LPU-Laguna Journal of Engineering and Computer Studies
Vol. 4 No. 2 October 2019

Design and Implementation of Water Velocity Monitoring System Based on Hydropower Generation and Antonyan Vardan Transform (AVT) Statistics

[1]John Darell C. Aguda, [2]Ma. Ramona A. Alcantara, [3]Jomalyn F. Bueser, and [4]Favis Joseph C. Balinado
[1]aguda.darell@gmail.com, [2]rmona.alcantara@gmail.com, [3]alybueser@gmail.com,
favisjoseph.balinado@lpulaguna.edu.ph
Lyceum of the Philippines — Laguna, Philippines

***Abstract*—Philippines is an archipelago situated along the typhoon belt in the western Pacific Ocean that makes it susceptible to flooding. Although flood can be easily anticipated, instances occur wherein it can rise at a very short notice. On cases like this, in order to reduce the risk of disaster before the danger materializes, the study, design and implementation of water velocity monitoring system based on hydropower generation and Antonyan Vardan Transform (AVT) Statistics is presented. The project aims on designing and implementing a system capable of monitoring river flow velocity and transmitting warning messages based on the water velocity of the San Juan River through the employment of sensor, microprocessors, and wireless technology. The hardware structure of the system comprised of a voltage sensor, Arduino Uno, Raspberry Pi 3, HC-12 module, and GSM module. The software structure, on the other hand, employed the Arduino IDE and Raspbian Jessie platforms. The AVT statistics is used to filter out unacceptable readings. During system testing, an average accuracy of 98.33 percent and standard deviation of 0.0032 were observed.**

***Keywords*—Arduino Uno, Arduino IDE, AVT statistics, HC-12, GSM, Raspberry Pi 3**

INTRODUCTION

Background of study

The Philippines is an archipelago situated in the western Pacific Ocean. Due to the country's geographical location along the typhoon belt in the Pacific, the country is visited by 20 typhoons on the average per year, five of which are destructive. In addition to typhoons, the country's topography makes it highly susceptible to flooding brought by storm surges, sea level rises, and monsoons [1]. In a paper, entitled: *The human cost of weather-related disasters*, the Philippines was ranked fourth as the most disaster-prone country in the world having experienced 274 natural calamities with a total of 130 billion causalities over the past two decades. Four out of 10 disaster-related deaths are accounted to storms. Storms commonly result to floods which then comprise a vast majority of all the natural disasters over the past years affecting billions of people worldwide [2].

Early in August 2018, the Laguna Lake Development Authority (LLDA) announced that the aforementioned lake has reached its maximum water level at 12.5 meters, two months early than usual. The 12.5-meter elevation is usually recorded on the months of October and November. This implies that if a typhoon or monsoon rain is to occur in the coming days, the areas along the lake will experience heavy flooding due to the lake's overflow [3].

The Laguna Lake's basin is filled with 21 major tributaries, all of which are regularly monitored by the LLDA. One of the major tributaries is the San Juan River which stretches from Malvar to Santo Tomas and then Tanauan in the province of Batangas then crosses Calamba City and finally, drains to Laguna Lake [4].

Although flood can easily be anticipated, especially for those who have frequently experienced them, instances occur wherein it can rise at a very short notice. On cases like these, hydrological sensing and flood prediction can be taken into account to reduce the risk of disasters even before the danger materializes [5]. Due to this, the researchers were motivated to employ sensor technology to detect current river flow rate. Wireless data transmission is to be employed among the system's microcontroller, microcomputer, the main server, and cellular phones of community officials.

The study will be a part of the Commission on Higher Education's (CHED) commissioned project, named: *Project EFF*. The research project, entitled: *Design and Implementation of a Community-Installed Earthquake, Flood and Fire Monitoring, Data Acquisition, GSM and Web-Based Warning System* funded by the CHED under the Discovery Applied Research and Extension Trans/Inter-Disciplinary Opportunities (DARE TO Grant-in Aid). The project is a collaborative work among the participating higher educational institutions including the AMA Computer University, Technological University of the Philippines – Manila, University of the Philippines – Los Baños, Colegio de San Gabriel Arcangel, Holy Angel University, and the Lyceum of the Philippines – Laguna [6].

