Smart Sump-Pump Using Fuzzy Logic Controller

Adnan Shaout and Husein Dakroub

The University of Michigan-Dearborn
The ECE Department
Dearborn, MI 48128
shaout@umich.edu

Abstract—In the USA home can be the greatest asset a citizen might own. Homes can be very costly to maintain and damages can become a hefty payment on homeowners. The Midwest region of the United States can have excessive rainfalls that can exceed one inch per hour for many hours at a time. Public drainage system is outdated in many parts of the Midwest region which can lead to horrific flooding of home basements. To prevent water from seeping into basements, a sump pump was invented in 1946 to pump water out of your basement. These pumps can be very costly, consume a great amount of energy, and work very inefficiently. This paper presents a fuzzy controller modeled in Matlab that would enhance the efficiency and structure of a sump pump system. This paper will depict different defuzzification methods and showcase the efficiency of this fuzzy system compared to a non-fuzzy systems.

Keywords*:* Flood, Sump Pump, Fuzzy LogicController, Efficiency, MatLab

1. INTRODUCTION

The National Flood Insurance Program also known as FEMA, which is owned and operated by the USA government, stated that floods are the #1 natural disaster in the United States and the average flood claimed amount by insurance companies is nearly $42,000 [1]. From 2005 to 2014, the total flood insurance claims have averaged more than $3.5 billion per year. Table 1 shows the 2014 claim report for the top 10 states in the USA.

Table 1- 2014 Flood Claims - FEMA [1]

State	2014 Claims	Total 2014 Claim payments
Florida	2655	$117,861,100
Alabama	1121	$5,266,8831
NewYork	974	$14,942,952
Texas	741	$13,808,268
Pennsylvania	547	$15,751,428
Louisiana	515	$15,697,280
Michigan	495	$8,816,751
Iowa	487	$9,406,938
Ohio	438	$12,385,821
Illinois	230	$7,428,119

Based on the statistics shown in table 1the amount of floods and claims in these regions has lead to the mandatory installment of sump pumps by insurance companies in flood zone areas.

What is a sump pump?It is a pump used to remove water that has accumulated in a water-collecting basin [2]. Sump pumps are used to solve dampness and water collecting above the foundation of the home. Sump pumps, discharge water away from the house so it's no longer a problem. The sump pumpis usually connected to the house electrical system and consists of a battery backup. It can also be connected to the home's water system and operates without the need of electricity. A backup system is sometimes used because there's a possibility of an overflow within the sump pump basin.

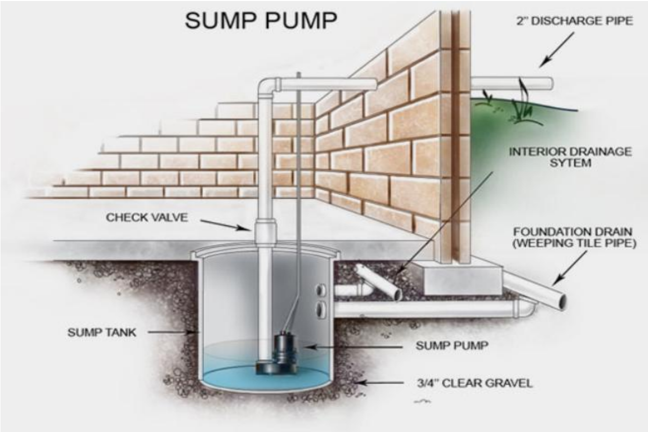

Figure 1- Sump Pump Architecture [3].

Current sump pump architecture shown in figure 1consists of a check valve, pump, sump tank, mechanical float, impeller, interior drainage system and discharge pipe. Innormal operation the sump tank would get filledwith water and when the mechanical float starts to float higher it opens the drainage system and the water begins to discharge out of the basin tank by the pump [3].

