

**DESIGNING**  
**A LOW-COST EDUCATIONAL LEARNING KIT**  
**BASED ON ARM CORTEX-M CORES**

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**by**

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# TABLE OF CONTENT

<b>Acknowledgement</b> .....	<b>ii</b>
<b>Table of Content</b> .....	<b>iii</b>
<b>List of Tables</b> .....	<b>vi</b>
<b>List of Figures</b> .....	<b>vii</b>
<b>List of Abbreviations</b> .....	<b>viii</b>
<b>Abstrak</b> .....	<b>x</b>
<b>Abstract</b> .....	<b>xi</b>
<b>Chapter 1 Introduction</b>	
1.1 Overview.....	1
1.2 Problem Statement.....	2
1.3 Objectives of Research .....	2
1.4 Scope of Research.....	3
1.5 Report Outline.....	3
<b>Chapter 2 Literature Review</b>	
2.1 Overview.....	5
2.2 History of ARM Processor .....	5
2.3 ARM Processor Organization.....	7
2.4 Evolution of Processors Architectures in Mobile Phone .....	8
2.5 Performance of ARM Processor .....	9
2.6 Application of ARM Processor.....	11
2.7 Uses of ARM Processor for Education Purpose.....	12
<b>Chapter 3 Research Methodology</b>	
3.1 Overview.....	14
3.2 Project Implementation Flow.....	14
3.3 Project Requirement .....	16
3.3.1 Hardware.....	16
3.3.1(a) NXP FRDM-KL25Z Development Board .....	16
3.3.1(b) LED Dot Matrix .....	18
3.3.1(c) Seven-Segment Display .....	18
3.3.1(d) 4x4 Keypad .....	19

3.3.1(e) Liquid Crystal Display (LCD).....	20
3.3.2 Software .....	20
3.3.2(a) ARM Mbed Online IDE .....	21
3.3.2(b) HyperTerminal .....	22
3.4 Experiment Setup.....	23
3.4.1 Basic I/O control on NXP FRDM-KL25Z .....	23
3.4.2 Serial Monitor Communication .....	25
3.4.3 Capacitive Touch Sensor Slider Interfacing .....	25
3.4.4 3-Axis Accelerometer Interfacing .....	25
3.4.5 LED Dot Matrix Interfacing .....	26
3.4.6 Seven-Segment Display Interfacing .....	27
3.4.7 4x4 Keypad Interfacing .....	28
3.4.8 LCD Interfacing .....	30
3.4.9 Interrupt Enable .....	31
<b>Chapter 4 Result and Discussion</b>	
4.1 Overview.....	32
4.2 Result & Discussion.....	32
4.2.1 Basic I/O control on NXP FRDM-KL25Z .....	32
4.2.2 Serial Monitor Communication .....	33
4.2.3 Capacitive Touch Sensor Slider Interfacing .....	35
4.2.4 3-Axis Accelerometer Interfacing .....	36
4.2.5 LED Dot Matrix Interfacing .....	38
4.2.6 Seven-Segment Display Interfacing .....	40
4.2.7 4x4 Keypad Interfacing .....	41
4.2.8 LCD Interfacing .....	42
4.2.9 Interrupt Enable .....	43
4.3 Install Driver for NXP FRDM-KL25Z.....	44
4.4 Laboratory Manual Preparation .....	45
4.5 Summary.....	47
<b>Chapter 5 Conclusion</b>	
5.1 Conclusion .....	48
5.2 Recommendation for Future Work .....	49
<b>Reference .....</b>	<b>50</b>

## **APPENDICES**

### **Appendix A – Laboratory Manual for NXP FRDM-KL25Z**

## LIST OF TABLES

Table 2.1 ARM® Cortex®-A Portfolio (ARM Limited, 2016) .....	6
Table 2.2 ARM® Cortex®-R Portfolio (ARM Limited, 2016).....	6
Table 2.3 ARM® Cortex®-M and SecurCore Portfolio (ARM Limited, 2016) .....	6
Table 4.1 Result of each experiment carried out for basic I/O control.....	32

## LIST OF FIGURES

Figure 2.1 Simplified ARM Organisation (Stallings, n.d.).....	8
Figure 3.1 Project implementation flowchart .....	16
Figure 3.2 NXP FRDM-KL25Z Development Board .....	17
Figure 3.3 8x8 LED dot matrix.....	18
Figure 3.4 seven-segment display.....	19
Figure 3.5 4x4 keypad .....	20
Figure 3.6 Liquid Crystal Display (LCD).....	20
Figure 3.7 ARM mbed online compiler user interface .....	22
Figure 3.8 HyperTerminal user interface.....	23
Figure 3.9 Circuit connection for second experiment.....	24
Figure 3.10 Circuit connection for fourth experiment .....	24
Figure 3.11 Circuit connection for fifth experiment.....	25
Figure 3.12 8x8 LED dot matrix pinout .....	26
Figure 3.13 8x8 LED dot matrix connection with NXP FRDM-KL25Z.....	26
Figure 3.14 seven-segment display pinout .....	27
Figure 3.15 seven-segment display connection to NXP FRDM-KL25Z.....	28
Figure 3.16 4x4 keypad internal connection pinout .....	28
Figure 3.17 4x4 keypad connection to NXP FRDM-KL25Z .....	29
Figure 3.18 LCD connection to NXP FRDM-KL25Z.....	30
Figure 3.19 Switch connection for hardware interrupt.....	31
Figure 4.1 Word printed on HyperTerminal for experiment 1 .....	34
Figure 4.2 Word printed on HyperTerminal for experiment 2 .....	34
Figure 4.3 The LED is dimmer when LHS of the slider is touched .....	35
Figure 4.4 The LED is brighter when RHS of the slider is touched.....	36
Figure 4.5 Acceleration in x, y and z-axis are shown in HyperTerminal .....	37
Figure 4.6 Display character "H" on LED dot matrix .....	39
Figure 4.7 Display character "L" on LED dot matrix.....	39
Figure 4.8 LED dot matrix connection to NXP FRDM-KL25Z.....	40
Figure 4.9 Display "0" on seven-segment display .....	41
Figure 4.10 Keypad connection with NXP FRDM-KL25Z .....	41
Figure 4.11 "Hello World!" displayed on LCD.....	42
Figure 4.12 PEmicro website.....	44
Figure 4.13 Serial port driver and COM number are shown after driver is installed .....	45