Problem statement

With the increasing extreme climatic conditions, rural and urban flood have become more severe and frequent. Practically, nobody has the power to exterminate the effects of floods in different properties, infrastructures and on agricultural and forest lands; however, zero casualty situations can be accomplished. Through real-time data gathering, appropriate early flood warning messages can be broadcast to community officials of the affected area. This can alleviate the risk of having casualties and will aid authorities regarding areas to be prioritized during evacuation procedures. Due to this, the researchers designed and implemented an early flood warning system equipped with sensor, processors and wireless communication technology. Specifically, the system utilized the energy converted by the alternator from the mechanical input of the turbine as sensed by the voltage sensor. The electrical signal on the output of the alternator is used in the computation of water velocity. The signal processing occurred on the Arduino Uno microcontroller. Information-dissemination was accomplished with the Raspberry Pi 3 and the GSM module.

Objectives of the study

General objective

To design and implement a system that will sense the flow velocity of San Juan River in Brgy. Makiling, Calamba City, Laguna. The data gathered from the sensing system is transmitted to a local server. Short message service (SMS) technology is employed to alert local officials regarding the impending flood.

Specific objectives

1. Design the system based on the hardware and software requirements of the sensing and information transmission structures;
2. Apply Antonyan Vardan Transform Statistics algorithm in flow velocity data filtering; and
3. Test the reliability of the system in terms of measurement accuracy and transmission speed of the short message service.

Significance of the study

Local Community. The use of short message service (SMS) technology as an information-dissemination tool promotes disaster preparedness and awareness for locals, especially those living along the river and on flood-prone areas. Appropriate actions can be taken early on by citizens and mishaps due to lack of information can be prevented.

Government Authority. This will aid local authorities in modeling the recurrence interval of floods based on real-time information transmitted through wireless technology. This data gathered by the system will serve as a reliable source of information during planning, decision-making, and implementation processes. In addition to that, precautionary measures can be taken on the onset of a predicted flooding. The utilization of SMS technology as an information broadcasting medium will make information-dissemination easier for local authorities.

Academic Community. The research will serve as a reference to the academic community. Additionally, the study will promote the significance of sensor and wireless communication technology in relation to disaster management and data gathering.

Future Researchers. For future similar research endeavors, the study can serve as a reference. In addition to that, the system can be innovated in a way that will meet the present environmental and technical requirements.

METHODOLOGY

Conceptual framework

The conceptual framework is represented through the system's IPO chart that includes requirements needed to output the desired system, block diagram to show the process as to how it will be interpreted, and system flowchart to represent the overall flow of the system and to visualize the summary of steps.

