ENERGY EFFICIENCY OF THE BITCOIN MINING HARDWARE AND RELATED BLOCKCHAIN TECHNOLOGY

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ABSTRAK

Pada masa kini, pelabur menggunakan bitcoin sebagai platform untuk melakukan transaksi seperti pertukaran wang tanpa melibatkan pihak ketiga ataupun bank berpusat. Bitcoin menjadi satu fenomena pada zaman moden ini namun penyelidikan yang lebih tertumpu kepada kecekapan kuasa bitcoin dan rangkaian blok (blockchain) adalah lebih sedikit daripada yang dijangka dalam konteks kesusateraan saintifik. Terutamanya dari segi kecekapan tenaga perkakasan untuk melombong bitcoin yang mana kecekapan tenaga dan penggunaan kuasa tidak dikira sebagai satu masalah dalam perlombongan bitcoin.

Pendekatan yang sedia ada dalam model teknologi bitcoin dan perkakasan untuk melombong bitcoin telah dianalisis melalui penyelidikan ini. Penyelidikan ini mencadangkan formula baru dan algoritma yang membenarkan penilaian kecekapan tenaga untuk perkakasan melombong bitcoin dibuat. MATLAB digunakan untuk membina dan mengesahkan algoritma. Set data diambil daripada sumber terbuka dan diaplikasikan dalam formula yang dicadangkan untuk menilai dan meramal kecekapan tenaga perkakasan dalam melombong bitcoin. Pengguna yang akan menggunakan formula dan algoritma yang dicadangkan ini adalah penaung sistem bitcoin dan pelombong bitcoin.

ABSTRACT

Nowadays, traders used bitcoin as a platform in making transaction such as exchanging money, without any involvement of a third party or central bank. Bitcoin becomes a phenomenon in this modernization era but the research devoted to the energy efficiency of bitcoins and related blockchain technology is still weakly considered in scientific literature. Especially the energy efficiency for the hardware of bitcoin mining were not considered as a problem in bitcoin mining.

The existing approaches in modelling the of bitcoin technology and the hardware of bitcoins were analyzed through this research. The research proposes new formula and algorithm which allows the evaluation of energy efficiency for the hardware of bitcoins mining. MATLAB is used in developing and validation the algorithm. Dataset was selected from open sources and applied in the proposed formula to evaluate and predict energy efficiency of bitcoin mining hardware. Developers of bitcoin hardware systems and bitcoin miners are the possible users of proposed formula and algorithm.

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LIST OF SYMBOLS

$\mathcal{E}$	Energy Efficiency of Hardware
$	Cost
®	Registered Trademark
™	Trademark
P	Power Consumption
E	Energy Efficiency of Bitcoin
R	Hash Rate
P(t)	Power Consumption over Time
W	Power
D	Difficulty
T	Target
T_{max}	Largest Possible Value of Target
p	Probability (Nonce Value that yields Valid Hash)
R(t)	Hash Rate over Time
ϵ	Error Term
β_0	y-intercept
β_1	Slope / Regression Coefficient

LIST OF ABBREVIATIONS

MATLAB	Matrix Laboratory
GUI	Graphical User Interface
CPU	Central Processing Unit
GPU	Graphics Processing Unit
FPGA	Field Programmable Gate Arrays
ASIC	Application-Specific Integrated Circuits
CELL	Cell Broadband Engine Architecture
SSE2	Streaming SIMD Extensions 3

CHAPTER 1

INTRODUCTION

1.1 Overview

Nowadays, bitcoin has become a platform for traders in exchanging money without transactions involving central banks or other third party (Gervais, Karame, Capkun, & Capkun, 2014).

Bitcoin is a digital currency, which implementing encryption techniques to verify and validate any funds that have been transferred (Giungato, Rana, Tarabella, & Tricase, 2017). It is stored in a digital wallet which is very portable and difficult to counterfeit compared to the real money. Traders do not have to carry about any credit card or cash.

By using bitcoin, any transaction can be done easier and faster than usual even if the transaction made across the national border. Traders will not be charged for any transaction made in bitcoin system, unlike the transaction made via online banking. However, number of bitcoins are limited and currently only 21 million of bitcoins created through the bitcoin mining in the bitcoin cryptocurrency. This resulting in the increasing value of bitcoins which by some prognosis can reach a hundred million US dollars for a single bitcoin (Yermack, 2015). Huge companies such as Microsoft, Dell, PayPal and WordPress also use bitcoins as the platform to widen their business and to increase the profit of their companies.

On the other hand, blockchain is a digital record of ledger for transactions made in cryptocurrency which are stored in a chronological order (Crosby, Nachiappan, Pattanayak, Verma, & Kalyanaraman, 2016). Besides that, the record of ledger is shared publicly through the whole bitcoin network (Lewis, 2015). There is a list of records (called blocks), which is gradually growing, using cryptography to guarantee the security of the bitcoin cryptocurrency. Each block contains the data of a transaction made, a

timestamp and a cryptographic hash, which is a mathematical algorithm performing a one-way function in the cryptography (Nakamoto, 2008).

Apart from that, the energy efficiency of bitcoin mining hardware and related blockchain technology also help in reducing the demands of energy consumes in preventing the double spending of bitcoin. The more efficiency the energy of hardware, the lesser the energy consumes throughout the process of bitcoin transaction (Karame, Androulaki, & Capkun, 2012).

This resulting in the types of hardware used in the mining of bitcoin where the hardware which provide much efficiency in terms of energy and power consumption is preferable in the market of bitcoin mining.

1.2 Problem Statement

The problem of energy efficiency of hardware used for bitcoin mining was weakly considered in scientific literature. Several existing formulas not focusing on the energy efficiency of hardware for bitcoin mining. Existing formulas do not allow to predict trends of bitcoin mining hardware.

1.3 Objective

Based on the problem statement, the objectives of this research are:

i. To analyse existing approaches for the modelling energy efficiency of the bitcoin mining hardware and related blockchain technology.

ii. To develop the model allowing to predict an energy efficiency of the hardware of bitcoins mining.

iii. To evaluate the model on the existing datasets for energy efficiency of bitcoin mining in terms of hardware.

1.4 Scope

i. This research focuses on the current trends of energy efficiency of hardware used for bitcoin mining.

ii. Users of proposed formula and the algorithm are the developers of bitcoin hardware systems and bitcoin miners.

iii. For the algorithm development, MATLAB is used.

iv. Linear Regression method is used for trends analyses.

v. Proposed formula takes into account four parameters which are the year, energy efficiency, hash rate and power consumption.

vi. Validation is based on open data sets available at www.blockchain.info, www.tradeblock.com and https://en.bitcoin.it/wiki.

1.5 Thesis Organization

This thesis consists of 5 chapters which are Introduction, Literature Review, Methodology, Result and Discussion and Conclusion. Chapter 1 briefly describes the introduction of bitcoin systems. It also includes the problems within the bitcoin systems which are related to this research. Besides that, this chapter presents the objective, scope of research, and the organization of the thesis.

Chapter 2 gives a systematic literature review. The literature review describes the studies related to this research. In this chapter, the selected research studies are compared to each other to find the existing approaches for modelling sustainability. Then, the analysed approaches that will be used throughout this research.

Chapter 3 describes the methodology used in this research such as systematic literature review, development of model and its validation based on the data obtained from the open sources (energy efficiency and power consumption of the bitcoin mining).

Chapter 4 shows the results and discussion of this research. The results have been obtained from the data analysis of energy efficiency and power consumption of bitcoin mining hardware, technical method of approaches and regulation of bitcoin. The methods of predictions the energy efficiency of future bitcoin mining hardware also considered.

Lastly, Chapter 5 gives the conclusion that have been made based on the results obtained.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter gives the literature review of papers that are related to this research. The literature review is based on the existing models of bitcoin and blockchain technology, and hardware of bitcoins mining where it will be used in develop a new model to predict the energy efficiency for future hardware. In this literature review, the techniques, methods and tools which are suitable are adapted and will be used in developing a new model.

2.2 Research Review

This review is made to survey on similar researches, which related to the modelling of bitcoin system and blockchain technology in term of the energy efficiency of bitcoin mining hardware. There are a few existing research studies which discussed the efficiency of energy consumption in bitcoin mining. The following subsections will explain the details of the research studies.

2.3 Related Works

The subtopics below discuss the existing research studies in detail:

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2.3.1 Sustainability of Bitcoin and Blockchains

This research studies the sustainability of bitcoin and blockchains, where it describes the operation and hardware of the bitcoin systems. The mining hardware that have been discovered through this research studies includes Central Processing Unit (CPU), Graphics Processing Unit (GPU), Field Programmable Gate Arrays (FPGA) and Application-Specific Integrated Circuits (ASIC), where it evolved through the first generation until the fourth generation. The evolution of the hardware increased the efficiency of energy consumption in bitcoin mining and the exponential increase of the performances through the generations (Vranken, 2017).

Table 2.1 shows the hash rate and energy in the order of magnitude of the four generations for bitcoin mining hardware (CPU, GPU, FPGA, ASIC).

Table 2.1 Hash Rate and Energy Efficiency in the Order of Magnitude of Four Generations of Bitcoin Mining Hardware

Hardware	Introduction	Hash rate (h/s)	Energy efficiency (h/J)
CPU	2009	10^5-10^8	10^4-10^5
GPU	Late 2010	10^6-10^9	10^5-10^6
FPGA	Mid 2011	10^8-10^{10}	10^7
ASIC	Early 2013	10^{10}-10^{13}	10^8-10^{10}

Figure 2.1 shows the power consumption with the orders of magnitude for the various bitcoin mining hardware.

