A METHOD FOR PRESERVING BATTERY LIFE IN WIRELESS SENSOR NODES FOR LORA BASED IOT FLOOD MONITORING USING FUZZY LOGIC-BASED ADAPTIVE SAMPLING ALGORITHM

BY

MOHD AIZAT BIN MOHD YAZID

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Kulliyyah of Engineering
International Islamic University Malaysia

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ABSTRACT

A common challenge in the implementation of Internet of Things (IoT) Wireless Sensor Networks (WSN) is that the sensor nodes are known to be power hungry devices. The energy stored in the batteries which power up these sensor nodes deplete quickly especially when more data is transmitted to the cloud or when multiple sensors are attached to a single sensor node. In the context of flood and environmental monitoring, increasing the number of sensor nodes in a Wireless Sensor Network is desirable to increase the spatial resolution of the data and hence achieve better representation about rising water levels and overall water quality in a particular city. However, having more sensor nodes in a Wireless Sensor Network results in more challenges for the power supply management of the overall Wireless Sensor Network. A drawback of the sensor nodes which are usually powered by Lithium-ion batteries is that there is a limited number of cycles in which a battery can be charged and discharged before the battery is fully degraded and therefore methods which can lengthen the duration of each charging and discharging cycle will be useful to increase the overall battery longevity. In this thesis, a method which combines solar energy harvesting together with a fuzzy logic-based algorithm for adaptive sampling is proposed to achieve a continuous source of energy for the sensor nodes and increase the duration between each charging and discharging cycle resulting in batteries which can last for a longer duration. The sensor nodes will also be using LoRa module for communications as this technology meets the requirement of having low power configurations. A comparison of the sensor node deployed for flood monitoring with and without the proposed algorithm is then presented in the results chapter.

Keywords*: Internet of Things (IoT), Wireless Sensor Network, Logic-based Algorithm.*

خلاصة البحث

من التحديات الشائعة في تطبيق شبكات المستشعر اللاسلكي(WSN) لإنترنت الأشياء (IoT) أن عقد الحساس معروفة بأنها أجهزة متعطشة للطاقة. تنفد الطاقة المخزنة في البطاريات التي تقوم بتشغيل عقد المستشعر هذه بسرعة خاصة عند نقل المزيد من البيانات إلى السحابة أو عند توصيل عدة مستشعرات بعقدة مستشعر واحدة. وفي سياق رصد الفيضانات والبيئة، من المستصوب زيادة عدد عقد الاستشعار في شبكة مستشعر لاسلكي لزيادة الدقة المكانية للبيانات ومن ثم تحقيق تمثيل أفضل بشأن ارتفاع مستويات المياه ونوعية المياه عموما في مدينة معينة. ومع ذلك، فإن وجود المزيد من عقد المستشعر في شبكة المستشعر اللاسلكي يؤدي إلى مزيد من التحديات لإدارة مورد الطاقة في شبكة المستشعر اللاسلكي الشاملة. من عيوب عقد المستشعر التي يتم تشغيلها عادة بواسطة بطاريات ليثيوم أيون أن هناك عددا محدودا من الدورات التي يمكن فيها شحن البطارية وتفريغها قبل أن تنخفض طاقة البطارية بالكامل وبالتالي يمكن أن تطيل مدة كل عملية شحن وتفريغ شحن ستكون الدورة مفيدة لزيادة عمر البطارية الكلي. في هذه الفرضية، ومن المقترح استخدام طريقة تجمع بين جمع الطاقة الشمسية والخوارزمية ذات المنطق الغامض لأخذ العينات التكيفية لتحقيق مصدر مستمر للطاقة لعقد المجس وزيادة المدة بين كل دورة شحن وتفريغ، مما يؤدي إلى بقاء البطاريات لمدة أطول. وسوف تستخدم أيضا عقد المستشعر وحدة LoRa للاتصالات حيث أن هذه التقنية تفي بمتطلبات تهيئة الطاقة المنخفضة. يتم بعد ذلك عرض مقارنة عقدة المستشعر التي تم نشرها لمراقبة الفيضان باستخدام الخوارزمية المقترحة أو بدونها في فصل النتائج.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science in Engineering.