IPO chart

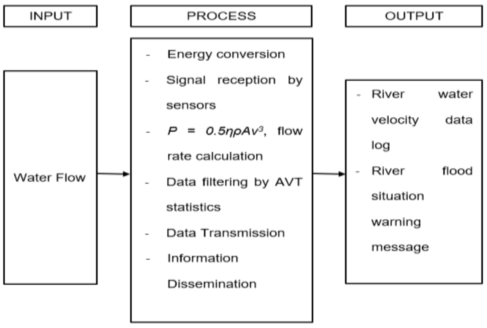


Figure 1. System input-process-output model

Block diagram

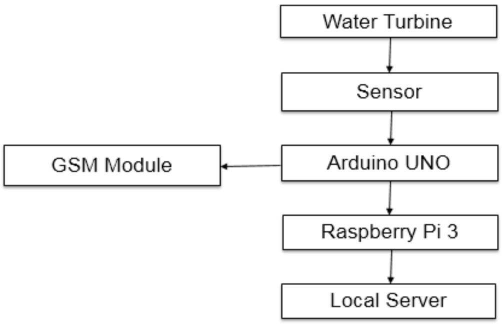


Figure 2. System block diagram

The system is composed of a water turbine, alternator, voltage sensor, Arduino Uno microcontroller, Raspberry Pi 3, and a GSM module. On the device built, the turbine is not directly coupled with the alternator. The power generated by the turbine detected using a voltage sensor and a 20Ω resistor connected across the output of the alternator. From the calculated power, the water velocity is obtained and filtered using AVT statistics, to filter out readings brought by electric spikes. A threshold value is set for the sending of a warning message to local officials via the GSM module at 2.4 meters per second. The classified speed of a flash flood is at 2.7 meters per second; however, since the study aims to provide early warning, notifications are sent prior to the occurrence of the flash flood. The processed data from the Arduino is sent to the Raspberry Pi 3 via radio frequency (RF) using the HC-12 module. The Raspberry Pi 3 then sends this data to the local server via a Wi-Fi connection.

System flowchart

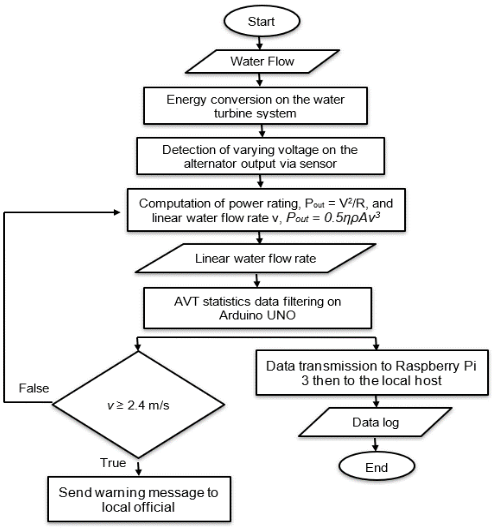


Figure 3. System flowchart of the water velocity monitoring system based on hydropower generation and Antonyan Vardan Transform (AVT) statistics

Generally, the water flow served as the input to the whole system. The linear flow rate is derived from the power generated by the turbine system. The power is computed from the input given by the voltage sensor. The flow rate v, is then calculated from, $P_{out} = 0.5\eta\rho Av^3$, wherein P_{out} is the power generated; η is the turbine efficiency; ρ is the density of water; A is the effective area of the turbine; and v is the linear water velocity. The computation, as well as AVT filtering, took place on the Arduino Uno. A pre-programmed warning message is sent to local officials once the data reading exceeds the predetermined threshold value of 2.4 meters per second.

The processed data is sent to the Raspberry Pi 3 through the HC-12 module. The microcomputer then sends the data to a local server for data logging.

Standards used

1. Wi-Fi (IEEE 802.11). The standard focuses on discussions about Wi-Fi applications and usage of personal hotspots that will not interfere with the strict use of government and military.

2. Flood Advisory (NDRRMC). The rainfall warning levels given will be issued to people of the affected area. It also includes other watercourses that can be affected. Yellow: 7.5 - 15 mm rain observed in one hour and expected to continue in the next two hours. Flooding is possible in low-lying areas and near river channels. Orange: 15 - 30 mm rain observed in one hour and expected to continue in the next two hours. Flooding is a threat in low-lying areas and near river channels. Red: more than 30 mm rain observed in one hour and expected to continue in the next two hours. Serious flooding expected in low-lying areas. Take necessary precautionary measures.

3. Electronic and Electrical Components (Philippine Electronics Code – Volume 1 Safety). It is stated in the Philippine Electronics Code instructions on how to handle electricity properly and how to be safe from danger while working with electronic and electrical components.

4. Academic Documents (APA referencing based on APA Manual, 6th ed.). APA referencing uses numerical values to cite authors, documents, and/or websites. APA referencing still states the surnames of the authors in the documentation for formality.

