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WSN and Fuzzy Logic for Flash Flood and Traffic Congestion Detection

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Abstract

Floods are the most common natural disaster and source of significant damage to life, agriculture and economy. Flash Floods are particularly deadly because of short timescales on which they occur. Most flood casualties are caused by a lack of information. There is no dedicated flood sensing systems that monitor propagation of flash floods in cities. .Human being do not have power to totally uproot natural calamity but they can predict natural calamity & take major steps to prevent it. Wireless Sensor Network (WSN) and Internet of Things (IoT) technology is used for predicting & detecting flooding condition in this study. WSN is preferred due to its cost effectiveness, faster transfer of data & accurate computation of required parameter for flood prediction. IoT combines embedded system hardware techniques along with data science or machine learning models. The model uses a mesh network connection over ZigBee for the WSN to collect data, and a GPRS module to send data to the internet. Data sets are evaluated using fuzzy logic to detect floods then broadcast alerts. Floods rarely occur hence the system is dedicated for traffic congestion notifications.

Keywords: Flash flood; Wireless Sensor Network; Internet of Things; fuzzy logic.

1. Introduction

Every year, floods lead to significant damage to agriculture, economy and infrastructure. Changes in environment and geographic conditions are agents of disaster including floods in urban cities. Heavy rainfall and poorly developed drainage systems lead to rapid increase in water levels.

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In 2011, a huge tsunami hits Japan causing sea water flood part of the coastline. That flooding caused massive leakage in nuclear plants which lead to high radiation in that area. Authorities in Japan fear that Fukushima radiation levels were 18 times higher [27].

In 2014, a landslide occurred in the village of Malin in Ambegaon taluka of Pune district in Maharashtra, India. The landslide, which hit early in the morning while residents were asleep, was believed to have been caused by a burst of heavy rainfall, and killed more than 160 people [28].

Current technologies can accurately track rainfall or storm paths. However, numerous other factors that are essential for detection such as flow rate and water level can be collected by sensors. Internet of Things (IoT) paradigm allows merging a wireless sensor network and a communication framework to rapidly transmit data to specific control centers. These centers, in turn, can analyze the data and deliver appropriate mitigations against floods.

Internet of Things (IoT) is expected to usher a new era of increased connectivity, with an estimated 50 billion devices to be connected to the Internet by 2020 [1]. The aim of IoT is to connect previously unconnected devices to the Internet [2], thus creating smart devices capable of collecting, storing and sharing data, without human interaction [3].

Rapid growth of IoT and technological development of sensors, Wireless Sensor Networks (WSNs) have become a key technology for IoT [4]. These networks consist of self-organized sensor nodes, communicating through a wireless medium and are used to perform distributed sensing tasks. The low cost nature and easy implementation has seen them deployed in a wide range of fields such as climate change detection, environment monitoring, and numerous healthcare applications [5].

Several flood prediction schemes have been proposed. Traditional flood forecasting methods have been based on physical parameters, as used in hydrological models and tend to be deterministic. Other approaches involve statistical models, such as the Markov method [3]. Machine learning approaches are also possible for flood forecasting including support vector machines, artificial neural networks, fuzzy logic etc.

Monitoring floods in real time requires sensing the flooding conditions [6]. Fixed water level sensors are only adapted to river monitoring, and instrumenting entire hydrological basins, that cover hundreds of square kilometers, this is economically infeasible. Satellites are similarly unable to monitor water levels and flows remotely: optical measurements are impossible during floods, and the vertical resolution of current synthetic aperture radars is insufficient for the task.In this work, we propose an IoT approach based on a mesh-connected WSN, and a detection algorithm based on fuzzy logic technique. The sensors (ultrasonic) check water level and are also able to check traffic congestion on roads. Section 2 discusses related work. Section 3 methodology. Section 4 results and Section 5 conclusion.

2. Related work

Existing work [7 , 8, 9, 10] relies on either contact based sensors, or non-contact camera-based sensors which are unable to provide a direct water level measurements (such sensors can only report presence of water or not). In [11], the authors used ultrasonic rangefinders to monitor floods, but did not consider environmental perturbations to the measurement, which is the focus of this study. Such perturbations affect accuracy of the sensor, and leads to false or missed detections.

