DESIGN AND DEVELOPMENT OF ULTRA LOW POWER EMBEDDED SYSTEM FOR IOT DEVICES

CHUA ENG SENG

This Report Is Submitted in Partial Fulfilment of Requirements for The Bachelor Degree of Electronic Engineering (Telecommunication Electronics) with Honours

Faculty of Electronics and Computer Engineering

Universiti Teknikal Malaysia Melaka

June 2017

UNIVERSITI TEKNIKAL MALAYSIA MELAKA
FAKULTI KEJURUTERAAN ELEKTRONIK DAN KEJURUTERAAN KOMPUTER

BORANG PENGESAHAN STATUS LAPORAN
PROJEK SARJANA MUDA II

Tajuk Projek : DESIGN AND DEVELOPMENT OF ULTRA LOW POWER EMBEDDED SYSTEM FOR IOT DEVICES

Sesi Pengajian :

1	6	/	1	7

Saya CHUA ENG SENG

mengaku membenarkan Laporan Projek Sarjana Muda ini disimpan di Perpustakaan dengan syarat-syarat kegunaan seperti berikut:

1. Laporan adalah hakmilik Universiti Teknikal Malaysia Melaka.
2. Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan laporan ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. Sila tandakan (√) :

☐ **SULIT*** — *(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)

☐ **TERHAD**** — **(Mengandungi maklumat terhad yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)

☑ **TIDAK TERHAD**

Disahkan oleh:

(TANDATANGAN PENULIS)

(COP DAN TANDATANGAN PENYELIA)

Dr. WONG YAN CHIEW
Pensyarah Kanan
Fakulti Kejuruteraan Elektronik & Kejuruteraan Komputer
Universiti Teknikal Malaysia Melaka (UTeM)
Hang Tuah Jaya
76100 Durian Tunggal, Melaka

Tarikh: 02/06/2017

Tarikh: 02/06/2017

"I hereby declare that the work in this project is my own except for summaries and quotations which have been duly acknowledge."

Signature :..

Author : CHUA ENG SENG

Date : 2nd JUNE 2017

"I acknowledge that I have read this report and in my opinion this report is sufficient in term of scope and quality for the award of Bachelor of Electronic Engineering Electronic Telecommunication with Honours."

Signature :...

Supervisor's Name : DR. WONG YAN CHIEW

Date : 2nd JUNE 2017

Special thanks to my family, project supervisor, Dialog Semiconductor, friends and other staff in UTeM

ACKNOWLEDGEMENT

First and foremost, I would like to thank my project's supervisor, Dr. Wong Yan Chiew for her advice and encouragement in this project that make this project achievable with a marvelous outcome. Her guidance has always keep me on the right track for the project development. Besides that, I would like to thank her for the funding she has given to this project especially in the hardware's expenses. It is an honor for me to work along with her in completing this project.

The process of completing this project is through thick and thin but it has been completing successfully due to the team that has always lend a helping hand. With this, I would like to thank the Dialog Semiconductor's team especially JT_Dialog and MT_Dialog for always giving the 100% in their customer service's forum. All the obstacles on the firmware of the development kit has been solved because they are giving the best guidance to me in programming the firmware and they have taught me a lot about the potential of the development kit.

Besides that, I would like to thank some of my friends who gives me encouragement and advice when I am in dire straits. They have even lent me their equipment in order for me to make measurement. Besides, I would like to pay the deepest gratitude to my love ones which includes my parent, my siblings and my beloved for their understanding and compassion when I am having the hard times.

Finally, I am grateful that I am able to complete this project in time and I would like to thank those who have contributed to the accomplishment of this project.

ABSTRACT

There will be billions of IoT devices in the near future and each need to be powered up by a constant power supply, these devices will sooner or later be running out of power since most of the IoT devices are powered up by battery. Changing the battery supply constantly will need many resources such as manpower, capital and time. The Ultra Low Power (ULP) properties allow system to work for longer hours and hence this decreases the maintenance time. Due to increasing of IoT wearables in the medical fields, the embedded system will be built based on the medical application especially the Cognitive Heart Failure (CHF) since it is the number one killer among other diseases according to the World Health Organization (WHO). To allow long term monitoring of the patient with CHF, the ULP Electrocardiogram (ECG) Embedded System is designed and developed. Different ULP Microcontroller (MCU) that are available in the market are being compared and the DA14580 basic development kit with low current consumption is chosen to be connected with the AD8232 module to capture ECG signal and thus sending the ECG values via Bluetooth Low Energy (BLE) to the android smartphone. ECG signal with different BLE sending rate and during different physical activity are compared and data obtained via Universal Asynchronous Receiver or Transmitter (UART) communication is analyzed. The current consumption is determined to validate the whole system. Lifetime of the embedded system is validated through the battery level measurement. The system is able to achieve a current consumption of 2.82 mA and an approximate power consumption of 356.48 mW. It is found that the battery level maintains at 37% for the next 2 hours after 3 hours of operation during extended sleep mode and able to last for 7 days continuously. This project demonstrates that the ULP ECG embedded system is developed and it is able to send the ECG values through BLE for ECG signal detection.