The history of sump pumps began when a U.S Navy electrician decided to use large sump pumps to raise ships out of the water in the middle of the ocean. In 1946, the battery powered backup sump pump was born. Homeowners were able to pump their basements with slow rate and minimal battery capacity [13]. In 1979, Circuit boards were implemented and pumping/battery capacities were improved. Current state of the art is similar to the past but with an improved mechanical structure of the system and an improved back up battery performance. With backup batteries being the focal point per each innovation, the future of the art would consist of a fuzzy controller that will efficiently enhance the battery life and performance of the system.

During excessive rain and water levels the sump pump is the best system to insurethat a home basement does not flood, but it is not all guaranteed. According to the news service [4] the following are some of the problems the sump pump system may face:

- Power failure
- Sump pump motor size inefficiency
- Improper installation
- Switch problems
- Lack of maintenance
- Clogged discharge lines

Electrical failures are the most common cause for sump pump failures. Backup battery system is used to prevent this issue. A backup battery generally has a short life due to the inefficiency of the current sump pump system.

The size of the motor sump pump can be inefficient, for example, if a small water basin is used then there is no need for the motor to run at full speed. It makes the sump pump work harder than it needs and resulting in shorter lifespan for the backup battery.

Improper installation of the mechanical float can lead to the system clogging up and water levels raising into the basement. Since the mechanical float is fully dependent on water opening the discharge pump, if the float is stuck and doesn't rise up then this will lead to a flood.

The issue of switch problems can cause the sump pump to run indefinitely or never run, leading to inefficiency.

Lastly, a lacked of maintenance and clocked discharge lines can lead the system to fail mechanically through not seeing the need to run the sump pump's motor.[4]

The system presented in this paper will give homeowners the ability to be worry free, by guaranteeing a working sump pump that is efficient and can handle any disaster. The "smart" sump pump will be able to adapt autonomously, using a fuzzy controller, to the precipitation and flooding conditions, by being able to know the current and future conditions of the sump pump system. The advantage of the proposed smart system compared to current state of art is the ability of the proposed system to know the conditions of the rain and water levels by adding sensors. The current state of the art uses a mechanical float method that will dictate if a basement has already flooded or not. Using these sensors, the new smart system will have the ability to command the working conditions of the sump pump at various scenarios efficiently.

The paper is organized as follows: section 2will present the architecture of the proposed smart sump pump design.Afuzzy controller will be created using Matlab; input/output, fuzzification, rule base, computation, and defuzzification; section3 will present the results and a comparison of the results to current non-fuzzy state of the art will also be presented; section 4 will present the conclusions.

2. DESIGN

The new smart system that will be presented in this paper adds two sensors, one for precipitation level and the other is for water level. The addition of these two sensors gives the sump pump the ability to command the current state of the system at all times. It will also give the system the ability to use a fuzzy logic controller to dictate the speed of the pump in RPM to work more efficiently. Figure 2 shows the new architecture of a smart sump pump.

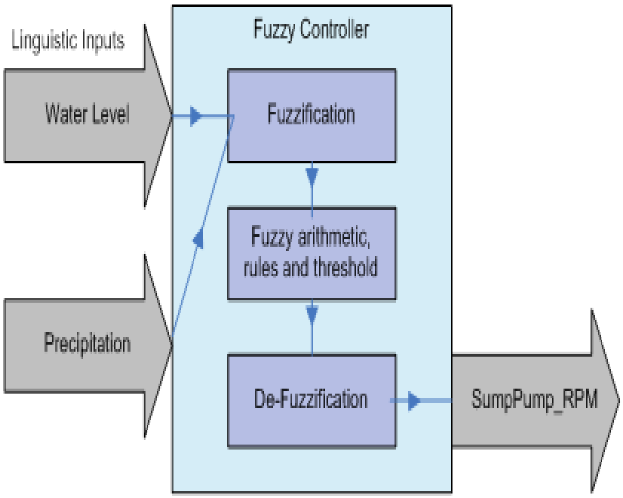

Figure 2- Smart Sump Pump Architecture.