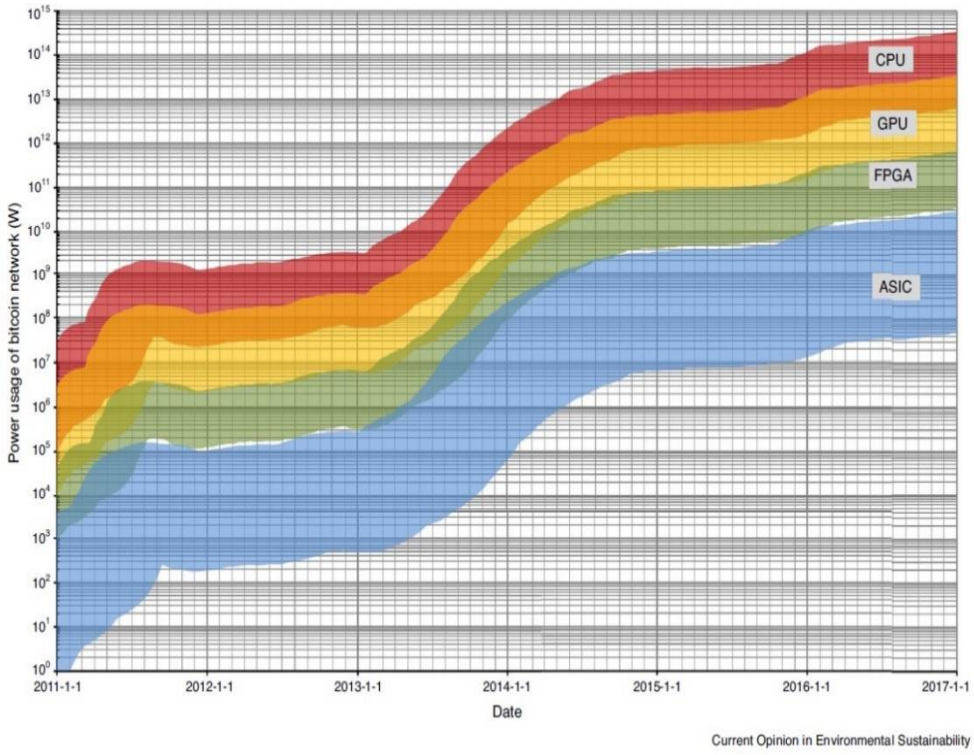


Figure 2.1 Power Consumption with the Orders of Magnitude for the Various Bitcoin Mining Hardware

Source: (Harald, 2017)

Besides that, this research study emphasized on the proof-of-work scheme which is very important in solving the double-spending problem and the secureness of blockchain. However, this scheme required a lot of energy and demands a lot of computational resources. There are a few of alternative schemes also briefly reviewed such as proof-of-stake and proof-of-space where these alternatives are made to reduce the energy consumption of bitcoin mining.

The equations and formulas used in cited research paper to calculate the power consumption of bitcoin network are:

$$P = \frac{R}{E} \qquad 2.1$$

Which approximately:

$$\frac{2^{32}D}{600E} \qquad 2.2$$

where

P : Power Consumption

R : Hash Rate

E : Energy Efficiency of Bitcoin Mining

D : Difficulty

In finding the difficulty of valid hash, the target of every 2016 blocks need to be adjusted.

$$\mathrm{D} = \frac{\mathrm{T_{max}}}{\mathrm{T}} \qquad 2.3$$

where

D : Difficulty

T_{max} : Largest possible value of target

T : Target

The probability is the nonce value that yields valid hash.

$$p = \frac{T}{2^{256}} = \frac{T_{max}}{(2^{256}D)} \qquad 2.4$$

Which approximately:

$$\frac{1}{(2^{32}D)} \qquad 2.5$$

where

p : Probability

T_{max} : Largest possible value of target

T : Target

D : Difficulty

The equation of expected time to find valid nonce value at rate R, Hash Rate is:

$$\frac{1}{(pR)} = \frac{2^{32}D}{R} \qquad 2.6$$

Which it is equal to 600 seconds:

where

p : Probability

R : Hash Rate

D : Difficulty

All of the equation combined together to find the estimated power consumption of bitcoin network which becomes:

$$P = \frac{R}{E} \approx \frac{2^{32}D}{600E} \qquad 2.7$$

2.3.2 Bitcoin Mining and its Energy Footprint

The research of Bitcoin Mining and its Energy Footprint studied the aspects of bitcoin systems which are related and relevant to bitcoin mining and its energy footprint. There are different impacts when different hardware used and the calculation for the efficiency of energy issues that lies within bitcoin mining also different, depending on the type of hardware (Malone & O'Dwyer, 2014).

Table 2.2 shows the power used and the energy efficiency of bitcoin mining based on the hardware used.

Table 2.2 Power Used and Energy Efficiency of Bitcoin Mining

(Karl & David, 2014)

Name	**Type**	**Hash Rate, R (Mhash/s)**	**Power Use, P (W)**	**Energy efficiency, Ɛ (Mhash/J)**	**Cost ($)**	**Reference**
Core i7 950	CPU	18.9	150	0.126	350	[8,9]
Atom N450	CPU	1.6	6.5	0.31	169	[10,9]
Sony Playstation 3	CELL	21.0	60	0.35	296	[11,9]
ATI 4850	GPU	101.0	110	0.918	45	[12,9]
ATI 5770	GPU	214.5	108	1.95	80	[13,9]
Digilent Nexys 2 500K	FPGA	5.0	5	1	189	[14,9]
Monarch BPU 600 C	ASIC	600000.0	350	1714	2196	[15,9]
Block Erupter Sapphire	ASIC	333.0	2.55	130	34.99	[16,9]

Figure 2.2 shows the estimated power consumption of the bitcoin mining network.

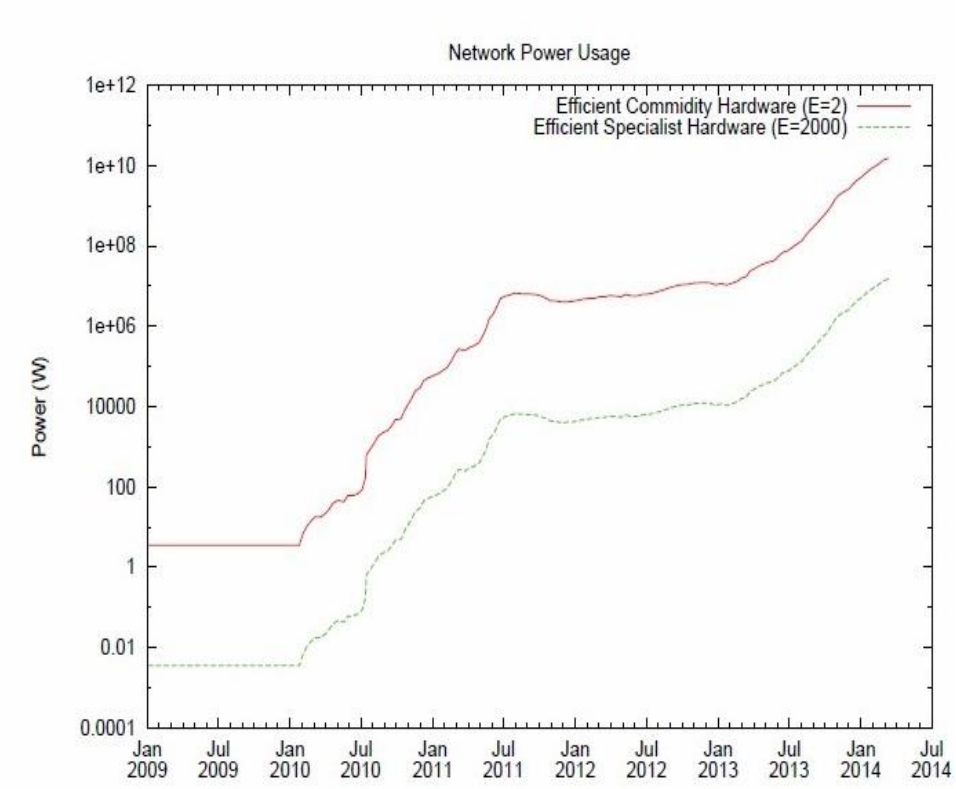


Figure 2.2 Estimated Power Consumption of the Bitcoin Mining Network

Source: (Karl & David, 2014)

On top of that, the research briefly explained the bitcoin mining which include the complexity of bitcoin mining, the changes in technologies, and rewards in bitcoin mining. It also gave details on the hardware arms race where it stated the hardware that can be used to perform the bitcoin mining. Energy cost and reward trade off also being discussed in this research study.

The formula used to calculate the energy efficiency of bitcoin mining based on the hardware used is:

$$\varepsilon = \frac{R}{P} \qquad 2.8$$

where

ε : Energy Efficiency of Hardware

R : Hash Rate

P : Power Usage

The hash rate, R, is measured in millions of hashes per second or known as Mega hashes (Mhash/s). It combined with power usage in order to get and achieve the energy efficiency of hardware, depending on the type of hardware used. The unit used for energy efficiency of hardware is Mhash/J. The higher the hash rate and lower energy footprint of the hardware used, the better that hardware to mine the bitcoin.

2.3.3 Modelling and Simulation of the Economics of Mining in the Bitcoin Market

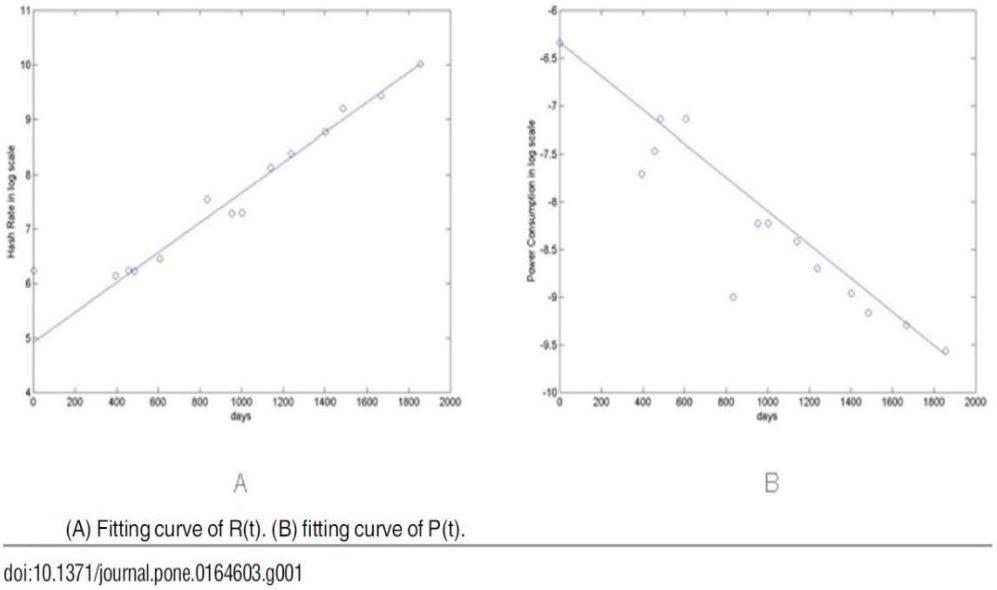
In *Modelling and Simulation of the Economics of Mining in the Bitcoin Market*, it studies and analyses bitcoin mining process where it is also proposed a heterogeneous agent model. The proposed model stimulated bitcoin transaction and the bitcoin mining and implemented mechanism which related to the processes (Cocco & Marchesi, 2016). The main output then analysed and compared in order to produce the best model.

Table 2.3 shows an average of hash rate and of power consumption over time.