....
Ahmad Jazlan Bin Haja Mohideen
Supervisor

....
Muhammad Afif Bin Husman
Co-Supervisor

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science in Engineering.

....
Zulkifli Zainal Abidin
Internal Examiner

Professor Dr.Che Zalina Zulkifli
Computing Department
Faculty of Arts, Computing & Creative Industry,
Universiti Pendidikan Sultan Idris
35900 Tanjong Malim, Perak, Malaysia

....
Che Zalina Zulkifli
External Examiner

This thesis was submitted to the Department of Mechatronics Engineering and is accepted as a fulfilment of the requirement for the degree of Master of Science in Engineering.

....
Ali Sophian
Head, Department of
Mechatronics Engineering

This thesis was submitted to the Kulliyyah of Engineering and is accepted as a fulfilment of the requirement for the degree of Master of Science in Engineering.

....
Sany Izan Ihsan
Dean, Kulliyyah of Engineering

DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted for any other degrees at IIUM or other institutions.

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TABLE OF CONTENTS

Abstract ii
Abstract in Arabic iii
Approval Page iv
Declaration v
Acknowledgements vii
Table of Contents viii
List of Tables x
List of Figures xi
List of Abbreviations xivv
List of Symbols xv

CHAPTER ONE: INTRODUCTION 1
1.1 Background of the Study 1
1.2 Statement of the Problem 5
1.3 Research Scope 6
1.4 Thesis Contribution 7
1.5 Research Objectives 7
1.6 Thesis Organization 8

CHAPTER TWO : LITERATURE REVIEW 9
2.1 Chapter Introduction 9
2.2 Wireless Sensor Network 9
2.3 WSN-Based Flood Monitoring 12
2.4 Energy Harvesting 15
2.4.1 Photovoltaic Cells 16
2.4.2 Hydropower 17
2.4.3 Piezoelectric 18
2.4.4 RF and Wi-Fi Harvesting 19
2.4.5 Thermo Electric Generator (TEG) 19
2.5 Power Requirements 22
2.6 Fuzzy Logic Algorithm 24
2.7 Chapter Summary 25

CHAPTER THREE : RESEARCH METHODOLOGY 27
3.1 Chapter Introduction 27
3.2 Sensor Node Hardware Setup 28
3.2.1 Circuit Design 28
3.2.2 Energy Harvesting Circuit 30
3.2.3 Power Circuit 30
3.2.4 Communication Circuit 31
3.2.5 Sensor Circuit 32
3.3 Software Development 32
3.3.1 Sensor Node Software Development 32

A) Sensor Node Arduino Setup Function 32
B) Fuzzy Logic Algorithm Setup 33
C) Sensor Node Arduino Loop Function 35
3.3.2 Gateway Node Setup.. 38
3.3.3 Losant Dashboard 41

CHAPTER FOUR : RESULTS AND DISCUSSION 47
4.1 Chapter Introduction... 47
4.2 Indoor Experimental Results 48
4.3 LoRa Network Range 56
4.4 Real Time Monitoring Using Fixed and Mobile Sensor Nodes 58
4.5 Chapter Summary 61

CHAPTER FIVE : CONCLUSION AND FUTURE WORK......................... 62
5.1 Conclusion 62
5.2 Future Work 63

REFERENCES.. 64

Appendix A: Sensor Node Arduino Code 69
Appendix B: Gateway Node Arduino Code.. 84
Appendix C: Gateway Node Python Code.. 85

LIST OF PUBLICATIONS 87

LIST OF TABLES

Table 2.1	Battery Technologies with their Advantages and Disadvantages	24
Table 3.1	Fuzzy Logic Rules for the Inputs and Output	34
Table 4.1	Comparison of the Number of Charge-Discharge Cycles Between the Proposed Sampling Proposed Method and the Baseline Fixed Sampling Rate Method	55