WSN model with statistical or machine learning process for forecasting in modern approached of flood prediction was presented [12,13,14].Non-WSN based approaches include hydrologic models that use physical detection systems to predict floods based on parameters obtained [15].

In [16], artificial neural networks (ANN) study is presented, use of adaptive neuro-fuzzy inference systems (ANFIS), multiple linear regression (MLR) and multiple nonlinear regression (MNLR) for forecasting maximum daily flow at the outlet of the Khosrow Shirin watershed, located in the Fars Province of Iran.

Seal and his colleagues [17] presented a forecasting model using WSNs to predict flood in rivers. The prediction model used multiple variable robust linear regression which is easy to understand,simple and cost effective in implementation. It provided real time predictions with reliable accuracy however false alarms sometimes occurred due to uncertainty of sensors. Reference [6] proposed use of linear least squares estimation problem for prediction [18]. In [19], underwater static sensors were used for tracking various parameters. An unsupervised learning algorithm was proposed for prediction. Similar models have also been presented in [20,21]. However, majority of data analysis models involve significant processing power, and several sensors connected in a star connection to a central hub. Our work is based on simple, fast and scalable mechanism to allow flash flood detection. In [22] a portable flood alert system to be implemented and used by the Malaysian authorities is proposed with the use of analog water level sensors that emit electrical pulses when triggered. The server then stores every single level variation in a database. If water levels reach sensor 4 (dangerous level) the server then send an SMS text message with an alert to users and local authorities. While the system does achieve its threshold, it needs constant power to operate, also the wired serial communication with the server is an inconvenience for remote sensor locations. This study [23] presents a flood forecasting model using autoregressive methods with stochastic parameters. Data for these forecasts were obtained with two different types of radars for the Mayaguez Bay Drainage Basin Area. These radars (Off-the Grid and TropiNet) are able to detect rainfall events missed by the NOAAs NEXRAD. A distributed hydrologic model was used to obtain flood depths. Real-time Flood Monitoring System with Wireless Sensor Networks deployed in two volcanic islands Ulleung-do and Dok-do located in the East Sea near to the Korean Peninsula was developed [25]. RFMS Measures River and weather conditions through wireless sensor nodes equipped with different sensors. In Real-time Flood Monitoring System with Wireless Sensor Networks WSN base station Collects the packets from sensor nodes & then transfers them to back-end server via CDMA/ADSL. a web-enabled camera is used to survey the current status of actual environment. Back-end networks verify the measured data delivered from sensor nodes in real-time. Data from each river is stored in the database which is designed to the measured data by rivers and sensor nodes. GUI-based web service providing 3D model, data graph, and other representation materials for better readability for users. In [26] the authors investigated machine learning (ML) classification techniques to assist in the problem of flash flood mitigation and evaluated forecasting. In Combining Wireless Sensor Networks and Machine Learning for Flash Flood they carried out an investigation with machine learning classification techniques to help in flash flood monitoring. They also build a Wireless Sensor Network that collects measurements from a river located in an urban area. They also used machine learning classification for flash flood monitoring. This enabled the WSN to give alerts to the local population and authorities. They evaluated several types of ML with the help of WEKA for a better comparison of the results.

3. Method

This research uses a wireless sensor network based on ZigBee specification, which make use of IEEE 802.15.4 protocol. It mainly operates on a 2.4 GHz radio frequency, with a data rate of 250 Kbit/s. It is much simpler and energy efficient than conventional wireless personal area networks (WPANs) such as Wi-Fi or Bluetooth. The physical range (line of sight) of each sensor node varies between 10-100m. The model is based on a modified mesh network. ZigBee supports tree, star and mesh networks. Out of these a mesh network is the most energy efficient and provides alternate routes between nodes (so that a backup route of Wireless sensor network structure is always available if Wireless sensor network structure particular route fails). This is specifically useful for areas floods due to the likelihood of central node failing. The proposed system consists of two main components: Wireless Sensor Network (WSN) and a Server as presented on Figure 1. The wireless sensor network is used to constantly monitor the flood levels in the area of interest while the server will receive, analyze, store the data, and sends the alerts when level thresholds are reached.

The sensor network defines two types of nodes: Sensor Nodes and the Sink node.