Table 2.3 Average of Hash Rate and of Power Consumption over Time (Luisanna & Michele, 2016)

Date	**Simulation Step**	**Average of Hash Rate** $\frac{\mathbf{GH}}{\mathbf{sec} * \$}$	**Average of Power Consumption** $\frac{\mathbf{W}}{\mathbf{GH/sec}}$
September 1, 2010	1	0.0017	454.87
September 29, 2011	394	0.0014	19.8
December 2, 2011	458	0.00175	34.4
December 28, 2011	484	0.0017	72.575
May 1, 2012	608	0.0029	72.575
December 17, 2012	835	0.03565	1
April 10, 2013	953	0.0194	6
May 31, 2013	1004	0.0201	6
October 15, 2013	1141	0.1351	3.84
December 10, 2013	1197	0.0595	3.84
January 22, 2014	1240	0.245	2
July 4, 2014	1403	0.583	1.1
October 23, 2014	1484	1.6	0.69
March 25, 2015	1667	2.756	0.51
September 30, 2015	1856	10.42	0.27

Figure 2.3 shows the graph of hash rate and power consumption of log scale.



(A) Fitting curve of R(t). (B) fitting curve of P(t).

doi:10.1371/journal.pone.0164603.g001

Figure 2.3 Hash Rate and Power Consumption of Log Scale

Source: (Luisanna & Michele, 2016)

The formula used in this research paper to calculate the power consumption of bitcoin over time is:

$$P(t) = a * e^{(b*t)} \qquad 2.9$$

where

a : Constant Value ($4.649*10^{-7}$)

b : -0.004055

P(t) : Power Consumption over Time

In finding the power consumption of bitcoin over time, the general exponential model is used to fit the curve of the power consumption. The fitting curve for power consumption over time for bitcoin is P(t), power consumption per H/sec in which it then will be analysed. In this research paper, the power consumption computed is basically based on the real market data which is in a specific range of time.

2.4 Comparison Among the Existing Research

This section will compare the three research papers that have been selected. Table 2.4 shows the comparison between existing research.

Table 2.4 Comparison Between Existing Research

Paper	Sustainability of Bitcoin and Blockchains (Harald, 2017)	Bitcoin Mining and its Energy Footprint (Karl & David, 2014)	Modelling and Simulation of the Economics of Mining in the Bitcoin Market (Luisanna & Michele, 2016)
Focus	Sustainability of bitcoin and blockchains.	Energy of bitcoin mining and solving the computational problems.	Agent-based artificial cryptocurrency model in studying and analysing bitcoin mining process.
Questions of research study	i. What factors play role in energy consumption of bitcoin mining? ii. Are there alternatives that can reduce energy consumption?	i. How energy of bitcoin mining can be calculated? ii. What is the impact of using different types of hardware in the computation?	i. What type of mechanism can be implemented for the formation of the model? ii. Which scheme can be used in the process?

Formula used	$P = \frac{R}{E}$ which approximately: $\frac{2^{32}D}{600E}$ where: P:Power Consumption R: Hash Rate E: Energy Efficiency of Bitcoin Mining D: Difficulty In finding the power consumption, P, of bitcoin mining, it includes the combination of various equations and formulas of the difficulty of valid hash, probability that yields valid hash, expected time of valid nonce value and hash rate of bitcoin network.	$\varepsilon = \frac{R}{P}$ where: Ɛ: Energy efficiency of hardware P: Power Usage R: Hash Rate The energy efficiency of bitcoin mining is calculated based on the hardware used for the mining. It includes the power usage used by the hardware and the hash rate of the hardware. The combination of power usage and rate of hash (measured in Mhash/s) resulting to the energy efficiency of bitcoin mining based on the type of hardware used. The unit used for energy efficiency of hardware is Mhash/J.	$P(t) = a * e^{(b*t)}$ where: a: constant value $(4.649 * 10^{-7})$ b: -0.004055 P(t):Power Consumption over Time The power consumption of the bitcoin mining is analysed by the fitting curve of its model over time. P(t) power consumption per H/sec. General exponential model used to fit the curve for the consumption of power.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Methodology is a development guideline in ensuring research project run accordingly to phases and framework which have been decided throughout the research. It is a theoretical framework for the stages of development of research project and it is used to describe methods, techniques, tools and instruments. The methodology chapter describes the application of techniques and specific procedures in analysing energy efficiency of the bitcoin mining hardware and related blockchain technology. It includes definition of theoretical concepts, tools and techniques, specific methods which having relevance to the research problem. In this research, we use Matrix Laboratory, or known as MATLAB, where the enhanced formula and algorithms for energy efficiency and power consumption of bitcoin mining hardware can be developed.

3.2 Methodology

During research, the literature review and analyses to be done in order to identify the applicability of MATLAB in development of enhanced formula and algorithms for identification future energy efficiency and power consumption of bitcoin mining hardware. The comparison of three existing approaches results in the finding of the improved formula that can be used to predict energy efficiency and power consumption of bitcoin mining between bitcoin mining hardware.

3.3 Flowchart of the Research

The flowchart of this research consists of 6 stages which are the literature review of existing research studies, formulation of the problem, objectives and scope, development of enhanced formula, implementation of formula and algorithm with MATLAB, application of formula and algorithm and preparation of final report.

Figure 3.1 shows the flowchart of this research.

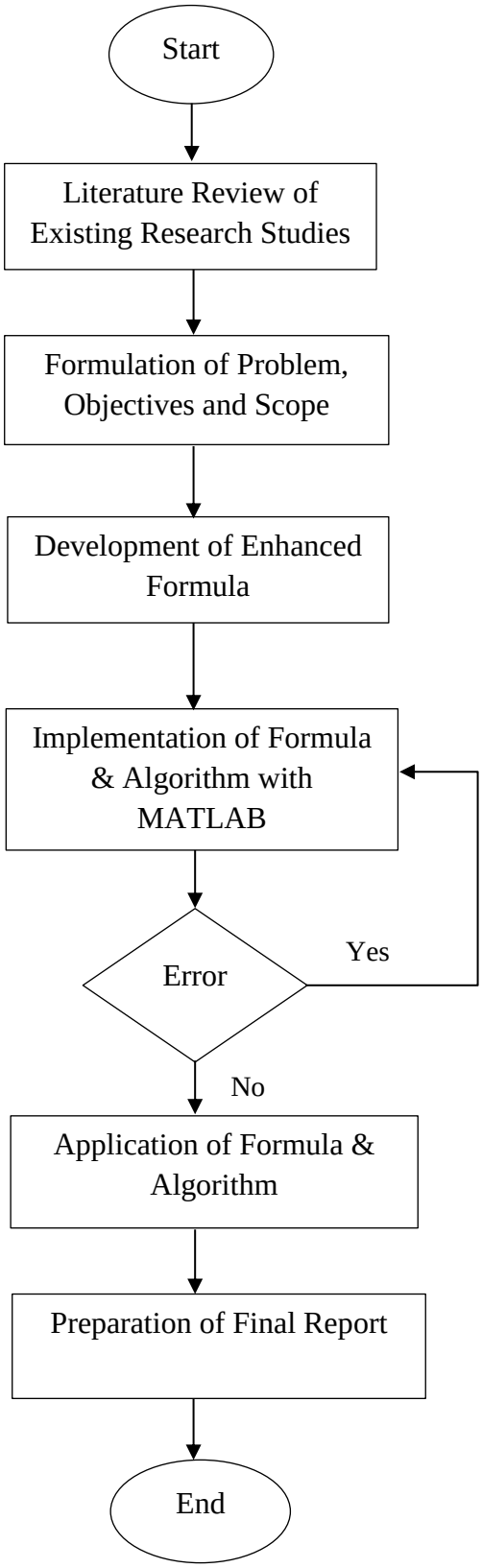


Figure 3.1 Flowchart of Research

3.3.1 Literature Review

In the literature review phase, existing research which are related to energy efficiency of bitcoin and blockchain system were compared and used to develop enhanced formula and algorithm. Through this literature review phase, the techniques, methods and tools which are suitable to the research will be used in developing the enhanced formula and algorithm.

In this research, next research studies were analysed:

i. Sustainability of Bitcoin and Blockchain (Harald, 2017)

ii. Bitcoin Mining and its Energy Footprint (Karl & David, 2014)

iii. Modelling and Simulation of the Economics of Mining in the Bitcoin Market (Luisanna & Michele, 2016)

3.3.2 Formulation of the Problem, Objectives & Scope

In this phase, after analysing the existing research studies and going through literature review phase, the problem of research, objectives and research scopes were formulated. Basically, there are a lot of types of hardware which are different in dealing with the phenomenon of bitcoin mining. It results in the problem where there are several existing formulas not focusing on the energy efficiency of hardware for bitcoin mining and predicting the trends of bitcoin mining hardware.

Based on the problem discovered from the existing research, the objective is formulated to propose an enhanced formula, which allows to evaluate and predict the energy efficiency in the bitcoin mining hardware. Next stage is to form the dataset for evaluating the energy efficiency of bitcoin mining hardware.

This research scope focuses on the bitcoin mining hardware in which it is used to predict energy efficiency of bitcoin mining hardware in where the user of proposed enhanced formula and algorithm are the developers of bitcoin hardware systems and bitcoin miners.

3.3.3 Development of Formula & Algorithm

After analysing and comparing the existing research studies, the enhanced formula for energy efficiency and power consumption of bitcoin and blockchain technology will be developed. The formula and algorithm will be implemented in Matrix Laboratory (MATLAB) where it then will use the data from the open source www.blockchain.info, www.tradeblock.com and https://en.bitcoin.it/wiki. The data will be used to produce the model of energy efficiency hardware of bitcoin mining and related blockchain technology where the prediction of future hardware of ASICs can be made based on the results.

3.3.4 Implementation of Formula & Algorithm

The formula that have been developed by the modification of three compared formulas will be applied to find the energy efficiency and power consumption of the bitcoin and blockchain technology hardware. The formula will be implemented in MATLAB to predict the energy efficiency of future of bitcoin mining hardware. MATLAB GUI and libraries will be used in implementing the algorithm.

3.3.4.1 Linear Regression, Polyfit & Polyval Functions

In developing the algorithm and plotting graph, linear regression, especially MATLAB polyfit function and polyval function are used to predict the energy efficiency of future hardware of bitcoin mining.

Linear regression used to describe the relationship between the variables of predictor and response, where it is the relation between dependent, or response, variable y and one or more independent or predictor.

Linear regression considers one independent variable in which it is used in the relation of:

$$y = \beta_0 + \beta_1 x + \epsilon$$

where
β_0 : y-intercept
β_1 : Slope / Regression Coefficient
ϵ : Error Term

For polyfit function, it is a polynomial curve fitting where the syntaxes are:

$$p = polyfit\ (x, y, n)$$

This syntax returns coefficient of polynomial p(x) of *n* degree which is the best fit for data in *y*.

For polyval function, it is the polynomial evaluation where the syntaxes are:

$$y = polyval(p, x)$$

This syntax returns value of polynomial of *n* degree which evaluated at *x*.

3.3.5 Application of Formula & Algorithm

The application of enhanced formula and algorithm in this research is predicting the energy efficiency and power consumption of bitcoin mining and related blockchain technology. After the testing of formula and algorithm, it will be used in predicting the energy efficiency of the hardware of bitcoin mining.

