely deep	0	0

Having successfully generated the consequent values during the inferencing operation, the next step done was to calculate the root-sum-square (RSS) of those triggered consequents and have them aggregated into the output fuzzy set array. Said output shown in Table 2, has to be translated back to crisp values known as defuzzification.

Table 2. Implication result for the Flooding output variable

Output fuzzy sets	RSS
Negligibly deep	$\min(a, b)^2$
Slightly deep	0
Fairly deep	0
Very deep	0
Extremely deep	$\min(a, b)^2$

The popular method for executing defuzzification process proven for its accuracy known as the center of gravity (COG), is hereby employed in the operation [7]. This method, which is also known as centroid calculation as graphically depicted in Figure 3, returns the x-axis location of the center of area under the curve of interest. Its result is a crisp value governed by this mathematical relationship:

$$\text{Center of gravity} = \frac{\sum_i \mu(\min(a, b))\ \min(a, b)}{\sum_i \mu(\min(a, b))}$$

where:

$\mu(\min(a, b))$ – strength of the fuzzy set which is the membership value in the membership function

$\min(a, b)$ – is the point on the x-axis where the membership value falls

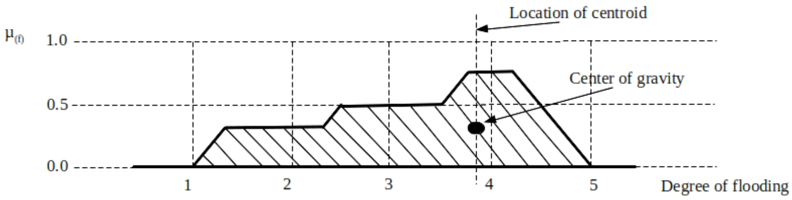

Figure 3. An instance of the outcome of aggregation in Flooding output linguistic variable

4 Experimental Evaluation and Simulation

In evaluating the effectiveness level of the proposed layered fuzzy forecasting algorithm, a web browser-based application was developed. Because browsers are platform-independent, a wide array of environments can therefore host said simulation application. The crisp input data for water level above normal, rate of water level rise/fall, ambient temperature as well as the relative humidity are rather manually entered by the user on an interface as shown in Figure 4, rather than values to be taken direct from sensors. The sections of the user interface include, among other features, the periodic Daguitan River condition and the corresponding SMS advisory.

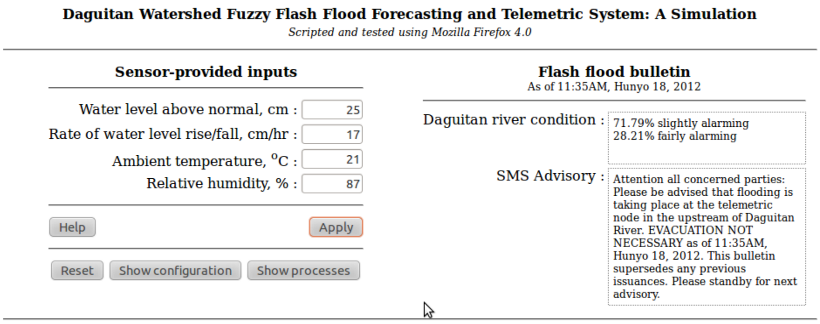

Figure 4. Screen shot of the Fuzzy Forecasting System Simulator

4.1 Simulation Results

With the proper crisp values entered, the simulation application gives two essential crisp outputs in almost real time. Based on several simulation tests conducted, the results stayed flawlessly consistent as they are literally dependent on the facts stipulated in the fuzzy rules table. When these fuzzy rules are presumed to be realistic as provided by an expert (dam engineer in this case), then the outputs are likewise correspondingly reliable.

In a multiple simulation run, the operational facts shown in Table 3 are considered with the corresponding outcomes, as illustrated.

Table 3. Simulation results

Run	Crisp inputs				Crisp outputs	
	Water level above normal (cm)	Rate of water level rise/fall (cm/hr)	Ambient temperature (ºC)	Relative humidity (%)	River condition	SMS advisory
1	5	1	27	80	100% NA*	None
2	25	17	21	87	72% SA* 28% FA*	Evacuation not needed
3	32	29	21	83	95% VA* 5% FA*	Evacuation Alarm level 1

* NA-Not alarming; SA-Slightly alarming; FA-Fairly alarming; VA-Very alarming

5 Conclusion and Recommendations

The researchers proposed a layered fuzzy flash flood forecasting system and an associated watershed telemetric system. They have proven and concluded that the parallel approach of setting two fuzzy networks providing inputs to an outer layer of another is an efficient and cost-effective strategy of arriving at a reliable flash flood forecast if only to save hundreds if not thousands of lives during disasters.

As natural peculiarities are imminent from one watershed basin to another, it is hereby recommended that future studies of this sort be somehow focused more on a generically scalable and context-adaptive solutions.

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