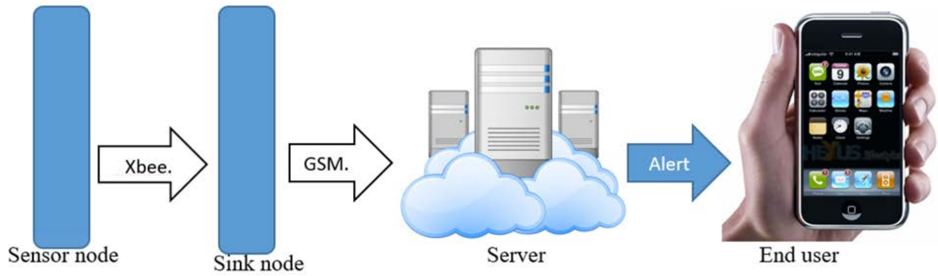

Figure 1: conceptual framework.

Sensor Node

The sensor nodes are responsible of measuring flood levels using ultrasonic sensors and reporting it to a sink node.

The main component for these sensor nodes is the microcontroller unit (MCU). When the MCU has the data it sends the gathered data to a sink node using a 2.4GHz XBee Series 1 module (XB24-DMWIT-250). After transmission of the data, the node will go to sleep for a set amount of time.

Sink Node

The sink nodes gather all data from sensor nodes and send it to the server for processing via GSM. It uses the same XBee module (XB24-DMWIT-250) as the sensor nodes for communication with the WSN. Once it has aggregated the sensed data it sends said data via internet using a SIM900 GSM Module. Then sink node also provide sleep coordination for the rest of the WSN.

Server.

The systems server is responsible for processing acquired data sent by the sink nodes. The server manages multiple networks located in different locations.

The server keeps and update database with the registered users and the flood data. After it has processed all of the data it sends notification to the registered users in the area when the flood level threshold has been reached and traffic congestion on the street.

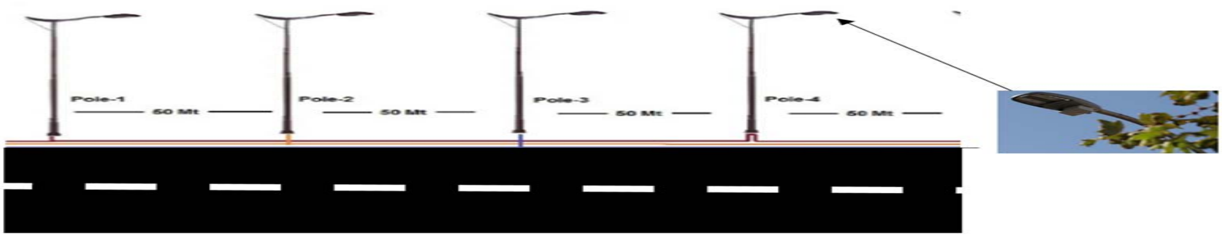

Figure 2: sensors location.

Fuzzy logic is stimulated from the outstanding capacity of human being to make suitable models.

It is an instrument for modelling ambiguous systems by enabling common sense reasoning in decision-making in deficiency of thorough and accurate information.

It enables arrival of a confident conclusion based on input information, which is uncertain, unclear, imprecise and noisy.

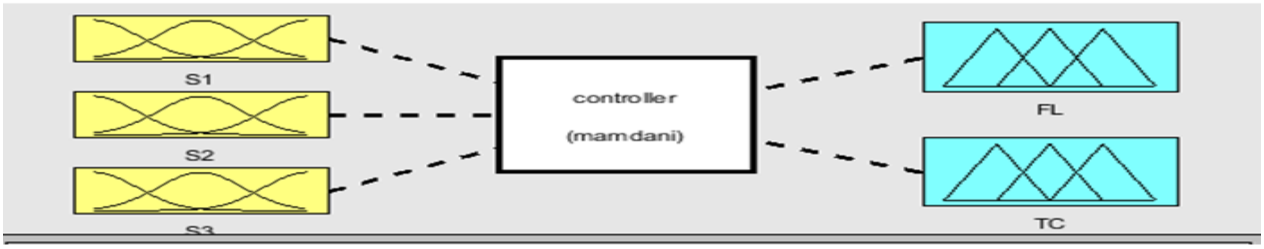

Figure 3: Fuzzy logic model.

