A

PROJECT REPORT

ON

"A Real Time Flood Monitoring System and Warning System Via Social Media using IoT and Wireless Networks"

SUBMITTED TO THE SAVITRIBAI PHULE PUNE UNIVERSITY, PUNE, IN THE PARTIAL FULFILMENT FOR THE AWARD OF THE DEGREE OF

BACHLOER OF ENGINEERING

Computer Engineering

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CERTIFICATE

This is to certify that the Project Entitled

A Real Time Flood Monitoring System and Warning System Via Social Media using IoT and Wireless Networks

Submitted by

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is a bonafide work carried out by them under the supervision of Prof. J.Y. Kapadnis and it is approved for the partial fulfillment of the requirement of Savitribai Phule Pune University for the award of the Degree of Bachelor of Engineering (Computer Engineering). This project report has not been earlier submitted to any other Institute or University for the award of any degree or diploma.

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Acknowledgement

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Abstract

Flood is the most significant disaster happened in almost every part of the world. When the event occurred, it causes great losses in economic and human life. Implementation of the advancement of ICT brings significant contribution to reduce the impact of flood toward the people and properties. This paper attempts to investigate the capability of internet of things (IoT) technology in reducing the impact of natural disaster specifically in flood disaster scenario. First, the concept of Internet of Things (IoT), key technologies and its architecture are discussed. Second, related research work on IoT in disaster context will be discussed. Third, further discussion on the propose Internet of Things (IoT) architecture and key components in the development of flood prediction and early warning system. The smart sensors will be placed at river basin for real-time data collection on flood related parameter such as rainfall, river flaw, water level, temperature, wind direction and so on. The data will be transmitted to data centre via wireless communication technology which will be processed and measured on the cloud service, then the alert information will be sent users via smart phone. Thus, early warning message is received by the people in terms of location, time and other parameters relate to flood.

Keywords:- *flood,dissaster management, nodemcu, social media alerts, ultrasonic sensor, mqtt.*

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Chapter 1

Introduction

Flood is the biggest natural disaster happens in worldwide without prior warning. Floods will damage the crops, cars, buildings, homes and anyone in their path. Reservoir is the most efficient tool to save the water resource; Reservoirs are serving for different purposes in spatial and temporal method such as a hydropower generation, flood control, navigation, ecology and recreation. The flood-limited water level (FLWL), is the parameter to manage between the flood control and conservation, from that the annual maximum value is determined. It is done mainly according to design flood estimation flood series, while it neglects seasonal flood information. At present, many research works on IoT in disaster domain have been conducted. This section will provide a summary on research works that implement IoT technologies for addressing natural disasters. IoT technologies give benefits in terms of monitoring, tracking, controlling and sensing the

environment using real time data. The use of IoT to improve environmental monitoring and management tasks. The results from their case study demonstrate that the Integrated Information System (IIS) based on IoT is valuable and efficient for complex tasks in environmental monitoring and management. The use of IoT technologies in tackling the complexity in monitoring the flood specifically using rain gauges. IoT provides an interface for data streaming management in real time and at the back end provide data analysis and visualization. In this approach the data collected will be continuously transmitted via the Internet communication infrastructure, to the software components. The software components are designed to compute the stream flow and to quantify the spatial distribution of flood risk for each controlled watershed. The use of IoT and machine learning based embedded system to predict the probability of floods in a river basin. To develop A Real Time Solution to Flood Monitoring Using IoT and Wireless Sensor Network, we proposed a flood warning system which requires attention to three basic factors: Data collection via gaging, data processing, and the hardware and software required, and the dissemination of flood warning information. While automated flood warning systems are often surprisingly inexpensive to implement, the primary factor determining cost for any such system is the number of gage site locations. Severe flooding affected Indian state of Kerala due to unusual high rain during monsoon season. It was the worst flooding in Kerala in nearly a century. In which over 373 people died within fortnight. Thirty-five out of 42 dams within the state open for the first time in history. Kerala received heavy monsoon rainfall on the midevening of August and resulting in dams filling to capacity in the first 24 hours of rainfall the state received 310 mm of rain.

1.1 Motivation

In the current year i.e. 2019 maharashtra and kerala states faces several flood situations; in which many districts and millions were affected by the flood. Kolhapur , Pune and Nashik district mainly faces flood situation during the July, august and September month.

Millions were affected by the situation. So many lost their lives and day to day life is disturbed and destroyed. This can be overcome by providing early warning of upcoming disaster by using available resources. Our main aim of this proposed system is to avoid upcoming disastrous situation by alerting those people who are going to face such situation. The People who faces flood situation mostly located nearby river bank. In the current year nashik mega flood level raised up to 25 to 30 feet. In Kolhapur district most of rural and urban areas were underwater.

1.2 Problem Definition

To design and develop a real time system that sense rising water level of river basin by using sensors which is going to transfer and store to database ; and as per condition a warning message is going to deliver to those people whos going affected by such situation.

Chapter 2

Literature Survey

[1] DIAO YanFang WANG BenDe ,Risk analysis of flood control operation mode with forecast information based on a combination of risk sources.Sci.China Tech. Sci. MAY 2008.

Flood Control Operation Mode with forecast information (FCOMFI) is an important base for risk analysis of the reservoirsDIAO YanFang& WANG BenDe have analyzed the four uncertainties that is hydraulic, hydrological, stage-storage uncertainty and time-delay uncertainty, and also their probability distributions. This proposed model was estimate by Monte Carlo simulation, based on Latin hypercube sampling. The major potential risks are includes in two methods i. Risk of reservoir ii. Risk of lower reach. Monte Carlo simulation is a statistical sampling technique that generates random variables that preserve the distributional properties and provide numerical evaluations of the probabilistic features of the system response. The risk analysis of FCOMFI aims at the safety of the reservoir and the effective utilization of the flood water resources.

[2]Ruan Yun, Vijay P. Singh ,2008, Multiple duration limited water level and dynamic limited water level for flood control, with implications on water supply, (2008)

Flood control, which may be equally important in semi-arid areas, correspond to two different reservoir water levels. The first is the limited water level it can be used for flood control. There are two approaches are proposed byRuan Yun, Vijay P. Singh ,one is multiple duration limited water level and second is dynamic limited water level. This paper also proposed a dynamic limited water level for flood control build on conditional probabilities of large storms. This means that the annual limited water level for the flood season can be modified by the several multiple duration limited water levels such as monthly duration limited water levels or weekly duration limited water levels.

[3]HEIKO APEL, ANNEGRET H. THIEKEN, BRUNO MERZ andGU NTER BLO SCHL, A Proba- bilistic Modelling System for Assessing Flood Risks,2016

Flood disaster mitigation based on a comprehensive assessment of the flood risk. German Research Network Natural Disasters project, the working group on Flood Risk Analysis searching complete flood disaster chain from the triggering event down to its various consequences. The Flood Risk Analysis group developed complex, spatially distributed models. It represent the relevant hydrological, hydraulic, meteorological, geo-technical, and socio-economic processes. The flood disaster chain represents the two way approaches (simple probabilistic and complex deterministic). This approach allows the various number of simulation runs in a Monte Carlo framework and provides the support for a probabilistic risk assessment. The proposed model is useful to integrated assessment of flood risk in flood prone area.. Applying this concept, it is the most important failure mechanism for new river levees. The breach criterion is scope as the difference between the actual overflow and the critical overflow.All modules are combined in a Monte Carlo framework. First, a discharge value was randomly chosen from the composite flood frequency. Second flood type was randomly chosen.

[4]BastianKlein,MarkusPahlow, Yeshewatesfav Hundecha and Andreas Schumann, 2005,Probability Analysis of Hydrological Loads for the Design of Flood Control Systems Using Copulas.J. Hydrol. Eng

The risk analysis of a flood control system is presenting a method, to estimate the probability of generated hydrological scenarios. Using copulas bivariate probability analyses of different flood variables are applied univariate probability to overcome that analysis may lead to an over- or underestimation of the hydrological risk. Which consists of two reservoirs located downstream of the main tributaries and flood polders. The joint probability of the inflow peaks at the two reservoirs are analysed the spatial distribution of flood events within the river basin. Risk analysis of the individual flood detention structures are use in second application copulas. Recent researches in flood prediction depict the use of wireless sensor networks and advanced artificial neural networks.

[5]Simon Haykin, Neural Networks A Comprehiensive Approach.