ABSTRAK

Terdapat berbilion alat-alat IoT pada masa akan datang dan tiap-tiap satu memerlukan kuasa elektrik untuk berfungsi dan biasanya menggunakan kuasa bateri. Akan tetapi, kuasa bateri akan kehabisan lama-kelamaan. Sistem terbenam yang berkuasa ultra rendah dapat berfungsi untuk tempoh yang lebih panjang. Aplikasi IoT yang dipilih bagi membina sistem terbenam ini ialah aplikasi yang berkaitan dengan bidang perubatan terutamanya berkaitan dengan penyakit jantung kerana penyakit jantung ialah pembunuh utama mengikut statistik daripada WHO. Oleh itu, alat penerimaan Elektrokardiogram (EKG) yang berfungsi menggunakan kuasa ultra rendah (ULP) telah dibina melalui pelaksanaan projek ini. Selain itu, perbandingan antara pelbagai Mikorpengawal (MCU) yang tersedia di pasaran telah dibuat. Mikropengawal DA14580 telah dipilih dan dikonfigurasikan supaya data dapat dihantar melalui Bluetooth Kuasa Rendah (BLE) dan diterima oleh telefon pintar. Isyarat EKG yang dihantar dengan kadar penghantaran yang berbeza dan ketika melakukan aktivit fizikal yang berbeza telah dibandingkan dan corak isyarat EKG telah dianalisakan menggunakan data yang diterima melalui komunikasi UART. Pengunaan arus telah diukur dan dianalisakan juga. Tempoh hidup bagi sistem terbenam telah disahkan melalui pengukuran tahap bateri. Melalui projek ini, alat ini telah dibuktikan dapat berfungsi dengan arus yang bernilai 2.82 mA dan kuasa elektrik yang bernilai kira-kira 356.48 mW. Nescaya, projek ini mencapai matlamatnya. Tambahan lagi, alat ini didapati bahawa dapat mengekalkan tahap baterinya pada 37% bagi 2 jam yang seterusnya setelah alat tersebut telah berfungsi untuk 3 jam dalam mod tidur lanjutan dan dapat bertahan untuk 7 hari secara berterusan. Projek ini menunjukkan sistem terbenam yang berkuasa rendah ultra ini dapat menghantar nilai EKG melalui BLE bagi pengesanan EKG.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVATIONS

ULP	-	Ultra Low Power
IoT	-	Internet of Things
ECG	-	Electrocardiography
CHF	-	Cognitive Heart Failure
SA	-	Sino-atrial
AV	-	Atrio-ventricular
BLE	-	Bluetooth Low Energy
ES	-	Embedded System
SoC	-	System-on-Chip
MCU	-	Microcontroller
AFE	-	Analog Front End
RF	-	Radio Frequency
PPG	-	Photoplethysmography
PWM	-	Pulse Width Modulation
PD	-	Photodiode
LED	-	Light Emitting Diode
MOSFET	-	Metal–Oxide–Semiconductor Field-Effect Transistor
bpm	-	Beat per Minute
WSN	-	Wireless Sensor Network
QoS	-	Quality of Service
IC	-	Integrated Circuit
CMOS	-	Complementary Metal–Oxide–Semiconductor
PMU	-	Power Management Unit
ITU	-	International Telecommunication Union

PCB	-	Printed Circuit Board
RAM	-	Random Access Memory
Micro SD	-	Micro Secure Digital
FAT	-	File Allocation Tab
AR	-	Activity Recognition
RA	-	Right Arm
LA	-	Left Arm
RL	-	Right Leg
LL	-	Left Leg
ADC	-	Analog to Digital Converter
GPIO	-	General Purpose Input and Output
LDO	-	Low Dropout
ACC	-	Accelerometer
AC	-	Alternating Current
DC	-	Direct Current
DMM	-	Digital Multimeter (DMM)
DAQ	-	Assembled Data Acquisition
ABS	-	Acrylonitrile Butadiene Styrene
EEG	-	Electroencephalogram
R&D	-	Research & Development
SMD	-	Surface Mounted Device
JTAG	-	Joint Test Action Group
SPI	-	Serial Peripheral Interface
I2C	-	Inter-Integrated Circuit
UART	-	Universal Asynchronous Receiver Transmitter
ATT	-	Attribute Protocol
GATT	-	Generic Attribute Protocol