5. NTC M.C. 02-10-2011 (Interconnection Charge for Short Messaging Service). The NTC M.C. 02-10-2011 entails that messages are received 30 seconds after sending

Layout and schematic diagram

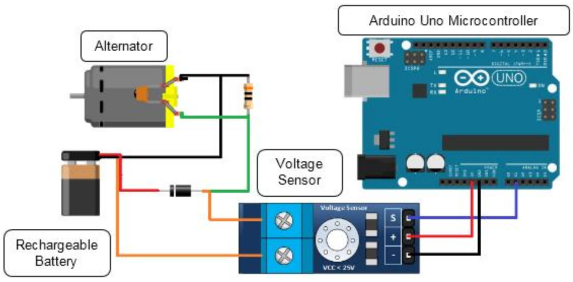


Figure 4. 25V voltage sensor interfaced with the Arduino microcontroller schematic diagram

The connection “S” and “pins” of the voltage sensor is wired to the A1 (Analog input) and GND of the Arduino respectively and uses 5V to power up and enable the module. The skew terminal pins of the voltage sensor are marked as VCC and GND and are connected to the external source voltage which is the alternator to measure the voltage produced. The use of diode is to conduct current in only one direction.

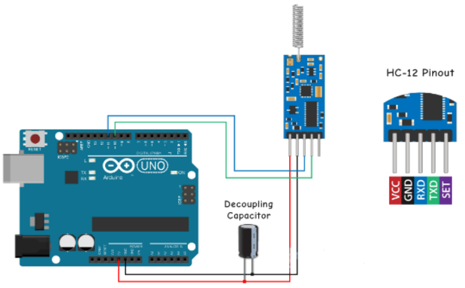


Figure 5. HC-12 long range wireless transceiver module with Arduino Uno schematic diagram

The operating voltage of the module is from 3.2 V to 5.5 V and for more stable work, it is recommended to use a decoupling capacitor and an external power supply. Notice that VCC (red) is connected to 5V to power up and enable the module. The RXD and TXD pin of HC-12 is wired to the digital pins of the Arduino to make transmitting and receiving possible.

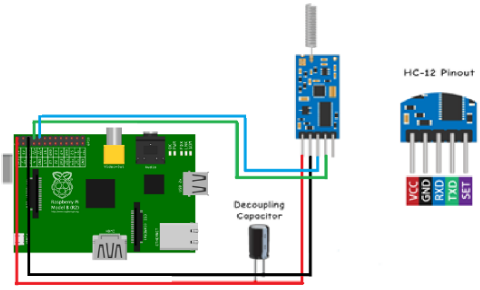


Figure 6. HC-12 long range wireless transceiver module with Raspberry Pi 3 B+ schematic diagram

The operating voltage of the module is from 3.2 V to 5.5 V and for more stable work, it is recommended to use a decoupling capacitor and an external power supply. The VCC (red) of the HC-12 module is connected to 5V of the Raspberry Pi and GND to GND. The RXD and TXD pins of the HC-12 is wired to GPIO14 and GPIO15 respectively of the Raspberry Pi to make transmitting and receiving possible.

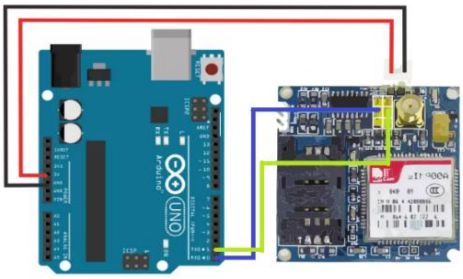


Figure 7. GSM/GPRS TTL UART MODEM-SIM900 with Arduino Uno schematic diagram

A separate power source (5V-1A) was provided to the GSM modem for proper functioning as it drives much current. It requires a 2G activated SIM card, with working data connection, and power up modules. The SIM will take a few seconds to get registered to the network. The use of an Arduino code that transmits an AT command and verifies whether an OK is received as acknowledgement is needed to check the communication between the Arduino and the module.

CAD illustrations

Figures 8, 9, 10, and 11 show the structural design of the Water Velocity Monitoring System Based on Hydropower Generation designed in Autodesk AutoCAD 2017 where the sensors, microcontrollers and wireless communication modules takes place.