Seal et al. have utilized a wireless sensor network (WSN) to collect data and used a linear regression model with multiple variables for real-time and accurate flood prediction results. Increase in water level indicates flood if it exceeds the flood line.

[6]V. Seal, A. Raha, S. Maity, S. Mitra, A. Mukherjee and M. Kanti Naskar, A Simple Flood Forecasting Scheme Using Wireless Sensor Networks, 2012.

Furquim et al. have also utilized WSN and various types of machine learning classification techniques for flash flood nowcasting. They have made a comparison of the performance of these techniques with different data representations. The multilayer perceptron technique has shown better results in their work. However, some of the used sensors have not been tested in their work.

[7] G. Furquim, F. Neto, G. Pessin, Jo Ueyama, J. P. De Albuquerque, Combining Wireless Sensor Networks and Machine Learning for Flash Flood Nowcasting, IEEE, 2014.

Nuhu et al. have utilized 6 Low power Wireless Personal Area Network (6LoWPAN) as a communication technology with the help of XM1000 motes for real-time flood monitoring. A water level monitoring is done based on pre-defined rule based system. Though the system shows good accuracy with lower power consumption, the cost of motes in the work is very high.

[8]B. Kontagora Nuhu, T. Arulogun, I. Adeyanju and Abdullahi I.M., Wireless Sensor Network for Real-time Flood Monitoring Based on WPAN Communication Standard, 2016.

Ancona et al. have discussed an IoT approach for flood monitoring using highly dense grid of rainfall sensors and river gauges to measure water level. It also discusses about the integration of sensors infrastructure with various IoT cloud platforms. It also speaks of development of ultra-low power sensors or devices for the purpose.

[9]S. Gangopadhyay and M. Mondal, A Wireless Framework for Environmental Monitoring and Instant Re- sponse Alert, 2016.

Gangopadhyay et al. have implemented wireless IoT framework using Arduino Uno and an array of sensors connected to it. They utilize Xbee transceivers for communication and upload the data on ThingSpeak and Xively cloud servers. Their experiment shows that ThingSpeak is a better IoT cloud platform for this purpose. Also an instant alert is sent to the users through Twitter or the android app developed. However the system cannot accurately predict the event of flood in their work as they have not deployed a model for it. [10] Mitra et al. have proposed an IoT based WSN system for flood forecasting purpose. They have used Zigbee technology for communication between nodes and CC2650 MCU as a central controller. For communication over internet they have made use of GPRS Sim300 module. Further they have proposed use of simple ANN structure with five input parameters and water level as output. They have simulated the entire system and tested ANN model on old satellite data. They have not yet practically implemented the system and have also not used the real-time WSN data for prediction purpose. Also no alert system is developed.

[10]P. Mitra, R. Ray, R. Chatterjee, R. Basu, P. Saha, S. Raha, R. Barman, S. Patra, S. Saha Biswas and Saha, Flood forecasting using Internet of things and Artificial Neural Networks, 2016.

S. Ruslan et. al. have proposed Nonlinear Auto Regressive with Exogenous Input (NARX) model to mitigate the problem of nonlinear flood prediction problem. The system predicts the occurrence of flood in Kelang River with a lead-time of 10 hours. In this work, we have developed a ultra low power IoT flood monitoring system using low-power sensors and a dashboard developed by ThingSpeak is used to depict the real-time data collected by the system. The ANN flood prediction model is implemented on the real-time collected data and the prediction of flood event is done. Also an alert system is proposed based on the ThingSpeak messages on registered Twitter accounts.

Chapter 3

Software Requirement Specification

3.1 Introduction

3.1.1 Project Scope

This flood alert system is basically useful to get idea about flood in forecast to do the sensing of the incoming water level for detection of flood is done by implementing sensors. In this way water level will be sensed by the sensor and concerned messages will be given to the controller then it will take the further action on that command.

3.1.2 User Classes and Characteristics

1. User:-

The user is the authority will monitor the system by using the website. The system will notify the user using text and mails. The user is may be the municipalty officer or any other higher authority who will maintain the sewage system of the city.

2. NodeMCU:-

NodeMCU is an open source IoT platform. It includes firmware which runs on the ESP8266 Wi-Fi SoC from Espressif Systems, and hardware which is based on the ESP-12 module. The term

"NodeMCU" by default refers to the firmware rather than the development kits. The firmware uses the Lua scripting language. It is based on the eLua project, and built on the Espressif Non-OS SDK for ESP8266. It uses many open source projects.

3.Cloud System:-

The Cloud system is storage where we can store our data coming from sensors like ultrasonic sensor and water level sensor. The cloud system will display the readings using the website.

4. Sensors:-

The sensors will play the main role in this system. The sensors include the ultrasonic and water level sensor which will read the input coming from the drainage system and send this readings to nodeMCU.

3.1.3 Assumptions and Dependencies

1. Assume that laborotory is equiped with all facilties.
2. We assume that user knows how to operate system.

3.2 Functional Requirements

1. Administrative functions:-

This system should provide the administrative functions like registration and login for normal users.

2. Authentication:-

Thr proposed system authenticate user by their username and password for security reasons.

3. External Interfaces:-

The system should provide the interface to other systems for external system for better performance.

4. Historical Data:-

For performance improvement we have to store the historical data of the system so that we can compare the performance of system.

3.3 Extrenal Interface Requirements

3.3.1 User Interfaces

The web based application is used to communicate with the system.

3.3.2 Hardware Interface

The computer system is used to control the system.

3.3.3 Software Interface

We need the Textlocal API for the text message alerts for users.

3.3.4 Communication Interface

The http protocol is used as communication protocol for this system.

3.4 Nonfunctional Requirements

3.4.1 Performance Requirements

The system should have a high throughput.It should handle complexity. The response time of the system should be mini- mum. System must be user friendly so, that user interaction will be smooth and efficiency increases.sample user logs should be analyzed properly. system classification should be done prop- erly in less amount of time.system recommendation should be accurate enough that satisfy the user.

3.4.2 Safety Requirements

The system should have a high throughput.It should handle complexity. The response time of the system should be minimum. System must be user friendly so, that user interaction will be smooth and efficiency increases.sample user logs should be analyzed properly. System classification should be done properly in less amount of time.system recommendation should be accurate enough that satisfy the user.

3.4.3 Security Requirements

1. Working must be in formatted way.
2. No losses or causes due to the use of this system.

3.4.4 Software Quality Requirements

1. Adaptability:

Proposed System can be adapted easily to various operating environments.

2. Availability:

Can easily execute on currently available minimum configuration of hardware and software.

3. Correctness:

It will work correctly according to the valid input requirements.

4. Usability:

This system used in different mobile phones or any device.

3.5 System Requirements

3.5.1 Databse Requirements

The database required in this system is stored on the cloud. We store the historical data on cloud for future use.

3.5.2 Software Requirements

- Ardiuno IDE
- Google API
- Textlocal API
- Php Myadmin
- HTML,CSS

3.5.3 Hardware Requirements

- NodeMCU ESP8266 12E
- Ultrasonic Sensor
- Water Level Sensor
- Water Flow Sensor
- Temp Sesnor