GAP	-	Generic Access Profile
SIG	-	Special Interest Group
ADC	-	Analog to Digital Converter
HCI	-	Host Controller Interface
L2CAP	-	Logical Link Control & Adaption Protocol
ATT	-	Attribute Protocol
SM	-	Security Manager Protocol
SDK	-	Software Development Kit
OTP	-	One-Time Programmable
QFN	-	Quad-Flat No Leads

CHAPTER 1

INTRODUCTION

1.1 Project Overview

This project revolves around the design and development of Ultra Low Power (ULP) embedded system for Internet of Things (IoT) devices. Since there are many applications in the field of IoT, this project choses medical application because there are many opportunities in medical applications. This project has narrowed down its scope to long term Electrocardiogram (ECG) signal monitoring for patients with Cognitive Heart Failure (CHF). A long-term monitoring of ECG signals will be developed and will achieve the ULP properties. Different type of elements will be compared in order to obtain the lowest power consumption while maintaining its performance. All the final compared components will be assembled together that will make up the whole embedded system. A smartphone will become the gateway for displaying the ECG signals obtained from the patients via Bluetooth Low Energy (BLE). Android application will be used to display the ECG signals obtained. The data that is being displayed on the smartphone will be used by the doctors for analysis. This will help the medical practitioners to predict the next seizure of CHF so that the patients and the doctors can be aware of it. Hence, this increase the response times for the medical practitioners in the hospital because they can monitor their patients condition outside the patients' room. Due to the fact that the long-term monitoring is very important, thus the embedded system needs to last long so that it is able to measure the ECG signals of the patient at critical times. Besides, the doctors do not need to send the nurses to the patient's room to continuously monitor their ECG signal pattern since the doctors can do them in their own room which make the response time to be faster in predicting any seizures.

1.2 Problem Statement

There will 20.8 billion of IoT devices on 2020 [1] and since there are so many IoT devices on the market, maintenance is indeed needed frequently most of the IoT devices required change of power supply when their batteries are depleted. By applying ULP technology in these devices, the power consumption of IoT devices decrease and able to sustain a longer operation period. This can lower the maintenance costs of IoT devices and they are more able to perform long term monitoring than the current IoT devices design. To achieve the state of ULP of an IoT device, the form factor of the device is of great consequences. This is because the form factor of the device plays a main role in consuming power from the battery supply. For instance, the design of microprocessors is getting smaller and smaller in order to consume less power and while maintaining its overall performance. This apply to the ULP embedded system that this project focuses on. As a result of lowering the form factor of the device, the manufacturing cost of the device decreases significantly as IoT devices are tend to be produced massively in Industry 4.0 which is the latest generation of industry. However, there are plenty of IoT devices out there and the concern will be put on the IoT devices on the medical field since health is the paramount of living in the 21st century. According to the statistical data obtained from the Internet, IoT electronics will be facilitating 322.69 million lives by the end of 2017 and medical wearables have made a rising share of 25-30% in the market [2]. This will become the additional factor for the choice of ULP to be done on medical applications. Since there are also many medical applications that the ULP technologies can apply, this project will focus especially on ECG signal acquisition system for long term monitoring on the patient who is diagnosed with CHF because CHF is the disease with the highest mortality rates among Asians and Europeans which causes 1 million of hospitalization annually in developing countries. The previously made ECG Holter monitor which exists since 1960s is cumbersome to wear, required highly skilled staff to use it, high power consumption which forbids long term monitoring applications and this long term monitoring embedded system for ECG signal acquisition is still in the premature stage whereby most of these type of devices are not very popular among medical practitioners due to they are not able to be used for long term monitoring due to high power consumption and lack of energy harvesting source. Hence, an Ultra Low Power ECG signal acquisition system for long term monitoring will be built in this project.

Long term monitoring means that the embedded system must be able to provide longer active time while maintaining ULP consumption throughout the whole monitoring process so that it can monitor for a long period of time without depleting the battery used fast.

1.3 Objectives

There are 4 main objectives for this project and they are:

1) To identify the low power processor and sensors for the ECG monitoring system.
2) To investigate the design methods and key functional blocks of ECG monitoring system.
3) To develop Ultra Low Power and long-term ECG monitoring system to monitor the ECG signals from CHF patients.
4) To verify the functionality and reliability of the developed ECG system.