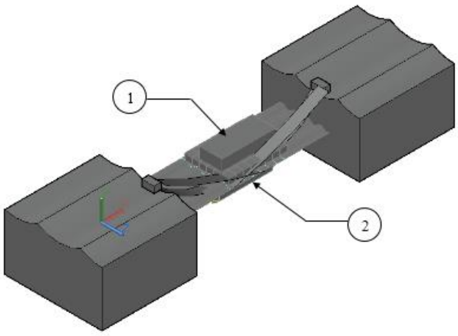


Figure 8. Actual proposed design: SE isometric view; [1] sensor case, [2] turbine

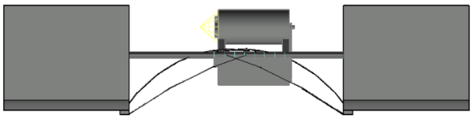


Figure 9. Actual proposed design: Right side view

Figure 10. Actual proposed design: Front view

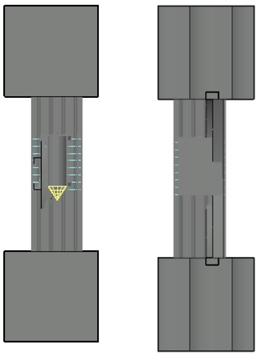


Figure 11. Actual proposed design: Top view (right), bottom view (left)

Algorithm discussion

AVT Statistical filtering algorithm is an approach to improving quality of raw data collected from various sources. One way to improve signal/noise ratio is to implement filtering to separate useful signals from noise. In an ideal situation, the useful signal has different frequencies than noise and noise is separated/filtered out by frequency discrimination using various filters [7]. AVT filtering is implemented in software and its inner working is based on statistical analysis of raw data. Its implementation used the formula of standard deviation and mean averaging.

The sample standard deviation:

$$s = \sqrt{\frac{1}{n-1}\sum(x_i - \bar{x})^2}$$

It measures how spread out the numbers in the mean of a sample. High sample standard deviation means that the numbers are very spread out while low sample standard deviation means the numbers are close to each other. The sample standard deviation is used for the normal distribution which helps if the value is accepted or not.

DATA, RESULTS, AND ANALYSIS

Software and hardware implementation

Figure 12. Hardware implementation

The voltage sensor is connected in parallel to the 20Ω resistor. This connection is parallel with the series connection of the diode and battery. Wherein, the anode is connected to the positive node of the sensor, while the cathode is connected to the positive terminal of the battery. The diode is employed so that, the sensor would only detect the voltage across the 20Ω load.

The Arduino IDE is used to implement the system program. Initially, the system neglects the first 10 readings of the sensor to give time for system stabilization. Consequently, the system then starts displaying the first reading when the system is considered stable. On the sensing part, the code simply follows the formula used in computing power from water turbines. In addition to that, the algorithm works by getting the five consecutive readings, acquiring its mean, a deviation of 0.40 is preprogrammed. This deviation is added and subtracted from the mean creating a range of acceptable values.

The upper and lower cut-off values are used as the filtering values whereas readings above the upper limit and lower than the lower limit are filtered off. This prevents mistaken readings from power spikes, common to electrical systems and unstable reading due to the multidirectional flow of water.

System calibration

This section shows the output voltage of the alternator measured using the tester and the voltage sensor. The value read by the voltage tester is considered as the true value. The comparison is quantified by computing the percent difference between the two readings, the percent difference is given by

$$Percent\ Difference(\%) = \frac{|true\ value - experimental\ value|}{true\ value} x100$$

Table 1. System calibration

Trial	Sensor Voltage (V)	Tester Voltage (V)	Accuracy (%)
1	0.39	0.388	99.48
2	0.46	0.449	97.55
3	0.61	0.605	99.17
4	0.71	0.697	98.13
5	0.73	0.730	100.00
6	0.78	0.775	99.35
7	0.81	0.807	99.63
8	0.76	0.759	99.87
9	0.73	0.729	99.86
10	0.71	0.71	100.00

The differences in voltage readings is due to the rounding off of values to two decimal places on the sensor part and some delay in the display of the reading due to the connection of the GSM module. Nonetheless, a minimum of 97.55 percent accuracy is achieved in the Trial 2, as well as a maximum accuracy of 100 percent in Trials 5 and 10.