3.3.6 Preparation of Final Report

After going through all of the stages, final report will be prepared in order to keep the framework of the research and documenting result of the research. Final report will include the introduction, literature review and methodology for PSM1, development, results and discussion, and lastly conclusion for PSM2.

3.4 Research Planning

Gantt chart used in this research to show the time duration and scheduled flow of the research in planning phase where this phase identifies the problem statements, objectives and project scopes of this project, followed by literature review. Besides that, the requirements of hardware and software that need to be used for this research also identified in this phase. Existing researches will be references in determining the requirements of hardware and software.

3.4.1 Gantt Chart

For this research, the Gantt chart scheduled the tasks and total time spent for each of the phase. This research started from 12th February 2018 and had been estimated to end on 15th May 2018 for the first semester. For the second semester, it started from 13th September 2018 and estimated to end on 20th December 2018. The Gantt chart cover the research of the first and second semester and estimated duration for the phases of this research. (Refer Appendix A)

3.5 Requirement of Hardware and Software

This subchapter discusses about hardware and software which used in the process of completing this research, alongside with the required specification of the hardware and software. The hardware and software needed for this research are:

3.5.1 Hardware

Hardware is a peripheral device where it is an important component in this research. Subtopic below shows the hardware that have been used in this research.

i. Personal Computer (Laptop)

There personal computer which being used in this research is very convenience since it is portable and lighter than desktop computer. This personal computer is used to operate and perform tasks, as well as preparing required documentation through this research.

3.5.2 Software

Software comes in various forms such as operating systems, programs, and other applications where it enables computer to function. Subtopics below shows the software that have been used in this research.

i. Microsoft Office

There are many types of Microsoft Office applications. For this research, Microsoft Office applications such as Microsoft Word, Microsoft Project and Microsoft PowerPoint used in order to prepare and document the report, presentation slide and also Gantt chart.

ii. Draw.io

Draw.io is an open source software which it is the platform where various diagram can be drawn such as use case diagram. For this research, this open source software used in order to draw flowchart, which indicates the flow of this research.

iii. Matrix Laboratory (MATLAB)

MATLAB is a GUI and programming language which can manipulates matrixes, implement algorithms and plot numerous functions and data. This software is written on C, C++, Java and can operate well in various operating systems such as Windows, MacOS and Linux. In this research, MATLAB used to formulate future energy efficiency and power consumption of bitcoin mining.

Table 3.1 shows the specification of hardware and software requirements for this research.

Table 3.1 Hardware and Software Requirements

Hardware/Software	Specification
Personal Computer (Laptop)	• ACER • Windows 8.1 • Intel® Core™ i5-5200U CPU @ 2.20GHz 2.20 GHz • 4.00 GB • 64-bit Operating System, x64-based processor
Microsoft Office (Word, Project, PowerPoint, Excel)	None
Draw.io	Open source software
Matrix Laboratory (MATLAB)	• Intel/AMD x86 processor supporting SSE2 instruction set • 1GB only for MATLAB • 3-4 GB for typical installation • 1024MB RAM

3.6 Tools and Method Used

3.6.1 Matrix Laboratory

MATLAB which stands for Matrix Laboratory, is a GUI and programming language, where it can manipulate the matrixes, implement algorithms and plot numerous functions and data. It is written in C. C++ and Java and can operate well in various operating systems such as Windows, MacOS and Linux.

In this research, MATLAB will be used in order to develop algorithms for energy efficiency and power consumption of bitcoin mining. MATLAB can help in being a platform in development and validation of the model by using the data obtained from www.blockchain.info, www.tradeblock.com and https://en.bitcoin.it/wiki.

3.6.1.1 MATLAB Interfaces

Model will be developed and plotted based on the dataset by using MATLAB. In MATLAB, it provides simulation and different types of Simulink which stored in '**Simulink Library**' at '**Home**' tab, in '**Simulink**' section. '**Simulink Library Browser**' will appear and shows the types of Simulink that can be used through the application. Figure 3.4 shows the main menu of MATLAB.

Figure 3.4 Main Menu of MATLAB

Figure 3.5 shows the Simulink library browser of MATLAB.

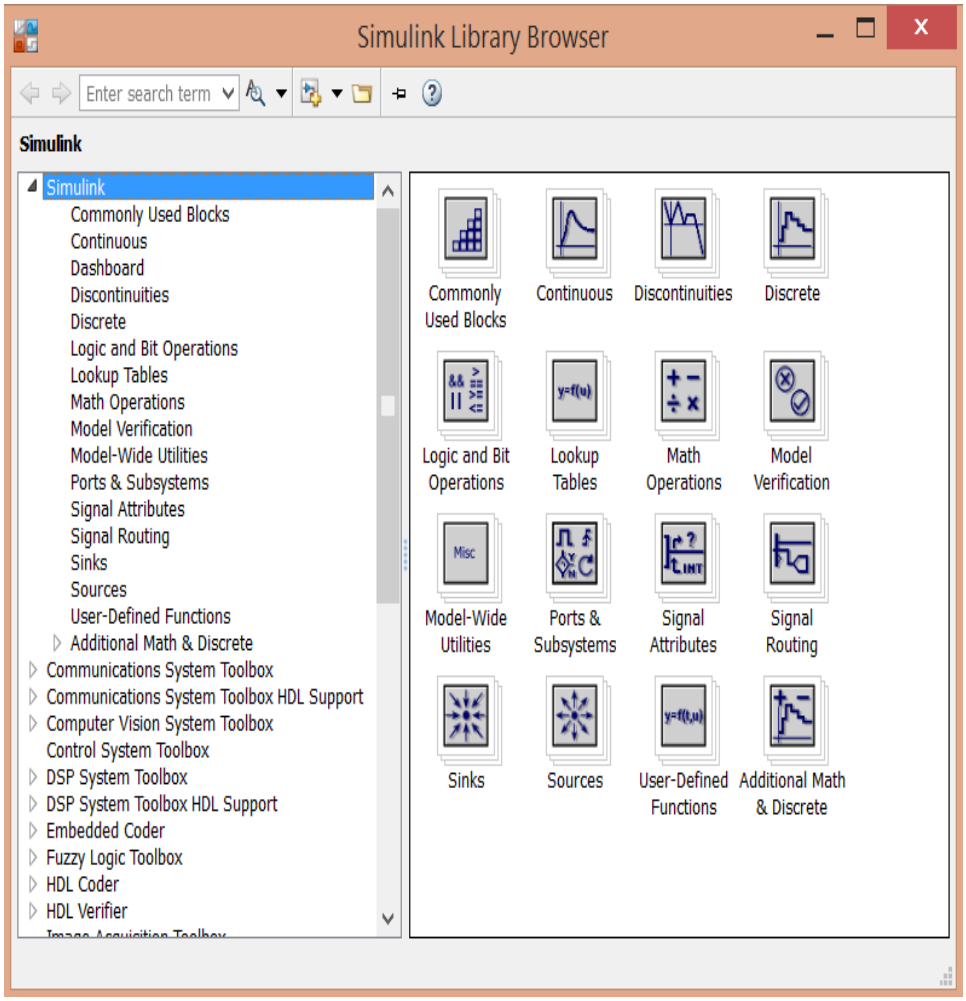


Figure 3.5 Simulink Library Browser

In '**Editor**' window, the variables and formulas will be declared to ensure that there is no error in the formula and the variables are the correct variables before the plotting of graph.

Figure 3.6 shows the editor window of MATLAB.

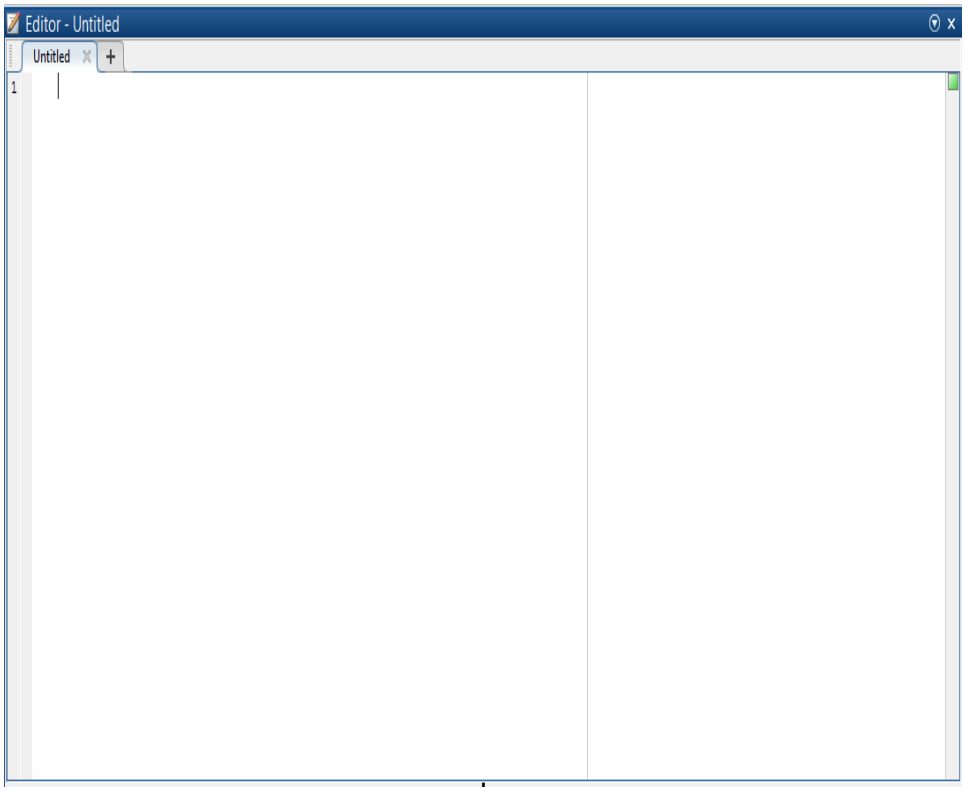


Figure 3.6 Editor Window of MATLAB

‘**Command window**’ will show the error that occur whether in the declared variables or in the formulas that is undefined and at which line that the error occurred.

Figure 3.7 shows the command window of MATLAB.

Figure 3.7 Command Window of MATLAB

In the '**Current Folder**' section, it shows the file and folder that is currently in use in MATLAB that is still in the process of developing.

Figure 3.8 shows the current folder section of MATLAB.