## LIST OF ABBREVIATIONS

1G	First Generation Communication System
2D	2 Dimensional
2G	Second Generation Communication System
ADC	Analogue to Digital Converter
ARM	Advanced RISC Machines
CISC	Complex Instruction Set Computing
CPU	Central Processing Unit
CSoC	Configurable System on Chip
DAC	Digital to Analogue Converter
DFS	Dynamic Frequency Scaling
DSP	Digital Signal Processor
EDP	Energy Delay Product
FPGA	Field Programmable Gate Array
GIPS	Giga Instructions Per Second
GND	Ground Signal
GPIO	General Purpose Input/output
GPU	Graphics Processing Unit
I/O	Input/output
I2C	Inter-Integrated Circuit
IC	Integrated Circuit
IIoTEED	Industrial IoT Edge Devices
ISR	Interrupt Service Routine
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LHS	Left-Hand Side

MIPS	Million Instruction Per Second
PCB	Printed Circuit Board
PWM	Pulse Width Modulation
RGB LED	Red Green Blue Light Emitted Diode (tri-colour LED)
RHS	Right-Hand Side
RISC	Reduced Instruction Set Computing
SCL	Serial Clock
SDA	Serial Data
SIMD	Single Instruction Multiple Memory
SoC	System on a Chip
STEM	Science, Technology, Engineering, and Mathematics
TEE	Trusted Execution Environment
USB	Universal Serial Bus
VLIW	Very Long Instruction Word
VSP	Variable Stage Pipelining

# MEREKA BENTUK KIT PEMBELAJARAN BERKOS RENDAH UNTUK PENDIDIKAN BERDASARKAN ARM CORTEX-M CORE

## ABSTRAK

Dalam projek ini, kit pembelajaran berkos rendah untuk pendidikan telah direka dan dibangunkan dengan menggunakan NXP FRDM-KL25Z lembaga pembangunan berdasarkan pemproses ARM sebagai platform pembelajaran. Beberapa peralatan telah antara muka dengan NXP FRDM-KL25Z untuk belajar pengaturcaraan sistem terbenam dalam C++. Objektif utama projek ini adalah untuk mereka bentuk kit pembelajaran berkos rendah untuk pendidikan berdasarkan pemproses ARM dan membangunkan langkah demi langkah tutorial untuk membimbing pemula. Walaupun lembaga pembangunan berdasarkan pemproses ARM tidak sukar untuk didapati sekarang, tetapi tutorial untuk ia adalah sukar untuk mendapatkan dan susah untuk difahami oleh pemula. Banyak pengkompil serasi kepada lembaga pembangunan yang sama pada masa kini. Tetapi ia sebenarnya adalah satu masalah untuk pemula memilih pengkompil dan platform yang sesuai sebagai permulaan untuk belajar pengaturcaraan sistem terbenam. Dengan kit pembelajaran untuk pendidikan dan langkah demi langkah tutorial, pemula boleh mempunyai pemahaman yang lebih baik dengan topik yang dipelajari. Beberapa latihan telah disediakan selepas setiap topik bagi meningkatkan kefahaman terhadap topik tersebut. Kit pembelajaran ini akan membantu pemula dalam memahami apa-apa yang perlu dilakukan dengan lembaga pembangunan berdasarkan pemproses ARM termasuk bagaimana untuk berkonfigurasi pengkompil untuk lembaga pembangunan yang berbeza, bagaimana untuk memasukkan *library* luar untuk pengkompil dan sebagainya. Kit pembelajaran ini adalah berguna dan penting untuk membantu pemula untuk belajar lembaga pembangunan berdasarkan pemproses ARM.

# DESIGNING A LOW-COST EDUCATIONAL LEARNING KIT BASED ON ARM CORTEX-M CORES

## ABSTRACT

In this project, a low-cost educational learning kit is designed and developed by using the NXP FRDM-KL25Z, an ARM processor based development board as a learning platform. Some peripherals is interfaced with the NXP FRDM-KL25Z to learn the embedded systems programing in C++. The main objective of this project is to design a low-cost educational learning kit for ARM processor and develop a step by step tutorial. Although the ARM processor based development board is not difficult to get now, but the tutorial for it is hard to get and understand by the beginner. A lot of compiler are compatible to the same development board nowadays. It is actually a problem to the beginner on which compiler and what platform to choose as the kick start on the embedded system programing. With the educational learning kit and the step by step tutorial to help them, they can have a better understanding to the topic learned. Some exercises are also provided after each topic to increase the understanding on that topic. The educational learning kit helped the beginner in understanding what to do with an ARM processor based development board including how to configure the compiler setting for different development board, how to include the external library to the compiler and so on. The educational kit is useful and important to help the beginner in learning the ARM processor based development board.

# CHAPTER 1

## INTRODUCTION

### 1.1 Overview

Advanced RISC Machines (ARM) processor has been becoming more and more widely used in the industry today. ARM processor has been used as the main processor in most of the low power consumption devices such as smartphones, tablets and other mobile devices such as two ways radio.

ARM processor is one of the latest members of the family of CPUs. It is a reduced instruction set computer (RISC) based processor. Fewer transistors are required for an ARM processor, thus the ARM processor is smaller in size, lower complexity and lower power consumption. The ARM processor can be divided into two types which is the 32-bits and 64-bits ARM processor, and each type can either be single core or multi-core processor (ARM Ltd., 2017).

The ARM processor can be operated at a high speed even more MIPS compare to other processors. The performance of ARM processor is not as good as the CISC processor for a single clock cycle. But the multi-stages pipelining had reduced the compilation time for a clock cycle. For example, a code that required only three clock cycles to compile in a CISC processor required five clock cycles to compile in ARM processor. But ARM processor used less time to compile the similar code compared to CISC processor due to the used of pipelining. The performance of ARM processor had been increased with the shorter compilation time.

## **1.2 Problem Statement**

Microprocessor is one of the basic and important topics for electrical and electronic engineering student nowadays. Although students learned to control microprocessor in the university with the basic assembly language and Intel x86 processor, but that is not the latest processor. They have to learn the latest and common uses processor in the industry nowadays and high-level programming language such as C and C++ from university level. ARM processor had been used widely nowadays in most electronic devices. Therefore it seems to be important for the students to learn to program an ARM processor nowadays. Although the ARM processor based development board can be easily obtained from the market now but there is a lack of the tutorials to teach the beginners. Besides School of Electrical & Electronic Engineering, Universiti Sains Malaysia having the problem where the number of ARM processor based development board in laboratory are very limited and expensive. It is impossible for every students to use and learn it.