A fuzzy system builds on a user specified rules which are based on linguistic values. The fuzzy system converts these linguistic values into their mathematical equivalents using computational and defuzzification methods [5]. In the sectionsthe elements that construct a fuzzy logic controller is presented using Matlab. The elements consists of input/output variables, fuzzification methods, rule base system, and computation and defuzzification methods.

2.1 *Inputs/Outputs*

To have the system well connected to the surroundings, the inputs added to thesmart sump pump system are the precipitation level sensor and water level sensor inputs. The output to this fuzzy controller is the speed of the motor.

Each of the two inputs has three linguistic values and the output has seven, so in theory the maximum number of rules/combinations can be is nine. In this specific fuzzy controller architecture, nine rules are constructed. The variables are mapped to a set of membership functions also knows as fuzzy sets [6].

2.2 Fuzzification

In the fuzzification part of the system it maps a crisp input universe of discourse into the interval [0, 1] that describes the membership of the fuzzy input variable [7]. Figures 3, 4 and 5shows the linguistic fuzzy membership functions for the precipitation level (with three linguistic valuesin inches), water level (with three linguistic values in feet) and the motor speed output (with seven linguistic values in RPM), respectively.

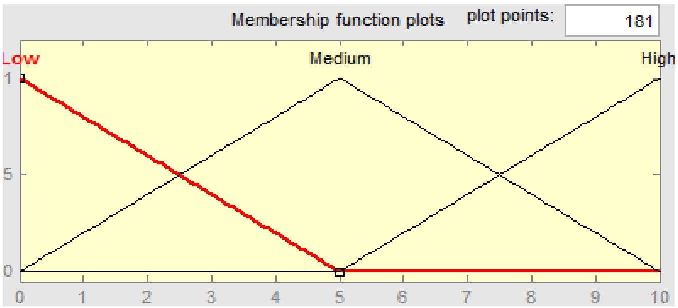

Figure 3- Precipitation Level Membership Function

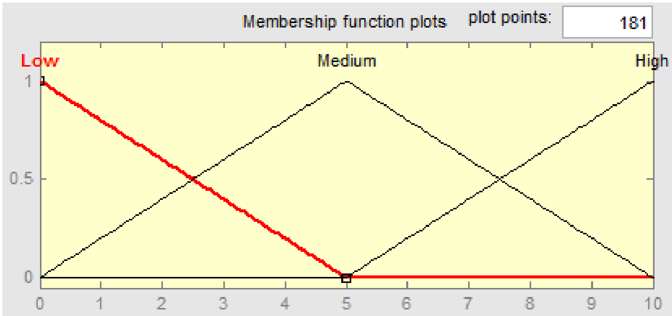

Figure 4- Water level Membership Function

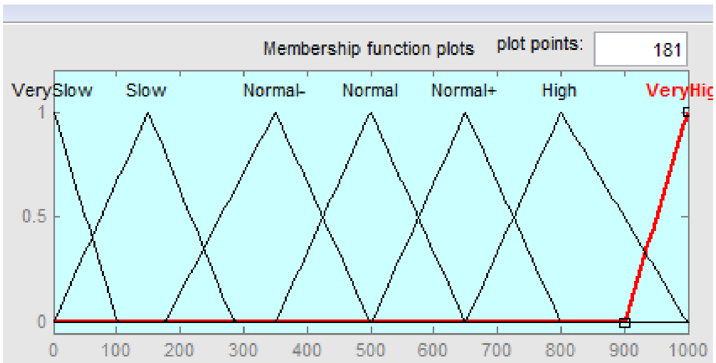

Figure 5- Motor Speed Output Membership Function

2.3 Rule Base

The fuzzy rules are linguistic IF-THEN functions that are used to map the membership functions into a controlling output variable that is mapped to the specified fuzzy input [8]. The fuzzy rules are derived using expertise and experience with the sump pump systems. Each rule is made with two inputs and one output. The two inputs are given a combined respective output, the specified linguistic output will later be presented as a crisp value using defuzzification techniques.