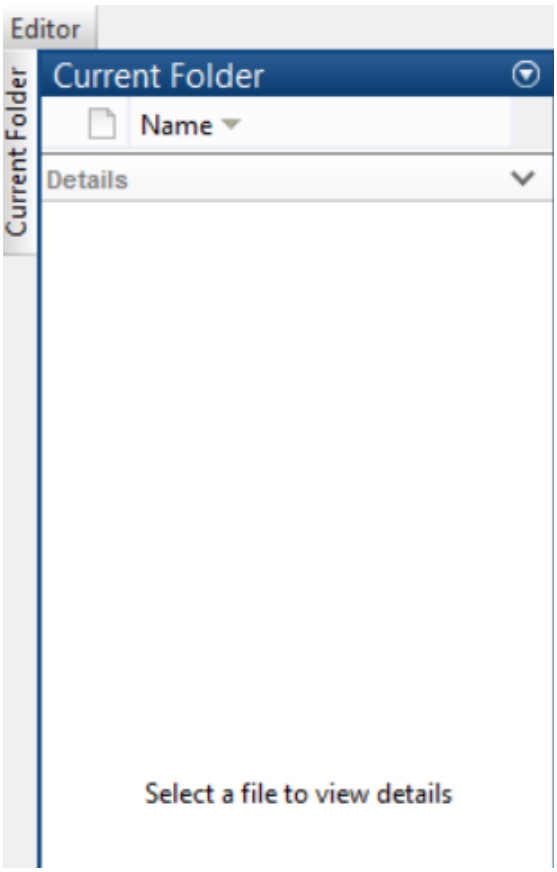


Figure 3.8 Current Folder Section of MATLAB

In '**Workspace**' section, it will show the variables that have been successfully declared in '**Editor**' alongside with the value of the variables.

Figure 3.9 shows the workspace section of MATLAB.

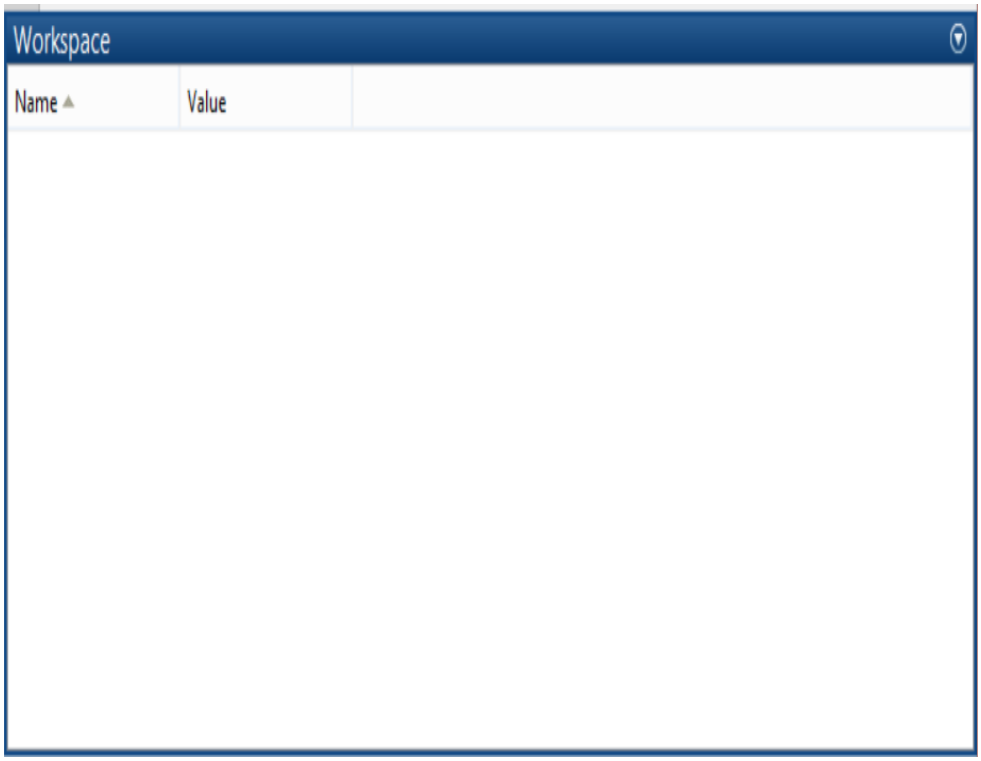


Figure 3.9 Workspace Section of MATLAB

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter describes the process of the development and the implementation of the enhanced formula and algorithm to predict the energy efficiency for hardware of bitcoin mining and related blockchain technology. The formulated formula and algorithm developed using MATLAB to build model of energy efficiency of bitcoin mining hardware.

4.2 Implementation Process

This section shows the specific implementation of the enhanced formula, algorithm. This implementation process begins with development of the new formula for the energy efficiency and the algorithm for bitcoin mining and related blockchain technology. The formulated and enhanced formula, and the algorithm will be implemented through MATLAB by using dataset from open source website, www.blockchain.info, www.tradeblock.com and https://en.bitcoin.it/wiki. These datasets and information of the mines of bitcoin and the details will be use throughout the research to prove that the results of enhanced formula and algorithm can be used to predict the energy efficiency of bitcoin mining.

4.2.1 Development of Enhanced Formula

Before developing the new model of energy efficiency for the hardware of bitcoin mining, the new enhanced formula is formulated. In this process, the enhanced formula is formulated by combining the three formulas that have been used in the three analysed in LR research papers. This enhanced formula then will be implemented in an algorithm and tested before it can be applied to predict the future energy efficiency for the hardware of bitcoin mining.

$$Em = \alpha * Y - b$$

where
α : 0.2094
Y : Year
b : 420.9868

4.2.2 Implementation of Enhanced Formula & Algorithm

4.2.2.1 Dataset

The datasets of hardware will be used to generate and plot graph of the energy efficiency of bitcoin mining. These datasets include the types of hardware, hash rate, energy efficiency of bitcoin mining and power consumption used by the hardware in the process of mining the bitcoin. The type of hardware used in this research is the Application-Specific Integrated Circuits (ASIC).

Table 4.1 shows the dataset of ASICs hardware.

Table 4.1 Dataset of ASICs Hardware

Product (ASIC)	**Energy Efficiency, E (Ghash/J)**	**Hash Rate, R (Ghash/s)**	**Power Consumption, P (W)**	**Year**
bi*fury	1.176	4.998	4.25	2013
Blue Fury	1.0	2.5	2.5	2013
Red/BlueFury	1.04	2.6	2.5	2013
Twinfury	1.174	4.4964	3.83	2013
TerraHash Klondike 16	0.14	4.48	32	2013
TerraHash Klondike 64	0.14	17.78	127	2013

ASICMiner BE Blade	0.129	10.707	83	2013
ASICMiner BE Cube	0.15	30	200	2013
Avalon Batch 1	0.107	66.34	620	2013
Avalon Batch 2	0.117	81.9	700	2013
BFL SC 5Gh/s	0.166	4.98	30	2013
BFL SC 25Gh/s	0.166	24.9	150	2013
AntMiner U1	0.8	1.6	2	2014
AntMiner U2+	1.0	2	2	2014
NanoFury NF2	0.74	3.7	5	2014
ROCKMINER R-BOX	0.711	31.995	45	2014
BFL SC 50Gh/s	0.166	49.8	300	2014
AntMiner U3	1.0	63	63	2015
AntMiner S2	1.0	1000	1000	2016
Klondike	0.16	5.12	32	2017
ASICMiner BE Sapphire	0.13	0.3315	2.55	2017
ASICMiner Value	3.33	3500	1050	2018

4.2.3 Application of Formula & Graph Development

During this phase, each graph is developed regarding to the used datasets. Through this phase, the upgraded and newest version of the hardware used to bitcoin mining can be proved either it is more efficient or not compared to the previous models.

4.2.3.1 Algorithm of Energy Efficiency of ASICs Hardware from 2013 until 2018

Table 4.2 Algorithm of Energy Efficiency of ASICs Hardware from 2013 until 2018

```
   % First COLUMN is year. next is the energy efficiency
,hash rate,and power consumption

    data =[ 2013 1.176 4.998 4.25; ...
            2013 1.0 2.5 2.5; ...
            2013 1.04 2.6 2.5; ...
            2013 1.174 4.964 3.83; ...
            2013 0.14 4.48 32; ...
            2013 0.14 17.78 127; ...
            2013 0.129 10.707 83; ...
            2013 0.15 30 200; ...
            2013 0.107 66.34 620; ...
            2013 0.166 4.98 30; ...
            2013 0.166 24.9 150; ...
            2014 0.8 1.6 2; ...
            2014 1.0 2 2; ...
            2014 0.74 3.7 5; ...
            2014 0.711 31.995 45; ...
            2014 0.166 49.8 300; ...
            2015 1.0 63 63; ...
            2016 1.0 1000 1000; ...
            2017 0.16 5.12 32; ...
            2017 0.13 0.3315 2.55; ...
            2018 3.33 3500 1050];

   % Fitting a polynomial f=a*e+b*p+c*r;
   % e: energy efficiency, p: power consumption, r: hash
rate

   r=[data(:,1);data(:,1);data(:,1)];
   eMeasured=[data(:,2);data(:,3);data(:,4)];
   a=polyfit(r, eMeasured,3);

   % Plot1
   rModel=min(r):0.1:max(r);
   eModelled=polyval(a,rModel);

   %Condition
   %value of variables should be positive/cannot less than 0
   if (r & eMeasured) > 0
   figure
   plot(rModel,eModelled,'r-','LineWidth',1);
   hold on
   plot(r,eMeasured,'kx','MarkerSize',10)
   legend('Fitted Line','Measured');

   else
   end
```

The data of ASICs hardware were implemented into the algorithm where the first column is year, followed by energy efficiency, hash rate and power consumption. Data of year declared as variable *r* whereas data of energy efficiency, hash rate and power consumption declared as variable *eMeasured.*

In variable *a*, the function of *polyfit* used with *r* and *eMeasured* to fit a 3rd-degree polynomial using centering and scaling. The scale of model is set to 0.1 in *rModel* which in between of the maximum and minimum value of year for the ASICs hardware. In variable *eModelled*, the function of *polyval* used with 2 inputs which are *a* and *rModel* to evaluate *a* with *rModel*.

The dependent variable in this algorithm is *r* (year) whereas the independent variables for this algorithm are *eModelled* (energy efficiency, hash rate, power consumption). The value of variables and data should not be less than 0 or else the graph cannot be plotted until the algorithm is fixed.

4.2.3.2 Flowchart of Algorithm for Energy Efficiency of ASICs Hardware from 2013 until 2018

Figure 4.1 shows the flowchart of algorithm for the energy efficiency of ASICs hardware from 2013 until 2018.