Chapter 4

System Design

4.1 System Architecture

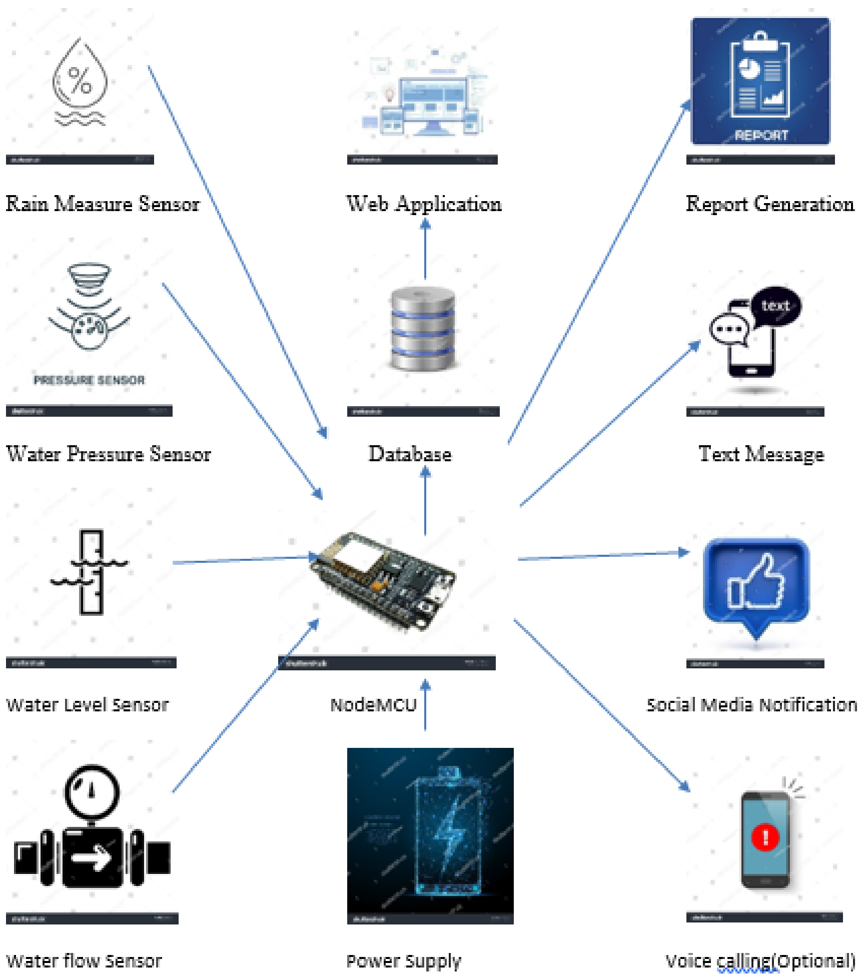

Figure 4.1: System Architecture

1. There will be a node as shown in above diagram.

2. This node is the independent flood monitoring node equipped with necessary sensors and connectivity modules.

3. It has three major stages, Including Sensors, Controller, Wi-Fi interface to upload the information on server.

4. Data from various sensors are collected by the ESP and is then computed and uploaded on the server.

5. The data uploaded on server is stored on the database.

6. The stored data is then routed to the front end web applications and mobile applications.

4.2 Working of the Proposed System

IoT technologies give benefits in terms of monitoring, tracking, controlling and sensing the environment using real time data. An introduction of the use of IoT to improve environmental monitoring and management tasks [11]. The results from their case study demonstrate that the Integrated Information System (IIS) based on IoT is valuable and efficient for complex tasks in environmental monitoring and management. The use of IoT technologies in tackling the complexity in monitoring the flood specifically using rain gauges [12]. IoT provides an interface for data streaming management in real time and at the back end provide data analysis. In this approach the data collected will be continuously transmitted via the Internet communication infrastructure, to the software components. The software components are designed to compute the stream flow and to quantify the spatial distribution of flood risk. Use of IoT and machine learning based embedded system to predict the probability of floods in a river basin.

Some Features we are going to implement in the proposed system are as follows: -

1) We are doing continuous monitoring of the river water level and record its data into relevant database.
2) Also we are monitoring the water level of the dam which is concerned with that particular region or provinces.
3) If due to heavy rain fall into that particular region or continuous rain into that region the administration authority release or discharge the water from the dam (Measures mostly in Cusec and Cumec); Then with the help of proposed system, we can calculate approximate level that is going to up rise into normal water level.
4) When heavy quantity of water discharged from the dam at that time warning message will be delivered to those people who having residence nearby river bank as well as the government authority who is responsible for help and relieve duties like municipal corporation and fire and rescue department.
5) If a consider a situation where a flood zone having active electricity supply or the flood water contains high voltage electricity (greater than 440 volts A.C.) then we deliver a message to the victims as well as the help and rescue department along with the local government like municipal corporation.
6) An advance module we are going to add into proposed system is that we are going to collect acknowledgement from the victims or the people to them we are going to deliver the warning message. Acknowledgement is collected by receiving and measuring the reply message that we have broadcasted. By comparing both data we an easy find out who is trapped into and need evacuation and help.
7) This acknowledgement report is going to submit to government authorities to help them start them relieve operation for the flood

victims.
8) An additional module is going to add is to detect land movement to nearby to high climbed or ridge zones to detect landslides. This used to help rescue lives before such disaster occur. Each city contains such kind of zones which needs to monitor on continuous basis. In heavy rainfalls landslides can be occur without any kind of warning and causes very big impact in the form of lives and wealth casualties.
9) If water increases rapidly and it is going higher than he road level of the bridge or the water level goes higher than the bridge then the alert message is delivered that the particular that bridge closed for vehicles and to the government authorities as well as on the social media platforms.
10) When that bridge is closed for vehicle then alter alternate road availability message is going delivered.

4.3 Implementation Details (Modules)

4.3.1 Hardware module

In this project, some hardware is used that are Microcontroller, sensors, components required for power supply. The Hardware collects the water level, Pressure of water, Rainfall measure to detect the levels of the flood. The hardware consists of Wi-Fi enabled controller which connects to the server and allows to share the data to through internet.
1. Microcontroller- This does the controlling with processing. Microcontroller will take the information from the sensor. This information will have sent to the admin through the database.
2. Sensors-This will collect the information from the particular nodes which are located at certain site. There are four sensors we are going

to use in this project.

They are as follows:

Water level measurement: This sensor is used to measure the water level height. For that we are going to use Ultrasonic sensor which emits short, high frequency sound pulses at regular intervals. If they strike an object, then they are reflected back as echo signals to the sensors.

Rainfall measurement: This sensor is used to measure the average rainfall. For that we are going to use same ultrasonic sensor. Ultrasonic sensor is 4 pin sensor. Those are ground connection (GND), Trigger, echo and last current (VCC).

Temperature and Humidity: This sensor is used to measure change in atmospheric temperature and humidity. For this we are using DHT11 sensor which works on one wire protocol and gives digital output. Pressure measurement: This sensor is used to determine the atmospheric pressure. For this we are going to use BMP 180 Barometric sensor.

3. Power Supply- In real time we get 230v AC, in actual project we do not need this amount of power supply so we convert this AC power supply to DC power supply.

4.3.2 Software Module

In this module, we have done an android application as well as the Website application for this project. Admin web page will contain and display the information like Login, Registration, Number of users registered to the app, status of the sensor, safe places near flood affected area where people can migrate and that places are shown on the Map. The Android application will be used by the users who are register. After registration the user can login with aunique username and password. And then user can access all facilities provided by application. Application is provided the information like current status of water level and temperature etc. This app contain map which are show the safe places near the user and also the current place where the user is.

4.3.3 Database Module

Microcontroller will send the values measured by the sensors to the server. This will contain the number of users registered to App; this will also show the safe places through the Map. The data uploaded on server is stored on the database. The stored data is then routed to the front end web applications and mobile application.