Research testing

The proponents used the manual floating method to affirm the measurement accuracy of the system. Observations were made at San Juan River in Makiling, Calamba City.

Sensing system

Table 2. Water velocities by floating method

Trial	Time (seconds)	Water Velocity (m/s)
1	3.61	0.5540
2	3.64	0.5495
3	3.72	0.5376
4	3.46	0.5780
5	3.99	0.5013
6	3.55	0.5634
7	3.83	0.5222
8	3.77	0.5305
9	3.70	0.5405
10	3.18	0.6289
AVERAGE		0.5506
Note: Measured at a distance of two (2) meters		

The test was conducted on the river to measure water velocity composed of 10 trials and the results were listed on a table (See Table 2). The second column shows the time taken by the float to travel two meters; the recorded time is used to determine water velocity. The water velocity is given by:

$$Water\ velocity\left(\frac{m}{s}\right) = \frac{distance}{time}.$$

From the formula: $P = 0.5A\rho v^3$, with v_{ave} = 0.5506 m/s, ρ = 1000 kg/m^3, A = 0.146438 m^2, the power possessed by the water is equal to 12.195 W. This serves as the input power of the system.

Table 3. Voltage reading of digital tester versus voltage sensor

Trial	OUTPUT VOLTAGE (V)		Accuracy (%)
	Tester	Sensor	
1	2.548	2.4658	96.77
2	2.551	2.4902	97.62
3	2.566	2.5146	98.00
4	2.577	2.5146	97.58
5	2.543	2.4902	97.92
6	2.562	2.5146	98.15
7	2.521	2.4658	97.81
8	2.580	2.5391	98.41
9	2.555	2.4902	97.46
10	2.557	2.4902	97.39
AVERAGE	2.556	2.4975	97.71

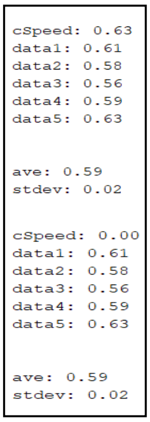
The readings obtained with the tester is used to compute for the electrical power output, given by:

$$P_{out}(Watts) = \frac{V^2}{20}.$$

The computed output power of P_{out} = 0.3267 W, is used to compute for the turbine efficiency given by:

$$\eta = \frac{P_{out}}{P_{in}}.$$

The efficiency is then written on the system program. The system error is computed by comparing the speed calculated by the system and the average speed using the float method, 0.5506 meter per second.



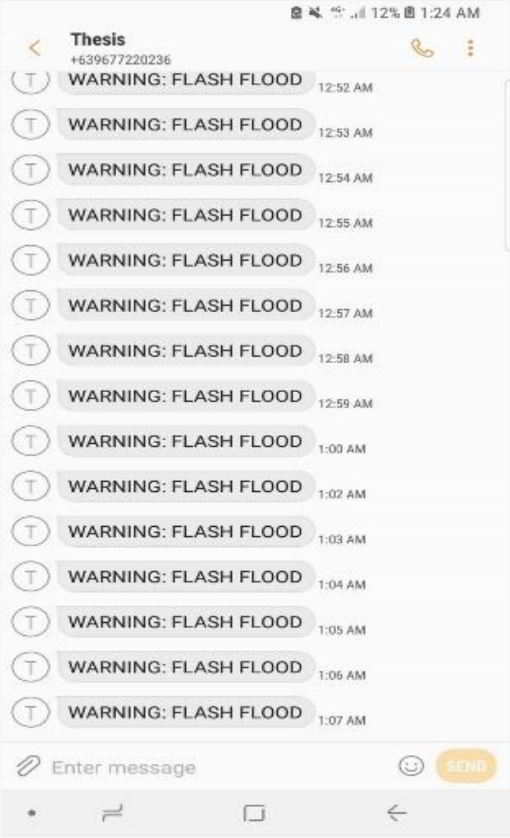
```
cSpeed: 0.63
data1: 0.61
data2: 0.58
data3: 0.56
data4: 0.59
data5: 0.63


ave: 0.59
stdev: 0.02


cSpeed: 0.00
data1: 0.61
data2: 0.58
data3: 0.56
data4: 0.59
data5: 0.63


ave: 0.59
stdev: 0.02
```