LIST OF FIGURES

Figure 1.1	Hardware setup of the flood sensor prototype done by Rodzi, Zakaria and Ismail (2017)	4
Figure 1.2	Mounting of sensor node done over river in Kemaman, Malaysia by Rodzi, Zakaria and Ismail (2017)	5
Figure 2.1	Sensor Nodes and a Gateway Arrangement in a Wireless Sensor Network	10
Figure 2.2	Internal Components of a Sensor Node	10
Figure 2.3	Photovoltaic Cell / Solar Panel	16
Figure 2.4	Micro Hydro Turbine	17
Figure 2.5	Piezoelectric Generators	18
Figure 2.6	RF and Wi-Fi Rectenna designed by Bjorkqvist et al. (2018)	19
Figure 2.7	Thermo Electric Generator	19
Figure 2.8	Block Diagram of Sensor node model with energy harvesting powering the system directly	21
Figure 2.9	Block Diagram of Sensor Node with Energy Harvesting Powering the System Through a Rechargeable Battery	21
Figure 2.10	Power generation and consumption in continuous operation by Mateu and Moll (2005)	22
Figure 2.11	Power generation and consumption in discontinuous operation by Mateu and Moll (2005)	23
Figure 3.1	Hardware setup proposed in this Thesis	27
Figure 3.2	Circuit Schematic of Sensor Node	28
Figure 3.3	LoRa Communication Module	30
Figure 3.4	Battery Voltage Membership Function as Fuzzy Logic Input 1	33
Figure 3.5	Charging Current Membership Function as Fuzzy Logic Input 2	33
Figure 3.6	Interval Membership Function as Fuzzy Logic Output	33

Figure 3.7 Flowchart for the Sensor Node 35

Figure 3.8 Flowchart for the Gateway Node 38

Figure 3.9 Losant Dashboard for the IoT Flood Sensor System 38

Figure 3.10 Losant Dashboard Workflow Setup for Alerts Through E-Mail 42

Figure 3.11 Condition Setup for Water Level Between 50cm and 100cm (Condition 2) 43

Figure 3.12 E-Mail Address and E-Mail Body Setup for Condition 2 43

Figure 3.13 Condition Setup for Water Level Exceeding 100cm (Condition 3) 44

Figure 3.14 E-Mail Address and E-Mail Body Setup for Condition 3 44

Figure 3.15 E-Mail Alert Sent by the System When the Water Level Reaches the Set Conditions 45

Figure 4.1 Sensor Node Battery Life with 60 Seconds Sampling Period 47

Figure 4.2 Charging and Discharging of the Battery for a 7-day Period with Adaptive Sampling Utilized 48

Figure 4.3 Charging Current for a 7-day Period with Adaptive Sampling Utilized 49

Figure 4.4 Variation in Sampling Period for a 7-day Period with Adaptive Sampling Utilized 49

Figure 4.5 Multiple Axis Plot Showing Interdependence Between Battery Voltage, Charging Current and Sampling Period During a 7-Day Duration 52

Figure 4.6 Charging and Discharging of the Battery for a 30-day Period with Adaptive Sampling Utilized 53

Figure 4.7 Charging Current for a 30-day Period with Adaptive Sampling Utilized 53

Figure 4.8 Variation in Sampling Period for a 30-day Period with Adaptive Sampling Utilized 54

Figure 4.9 Multiple Axis Plot Showing Interdependence Between Battery Voltage, Charging Current and Sampling Period During a 30-Day Duration 54

Figure 4.10 Range for the Coverage of the LoRa Network within the IIUM Campus 56

Figure 4.11	Internal View of Sensor Node Placed Inside a Weather-proof Container	57
Figure 4.12	Placement of Sensor Node Underneath a Bridge for River Water Level Monitoring	58
Figure 4.13	Placement of Sensor Node Underneath a Bridge for River Water Level Monitoring (Side View Illustrations)	58
Figure 4.14	Variation in River Water Levels for a 3-day Period	59