4.4 Data Flow Diagrams

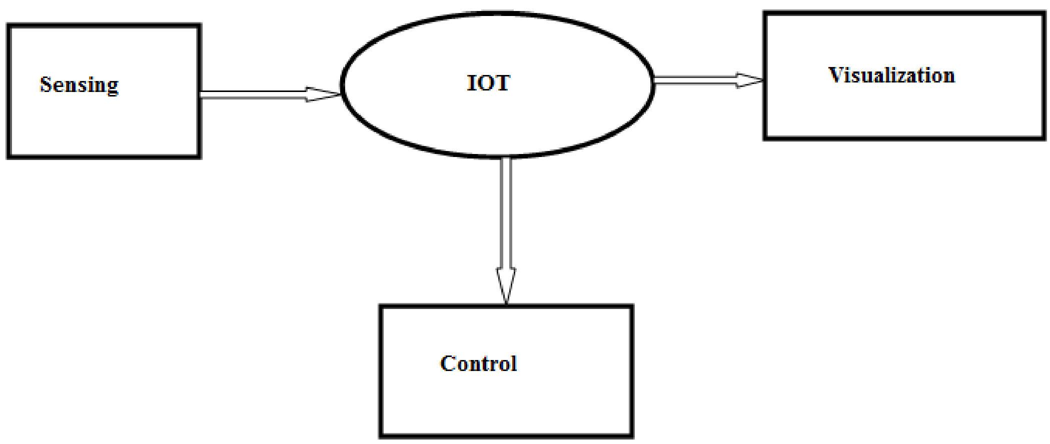

Figure 4.2: DFD: Level 0

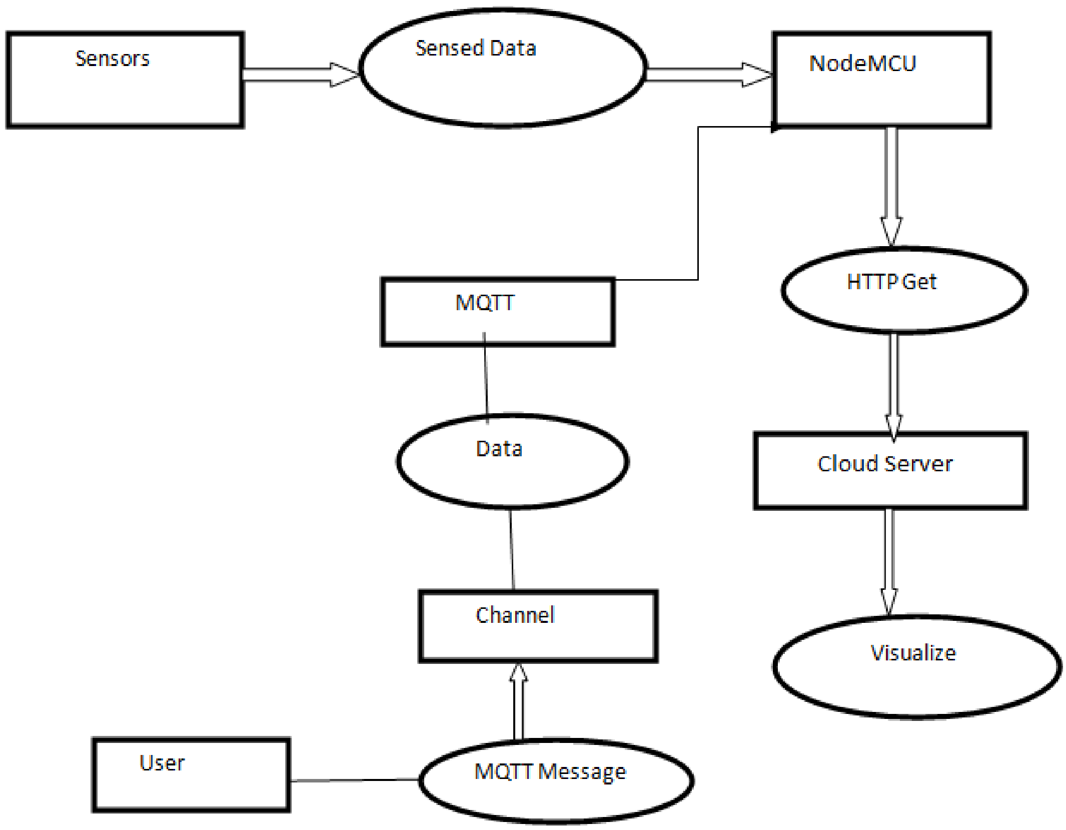

Figure 4.3: DFD: Level 1

4.5 Use Case Diagram

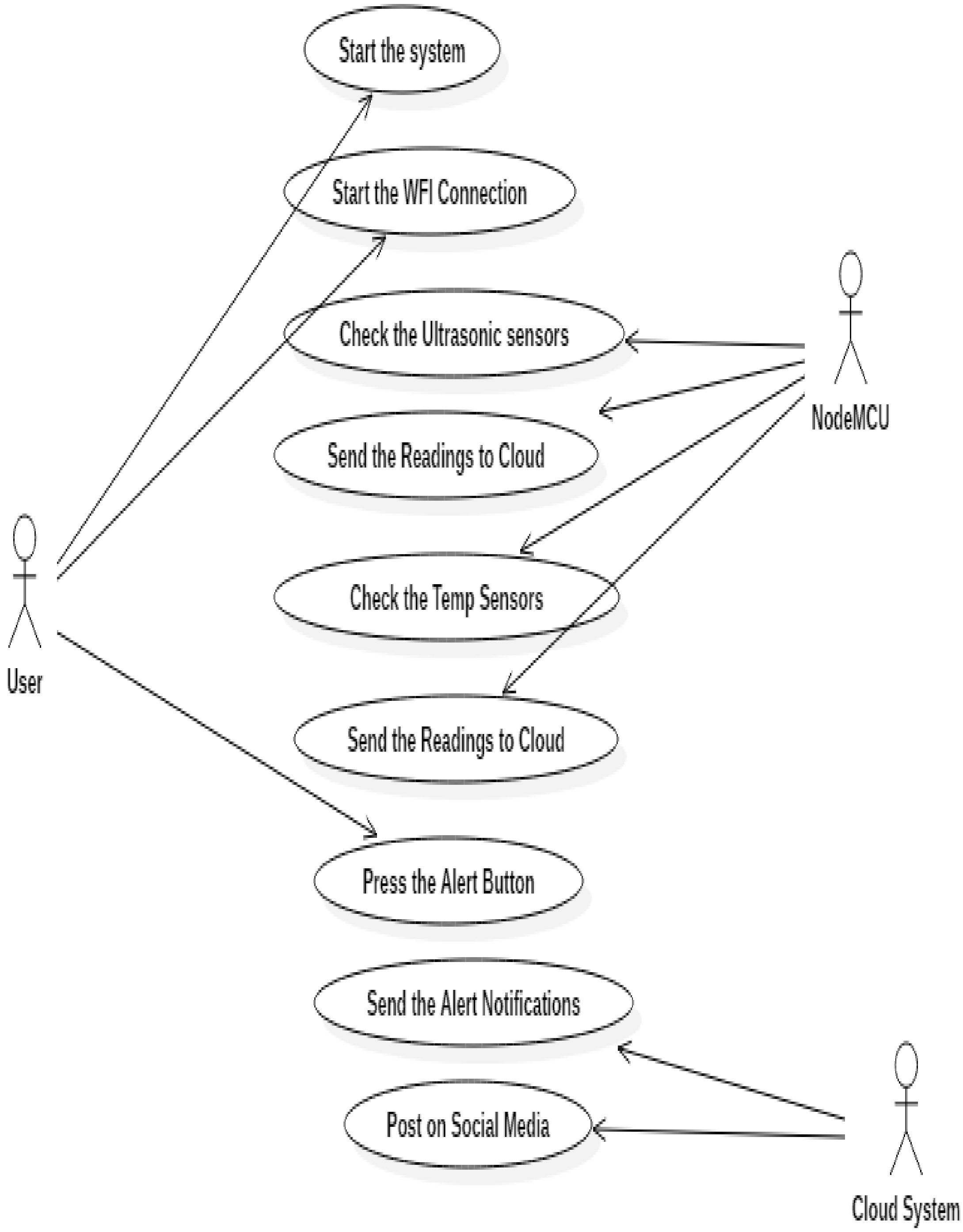

Figure 4.4: Use Case Diagram

4.6 Activity Diagram

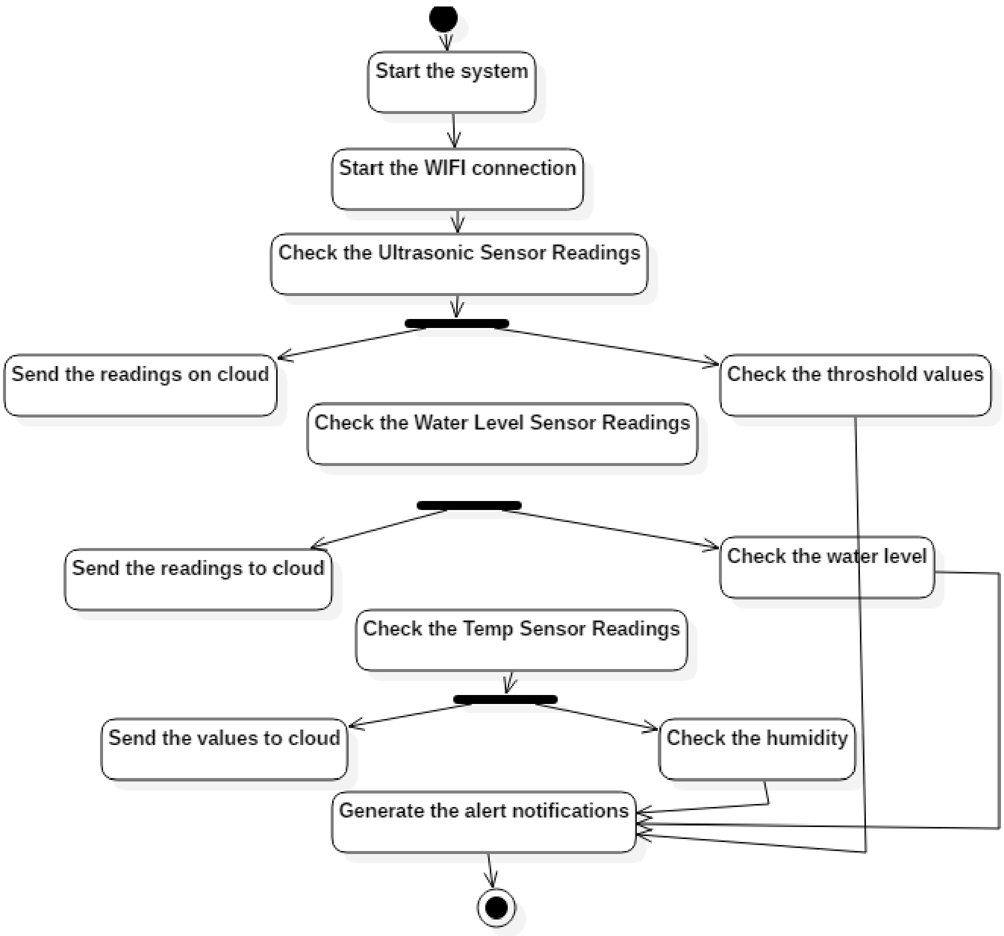

Figure 4.5: Activity Diagram

4.7 Class Diagram

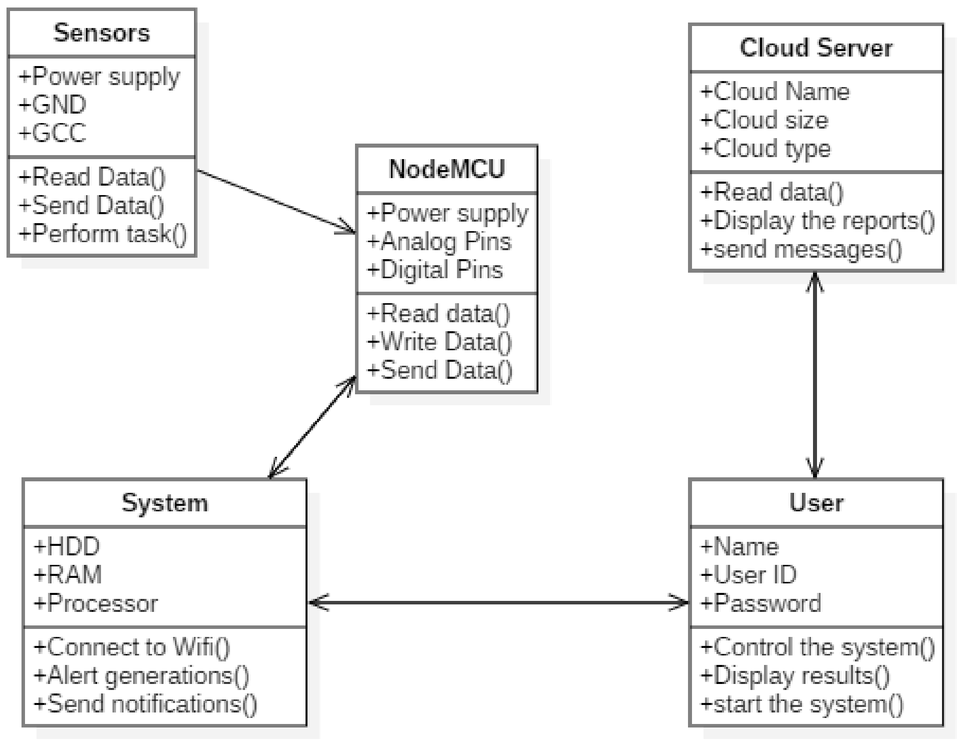

Figure 4.6: Class Diagram

4.8 Sequence Diagram

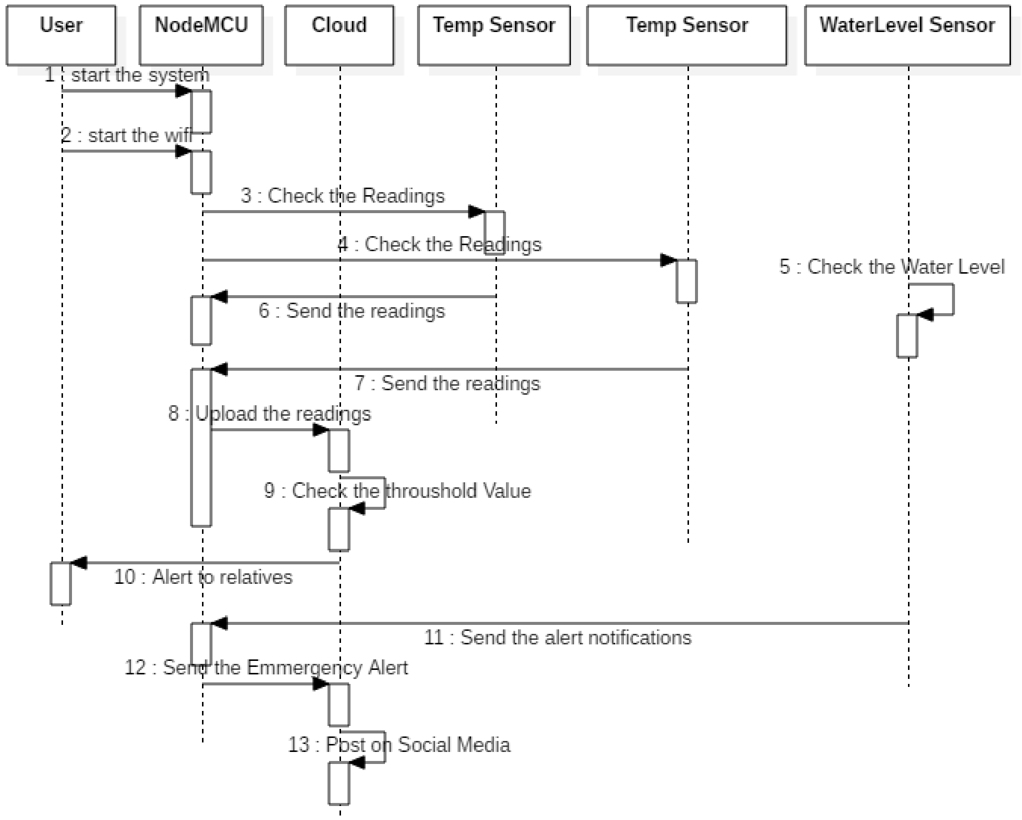

Figure 4.7: Sequence Diagram