The nine rules for this system are as follow:

1. If precipitation is HIGH and water level is HIGH then sump pump speed is VERY HIGH

2. If precipitation is MEDIUM and water level is HIGH then sump pump speed is VERY HIGH
3. If precipitation is LOW and water level is HIGH then sump pump speed is HIGH
4. If precipitation is HIGH and water level is MEDIUM then sump pump speed is NORMAL+
5. If precipitation is MEDIUM and water level is MEDIUM then sump pump speed is NORMAL
6. If precipitation is LOW and water level is MEDIUM then sump pump speed is NORMAL-
7. If precipitation is HIGH and water level is LOW then sump pump speed is SLOW
8. If precipitation is MEDIUM and water level is LOW then sump pump speed is VERY SLOW
9. If precipitation is LOW and water level is LOW then sump pump speed is VERY SLOW

2.4 Computation/Fuzzy Output Method

The Mamdani model and MAX-MIN composition was used for this paper. Mamdani's fuzzy inference method was among the first and most commonly used fuzzy methodology [11]. Mamdani is a non-additive modelmethod given by:

Minimum of inputs:

$$\alpha_{ij} = \sup(\mu_{A'j}(x_j) \wedge \mu_{Aij}(x_j))$$

Maximum of outputs:

$$\mu_{C_i}(y) = \max\left\{\mu_{C_1'}(y), \mu_{C_2'}(y), \ldots\ldots, \mu_{C_L'}(y)\right\}$$

Where uA(Xj) are the inputs and uC(y) are the outputs.

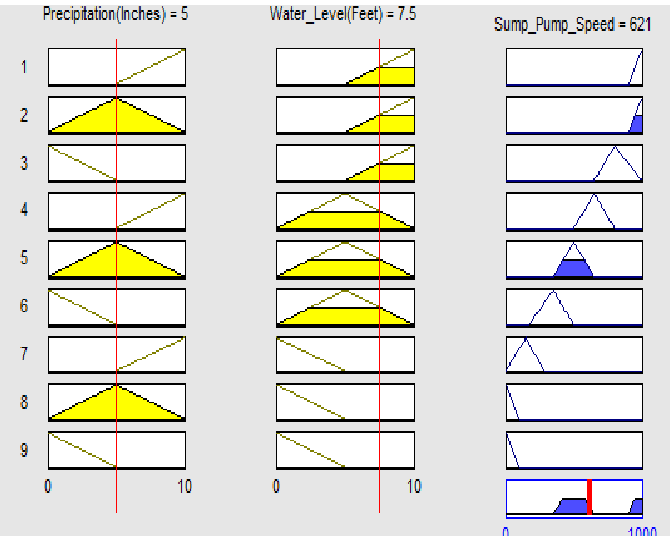

Figure 6-Computation for 2 Inputs using Max-Min

Figure 6shows the simulation of the proposed system when the precipitation is at 5 inches and water level is at 7.5 feet. The system takes the minimum of both inputs and then takes the Maximum of all outputs to give thefinal fuzzy output. Section 2.5 will presenthow the fuzzy output is given a crisp output using defuzzification methods.

2.5 Defuzzification Method

After a fuzzy output has been made from the respective computation method the system then outputs a single crisp value that shows the meaning of the fuzzy output. In thissection a comparison is made among multiple defuzzification methods to show the difference and to see which defuzzification techniques is best foroursmart sump pump system.