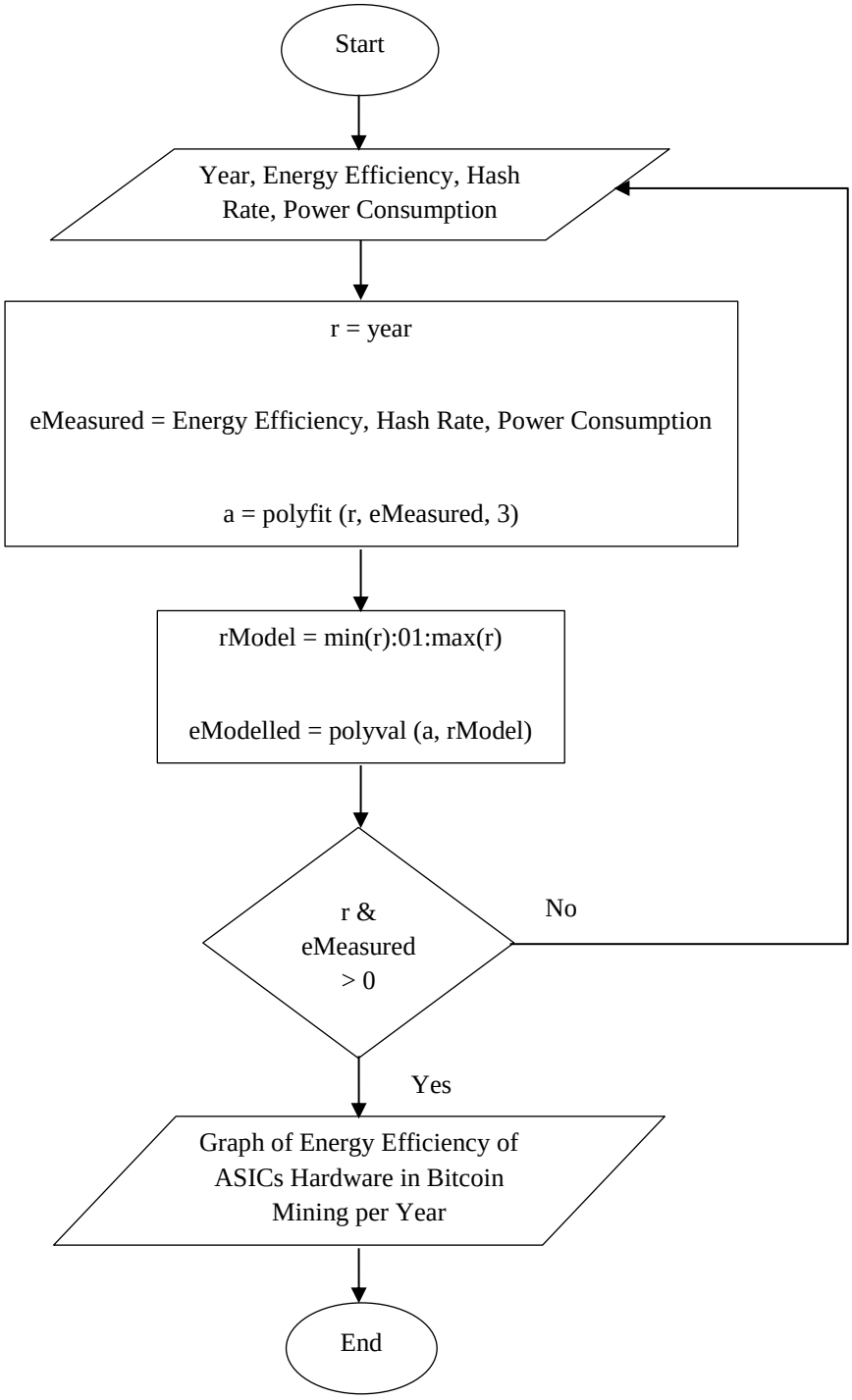


Figure 4.1 Flowchart of Algorithm of Energy Efficiency for ASICs from 2013 until 2018

4.2.4 Prediction of Energy Efficiency of ASICs Hardware in 2019

The enhanced formula used to predict the energy efficiency of ASICs hardware in 2019 where it is implemented in the algorithm.

4.2.4.1 Algorithm of Energy Efficiency of ASICs Hardware Predicted in 2019

Table 4.3 Algorithm of Energy Efficiency of ASICs Hardware Predicted in 2019

```
   % First column is year. next is the energy efficiency (E),
power consumption (P) and hash rate (R),

   data =[  2013 1.176 4.998 4.25; ...
            2013 1.0 2.5 2.5; ...
            2013 1.04 2.6 2.5; ...
            2013 1.174 4.964 3.83; ...
            2013 0.14 4.48 32; ...
            2013 0.14 17.78 127; ...
            2013 0.129 10.707 83; ...
            2013 0.15 30 200; ...
            2013 0.107 66.34 620; ...
            2013 0.166 4.98 30; ...
            2013 0.166 24.9 150; ...
            2014 0.8 1.6 2; ...
            2014 1.0 2 2; ...
            2014 0.74 3.7 5; ...
            2014 0.711 31.995 45; ...
            2014 0.166 49.8 300; ...
            2015 1.0 63 63; ...
            2016 1.0 1000 1000; ...
            2017 0.16 5.12 32; ...
            2017 0.13 0.3315 2.55; ...
            2018 3.33 3500 1050];

   % Fitting a polynomial E=a*E*E+b*E+c;
   % E: energy efficiency, P: power consumption, R: hash rate

   year=data(:,1);
   E=data(:,2);
   a=polyfit(year, E, 1);

   % Plot1
   rModel=min(year):0.1:max(year);
   eModelled=polyval(a,rModel);

   %Condition
   %value of variables should be positive/cannot less than 0
   if (year & E) > 0
   figure
   plot(rModel,eModelled,'r-','LineWidth',1);
   hold on
   plot(year,E,'kx','MarkerSize',10)
```

```
yr = 2019
% Enhanced Formula
Em = 0.2094*yr -420.9868

plot (yr, Em, 'kx', 'MarkerSize',20)
legend('Fitted Line','Measured', 'Predicted');

else
end
```

The data of ASICs hardware were implemented into the algorithm where the first column is year, followed by energy efficiency, hash rate and power consumption. In this algorithm, only data from the first column (year) and the second column (energy efficiency) used to predict the energy efficiency of ASICs hardware. Data of year declared as variable *year* whereas data of energy efficiency declared as variable *E*.

In variable *a*, the function of *polyfit* used with *year* and *E* to fit a 1st-degree polynomial using centering and scaling. The scale of model is set to 0.1 in *rModel* which in between of the maximum and minimum value of year for the ASICs hardware. In variable *eModelled*, the function of *polyval* used with 2 inputs which are *a* and *rModel* to evaluate *a* with *r*.

Figure 4.2 shows the flowchart of algorithm for the energy efficiency of ASICs hardware predicted in 2019.

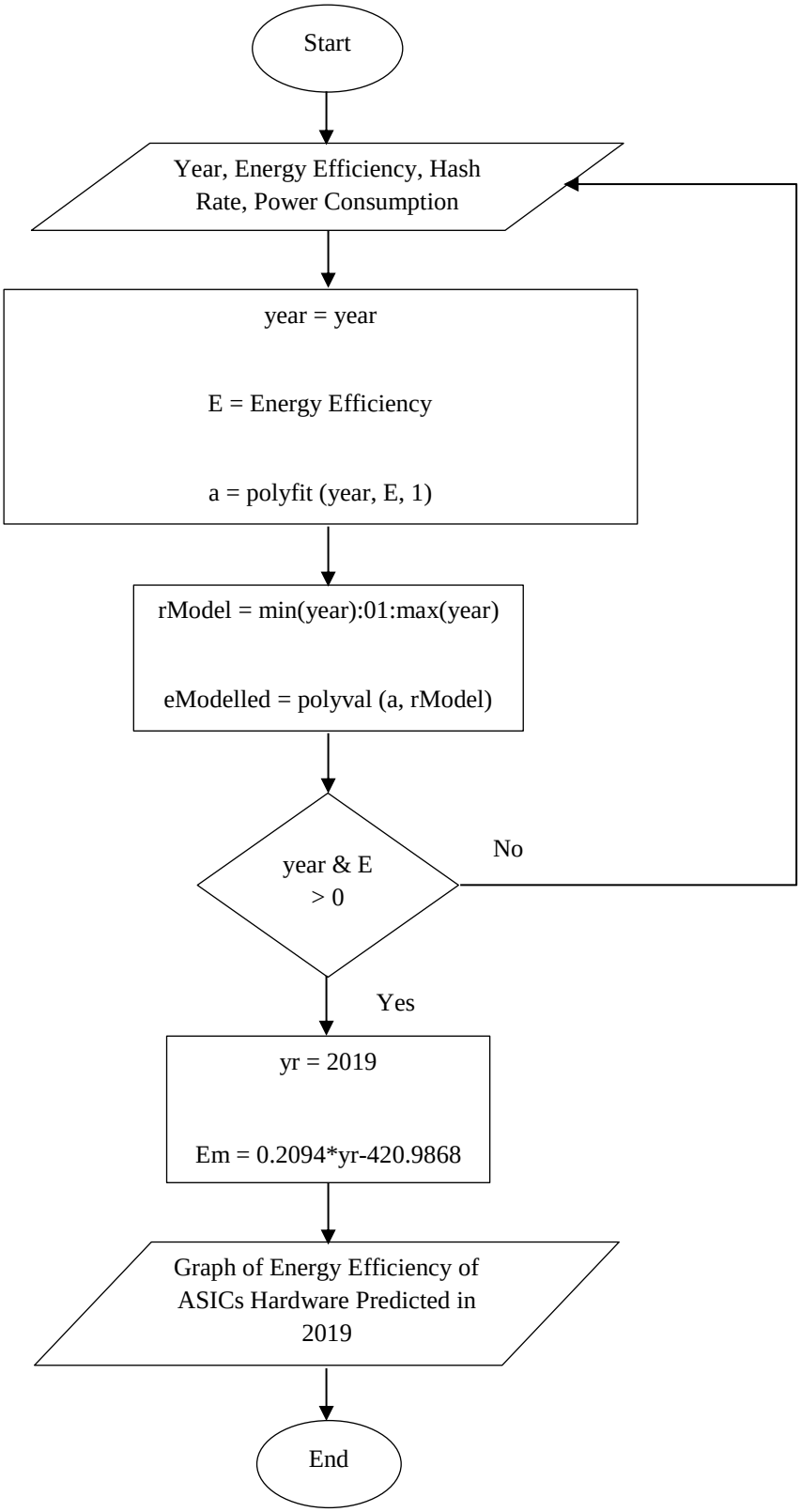


Figure 4.2 Flowchart of Energy Efficiency for ASICs Hardware Predicted in 2019

4.3 Result & Discussion

The energy efficiency of Application-Specified Integrated Circuit (ASIC) in bitcoin mining changes over years where it has been proved to be more efficient as the time goes by. Based on the graph plotted, it can be concluded that the energy efficiency of ASICs in bitcoin mining are increasing thus the prediction of the energy efficiency of future ASIC hardware in bitcoin mining can be made.