4.9 Deployement Diagram

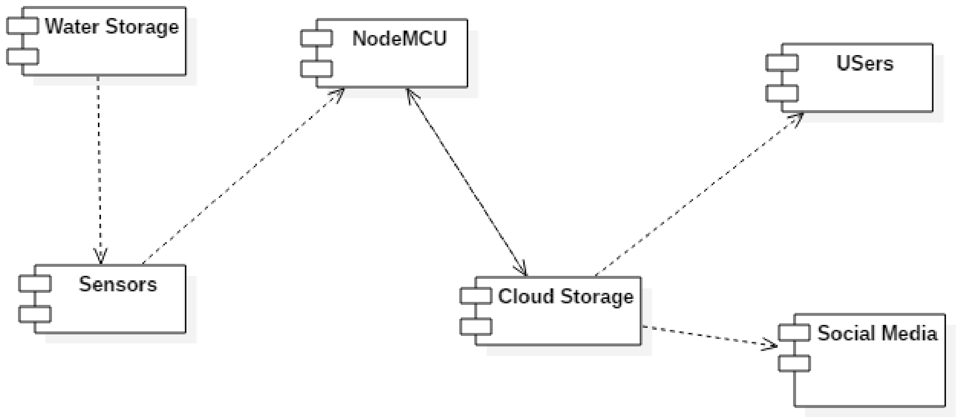

Figure 4.8: Deployement Diagram

Chapter 5

Other Specification

5.1 Advantages

- Automation of work
- Save the money
- Saves the resources

5.2 Limitations

- Complex Design of Network
- Safety issues of sensors

5.3 Applications

1) Municipal Corporations: -

The Municipal Corporation has The Emergency Response Team which faces natural and human involved disasters. By using proposed system an automated message is going to deliver to those Respond Teams to help victims.