2.5.1 Centroid method

Centroid defuzzification returns the center of area under the curve. The centroid is the point along the x-axis about which this shape would balance [9]. This procedure is the most prevalent and physically appealing of all the defuzzification methods; it is given by the algebraic expression:

$$z^* = \frac{\int \mu_C(z) \cdot z dz}{\int \mu_C(z) dz}$$

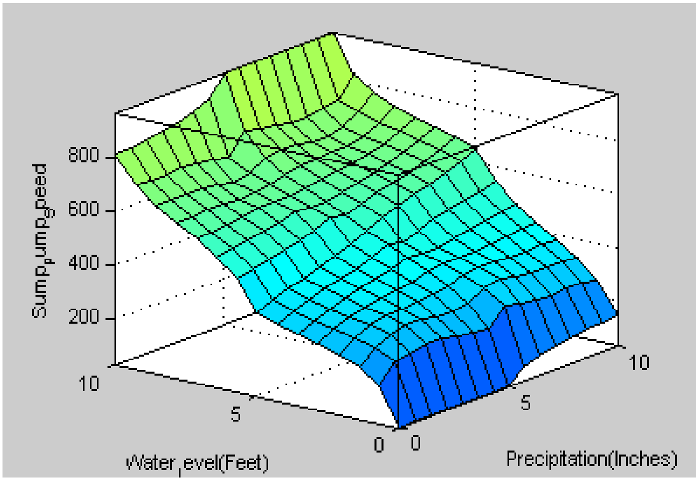

Figure 7-Centroid Surface

In Figure 7, a surface of the centroid defuzzification method is displayed. As water levels rise, the RPM of the sump pump system runs faster. Using this defuzzification method the motor is operating at input levels that are still not at critical stages with respect to flooding levels. To better enhance the efficiency of the system a test of other defuzzification methods is made.

2.5.2 Mean of Maximum (MOM)

Calculated the average of those output values that have the highest possibility degrees [10].

$$\frac{\sum_{y\in P} y^{*}}{|P|}$$

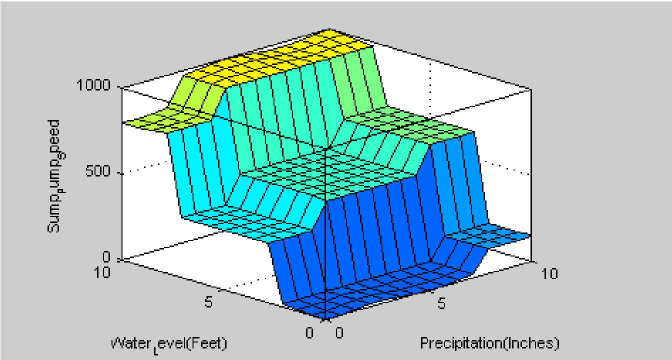

Figure 8 - Mean of Maximum (MOM) Surface

Figure 8 shows the MOM surface where the MOM defuzzification method is seen to be more efficient for a sump pump system because the RPM stays at 0 at low water levels and low precipitation levels. Flooding cannothappen at such low inputs and it is good for the system to stay in sleep mode during those conditions.

2.5.3 Smallest of Maximum (SOM)

SOM uses the minimum value of the aggregated membership function outputs [10].

$$z_0 \in \left\{ x \,\middle|\, \mu(x) = \min_{\omega} \mu(\omega) \right\}$$

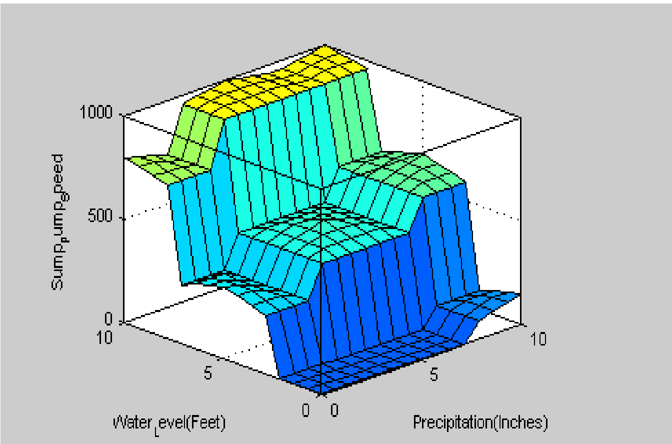

Figure 9 - Smallest of Maximum (SOM) Surface

This method is very similar to the MOM method but it gives more variances of RPM during stable portions as seen in figure 9. The system can be very inefficient if it keeps changing speed at parts when it needs to be consistent.