1.4 Scope of Project

The ULP embedded system for IoT devices will only cover ECG signal acquisition system for long term monitoring only and will not cover other IoT devices. The ULP properties will be made as the main concern of this project while other additional function will act as an extra advantage for this project. Besides, the ability to automatically perform diagnosis on the patients' condition and provide warning signs to alert a particular patient will not be included in this project. This is because the data obtained from the acquisition system per se is for the medical practitioners or doctors to perform medical diagnosis. All the parts or components that build up the embedded system are not components that are self-designed but they are the available components that will be bought from the market. Besides that, this project will not cover the utilization of energy harvesting source to validate its low power consumption but instead using current measurement method to validate that its power consumption is low compared to one of device from one of the journals picked in literature review section. This project also will not cover an always-on ECG embedded system since it is using a rechargeable battery source which the device need to be put to charge after sometimes. Cloud data storage is not covered in this embedded system design as the whole system design and development will end with the smartphone becomes the gateway via BLE to display the ECG signal obtained. Besides that, the ECG signal processing is not covered in this project and therefore the output values are in terms of ECG signal values and not heart rate. The flow rate of the ECG signals are not optimized in this project and the signal flow will be according to the existing BLE configuration of the device.

Basically, what will be covered for ULP embedded system is the long-term monitoring for CHF patients. The design of the embedded system is kept in a small form factor using surface mount. Besides, this project will also cover the comparisons between the power consumption of existing embedded system from the journals and the power consumption of the designed embedded system. Comparisons will also be done for each System-on-Chip (SoC) component used so the lowest power consumption SoC can be determined. Last but not least, this project will only cover the use of ECG electrodes but not any optical sensor for obtaining ECG signal. The long-term monitoring provided by this project will also has its limits whereby the power source will be depleted. Hence, the long-term monitoring ability of the embedded system will cover up to the capacity of the battery used itself. The higher battery capacity, the longer it will last. Besides that, this project will only cover the ECG values obtained in terms of instantaneous values displayed from the BLE android applications and not the whole waveform of the ECG signal.

1.5 Project Development

The project development can be summarized into 5 stages basically and they are the comparisons and research stage, the sourcing for materials stage, hardware and software development stage and connecting the embedded system to the smartphone via BLE through android application. The final stage will cover the power consumption validation of the embedded system. The comparisons and research stage will revolve around the utilization of information gathered from different journals to find the functional block diagram of the ECG acquisition system, algorithms that are being used, key parameters to look upon in determining the lowest power consumption, and the method of designing the ECG acquisition system based on previous research by others. The first stage also includes the comparisons between datasheets of different components used in designing the embedded system so each component is particularly chosen to achieve ULP. The second stage which comprises of sourcing the ECG module, development kit and other small parts to build the whole ECG embedded system. Thirdly, the validation process will be implemented to determine whether the designed embedded system able to be lowered than a certain amount so that it can be called as ULP embedded system. This amount will be determined through previous research and ULP embedded system done by other researches which the current consumption from previous researches will be the baseline to validate the ECG embedded system. The final stage of this project will be connecting the embedded system to the gateway which is the smartphone via BLE so that the ECG signal will be shown from the smartphone.

1.6 Report Outline

This report contains of 5 chapters and they are the introduction, literature review, methodology, results and discussion and finally the conclusion and future work. The report outline will describe each chapter briefly.

Chapter 1 – Introduction

This chapter explains about the overview of the whole project and the reason to do this report. The scope of the project will also be discussed in this section where what will be covered in this project and what will not be covered in this project. Finally, a brief explanation about the project development has also been included in this chapter.

Chapter 2 – Literature Review

This chapter discussed all the theoretical and background for about the design of cardiac monitoring system done by other researchers. Besides that, the design methods, key functional block which is the architecture of the embedded design, and key parameters in comparing each components of the embedded system have also been discussed in this chapter. The selections of components are also included in this chapter.

Chapter 3 – Methodology

Chapter 3 revolves around the design process of the ULP ECG embedded system. Different stages are being introduced to create a more systematic design process. Each stage is being discussed meticulously and the chapter also includes the flow chart of the whole design and development process.

Chapter 4 – Components in ECG Embedded System

This chapter will explain about the experimental set up of the ECG Embedded System. Besides, how the components are being tested and the initial hardware and software design are being discussed and described.

Chapter 5 – ECG Signal Analysis

This chapter will discuss about the ECG signal obtained from ULP ECG Embedded System but the ECG signal is not covered in this project. This chapter will verify the different conditions of ECG signal that can be detected by the embedded system. The heart rate values are calculated from the ECG signal obtained.

Chapter 6 – Current Consumption Validation

This chapter will validate the project reliability and functionality through the current consumption measurement. This will verify whether the embedded system has achieved the baseline current consumption which is being defined in Chapter 2. The power consumption will also be calculated so that it acts as the evidence that the system created by this project has achieved ULP.

Chapter 7 – Conclusion

This chapter concludes the whole project. Further possible improvement of the project will be discussed here. The objectives stated in Chapter 1 will be once again be verified.