2) Fire Department: -

The Fire Department is responsible to help the victims who are trapped into such flood situation where they can have at least information regarding upcoming disaster which going to prevent human casualties.

3) Smart City Management : -

If such ideas included into smart city development then it could improve the impression of that city over other cities regarding early warning relive support.

Chapter 6

Conclusion

The success of flood disaster management depends largely on how well flood related data can be collected, managed and utilized. Due to this importance, the use of IoT to facilitate flood data management is seen as a step in the right direction. With the proposed architecture, future research works on flood that makes use of IoT will have a reference to specify how the work can fit within the larger flood management system.

Annexure A

Laboratory assignments on Project Analysis of Algorithmic Design

A.1 Introduction to IDEA Matrix:

- To develop the problem under consideration and justify feasibilty using concepts of knowledge canvas and IDEA Matrix. Refer [?] for IDEA Matrix and Knowledge canvas model. Case studies are given in this book. IDEA Matrix is represented in the following form. Knowledge canvas represents about identification of opportunity for product. Feasibility is represented w.r.t. business perspective.

I	D	E	A
Increase	Drive	Educate	Accelerate
Improve	Deliver	Evaluate	Associate
Ignore	Decrease	Eliminate	Avoid

Table A.1: IDEA Matrix

A.2 Introduction to Knowledge of Canvas:

Knowledge is a familiarity, awareness or understanding of someone or something, such as facts, information, descriptions, or skills, which is acquired through experience or education by perceiving, discovering, or learning.

A.3 NP Hard - NP Complete Analysis:

Classification of Algorithms Class of computational problems for which a given solution can be verified as a solution in polynomial time by a deterministic Turing machine.

A.3.1 P

Informally the class P is the class of decision problems solvable by some algorithm within a number of steps bounded by some fixed polynomial in the length of the input. Thus P is a robust class and has equivalent definitions over a large class of computer models. Here we follow standard practice and define the class P in terms of Defect Tracking.

A.3.2 NP-hard

Class of problems which are at least as hard as the hardest problems in NP. Problems in NP-hard do not have to be elements of NP, indeed, they may not even be decision problems.

A.3.3 NP-complete

Class of problems which contains the hardest problems in NP. Each element of NP-complete has to be an element of NP.

A.3.4 NP-easy

At most as hard as NP, but not necessarily in NP, since they may not be decision problems.

A.3.5 NP-equivalent

Exactly as difficult as the hardest problems in NP, but not necessarily in NP.

Our system comes in NP Complete convention.

Annexure B

Base Paper

Smart river monitoring and early flood detection system in Japan developed with the EnOcean long range sensor technology

1) Dalibor Purkovic: EnOcean GmbH, Oberhaching, Germany, dalibor.purkovic@enocean.com
2) Lee Coates: EnOcean GmbH, Oberhaching, Germany
3) Marian Hönsch: EnOcean GmbH, Oberhaching, Germany
4) Dirk Lumbeck: EnOcean GmbH, Oberhaching, Germany
5) Frank Schmidt: EnOcean GmbH, Oberhaching, Germany

***Abstract*—Smart city is a term which is heard very often nowadays. It is a synonym for a variety of IoT solutions integrated into the daily city life, for the benefit of its inhabitants. One of these solutions, presented in this paper, is a river monitoring and early flood detection system. The proposed solution consists of an ultrasonic sensor adapted to the EnOcean solar-powered, long range sensor module. This maintenance free, self-powered sensor module was deployed in a couple cities in Japan to monitor river water level. The specially designed generic sensor interface allowed the adoption of the off-the-shelf MaxBotix ultrasonic sensor with a 10 meter measuring range. This can then be turned into a flood detection system which satisfies the standards prescribed by the Japanese River Bureau under the Ministry of Land, Infrastructure, Transport and Tourism. The detailed communication between the ultrasonic sensor and the sensor module via EnOcean Generic Sensor commands is shown. In addition, the transmission of the measured data over greater distances with the use of the EnOcean long range, low power communication protocol, is outlined.**

***Index Terms*—ultrasonic sensor, water level monitoring, EnOcean, energy harvesting, long range, sensor module.**

I. Introduction

With today's extreme climate changes and global warning effects, floods are continuously occurring on a global scale. In Japan, this situation is very unique, because the majority of rivers are very steep with a short distance from the source to the sea (Fig. 1). This results in rapid flow of water [1].

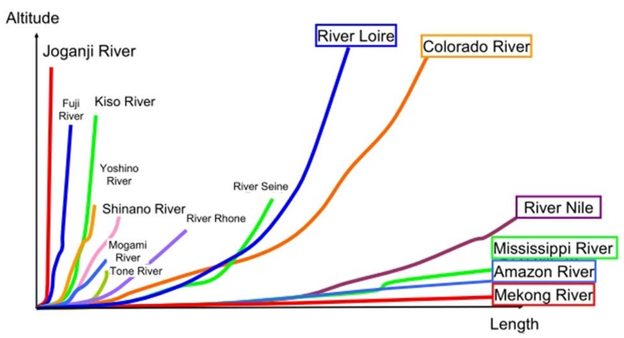

Fig 1. Comparison of different riverbeds from all around the world [1].

Additionally, approximately half of the population and three-quarters of total assets are concentrated in low-lying areas. Major damage is anticipated when flooding occurs. Furthermore, most urban areas are located in low-lying areas that are lower than the water level during floods [1]. Using the early flood detection system would save many assets and moreover, allow prompt evacuation thus, saving human lives.

River level monitoring is not a novelty and different sensors and techniques are used for this purpose. Authors in [2] developed a very large and expensive system based on the horizontal acoustic Doppler current profiler (H-ADCP). Attempts with a cheaper ultrasonic sensor resulted in a very simple prototype. However, it is not completely applicable in outdoor conditions due to lack of robustness and measurement accuracy [3]. Other authors rely on video surveillance systems [4] which require specific infrastructure and a deeper data analysis. There are also solutions with a rainfall sensor network [5], although these are not very applicable as an early flood detection system. Newer solutions include river monitoring with inclined LiDARs [6]. The proposed solution in this paper relies on a very robust and compact ultrasonic sensor. This is then attached to a completely energy independent, self-powered and maintenance free sensor module from EnOcean. Our solution is not expensive, allows easy installation and deployment, and transfer of measured data over larger distances.

This paper is organized into five sections. After the Introduction, Section II describes the ultrasonic sensor used. Section III provides more detail about EnOcean's self-powered module. Section IV describes the measurement protocol and the specifications required when water level is measured on Japanese rivers. Section V. contains experimental results and real use cases of the developed smart river and early flood detection system.

II. Ulatrasonic Sensor

As a measuring element, the ultrasonic sensor MB7383 from MaxBotix is used [7]. It has a maximum measurement range of 10 meters with a 10 mm resolution. The measurement values are obtained on the serial output pin and

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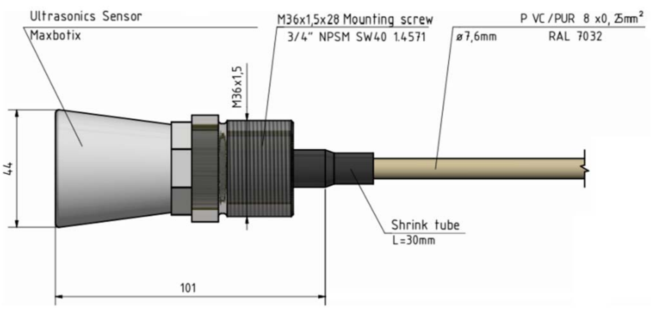

Fig. 2. MaxBotix ultrasonic sensor enclosed in housing with the attached cable.

the data format is TTL (transistor-transistor logic), where +Vcc represents logic 1, and 0 V represents logic 0. The maximum range reported is 9998 mm, while a range value of 9999 corresponds to no target being detected in the field of view. Different supply voltage levels have been tested to obtain the maximum range and accuracy of the ultrasonic sensor. Table I shows how different supply voltages affect ultrasonic sensor performance.

TABLE I. Measurements of the distance from the bridge to the river in mm for different ultrasonic sensor supply voltages. Value 1068 represents false measurement.