Figure 13. Application of AVT statistics

Six labels can be seen, 'cSpeed', and 'data1' to 'data5.' The 'cSpeed' represents the current speed reading of the system. The entries 'data1' to 'data5' are the input data for the AVT statistics. The 'cSpeed' is made equal to 'data5,' 'data5' is made equal to 'data4;' 'data4' to 'data3;' and so on. With this, the average is moving. The entries 'data1' to 'data5' are averaged; a deviation of 0.40 is then added and subtracted to the mean to form a range of acceptable values. As seen on the screen, a 'cSpeed' of zero (0) is not included in the roster of accepted values since it does fit into the range of accepted values, in this case, 0.19 to 0.99 meter per second.

Transmission system

The transmission system of the study comprised of the data transmission to the local server via the HC-12 and Raspberry Pi 3.



WARNING: FLASH FLOOD 12:52 AM
WARNING: FLASH FLOOD 12:53 AM
WARNING: FLASH FLOOD 12:54 AM
WARNING: FLASH FLOOD 12:55 AM
WARNING: FLASH FLOOD 12:56 AM
WARNING: FLASH FLOOD 12:57 AM
WARNING: FLASH FLOOD 12:58 AM
WARNING: FLASH FLOOD 12:59 AM
WARNING: FLASH FLOOD 1:00 AM
WARNING: FLASH FLOOD 1:02 AM
WARNING: FLASH FLOOD 1:03 AM
WARNING: FLASH FLOOD 1:04 AM
WARNING: FLASH FLOOD 1:05 AM
WARNING: FLASH FLOOD 1:06 AM
WARNING: FLASH FLOOD 1:07 AM

Figure 14. Flood notifications via GSM module

Figure 14 shows the warning messages sent by the flood monitoring system when the speed obtained is greater than the threshold value of 2.4 meters per second. The warning message is sent every one-minute interval. From the experiment, the messages are received within 10 seconds after sending of the message.

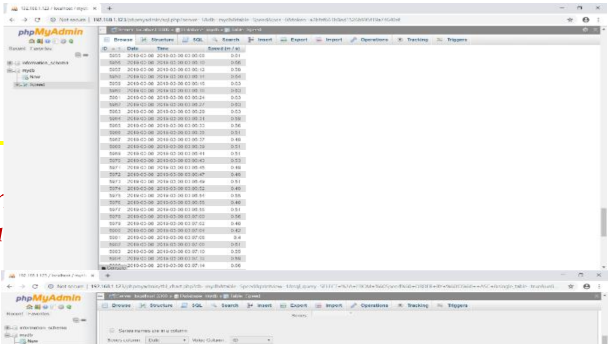


Figure 15. River velocity data log

Figure 15 shows the local server of the study. This is where the processed data can be accessed by authorized personnel. The data processed by the Arduino Uno is sent to the Raspberry Pi 3 via the HC-12 module. On the local server, the data is updated in real-time, in addition to that, the data can be downloaded at different formats, graphical representations are also possible, in this case, a line graph was used.