In 2019, the energy efficiency of ASIC hardware in the mining of bitcoin will become more efficient, allowing the bitcoin developers and bitcoin miners to keep using ASICs to mine bitcoin in the future. It is not impossible for the energy efficiency of ASICs to exceed more than 100 Tera Hash per seconds (THash/s) which indicates that the production of bitcoin mining hardware and the capabilities to generate a lot of energy, hash rate and power to mine the bitcoin is on another level.

Figure 4.3 shows the graph of energy efficiency of ASICs for bitcoin mining in 2013 until 2018.

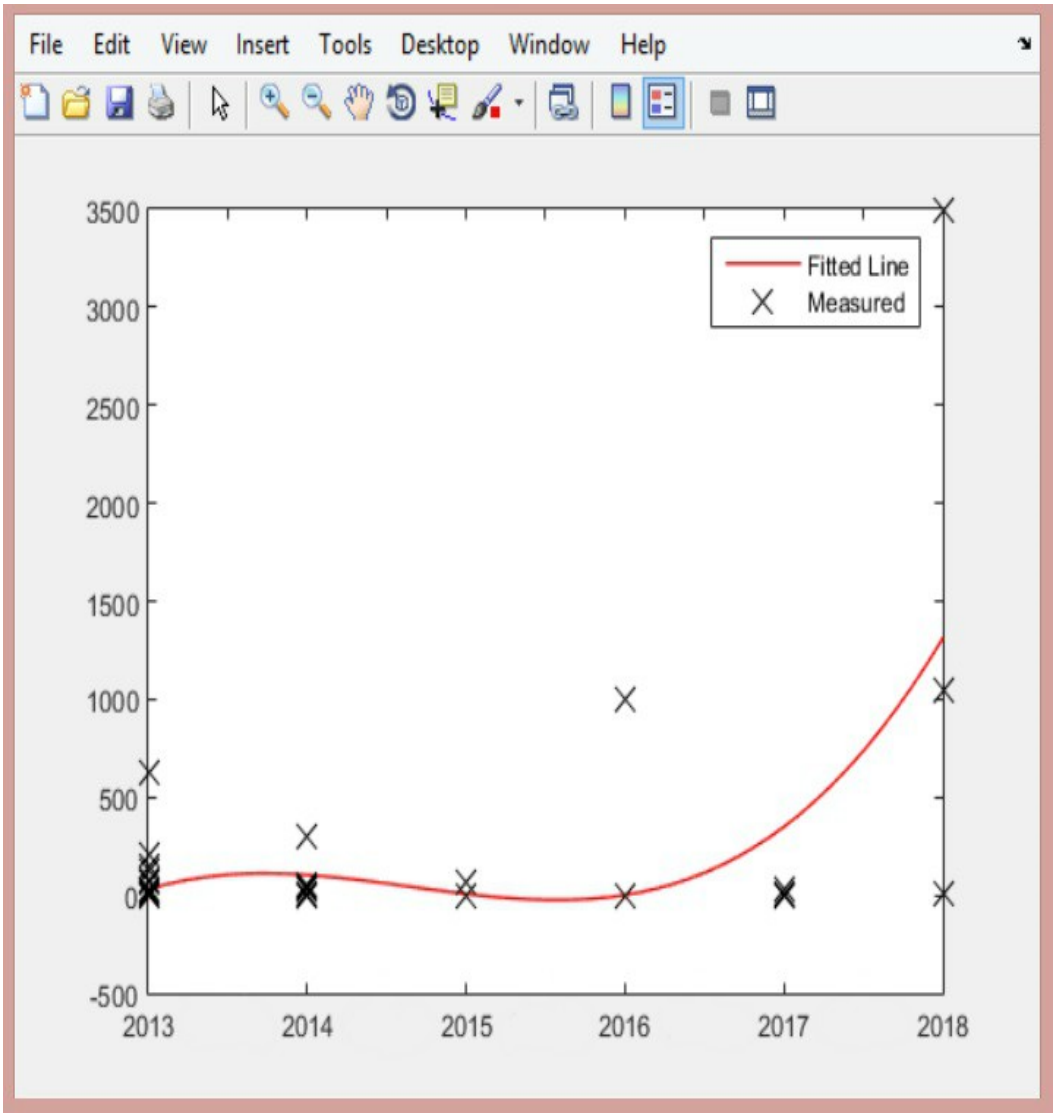


Figure 4.3 Energy Efficiency of ASICs for Bitcoin Mining in 2013 until 2018

The linear regression graph is developed using polyval and polyfit function, alongside with the implementation of the formula of linear regression. From the plotted graph, the energy efficiency of ASICs hardware increased staring from 2013 and 2018 which is at the peak of the efficiency of energy for the hardware. This result leads to the prediction of energy efficiency for the future ASICs hardware in 2019.

Figure 4.4 shows the graph of energy efficiency of ASICs hardware predicted in 2019.

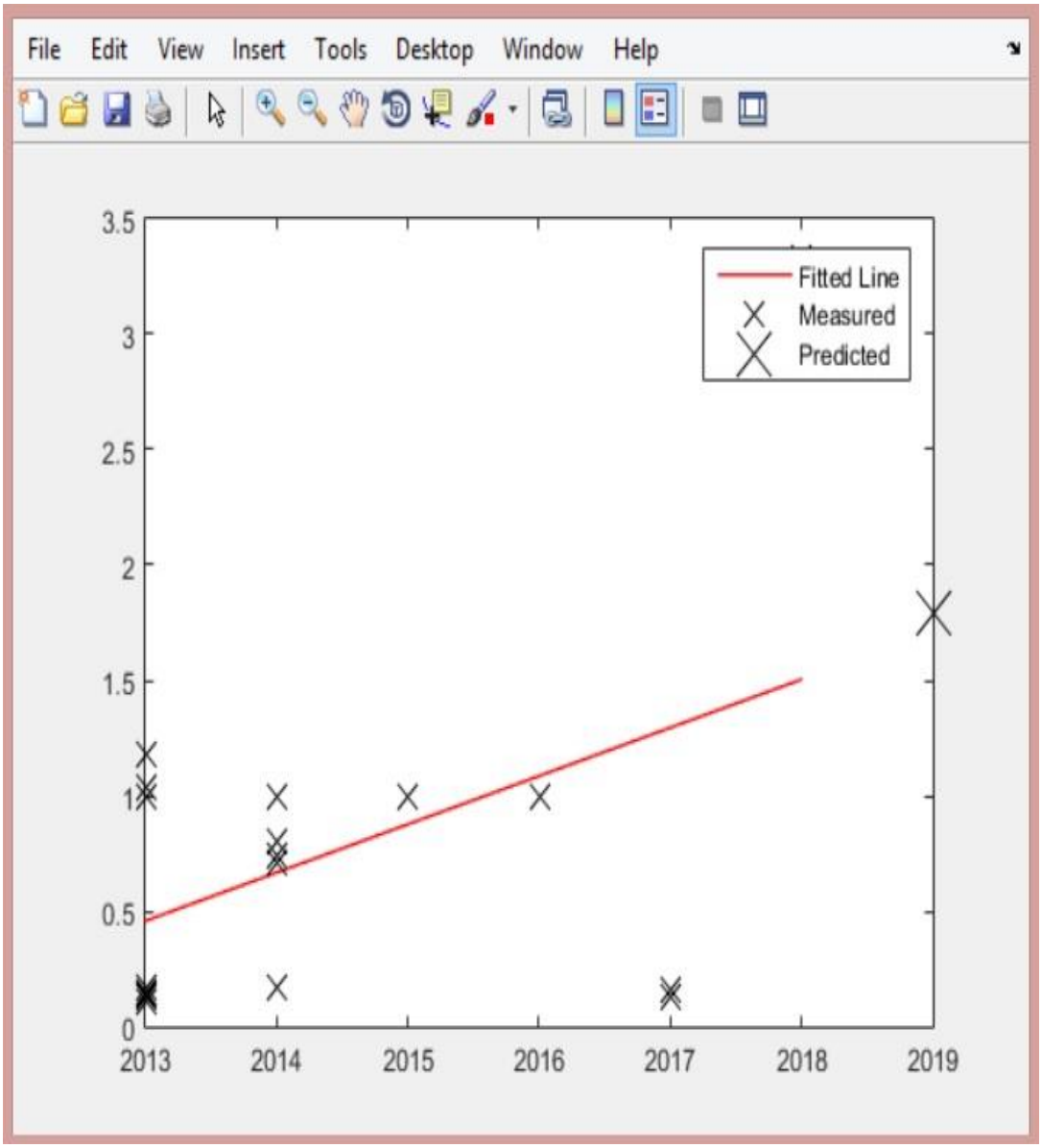


Figure 4.4 Energy Efficiency of ASICs Hardware Predicted in 2019

The prediction of energy efficiency for ASICs hardware in 2019 is made by using the enhanced formula which is $Em = \alpha * Y - b$. Based on the plotted graph, the next energy efficiency of ASICs hardware in 2019 is predicted to be 1.7918 GigaHash/Joule (Ghash/J). It can be concluded that the energy efficiency of ASICs hardware becomes more efficient as time goes by where it becomes the most preferable hardware used for bitcoin mining.

CHAPTER 5

CONCLUSION

5.1 Introduction

This chapter contains the conclusion throughout the research findings. Based on the research, it can be concluded that the energy efficiency of hardware in bitcoin mining and related blockchain technology depends on the use of ASICs hardware in the mining process. The evolution of hardware used in bitcoin mining consist of 4 generations of hardware which are Central Processing Unit (CPU), Graphical Processing Unit (GPU), Field Programmable Gate Arrays (FPGA) and Application-Specific Integrated Circuits (ASIC). It brings great impact in in terms of hash rate, energy efficiency and power consumption of bitcoin mining. This research focusing on Application-Specific Integrated Circuits (ASIC) where it is the most efficient hardware in bitcoin mining compared to other hardware.

The higher the hash rate that can be generated, the higher the need for energy used in the mining process. Hardware that have higher hash rate is capable to generate and to mine higher number of bitcoins. Through this research, the implementation of linear regression and functions of polyfit and polyval in MATLAB shows how hash rate, energy efficiency and power consumption basically related to each other and how each of them affects the performance of the hardware in the bitcoin mining process.

The energy efficiency of future hardware is predicted by using this function, referring to the graph plotted in MATLAB in which it depends on the types of hardware used. The future hardware of ASIC in 2019 is predicted after the implementation of enhanced formula and algorithm in which it is built by combining three formulas from different research studies, and dataset from open source. The dataset and enhanced formula used in the algorithm to plot the graph which consist of year of the hardware made, hash rate, energy efficiency and power consumption of bitcoin mining where the x-axis is the year of the hardware made and the y-axis is the hash rate, energy efficiency and power consumption.

This research on the energy efficiency of algorithm in bitcoin mining and related blockchain technology has met all the three objectives that have been stated at the beginning of the research. This research also has achieved the goal to develop enhanced formula for approximation, based on data from open sources and use it to plot graph where it shows the important information that can be use in analysing thus predicting the energy efficiency of bitcoin mining based on the types of hardware used. From that, we can predict the energy efficiency of bitcoin mining for the next hardware that will be used to mine the bitcoins. The idea of this research also can be implemented and enhanced in the future work.