	3.6 V			4.0 V			5.0 V	
1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
819	818	823	820	1068	820	823	817	819
817	819	1068	821	820	819	818	818	817
818	819	818	818	821	820	819	818	817
820	820	822	818	818	1068	817	818	818
1068	821	821	1068	819	817	819	817	1068
820	820	823	819	818	818	821	819	821
824	823	822	821	817	819	1068	817	818
824	1068	1068	820	819	821	819	819	817
826	823	822	819	1068	819	1068	817	819
823	1068	1068	821	821	820	823	822	821

Three times 10 measurements of distance have been recorded on a relatively steady river and the measurement success rate is expressed for 3.6 V, 4 V and 5 V. F-measure [8] from the results above gives the following measurement success rate: 80% at 3.6 V, 87% at 4.0 V and 90% at 5.0 V. A compromise can be made between a slightly lower measurement success rate and energy consumption. The ultrasonic sensor supply voltage level is proportional to the sensor`s current consumption. Table II shows the sensor's energy consumption for different supply voltages of 3.6 V and 5 V respectively. Due to the better success rate closer to the maximum measurement range, 5 V was chosen for sensor supply voltage.

A. Generic sensor PCB

To be able to communicate with the existing EnOcean long range sensor module, the ultrasonic sensor needs some additional logic components. A small PCB was built which contains a low power microcontroller STM32L071K and a step-up converter. This ensures a stable 5 V supply voltage to the ultrasonic sensor from the variable input voltage, which can be seen on the block diagram in Fig. 3.

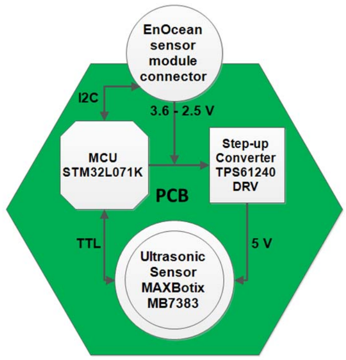

Fig. 3. Generic sensor PCB block diagram.

All the communication between the microcontroller on the generic PCB and the microcontroller on the EnOcean sensor module is done via I^2C lines. The same lines are also used to update the firmware when needed. This is done by triggering the bootloader mode of the STM32L0x microcontroller. The microcontroller on the generic sensor PCB is always powered, but 99% of time it spends in sleep mode. During this time, the ultrasonic sensor is shut down. The entire generic sensor PCB drains a constant current of around 3 μA. After connecting the MaxBotix ultrasonic sensor to the PCB in Fig. 3, the sensor becomes a generic ultrasonic sensor. It is then capable of communicating with the EnOcean sensor module via generic sensor commands described in chapter IV.

III. SOLAR-POWERED ENOCEAN SENSOR MODULE

The main source of the energy supply and central unit of the water level measurement system, is the EnOcean solar-powered long range sensor module. The sensor module characteristics and its unique communication protocol are described in [9]. Since the sensor module has a limited power supply in the form of a 40 F supercapacitor, the ultrasonic sensor needs to fulfill certain current consumption criteria so to not drain the supercapacitor within one measurement cycle. As it can be seen in Table II, at 5 V the sensor's average energy consumption per one measurement cycle is 8 mWs. The available energy from the supercapacitor (while taking into consideration the operating supply voltage from 3.6 V to 2.5 V) is expressed with (1):

$$Energy = \frac{1}{2}CV^2 = 134.2\ Ws \tag{1}$$

where,

C is the capacity of the supercapacitor (40 F).
V is the difference (1.1 V) between maximum and minimum supply voltage.

Equation (1) shows that the sensor module has enough energy stored to support 20 water level measurements, and three radio transmissions of measurement results per every wake-up cycle. Three radio transmissions need around 67.5 mWs, making it the most consuming operation.

TABLE II. Energy consumption of the MaxBotix ultrasonic sensor when powered with two different supply voltages.

Sensor@3.6V	Start-up time [s]	Average current [A]	Peak current [A]	Capacitance [F]	Measure time [s]	Energy [Ws]
MB7383-100	1.60E-01	2.30E-03	4.90E-02	4.70E-05	1.66E-01	**3.54E-03**
	34.32%		22.85%	7.23%	35.60%	**100.00%**
Sensor@5.0V	**Start-up time [s]**	**Average current [A]**	**Peak current [A]**	**Capacitance [F]**	**Measure time [s]**	**Energy [Ws]**
MB7383-100	1.60E-01	3.10E-03	9.80E-02	4.70E-05	1.66E-01	**8.09E-03**
	30.65%		30.28%	7.26%	31.80%	**100.00%**

The sensor module communicates with the ultrasonic sensor via the above mentioned generic PCB, and the specially developed GSI (Generic Sensor Interface) commands described in the next chapter. Fig. 4 shows the generic ultrasonic sensor attached to the EnOcean self-powered sensor module, with compact housing and small integrated solar cell.

Fig. 4. EnOcean self-powered sensor module with the attached generic ultrasonic sensor.

IV. Measurements and Communication

To satisfy the measurement criteria prescribed by the Japanese government [10], the developed river monitoring sensor system has to adapt its operation to the type of the river as shown in Table III.

TABLE III. Definition of measurement intervals and number of the observations for different types of rivers [10].

River size	Interval	Duration	# of observation
Great river	10min	24hrs	Ca 150
Mid and small	5min	12hrs	Ca 150
River with a rapid rise in water level	2min	5hrs	Ca 150

Besides measurement interval, it is also defined that the minimum measurement resolution has to be 1 cm and that water level should be measured in the following way:

1. One measurement sampling is done within 1 second.
2. Total measurements per cycle should last min. 20 seconds.
3. 2 maximum values or 2 minimum values can be neglected to minimize the influence of incorrect measurement data.

The generic ultrasonic sensor has two modes of operation: “monitoring” mode and “critical” mode. In monitoring mode, the measurements will be taken by default every 10 minutes, but only transmitted every 2 hours (default value). If the water level rises and the measured distance drops below a certain threshold level, the device will enter critical mode. In critical mode, measurements are taken by default every 5 minutes and every measurement will transmitted. After 150 (default value) measurements, if the distance to the surface of the water rises above the threshold level, the sensor system will return to normal mode. If the water level doesn’t drop enough, the device will remain in critical mode and take another 150 measurements before checking again. Each measurement cycle performed by the ultrasonic sensor will last for 20 seconds. During this time, the distance will be measured by the ultrasonic sensor every second. At the end of the measurement cycle, the median value will be selected and used as the result of the measurement.

It is intended that the ultrasonic sensor controls when the measurements are performed and when they should be transmitted. Interrupts will be generated to inform the EnOcean sensor module that a new measurement is available. If the sensor module requests a measurement, the last measured value will be reported, instead of starting a new measurement. If a measurement is requested before a measurement has been taken, a measurement value of 0 meters will be reported. This will happen when the generic ultrasonic sensor is for the first time connected to EnOcean sensor module. After start-up, the generic ultrasonic sensor will start a measurement cycle and then generate an interrupt. Before emitting an ultrasonic wave and measuring distance, the ultrasonic sensor, for about 120 ms on the UART line transmits factory stored data relevant to sensor identification. This is not optimal behavior of the MaxBotix ultrasonic sensor, as this action is consuming energy and it is not relevant for the measurement process. Current peaks, as well as UART communication and supply voltage level after ultrasonic sensor is powered, can be seen in Fig. 5.

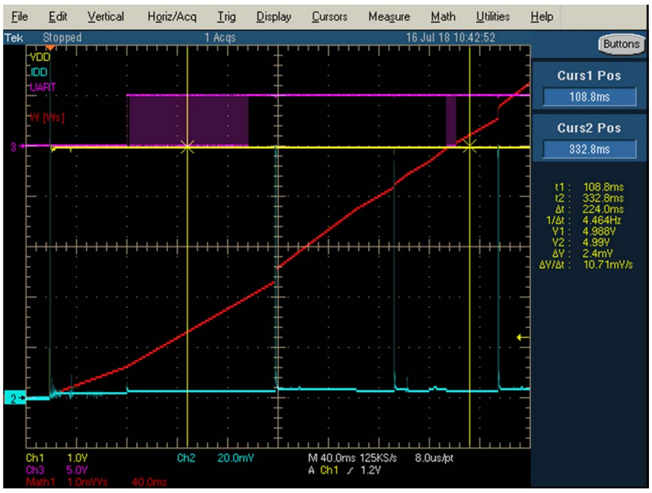

Fig. 5. Start-up of the ultrasonic sensor and measurement data transfer (purple line) together with the current peaks (blue line) and calculated energy consumption (red line).