Presentation and analysis of data

Table 4. Hydropower system water velocity measurement

Trial	**Power Output - Sensor (W)**	**Speed Sensor (m/s)**	**Accuracy (%) with reference value of 0.5506m/s**
1	0.3040	0.5372	97.57
2	0.3101	0.5407	98.20
3	0.3162	0.5442	98.84
4	0.3162	0.5442	98.84
5	0.3101	0.5407	98.20
6	0.3101	0.5407	98.20
7	0.3040	0.5372	97.57
8	0.3223	0.5478	99.49
9	0.3101	0.5407	98.20
10	0.3101	0.5407	98.20
		Standard Deviation: 0.0032	**Average: 98.331**

Table 4 presents the measured power and computed water velocity of the system designed. It includes the power generated by the turbine as seen by the voltage sensor and the computed water velocity from that power. The measurements are acquired right after performing the float method. The values computed were compared to that of the average water velocity measured through float method. From the acquired data, an average accuracy of 98.33 percent was achieved. Additionally, the computed values acquired a standard deviation of 0.0032 which indicates a high precision in measurement.

CONCLUSION

To encapsulate, the proponents were able to design and implement an early flood warning system based on river flow velocity via hydropower generation. To comply with the objectives of the study, the proponents arrived at the following conclusions:

1. The proponents were able to design the sensing system, with a ceramic resistor and voltage sensor. On the other hand, the transmission system comprised of the HC-12 and GSM module. Micro processing modules, such as Arduino Uno and Raspberry Pi 3 were used to interface the sensing and transmitting hardware. The Arduino IDE platforms as well as Raspbian Jessie were used to write the program to the microprocessors.
2. A modified AVT filtering technique was implemented. Instead of using the recorded data's standard deviation, a predetermined standard deviation is used to set up a range of values. This is because, since water velocity gradually changes, under natural conditions, a standard deviation of zero is achieved for a long period of time. Due to this, a range of values will not be established.
3. The system is determined to be reliable in terms of accuracy with a maximum percentage difference of 2.56 percent as well as precision with a standard deviation of 0.0032. In addition to this, the recorded speed of short message service transmission is within the National Telecommunications Commission's requirement of less than 30 seconds.

RECOMMENDATION

The utilization of hydropower generation for water velocity determination is proven to acquire accurate and precise measurements; however, along the accomplishment of the study, some insights are amassed. On the completion of the system prototype, the microprocessor was not fully utilized, if possible, it is recommended to have a personalized module for microprocessor just enough to cater the sensor and other modules. This will trifle the size of the system's case as well as diminish the power consumed by the microprocessor. In addition to this, for high power generating turbines, high rating resistors are advised to be used.

REFERENCES

[1] Asian Disaster Reduction Center. (2018). "*Information on Disaster Risk Reduction of the Member Countries.*" [Online] Available at: http://www.adrc.asia/nationinformation.php?NationCode=608. [Accessed 02 Oct, 2018]

[2] Centre for Research on the Epidemiology of Disasters. (2015) "The Human Cost of Weather-Related Disasters." Retrieved from https://www.unisdr.org/2015/docs/climatechange/COP21_WeatherDisastersReport_2015_FINAL.pdf

[3] Inquirer.net. (2018). "*Laguna de Bay now full, says LLDA.*" [Online] Available at: https://newsinfo.inquirer.net/1020881/laguna-de-bay-now-full-says-llda. [Accessed 02 Oct, 2018]

[4] Final List of Watersheds Supporting 140 River Irrigation System of the NIA (PDF), 2006, Retrieved 2007-09-30

[5] New Jersey Institute of Technology. (2018). "*The Importance of Flood Routing*". [Online] Available at: https://graduatedegrees.online.njit.edu/resources/msce/msce-articles/the-importance-of-flood-routing/. [Accessed 02 Oct, 2018]

[6] Project EFF. (2018). "Design and Implementation of a Community-Installed Earthquake, Flood and Fire Monitoring, Data Acquisition, GSM and Web-Based Warning System." Retrieved from http://projecteff.com/#. [Accessed 20 Nov, 2018]

[7] Wikipedia.com (2019). AVT Statistical Filtering Algorithm. Retrieved from wn.com/avt_statistical_filtering_algorithm [Accessed last 03 Mar, 2019