## **1.3 Objectives of Research**

The main contribution of this project is to design a low-cost educational kit that suitable for the beginners in learning to program an ARM processor based development board from zero basic. The educational kit is suitable for the institution such as School of Electrical & Electronic Engineering, Universiti Sains Malaysia for educational purpose.

The objectives of this project are:

1. To develop a low-cost educational learning kit based on ARM Cortex-M processor.
2. To develop the laboratory manual for ARM Cortex-M processor based development board with external peripherals.

3. To develop an educational learning kit that is suitable for the students of School of Electrical and Electronic Engineering, Universiti Sains Malaysia.

#### **1.4 Scope of Research**

In this project, a low-cost educational learning kit had been developed by using the NXP FRDM-KL25Z development board. NXP FRDM-KL25Z development board is an ARM Cortex-M0+ processor based development board. Some simple and basic experiments that suitable for the beginners are carried out and some peripherals are chosen to interface with the NXP FRDM-KL25Z development board. The result of all experiments is recorded so that the suitable experiment can be chosen and compiled as a laboratory manual for beginners to learn. The laboratory manual is written based on the result of each experiments carry out before and the example code provided in the laboratory manual is tested also. This helps the students by guiding them slowly and some exercises will be provided also after each experiment.

#### **1.5 Report Outline**

This thesis consists of five chapters, including introduction, literature review, research methodology, results and discussion, and conclusion.

Chapter 1 briefly described the background of the project. The problems faced now and the motivation of this project is stated in this chapter. The highlighted objectives to archive in the end and the scope of focus in this thesis is discussed here also.

Chapter 2 reviewed on the background of ARM processor. The architecture and performance of ARM processor, the evolution of processor architecture in the phone, the embedded system application based on an ARM processor and the use of ARM processor in education purpose is also reviewed in this chapter.

Chapter 3 discussed the methodology of the project. The overall project design flow is stated and discussed in this chapter. Besides, the hardware and software used in this project are also stated and the implementation of both hardware and software is discussed included the hardware connection of the experiments.

Chapter 4 shown the result of all the experiments that had been carried out and the command of each experiment is discussed. The peripherals used in each experiment is explained including the properties and the pinout. For each experiment, the problem facing during the experiment are also recorded for future reference. And the arrangement of laboratory manual is stated in this chapter also.

Chapter 5 concluded and summarized all the work that had been carried out throughout the project and commented on the overall project. Some ideas are also given on future implementation for the educational learning kit with the NXP FRDM-KL25Z development board.



# CHAPTER 2

## LITERATURE REVIEW

### 2.1 Overview

ARM processor is a powerful processor for the mobile devices nowadays with its low power consumption and high-performance properties. Besides the mobile devices, ARM processor is also a good choice for the embedded system design for different devices. The performances and the uses of ARM processor in an embedded system will be reviewed in the following section.

### 2.2 History of ARM Processor

ARM processor architecture was first designed and founded by ARM Holdings in the 1980s but now ARM Holdings is not the only producer for ARM processor. The chip design and instruction set customization licenses are given to some third party vendors like Apple, Qualcomm, Texas Instruments by ARM Holdings to design their own ARM processor (ARM Limited, 2016). ARM Cortex processor basically can be classified into four series which are:

- Cortex-A Processors (ARM Application Processors)
- Cortex-R Processors (ARM Embedded Real-time Processors)
- Cortex-M Processors (ARM Embedded Processors)
- SecurCore Processors (ARM Secure Processors)

There are many types of processor exist in each series of ARM processor. Some of the processors use nowadays consist of multi-core, such as the processors of smartphones. The processors of smartphones today mostly are combined few ARM processors, the

common used processor is ARM Cortex-A processor. For example, the Qualcomm Snapdragon 625 processor consists of eight Cortex A53 processor (Qualcomm Technologies, n.d.-a) while Snapdragon 650 processor is combining two Cortex A72 processor and four Cortex A53 processor(Qualcomm Technologies, n.d.-b). The types of ARM processor in each series are shown in Table 2.1, Table 2.2 and Table 2.3 respectively.

Table 2.1 ARM® Cortex®-A Portfolio (ARM Limited, 2016)

High performance	Cortex-A15	Cortex-A17	Cortex-A57	Cortex-A72	Cortex-A73
High efficiency	Cortex-A8	Cortex-A9	Cortex-A53		
Ultra-high efficiency	Cortex-A5	Cortex-A7	Cortex-A32	Cortex-A35	
	ARMv7-A		ARMv8-A		

Table 2.2 ARM® Cortex®-R Portfolio (ARM Limited, 2016)

Storage & modem	Cortex-R7	Cortex-R8	
Functional safety	Cortex-R4	Cortex-R5	Cortex-R52
	ARMv7-R		ARMv8-R

Table 2.3 ARM® Cortex®-M and SecurCore Portfolio (ARM Limited, 2016)

Performance efficiency	Cortex-M3	Cortex-M4	Cortex-M7	Cortex-M33
Lowest power & area	Cortex-M0		Cortex-M0+	Cortex-M23
SecurCore	SC000		SC300	
	ARMv7-M			ARMv8-M

Nowadays, ARM processor mostly used as the main processor for a System on a Chip (SoC). With either a single core or multiple cores ARM processor as the CPU and a coprocessor such as FPGA processor on a single integrated circuit (IC). SoC has been growing rapidly in this few years as it combined both benefits of the ARM processor and FPGA.

A lot of ARM processor based development boards are available in the market nowadays and many types of ARM processor can be chosen. From a simple Cortex-M0 processor which are suitable for beginners to a complex Cortex-A8 processor that can support high efficiency and accuracy task. This is a good trend for both the beginners who are new and interested in learning on embedded ARM processor programming and the developers who are going further for the more advanced task. Therefore ARM processor based development board is a good choice for learning embedded programming.

### 2.3 ARM Processor Organization

The organisation of ARM processor is different from time to time as the new design of the processor and different in series. However understanding the basic common organisation of ARM processor can make us understand more about it. Figure 2.1 shows the simplified ARM processor organisation.