LIST OF ABBREVIATIONS

IoT	Internet of Things
WSN	Wireless Sensor Node
NB-IoT	Narrowband Internet of Things
LoRa	Long Range
LoRaWAN	Long Range Wide Area Network
CSS	Chirp Spread Spectrum
API	Air Pollutant Index
PIC	Peripheral Interface Controller
GSM	Global System for Mobile communications
SMS	Short Message Service
LPWAN	Low-Power Wide Area Network
RF	Radio Frequency
DC	Direct Current
Wi-Fi	Wireless Fidelity
TEG	Thermal Electric Generator
PMIC	Power Management Integrated Circuit
BMS	Battery Management System
JSON	JavaScript Object Notation
MQTT	MQ Telemetry Transport
AWS	Amazon Web Service
GCP	Google Cloud Platform
APIs	Application Programming Interfaces
USB	Universal Serial Bus
PCB	Printed Circuit Board

LIST OF SYMBOLS

ΔS	Seebeck Coefficient
ΔT	Temperature Gradient
V	Voltage/Volts
A	Ampere
W	Watt
μ	Micro
M	Mega
Hz	Hertz
dBi	Decibel Relative to Isotrope

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Flooding is a common natural disaster that happens in Malaysia. The first common type of flood is the monsoon floods, which happens annually due to the monsoon season, commonly affecting the east coastal cities of Peninsular Malaysia. The worst monsoon flood that had happened in the past few decades locally was the 2014 monsoon flood, which had affected more than 200,000 people and had claimed 21 lives (Alias et al., 2019). The other type, which is the flash flood, can happen anywhere and anytime due to Malaysia's tropical rainforest climate whereby it rains throughout the year, commonly affecting areas around rivers such as along the Klang river in Kuala Lumpur and Kuantan River in Pahang, as well as areas which does not have good water channeling facilities. The Stormwater Management And Road Tunnel (SMART) in Kuala Lumpur was constructed to rectify the second issue in which when there is a sudden and sustained heavy rain and when the water level starts to rise, the tunnel can be used to drain out the water excess to reservoirs or other water channels. SMART tunnel under normal operations is otherwise used as an expressway for light vehicles to enter the heart of the city (Zabidi and De Freitas, 2013).

Other places, however, do not have this kind of mitigation and thus, quick responses and swift actions are needed to minimize damage as well as evacuation of people when need be. Therefore, a constant monitoring over the water level for rivers that is commonly causing flood to the nearby areas is needed. Traditionally, people are sent or stationed at key areas of the rivers, such as the upstream part of the river, or the intersection where multiple rivers converge to do the monitoring. This method is simple, but unreliable as a person might not be there all the time to monitor, and there could also be human error in the process. As such, Internet of Things (IoT) Wireless Sensor Nodes (WSN) could take over the process of monitoring, in which constant sampling of data can be done reliably as well as autonomously.

WSNs consist of multiple sensor nodes that can be densely deployed to gather information from large geographical areas of interest and these sensor nodes are equipped with the ability to transmit data to a cloud, enabling the data to be accessible in any part of the world. Each sensor node is fitted with at least one or more sensors, a radio transceiver, a microcontroller, and a power supply unit. Although WSNs are an effective means of gathering large amounts of valuable environmental data, the required energy consumption of these sensor nodes to maintain continuous operation is an ongoing challenge (Buurman, Kamruzzaman, Karmakar, and Islam, 2020; Wu, Redoute and Yuce, 2020; Azevedo and Santos, 2012; Moreno et al., 2019; Lazarescu, 2013; Mois, Folea, and Sanislav, 2017).

With the further development of cloud computing, grid computing and Peer-to-Peer networks and deep learning artificial intelligence, the need for WSN has been further expanded to a wider variety of applications. One of the promising applications of WSNs is for environmental and disaster detection systems such as monitoring flood, haze, and landslides. The developers of such WSNs would also need to ensure that there are no accidental false positive triggers in their systems. For flood detection system in particular, the easiest parameter that can be monitored to detect the flooding is the water level in ponds, rivers, or drains.

Therefore, many of the existing flood detection systems have used weatherproof, industry grade ultrasonic sensor to measure rising water levels as an indicator to detect the flood (Mousa, Zhang. and Claude, 2016; Kumar, Agrawal, and Khan, 2019; Arshad, Ogie, Barthelemy, Pradhan,Verstaevel and Perez, 2019; Acosta-Coll, Ballester-Merelo, Martinez-Peiro. and De la Hoz-Franco, 2018). The location of the WSN is crucial to collect information about an impending flood. It is preferable to place WSNs in ponds which accumulate water rather than in rivers or drains with flowing water (Qian, Sun, Li, Sun, Lin, and Jiang, 2019). In addition, there needs to be a lead time of at least one hour for a flood detection system to be useful.