5.2 Research Constraint

The constraint of this research is the proposed formula and algorithm only use 4 parameters which are year of the hardware made, hash rate, power consumption and energy efficiency. This formula and algorithm use polynomial approximation in determining the energy efficiency produced by future hardware in bitcoin mining.

5.3 Future Work

The research can be improved with several enhancement for the future advancement of Energy Efficiency for the Bitcoin Mining Hardware and Related Blockchain Technology which are software approaches and enhanced formula. The energy efficiency of bitcoin mining hardware can be analysed by using other software and approaches such as Cased Based Reasoning and Fuzzy Logic to predict the energy efficiency of bitcoin mining of hardware and related blockchain technology.

For the enhanced formula, to get more accurate amount of energy consumed and how efficient the energy of hardware for bitcoin mining, the enhanced formula can be specifically formulated for each of the types of hardware.

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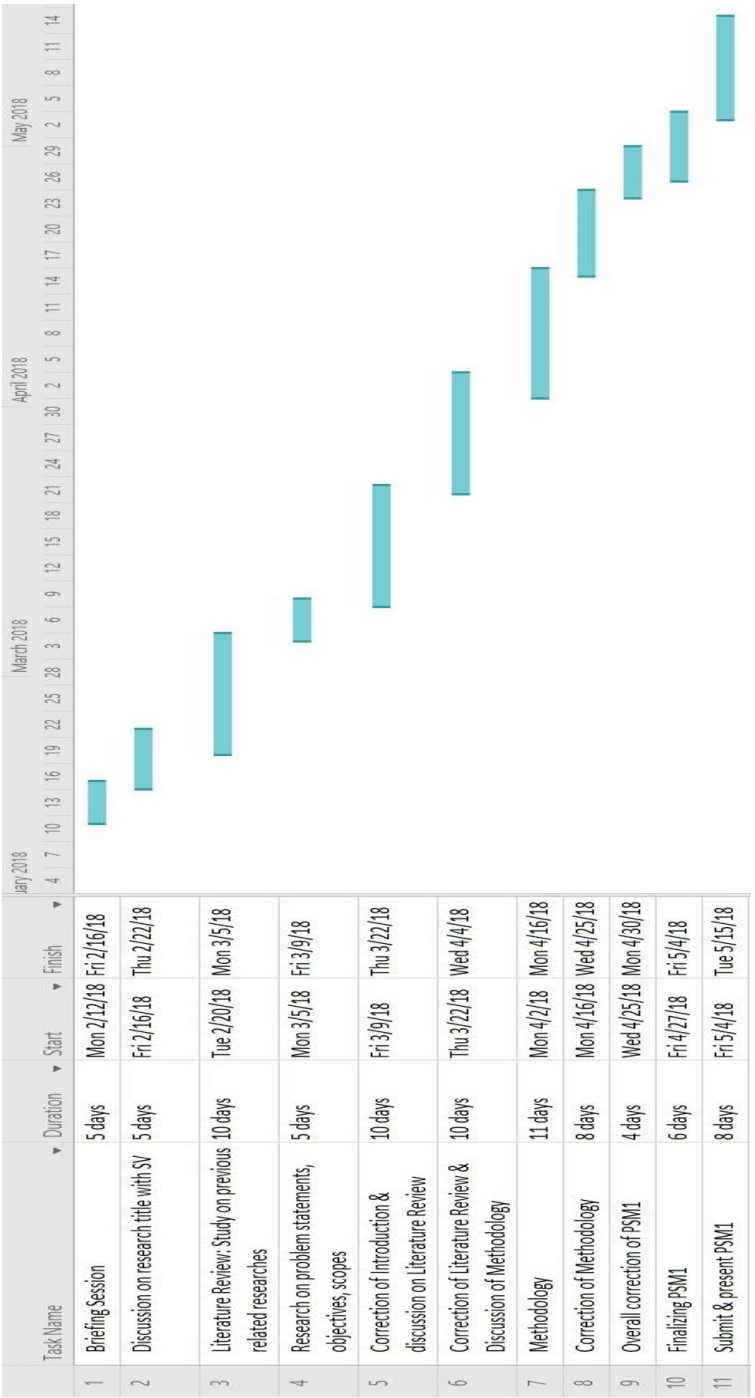
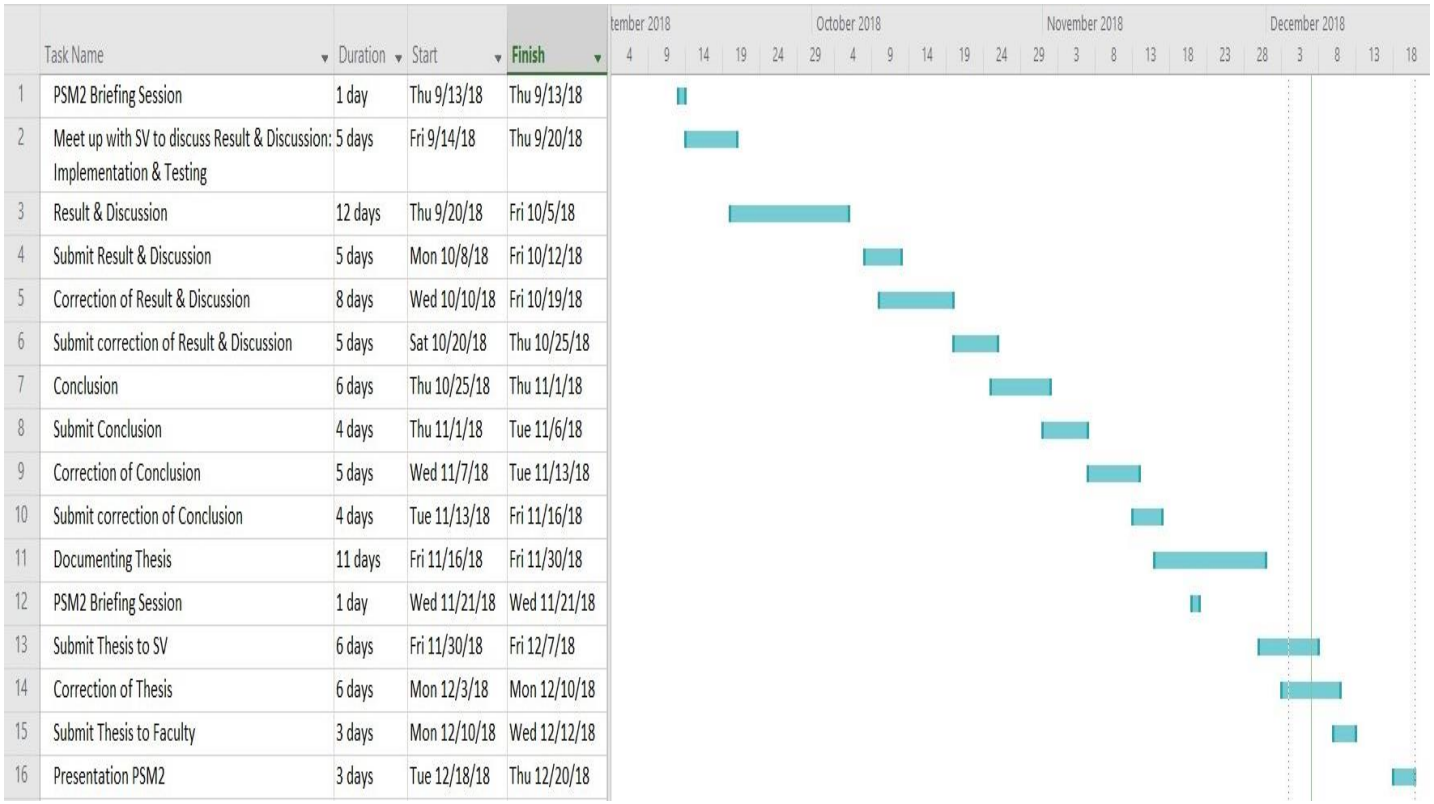
APPENDIX A



	Task Name	Duration	Start	Finish
1	Briefing Session	5 days	Mon 2/12/18	Fri 2/16/18
2	Discussion on research title with SV	5 days	Fri 2/16/18	Thu 2/22/18
3	Literature Review: Study on previous related researches	10 days	Tue 2/20/18	Mon 3/5/18
4	Research on problem statements, objectives, scopes	5 days	Mon 3/5/18	Fri 3/9/18
5	Correction of Introduction & discussion on Literature Review	10 days	Fri 3/9/18	Thu 3/22/18
6	Correction of Literature Review & Discussion of Methodology	10 days	Thu 3/22/18	Wed 4/4/18
7	Methodology	11 days	Mon 4/2/18	Mon 4/16/18
8	Correction of Methodology	8 days	Mon 4/16/18	Wed 4/25/18
9	Overall correction of PSM1	4 days	Wed 4/25/18	Mon 4/30/18
10	Finalizing PSM1	6 days	Fri 4/27/18	Fri 5/4/18
11	Submit & present PSM1	8 days	Fri 5/4/18	Tue 5/15/18

Figure 3.2 Gantt Chart of PSM1



	Task Name	Duration	Start	Finish
1	PSM2 Briefing Session	1 day	Thu 9/13/18	Thu 9/13/18
2	Meet up with SV to discuss Result & Discussion: Implementation & Testing	5 days	Fri 9/14/18	Thu 9/20/18
3	Result & Discussion	12 days	Thu 9/20/18	Fri 10/5/18
4	Submit Result & Discussion	5 days	Mon 10/8/18	Fri 10/12/18
5	Correction of Result & Discussion	8 days	Wed 10/10/18	Fri 10/19/18
6	Submit correction of Result & Discussion	5 days	Sat 10/20/18	Thu 10/25/18
7	Conclusion	6 days	Thu 10/25/18	Thu 11/1/18
8	Submit Conclusion	4 days	Thu 11/1/18	Tue 11/6/18
9	Correction of Conclusion	5 days	Wed 11/7/18	Tue 11/13/18
10	Submit correction of Conclusion	4 days	Tue 11/13/18	Fri 11/16/18
11	Documenting Thesis	11 days	Fri 11/16/18	Fri 11/30/18
12	PSM2 Briefing Session	1 day	Wed 11/21/18	Wed 11/21/18
13	Submit Thesis to SV	6 days	Fri 11/30/18	Fri 12/7/18
14	Correction of Thesis	6 days	Mon 12/3/18	Mon 12/10/18
15	Submit Thesis to Faculty	3 days	Mon 12/10/18	Wed 12/12/18
16	Presentation PSM2	3 days	Tue 12/18/18	Thu 12/20/18

Figure 3.3 Gantt Chart of PSM2