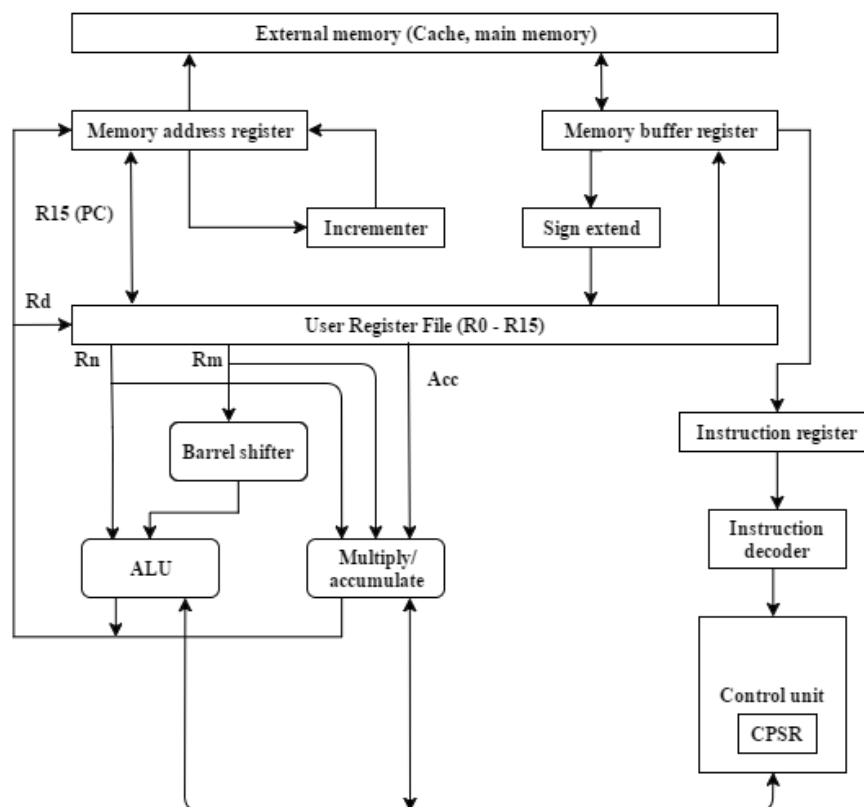


Figure 2.1 Simplified ARM Organisation (Stallings, n.d.)

The arrow indicated the flow of data when executing a code, the flow is briefly explained in below (Stallings, n.d.):

1. Data in the processor are exchanged with the external memory through a data bus for next execution.
2. Data are placed in the register file which consists of a set of 32-bits register.
3. Before the execution, the fetched instruction pass through an instruction decoder under control unit.
4. The value of the two source registers,  $R_n$  and  $R_m$  are feed into the ALU. However value of  $R_m$  can undergoes multiply or shifting and rotate before feed into ALU.
5. The result of the operation is fed back to the register.

#### **2.4 Evolution of Processors Architectures in Mobile Phone**

Back to the old time where the mobile phone is big in size and heavy, those mobile is actually using traditional DSP architectures, which is also known as the first generation mobile communication system, also known as 1G system. The system using the analogue transmission to communicate between devices.

From time to time improvement, when the second generation mobile communication system, 2G system is successfully implemented, the DSP processors become one of the most important classes of mobile embedded processors in that time. Traditional DSP using Harvard architecture where the storage and signal pathway for instruction and data is physically separated (Singh & Jain, 2014).

As the growing of the technology, modern DSP architecture was widely implemented in mobile phones to replace traditional DSP architecture, now the DSP

provided a more accurate real-time response with a lower power consumption and higher clock frequency. VLIW and SIMD architectures become more popular for mobile devices as they allow the reducing of frequency and voltage without losing its performance. With the new technologies, the performance of the same DSP chip was improved from 5 MIPS in 1980 to approximately 5 GIPS in 2000 and 50 GIPS in 2010 (Singh & Jain, 2014).

For modern communication systems, the processor for most of the smartphones today is the SoC based architecture. The SoC architecture is able to increase the performance for real-time responsiveness in mobile devices and lower the power operation in mobile devices by lowering the voltage of the chip. But there are some problems that the low power operation limited the architectural choices and fast memory systems like cache memories are needed to increase the throughput and hence to increase the performance (Singh & Jain, 2014).

In order to work solve the problem faced in SoC architecture, ARM Ltd. comes out with extensive instruction set customization, by encoding most used instructions in 16-bits which support most read-write operations, which is the first generation of ARM processor. After that, the reconfigurable processor was proposed as Dynamically Configurable System on Chip (CSoC) to optimise for most mobile devices.

## **2.5 Performance of ARM Processor**

As mentioned before the ARM processor is widely used in today's mobile devices because of the high performance with low power consumption. There are a lot of people working on analyses the performance of the ARM processor and also further increase the performance.

One of the way to further improve the performance of ARM processor is by implement Variable Stage Pipelining (VSP) and Dynamic Frequency Scaling (DFS) algorithm together in ARM processor(Ravichandran & Muralidharan, 2016). VSP combines adjacent stages when subsequent stages are inactive where DFS is a commonly employed technique which is used to manage power. From the research done previously, VSP algorithm is able to lead to a 6.2% reduction in power consumption whereas DFS algorithm can provide an increase of 32% in smartphone's battery life (Ravichandran & Muralidharan, 2016). By applying both methods together, the power consumption will be reduced 30% to 35% in estimation.

As a relatively new architecture, ARM processor always being compared with Intel x86 core as the Intel x86 core is being used for a long time and can be considered as the best processor architecture before the ARM processor. From an experiment that had been carried out before, the ARM processor with the power-efficiency system consumed at least 39% energy less than the Intel x86 system for the single processor fully loaded environment. Besides, although the ARM processor can be able to save up to 26% energy only in the quart-core experiment, but it can perform 11.8 times faster than the single core ARM processor with it 2 times higher operating frequency and 4 times larger last level cache (Xu & Chang, 2017).