Other than the measurement of rising water levels with ultrasonic sensors, other water level monitoring methods which have been previously used for detecting impeding floods involved measuring the rising water flow rate levels at the coastal areas. When the flow rate is higher than a threshold flow rate, this indicates the likelihood of flooding to occur (Basha, Ravela and Rus, 2008). In addition to detection of flooding itself, dissolved oxygen measurements can provide some cues about the health hazards posed by the flood such as the degree of contamination of the water in the flooded areas. Therefore, in this study we have dedicated one sensor node for the measurement of rising water levels.

The foundation for the research presented this thesis is a further development of a previous work done by the author in collaboration with Rodzi, Zakaria and Ismail (2017). The sensor node hardware setup for this research was placed over the Kemaman river in Terengganu, whereby an ultrasonic sensor was used to measure the water level at a location along the Kemaman riverbank. The ultrasonic sensor was connected to an Arduino microcontroller unit as shown in the block diagram presented in Figure 1.1. Since such sensor nodes are exposed to varying weather conditions, a waterproof container was needed to protect it. As for the placement, the node was mounted at a point of interest over the river, typically where two smaller rivers joined into a bigger one, as well as certain key points of the river (e.g. before reaching residential areas or nearby flood-prone areas). Figure 3.3 shows the mounting of the node on a bridge over the river for the setup by Rodzi, Zakaria and Ismail (2017) with Figure 1.2 (a) showing the solar panel being used and mounted with the sensor node, Figure 1.2 (b) showing how the node mounted at the side of a bridge directly above a river and Figure 1.2 (c) showing the weatherproof container used as the casing to protect the electronics from the rain.

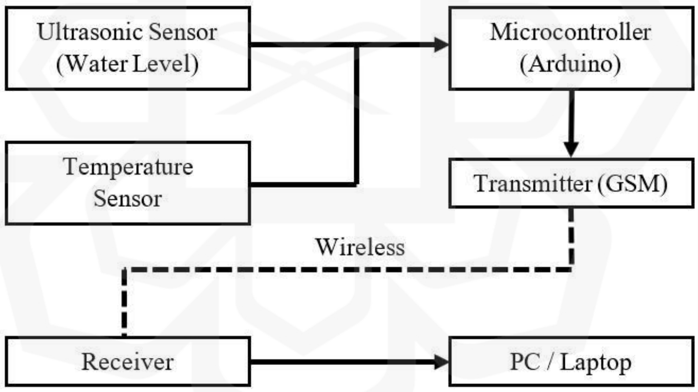

Figure 1.1: Hardware setup of the flood sensor prototype done by Rodzi, Zakaria and Ismail (2017)

a b c

Figure 1.2: Mounting of sensor node done over river in Kemaman, Malaysia by Rodzi, Zakaria and Ismail (2017)

During this study in collaboration with Rodzi, Zakaria and Ismail (2017), it was found that the GSM module consumes a lot of energy, subsequently draining the battery in 7 days. Batteries used in this setup were lead acid batteries that are heavy and bulky, making the sensor node unnecessarily heavy and large. Furthermore, even though solar panel was used in the system, it was not able to recharge the battery as the capacity was too large while the energy harvested was too little to ensure continuous running of the sensor node, resulting in the node only operating for only 7 days and unable to operate afterwards.

1.2 STATEMENT OF THE PROBLEM

Deployment of flood sensors is needed in areas that are prone to flooding as a means for early detection, quick responses, and damage mitigations. Remotely located WSN-based IoT sensor nodes will give a significant advantage over the traditional method of having a person to monitor over a period as IoT sensor nodes enable the data to be recorded autonomously and accurately in either fixed or varying sampling intervals.