Fuzzy logic algorithm

1. Define the linguistic variables and terms.

2. Construct the membership functions.

3. Construct the rule base.

4. Convert crisp input data to fuzzy values using the membership functions (fuzzification)

5. Evaluate the rules in the rule base (inference)

6. Combine the results of each rule (inference)

7. Convert the output data to non-fuzzy values (defuzzification)

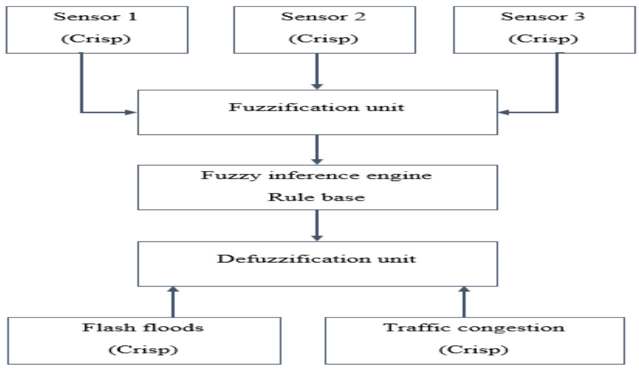

Figure 3: Controller architecture

Determination of input and output variables

The inputs of fuzzy logic flash flood and traffic congestion system are the response sensing distances sensor 1(S1), sensor 2 (S2), and sensor 3 (S3).

The fuzzy controller determines the action to be taken according to sensing distance. The outputs of the system are the flash Flood (FL) and Traffic congestion (TC). Assumption is that the output can be controlled to track the desired commands from the fuzzy inferred output.

The inputs S1, S2 and S3 are taken as the premise variables with three fuzzy linguistic sets labelled as "LOW (L)", "MEDIUM (M)", and "HIGH (H)".

The discussion region of S1, S2, and S3 belong to [0, 5000mm]. The output variables FL, TC are represented by three fuzzy linguistic sets labeled by "SMALL(S)", "MEDIUM (M)", and "BIG (B)" as illustrated in Fig.4(b), where the discussion regions for FL, TC are chosen as (0 to 100cm.Membership functions of all input and output variables are composed of triangular.

Fuzzy logic model has several testing software are available. For this experiment, we selected MATLAB and used the available fuzzy logic Toolbox.

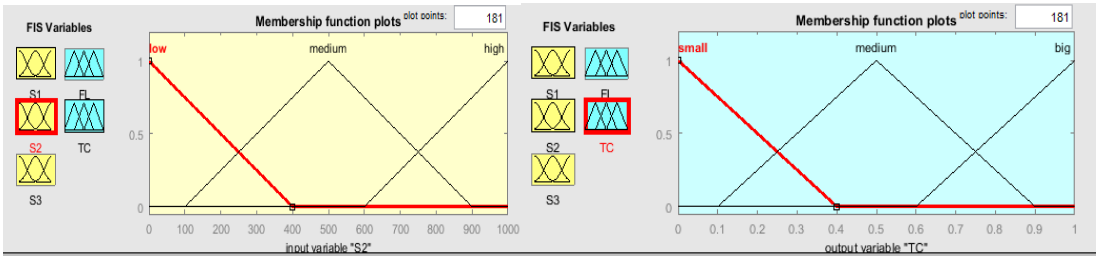

Figure 4: Membership functions for (a) the fuzzy premise variables S1, S2, S3; and (b) the fuzzy output variables FL, TC.

In order to detect flash floods or traffic congestion the fuzzy controller needs to respond appropriately according to distance information detected ultrasonic sensors. i.e., S1, S2, and S3. By involving the human's knowledge laws are constructed by the following fuzzy rules:

A total 27 fuzzy rules are built and summarized as in Table l. The general rules fulfil the following points:

Table 1: rules of system

Case	**S1**	**S2**	**S3**	**FL**	**TC**
1	L	L	L	S	B
2	L	L	M	S	B
3	L	L	H	S	B
4	L	M	L	M	M
5	L	M	M	M	M
6	L	M	H	S	M
7	L	H	L	S	S
8	L	H	M	S	S
9	L	H	H	S	S
10	M	L	L	M	M
11	M	L	M	B	B
12	M	L	H	B	B
13	M	M	L	B	M
14	M	M	M	B	M
15	M	M	H	M	M
16	M	H	L	S	S
17	M	H	M	B	S
18	M	H	H	B	S
19	H	L	L	S	S
20	H	L	M	S	S
21	H	L	H	S	S
22	H	M	L	M	S
23	H	M	M	M	S
24	H	M	H	M	S
25	H	H	L	B	S
26	H	H	M	B	S
27	H	H	H	B	S