ARM processor using the RISC instruction as the operand in the execution of the coding, as we know the RISC consists only limited instruction to perform the task. Hence the majority of the instruction it executed before will be repeated in future operation and the processor had been repeated the same execution process over and over again if the code is continuously repeated for few times. For example, a loop operation. By eliminating the repeated execution, the performance of the processor can be further improved if the value reuse techniques are implemented in ARM processor. The

performance can be further push up by 18.36% by implement value reuse techniques that allow the processor memorise the previously executed instructions, block or traces which may be reused (Moura, Torres, Pilla, Gomes, & St, 2016).

## **2.6 Application of ARM Processor**

ARM processor is also widely used for embedded system besides mobile devices nowadays. More and more embedded system change the processor to ARM processor now. Obviously, the low power consumption and high performance are the main concern for the change. However, the implementation of ARM processor in other field is still in research.

In the previous research said that the ARM processor is a good platform for learning Assembly language compare to the traditional hardware-based system (Cadenas, Sherratt, Howlett, Guy, & Lundqvist, 2015). From the research, we can say that the ARM processor is a good platform for the students to learn the embedded system programming even the Assembly language.

The performance of ARM processor is being tested with the Intel x64 processor for big data analysis server processing. ARM64 processor is being tested with x64 processor, also known as x86-64 in Micro-Benchmarks, Web Search Benchmarks, Hive Query Benchmarks, Machine Learning Benchmarks and reducer parallelism tuning. ARM64 shows a better performance than x64 processor. ARM64 server has a 3×smaller base power load than the x64 server and consumes 50 – 71% lower Energy Delay Product (EDP) than x64 (Kalyanasundaram & Simmhan, 2017).

Besides, there are also experiment of testing the performance of an embedded system for MP3 audio decoder with FPGA. It showed increases of 92% when changed to

ARM processor and the energy consumption had been decreased 77% compared to previous design (Šimunić, Benini, & De Micheli, 2001).

ARM processor has a hardware security mechanism for which is ARM TrustZone is the hardware security mechanism for ARM processor, there are at least a minimal hardware support for ARM TrustZone in the modern ARM-based SoC platform. The system is separated into two partitions, a secure world and a normal world. The secure world provided a Trusted Execution Environment (TEE) according to GlobalPlatform association standard that can be used to execute the Trusted Application (TAs). This TAs can be used by the normal world application as well (Hein, Winter, & Fitzek, 2015). With this mechanism, some Internet of Things (IoT) platforms are starting with the implementation of ARM processor to IoT such as Industrial IoT Edge Devices IIoTEED (Pinto, Gomes, Pereira, Cabral, & Tavares, 2013).

Besides, ARM processor is also being implemented for low cost embedded system design application such as indoor positioning system (Jose & Mathew, 2017), real-time surveillance application (Tseng, Liao, & Hung, n.d.), haze monitoring system (Engineering, 2016) and humidity, wind speed and direction monitoring system (SriLakshmi, Das, & Manikumar, 2017).

## **2.7 Uses of ARM Processor for Education Purpose**

An advanced, low-cost robot has been designed for the uses in science, technology, engineering, and mathematics (STEM) (McLurkin, Rykowski, John, Kaseman, & Lynch, 2013). The robot names the Rice r-one mobile robot. Most of the features of the robot is designed specific for educator. The robot has powerful sensor and high abilities with low-cost. Besides that the robot is used as a “life example” for the students in the problem-based learning. With the robot, it can be model for the design challenges and encourage



the students on thinking for the engineering solution of the robot. The robot is controlled by a 32-bit ARM processor based microcontroller and it can be programmed by either C/C++ or Python programming language.

The GreenEduComp device designed in Rural India is targeted as a low cost green computing system for education (Srinivasan, Narayanan, & Vijayaraghavan, 2013). It is targeted to the people who does not has the knowledge of computer because it is very simple to interface and provided a low-cost solution to the rural education. The main operation unit is an Arduino board and interface with Raspberry Pi as the computing unit. Raspberry Pi is a device running on an ARM processor.

Besides the Arduino, there are still a lot of development board that is suitable for to use for education purpose. Arduino are well known today due to its success in the “Maker” world, but other development board are also growing in the this field for self-learning project such as Raspberry Pi and BeagerBone Black board (Jamieson & Herdtner, 2015). This shown that the use of ARM processor is growing up rapidly now and become more and more important in “Maker” world.

In the Innovate Malaysia Design Competition, a lot of the companies are using the ARM processor based development board as the platform. For example, the MyRIO used by National Instruments is a development board with dual-core ARM Cortex-A9 processor (National Instruments, 2016). The MWi-Com platform by Motorola Solutions, Inc is powered by the BeagerBone Black which is using the Sitara AM3358BZCZ100 processor (Element14, 2014) which is an ARM Cortex-A8 processor (Texas Instruments Corp., 2016). And the DE1-SoC platform used by Intel (formerly known as Altera) is also a SoC platform consists of FPGA processor with dual-core ARM Cortex-A9 processor (Terasic Technologies Inc., 2015).

## **CHAPTER 3**

### **RESEARCH METHODOLOGY**

#### **3.1 Overview**

To develop an educational learning kit, firstly the development board has to be selected. After some research and consideration are made, NXP FRDM-KL25Z development board has been chosen as the development board for the educational kit. NXP FRDM-KL25Z development board is an ARM processor based development board with Cortex-M0+ core. Few experiments was setting up to study the properties and performances of NXP FRDM-KL25Z development board. Some peripherals was chosen to interface with it and the result is recorded for further consideration on laboratory manual preparation. After some consideration, the selected experiments is compiled as a laboratory manual for the beginners to understand and learn to program the development board. Some tasks will also be given after each experiment to increase their understanding on the laboratory and learn to apply the knowledge learn and provide an engineering solution to solve the problem.

#### **3.2 Project Implementation Flow**

At the beginning of doing this project, few weeks was being taken to study about the ARM processor. The study cover from the architecture until the application and the uses of ARM processer in education. The purpose of doing that is to have a brief idea on ARM processor and the uses of it.

After that, a study is carried out to check about the type of ARM processor based development board is available in the market now and which one is suitable to use in this project. At the end, NXP FRDM-KL25Z ARM processor based development board is

selected to use in this project. Because it can be considered as a low-cost development board and good enough for a beginner to study about ARM processor.

With the selected development board, a compiler had been selected in order to simplify the task. Although almost all the ARM processor compilers available today can be used to compile all type of ARM processor, but the is still necessary to choose a suitable compiler as some extra work can be reduced such as include the library for the processor, including the GCC compiler, and so on. Therefore, ARM mbed online compiler is used in this project and after that Keil  $\mu$ Vision compiler is also tested but not being used in this project.