However, deployment of these nodes in remote areas can be challenging since a constant power is always needed although no connections to the electricity grid are available. Furthermore, low-power configurations for the microcontroller and the communication module are needed for a battery-powered node to sustain for a longer duration. An energy harvesting method is therefore needed to supply enough energy to recharge the battery to keep it from depleting and ensure continuous operations. Additionally, a self-regulating method can be introduced to further prolong the operations of the battery-powered node by means of controlling the intervals of the sampling. Therefore, a self-sustained, low-power, self-regulating IoT sensor nodes are required for the deployment of flood early warning monitoring system in remote areas.

1.3 RESEARCH SCOPE

This research will explore and evaluate the usage of solar power-based energy harvesting for charging Lithium-Ion batteries which are used to power up an IoT Sensor Node. An ultrasonic sensor is used for water level monitoring. A LoRa-based module is selected for the wireless communication to meet the low-power requirements. A method which combines solar energy harvesting together with a fuzzy logic-based algorithm for adaptive sampling is proposed to achieve a continuous source of energy for the sensor nodes and increase the duration between each charging and discharging cycle resulting in batteries which can last for a longer duration in the long run. This research will not cover the optimizations of wireless communication over the LoRa wireless communication network such as the LoRaWAN system.

1.4 THESIS CONTRIBUTION

In this thesis, we present a method to lengthen the battery life of the sensor nodes in a Wireless Sensor Network by combining the usage of solar energy harvesting together with adaptive sampling using fuzzy logics. This proposed method reduces the number of charging and discharging cycles of the battery for a particular period, subsequently reducing the battery degradation over time, and resulting in longer lasting batteries A dedicated circuit is designed for each of these sensor nodes which consists of solar energy harvesting, boost converters, an Arduino microcontroller attached to a LoRa communication module, sensors, and trickle charge power management ICs. Fuzzy logics is then incorporated into the Arduino code to achieve adaptive sampling to minimize energy usage. Experiments are then conducted to test the battery life while data is being sent to the cloud and visualized using a Losant dashboard. The overall system is then commissioned to measure water levels on a river.

1.5 RESEARCH OBJECTIVES

This research aims to achieve the following objectives:

1. To design and develop the hardware circuitry for an IoT sensor node that combines energy harvesting and low power technologies, and suitable algorithm to lengthen the battery life of the sensor nodes in a Wireless Sensor Network by combining the usage of solar energy harvesting together with adaptive sampling using fuzzy logics.

2. To commission the developed system to measure water levels on a river for a 30-day duration and transmit the data to a cloud (Losant).

3. To analyze the performance of the sensor node running the algorithm.

1.6 THESIS ORGANIZATION

This thesis is organized into five chapters as presented follows.

1. Chapter 1 describes the background of the research, problem statement, research scope, and research objectives.
2. Chapter 2 describes the literature review of previous research conducted in this area.
3. Chapter 3 describes both the hardware and software development for this research.
4. Chapter 4 describes the results obtained from the deployment of the developed system over a river.
5. Chapter 5 provides the conclusion of this study and recommendations for future work.

CHAPTER TWO

LITERATURE REVIEW

2.1 CHAPTER INTRODUCTION

This chapter provides a literature review for the development of energy harvesting enabled IoT sensor nodes. This chapter is divided into four sections namely Wireless Sensor Network, Energy Harvesting, Power Requirements and Preliminary Work.

2.2 WIRELESS SENSOR NETWORK

Wireless Sensor Network (WSN) is a wirelessly interconnected network of nodes that has one or more sensors attached to each node that can provide meaningful data for various purposes be it environmental monitoring, early detection of disasters, surveillance, or other tasks. WSNs have not only been extensively developed as a means for battlefield surveillance but has currently been adopted into industrial and consumer applications as well (Nitin Kumar, Yadav and Verma, 2020).

The most basic model of a WSN involves one sensor node and a gateway. A sensor node includes not only sensors to gather data but also microcontrollers to operate and automate the process, batteries to power up the device and transmitter modules such as radio frequency modules to send data to the gateway. The latter will gather data from the sensor node to process it and alert users if a certain threshold is reached. Recent gateways are also equipped to be Internet of Things (IoT), the capability to connect to the internet and have the data be stored in a cloud-based