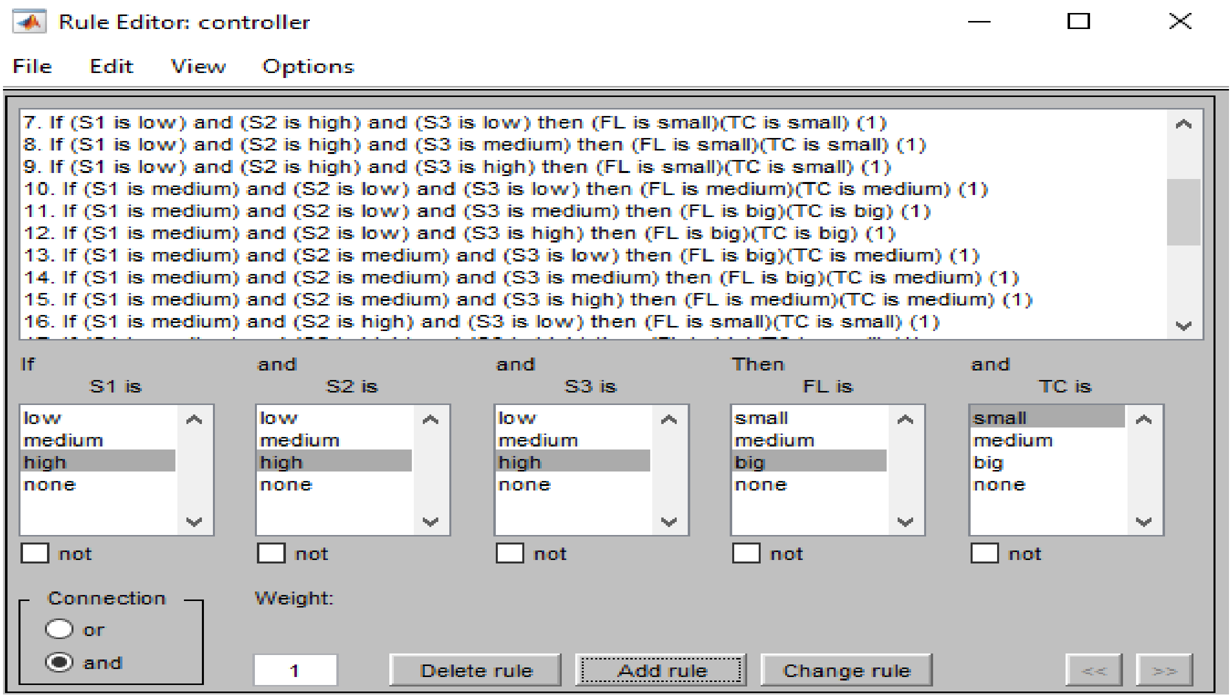

Figure 5: rule base

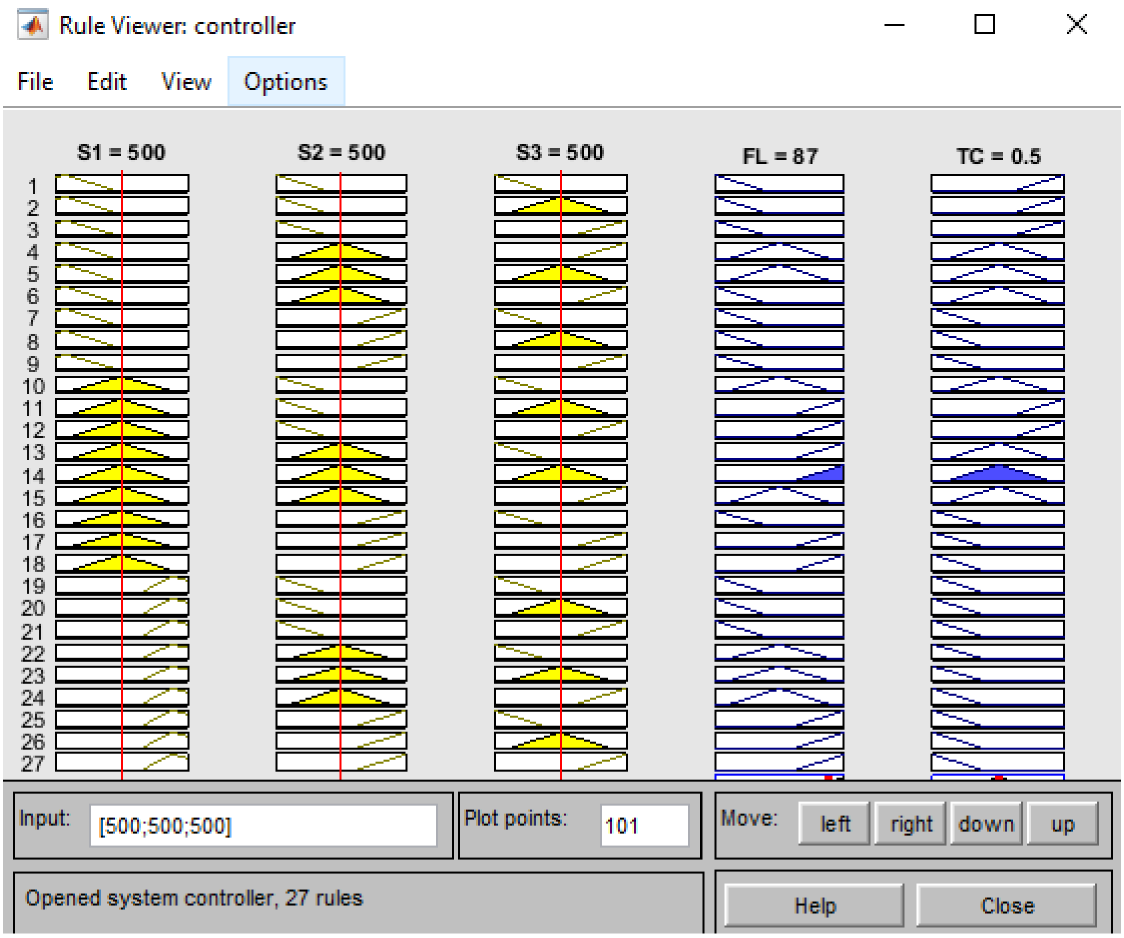

Figure 6: rules viewer

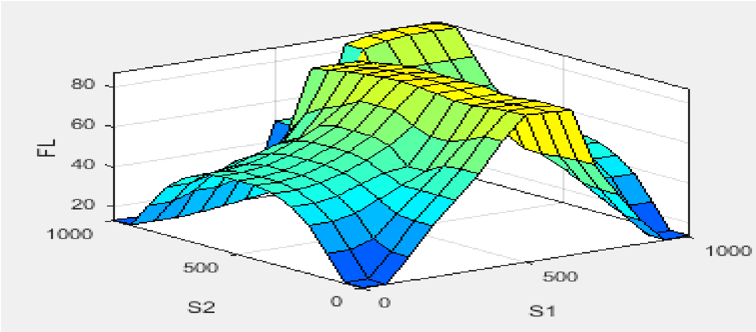

Figure 7: surface viewer

4. conclusion and recommendation

This paper presents implementation of sensor network for a real-time flash flood and traffic congestion alert system for cities. It has been shown that the integration of wireless communications and information technologies constitute an asset that can be used to protect human lives and infrastructure from natural hazards. However, fuzzy membership function is required to be designed by an expert. The solution can be extended to similar applications which involve public safety and civil defense.

When the node density increases System efficiency also increase and Average delay is decreases considerably. We observed that the impact of localization error may deviate from awakened nodes which may leads to wrong value and results in unsuccessful resolve of threat level. The level of deployment ensures proper coverage of each node is achieved to receive the data from remote place. With line of sight, the XBee radios used was able to have close to 70 meters of range in urban areas.WSN and fuzzy logic approach is presented to contribute to the literature of flash flood sensing using a custom-designed sensor comprising an ultrasonic rangefinder. Future work will be focused on the detection of rain using the reflections of the ultrasonic rangefinder. We wish to investigate the detection of water presence to be used to reduce ambiguities, to make sure that the change in ground distance is actually caused by water.

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