Programming with the NXP FRDM-KL25Z is then started. All peripherals is also interfaced one by one with the NXP FRDM-KL25Z development board until all the peripherals is successfully interfaced with it. After finishing with the experiments, a laboratory manual is prepared and compiled. There has total of eight laboratory with step-by-step guiding in the laboratory manual to help the students in program the NXP FRDM-KL25Z development board with those peripherals. In each laboratory, some exercises had been provided after each experiments. This will helps the student to have higher understanding on the experiment carried out.

The flowchart of the design process is shown in Figure 3.1.

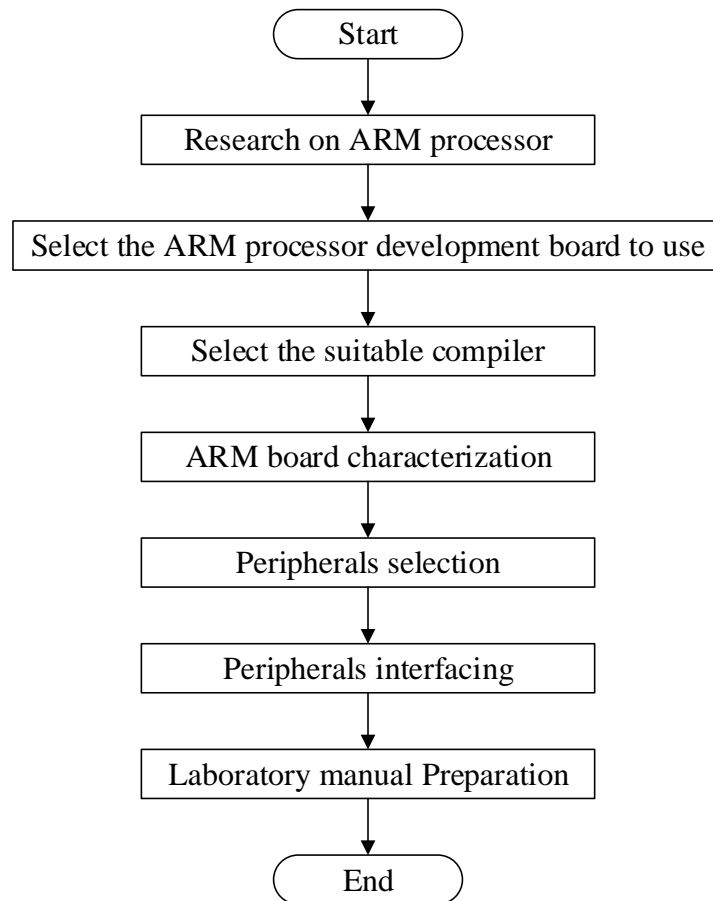


Figure 3.1 Project implementation flowchart

### 3.3 Project Requirement

In this project, both hardware and software had been used to carry out the project. The following section discussed the hardware and software that had been used in the project.

#### 3.3.1 Hardware

The following section discussed all the hardware used in this project.

##### 3.3.1(a) NXP FRDM-KL25Z Development Board

After gone through some research on the ARM processor, NXP FRDM-KL25Z is selected to be the development board used in this educational learning kit. There is some reasons for choosing this development board as the platform for the educational learning kit.

Firstly is the cost, NXP FRDM-KL25Z can be considered as a low-cost development board as it is powered by ARM Cortex M0+ processor (Freescale Semiconductor, 2012b). Although it is not a high performance ARM processor, but it is good enough for the beginner to learn the ARM processor based development board.

Besides that, the I/O pin for the NXP FRDM-KL25Z is enough for some basic external peripherals interfacing. NXP FRDM-KL25Z development board has total of 66 general purpose input output (GPIO) pins to configure with (Freescale Semiconductor, 2014).

Lastly, the NXP FRDM-KL25Z can be easily obtained at Malaysia with a low cost. If a large quantity are needed, it will become an importance criteria that the development board can obtain easily and can be replaced if the development board is spoiled. The NXP FRDM-KL25Z development board is shown in Figure 3.2.

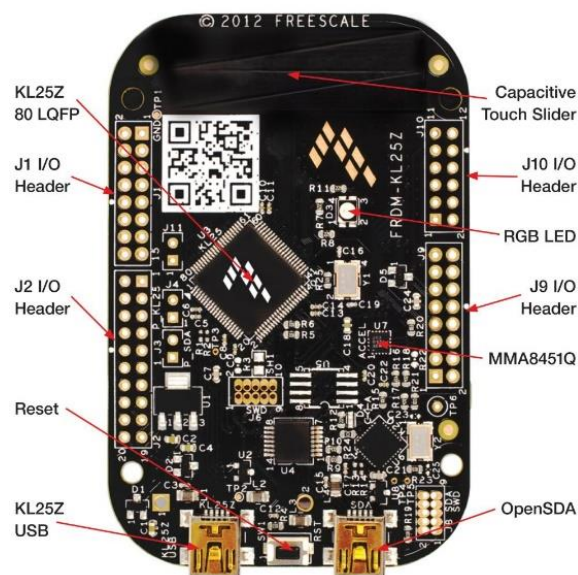


Figure 3.2 NXP FRDM-KL25Z Development Board

### **3.3.1(b) LED Dot Matrix**

LED dot matrix is a combination of LED in 2-dimensional (2D) array. The cathodes are connected in rows and anodes are connected in columns (or vice versa). It is a low-resolution form of dot-matrix display (Betlux, n.d.).

The dot matrix used in this experiment is an 8x8 LED dot matrix. To power up the LED dot matrix, a positive voltage (HIGH signal) is provided to the selected roll and the ground voltage (LOW signal) is provided to the selected column. An 8x8 LED dot matrix is shown in Figure 3.3.



Figure 3.3 8x8 LED dot matrix

### **3.3.1(c) Seven-Segment Display**

Seven-segment display is a display peripheral that using seven LED and a decimal point (dot) to display a number or character on it. We usually see it on the digital watch and elevator display. It is easy to use and control but the seven-segment display has its limitation on the character display due to it limited segment. The improvement of the seven-segment display is 14 segment display which can use to display all character (Kingbrighth, 2006).