In conclusion, for the final defuzzification method, MOM was chosen because it helps the system achieve greater efficiency and it is stable at regions where the speed should be consistent.

3. Results (Fuzzy Vs. Non-Fuzzy)

Table 2 presents a depiction of the results and a comparisonof fuzzy and non-fuzzy system. In the first two columns a sample of precipitation and water level valuesare given then a comparison of fuzzy and non-fuzzy outputs is made. Finally a calculation of the efficiency of the fuzzy system compared to the non-fuzzy is also shown.

Table 2 - Fuzzy vs. Non-Fuzzy System

Precipitation Level (In)	Water Level (Ft.)	Fuzzy-Crisp Value (RPM)	Non-Fuzzy Value (RPM)	Fuzzy Efficiency
1 in	1 Ft	10	1000	99%
5 in	1 Ft	10	1000	99%
10 in	1 Ft	145	1000	85%
1 in	5 Ft.	350	1000	65%
5 in	5 Ft.	500	1000	50%
10 in	5 Ft.	650	1000	35%
1 in	10 Ft.	805	1000	20%
5 in	10 Ft.	1000	1000	0%
10 in	10 Ft.	1000	1000	0%

In table 2, itpresents the efficiency of the fuzzy system and the possibility of being 99% more efficient than a non-fuzzy system [12]. When water levels are low the non-fuzzy system operates at full speed, compared to the fuzzy system that runs at slower speeds when water levels are low, which helps save energy and extending system's life.

4. Conclusion

The considerable amount of floods in North American regions has turned sump pumps into a household item. This paper presented the enhancement of traditional sump pumps by implementing a fuzzy logic controller modeled in Matlab and the addition of two sensors. The fuzzy logic controller applied in the smart sump pump was constructed using Mamdani's computation model and mean of maximum (MOM) for the preferred defuzzification method because of its consistent output in specified parameters. The results showed a greater efficiency compared to current state of the art sump pumps. Fuzzy has once again proven to be a solution to inefficient problems.

REFERENCES

[1] Floodsmart US Government Data https://www.floodsmart.gov/floodsmart/pages/media_resources/stats.jsp as of July 31, 2015.

[2] Sump Pump https://en.wikipedia.org/wiki/Sump_pump as of July31, 2015.

[3] Sani-Tredhttp://sanitred.com/category/blog/basement-waterproofing/sump-pumps/as of July 31, 2015.

[4] Renew Service Group http://renewservices.com/7-causes-of-sump-pump-failure-what-to-do/ as of July 31, 2015

[5] Fuzzy Logic and Its Uses http://www.doc.ic.ac.uk/~nd/surprise_96/journal/vol2/jp6/article2.html as of July 31, 2015.

[6] Fuzzy Control System https://en.wikipedia.org/wiki/Fuzzy_control_system#Fuzzy_sets as of July 31, 2015.

[7] IGI Global http://www.igiglobal.com/dictionary/fuzzification/11696 as of July 31, 2015.

[8] Fuzzy Control System https://en.wikipedia.org/wiki/Fuzzy_control_systemas of July 31, 2015

[9] Defuzzification Methods http://www.mathworks.com/help/fuzzy/examples/defuzzification-methods.html as of July 31, 2015.

[10] Basic Principles of Fuzzy Logic http://access.feld.cvut.cz/view.php?cisloclanku=2012080002 as of July 31, 2015.

[11] Mamdani Fuzzy Models http://www.bindichen.co.uk/post/AI/mamdani-fuzzy-model.html as of July 31, 2015.

[12] Methods For Calculating Efficiencyhttp://www.epa.gov/chp/basic/methods.html as of July 31, 2015.

[13] Trusty Warns http://www.trustywarns.com/history.htm as of July 31, 2015.