A. Generic Sensor Interface commands and communication protocol

The main aim of the interface is to enable the connection of different sensors to the EnOcean sensor module with no additional effort inside the sensor module itself. The protocol is specified on all OSI (Open System Interconnection) layers [11]. On the lower layers, it incorporates the I^2C standard with dedicated lines for interrupt handling. The Generic Sensor Interface defines the communication between the EnOcean long range sensor module and a generic sensor, which is in this case an ultrasonic water level sensor [12].
The flow of the data between the ultrasonic sensor and the EnOcean sensor module, is based on the exchange of the GSI commands (Tables IV-VII) and it runs using the following algorithm:

1. Sensor module wakes up generic ultrasonic sensor by pulling separate power-on line high.
2. The generic ultrasonic sensor creates an interrupt on the interrupt line. This tells the sensor module that it is ready for operation.
3. The sensor module sends a Start Measurement Request (SMS) via I^2C lines to the generic ultrasonic sensor.
4. After the measurement is done, the generic ultrasonic sensor creates an interrupt on the interrupt line. Then the sensor module receives the measurement result with the Get Measurement Result (GMS) command.

At the end of every command, the 16 bit cyclic redundancy check (CRC) 'CCITT-FALS' is used. Generator polynomial is 0x1021 with an initial value of 0xFFFF [12].

TABLE IV. Request command structure [12].

REQUEST	Offset	Size		Value	Description
	0	1	Add + Op	0xC4	I2C Slave Address: 0x62, Operation: Write
	1	1	Length	0xnn	Specifies length of DATA_PL
Data_PL	2	1	**Packet Type**	0b0XXX XXXX	
Data_PL	3	x	Content	0x...	Contains the actual data payload with topics: - Data (e.g. settings) - Function codes x = variable length of Content
Data_PL	3+x	2	CRC16	0xnnnn	Data integrity check over Data_pl

TABLE V. Response command structure [12].

RESPONSE	Offset	Size		Value	Description
	0	1	Add + Op	0xC5	I2C Slave Address: 0x62, Operation: Read
	1	1	Length	0xnn	Specifies length of DATA_PL
Data_PL	2	1	**Packet Type**	0b1XXX XXXX	
Data_PL	3	1	Return Code	0x00	Return code of the requested command.
Data_PL	4	X	Additional content	0x...	Additional content returned by the requested operation if available. Can be also none. If included or not is defined by REQUEST type, actual Return code value. It is also signalized by LENGTH of DATA_PL.
Data_PL	4+x	2	**CRC16**	0xnnnn	Data integrity check over Data_pl

TABLE VI. Examples of the request packet types [12].

Type	Name	Description
0x00	NA	Reserved
0x01	INFO_SIGNAL	Detecting presence of the slave by a default and short request message.
0x02	INTERRUPT_SIGNAL	Detecting & confirmation of interrupt by sensor signal.
0x03	START_MEASUREMENT	Triggering measurement.
0x04	GET_MEASUREMENT	Receiving measurement results
0x05	TUNNEL_COMMAND	Tunnels a command to another connected Sensor
0x06-0x0F	RESERVED	Reserved for future versions
0x10	SET_PARAMETER	Overall parameterization command to set parameters.
0x11	GET_PARAMETER	Overall parameterization command to get parameters.
0x12-0x1F	RESERVED	Reserved for future versions
0x20-0x2F	DEBUG	Debugging commands manufacturer specific
0x30-0x7F	RESERVED	Reserved for future versions

TABLE VII. Examples of the response packet types [12].

Type	Name
0x80	NA
0x81	INFO_RESPONSE
0x82	INTERRUPT_SIGNAL_RESPONSE
0x83	START_MEASUREMENT_ RESPONSE
0x84	GET_MEASUREMENT_RESPONSE
0x85	TUNNEL_COMMAND_RESPONSE
0x86-0x8F	Reserved for future versions
0x90	SET_PARAMETER_RESPONSE
0x91	GET_PARAMETER_RESPONSE
0x92-0x9F	Reserved for future version
0xA0-0xAF	DEBUG_ RESPONSE
0xB0-0xFF	Reserved for future versions

V. EXPERIMENTAL RESULTS

Before the developed sensor system was installed in the field, dark time run operation had to be tested. Dark time operation represents the sensor module operation time with the attached generic ultrasonic sensor and without the supercapacitor being recharged via the solar cell. During this test, one generic ultrasonic sensor was set in critical mode by changing the distance threshold to 2 meters. The solar cell of the EnOcean sensor module was also covered to prevent recharging of the supercapacitor. Measurements and the transmission of the measurement results over the air occurred every 5 minutes. The entire sensor system ran until the voltage on the supercapacitor dropped to 2.5 V. This is when the sensor module shuts down automatically until is recharged again. In parallel, another sensor module ran with another generic ultrasonic sensor, but now set in the monitoring mode. In this mode, measurements were triggered every 5 minutes while the transmission of the data over the air occurred every 2 hours. Fig. 6 compares the dark time operation for these two different operation modes.

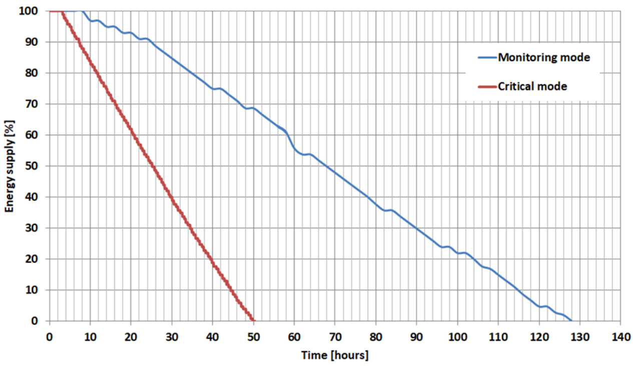

Fig. 6. Dark time operation of the sensor system for two different surveillance modes.

It can be seen when the generic ultrasonic sensor operates in critical mode, its dark time operating life is 57% shorter. This needs to be taken into the consideration so that entire sensor system has enough energy to operate, even in the worst case conditions.

After energy consumption is defined, different types of 3D printed cones for the ultrasonic sensor, were tested above different river flow variations. Table VIII summarizes the measurement success rate depending on the cone used and the river conditions. In Fig. 7 the different types of cones used are depicted and Fig. 8 shows an example of "calm" and "very wild" river flow respectively.

TABLE VIII. Measurement success rate for different cone types and different river flow.

Cone type	River type and the distance to the bridge		
	Calm (9.1 m)	Wild (9.6 m)	Very wild (8.5 m)
No cone	**100%**	**38%**	**14%**
Extended cone	100%	97%	24%
Cylinder cone	**100%**	**56%**	**4%**
Spy cone	100%	100%	69%

Fig. 7. Different 3D printed cone types used during water level measurements.

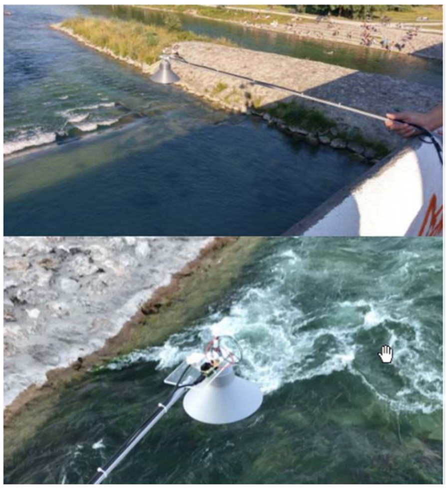

Figure 8. Measurements with the spy cone on a "calm" river flow and a "very wild" river flow.

The complete system installed above the river in Hyogo prefecture in Japan can be seen in Fig. 9. All the benefits of the EnOcean self-powered sensor module are exploited; compact size, self-powered, maintenance free and long-range transmission. The closest receiver is 2 km away from the EnOcean sensor module itself.

Fig.9. Complete smart river monitoring and early flood detection system installed above the river in Hyogo prefecture, Japan.

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Annexure C

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