Basically, seven-segment display has two type which known as common anode and common cathode (Cypress Semiconductor Corporation, 2014). As the name given, common anode type seven-segment display connected all the anode (positive) pin of the LED together and connected to HIGH signal or positive voltage when using. Supply a LOW signal or ground voltage to the respective pin to turn on the segment. While common cathode type seven-segment display connected all the cathode (negative) pin of the LED together and connected to LOW signal or ground voltage when using. Supply a HIGH signal or positive voltage to the respective pin to turn on the segment. A seven-segment display is shown in Figure 3.4.

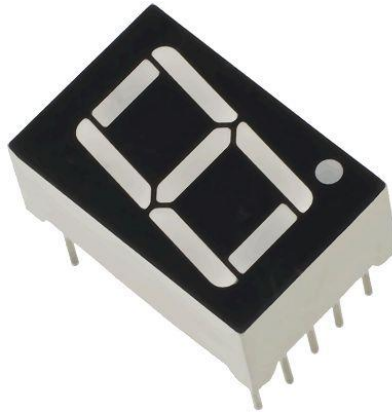


Figure 3.4 seven-segment display

#### **3.3.1(d) 4x4 Keypad**

The keypad is a combination of several buttons in the matrix form array that one pin is connected with other in the same column while the other pin is connected to those in the same row (Cytron Technologies, 2009). Normally the columns are connected to the output pins of the processor and the rows are connected to the input pins of the processor (or vice versa). A 4x4 keypad is shown in Figure 3.5.



Figure 3.5 4x4 keypad

### 3.3.1(e) Liquid Crystal Display (LCD)

Liquid Crystal Display (LCD) is a thin, flat display device made up of any number colour or monochrome pixels arrayed in front of a light source or reflector. It does not emit light directly but uses the light modulating properties of liquid crystals to produce images (Xiamen Amotec Display Co. Ltd., 2014). It is a low power consumption devices, therefore it is normally utilised with the battery-powered devices to reduce the power consumption of the overall system. A LCD is shown in Figure 3.6.

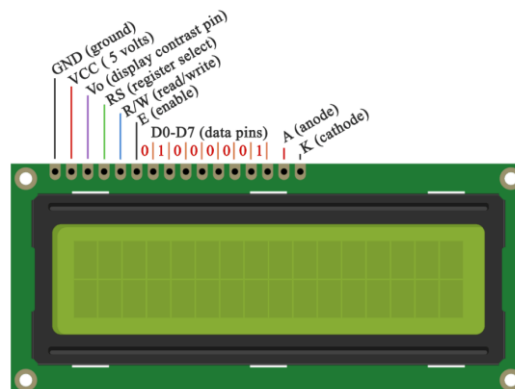


Figure 3.6 Liquid Crystal Display (LCD)

### 3.3.2 Software

The following section discussed all the software used in this project.



### **3.3.2(a) ARM Mbed Online IDE**

ARM mbed platform is an online based compiler that allows the user to save the coding online. The programmer can modified their program anytime with different computers without copy the coding through a flash drive to the computer. This help the programmer saves the time for copy or backup the program when using different computer to modify the program.

Most of the tutorial for NXP FRDM-KL25Z that can be obtained from the internet is based on the ARM mbed platform. It is good for a beginner as ARM mbed is an open sources compiler and a lot of example code and library is available in ARM mbed (ARM mbed, 2014). The forum of ARM mbed can helps the programmer when they are facing some problem on programming. With the suggestion and discussion from the forum, they can discuss their problem with all programmer around the world to find out the solution for the problem faced.

Besides, by using the ARM mbed platform, the setup for the board can be done easily and no extra internal compiler is needed to be installed (ARM Ltd, 2016). By comparing ARM mbed with the Eclipse and Keil  $\mu$ Vision, ARM mbed just need to click on the platform selection button to select or change the platform used. For the other two compiler, more steps are needed to setting up the platform used and some plug-in driver are needed to install (Boys, 2017).

But there are also some disadvantages by using the ARM mbed online compiler as the platform available is limited for some selected company only (ARM mbed, 2017). If the development board is changed, ARM mbed might not be suitable for the new development board. This is not good as the students have to find out other compiler to

compile the code when they changed to the other development board. The ARM mbed online compiler user interface is shown in Figure 3.7.

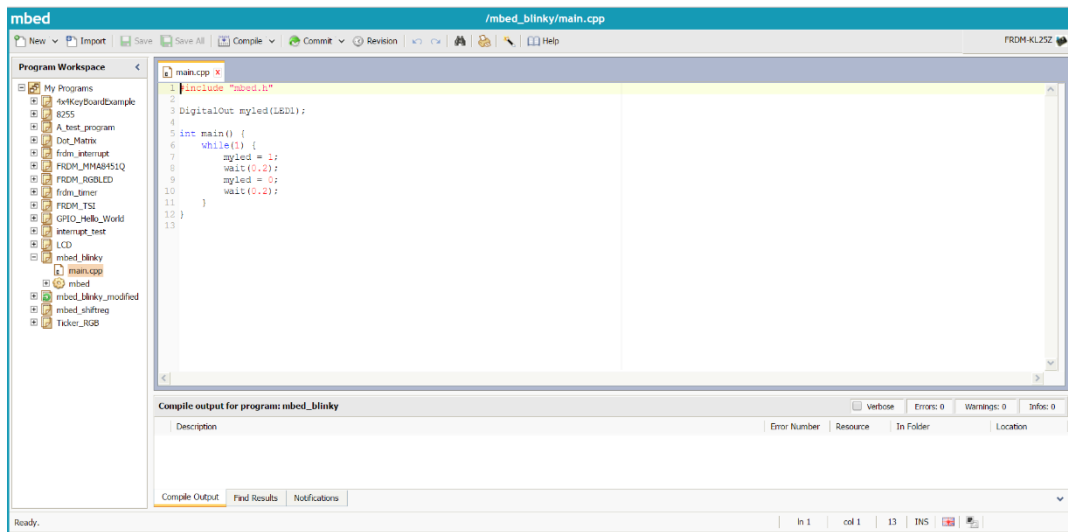


Figure 3.7 ARM mbed online compiler user interface

### 3.3.2(b) HyperTerminal

HyperTerminal is a terminal software that use to communicate and interface with NXP FRDM-KL25Z development board via PC to show the output of it. Unlike the other compiler, ARM mbed has no its built-in serial monitor or terminal software to interface with. Therefore an external terminal software is needed to use so that we can print the result output on it.

Serial monitor is a very important tool for a programmer especially during debugging the program. The HyperTerminal and NXP FRDM-KL25Z development board are communicated via serial communication through the USB port. In order to use serial monitor, the port number (COM number) of NXP FRDM-KL25Z development board on PC is needed to be confirm in order for the serial communication to be success (ARM mbed, n.d.). The user interface of HyperTerminal is shown in Figure 3.8.

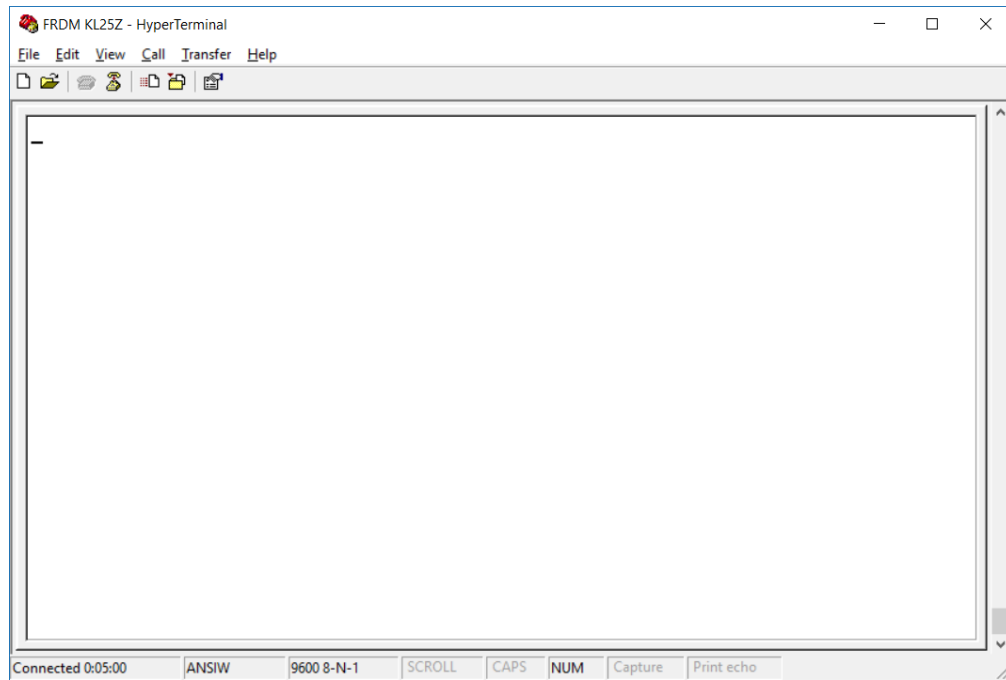


Figure 3.8 HyperTerminal user interface

### 3.4 Experiment Setup

To simplify the steps for initialise the platform used, ARM mbed online compiler had been selected as the compiler to use in this project. All the coding involved in this project are done and compiled by ARM mbed online compiler including the coding shown in the laboratory manual.

#### 3.4.1 Basic I/O control on NXP FRDM-KL25Z

From the study before, the NXP FRDM-KL25Z development board consists of two type of input and three type of output. The inputs are digital input and analogue input, while the outputs are digital output, analogue output and pulse width modulation (PWM) output (Freescale Semiconductor, 2012a).

Five simple experiments were carried out to verify the function and output of each and every mode of the input and output for NXP FRDM-KL25Z. First experiment is carried out for digital output by using the built-in RGB LED. Second experiment is carried

out for analogue output, a LED is connected to the NXP FRDM-KL25Z development board as Figure 3.9.

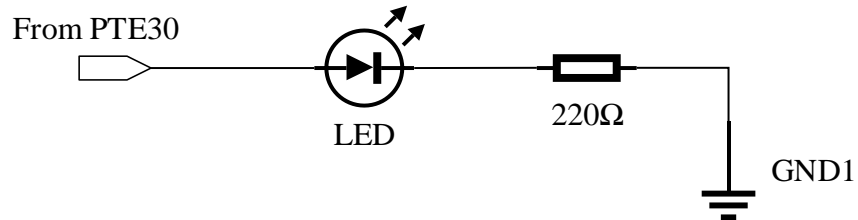


Figure 3.9 Circuit connection for second experiment

Third experiment is carried out for PWM output and the built-in RGB LED is used for this experiment. Fourth and fifth experiment is carried out for digital input and analogue input respectively. The circuit shown in Figure 3.10 and Figure 3.11 is connected to NXP FRDM-KL25Z for the fourth and fifth experiment respectively.

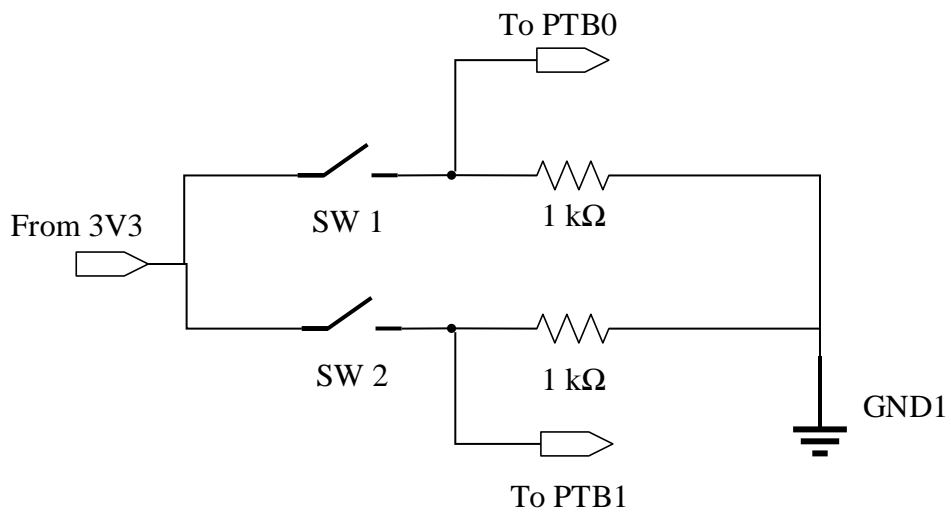


Figure 3.10 Circuit connection for fourth experiment