

**THE AUTOMATIC CARDIOPULMONARY
RESUSCITATION (CPR) MACHINE**



BY

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SCHOOL OF ENGINEERING
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ABSTRACT

Currently, the number of people who have cardiac arrest is highly significant, mostly occurred in elderly or patients who have cardiovascular disease and other underlying disease, while the number of medical staffs or well-trained persons are not sufficient to fulfill the need.

Cardiopulmonary resuscitation (CPR) is a method to help patients from cardiac arrest. CPR has to be performed as soon as possible to prevent brain injury from the effect of ischemia and reperfusion with the standard of 5 cm for the compression depth at the sternum, the force of 10 – 64 kg (100 – 640 N) and the rate of 100 – 120 per minute. The person who can perform CPR must be properly trained for, usually medical staffs, when patients or other people have cardiac arrest. This is one of the reason why CPR machine is needed to help and support medical staffs in order to save human lives. However, commercial CPR machines are expensive and not affordable in Thailand, so this thesis will develop the automatic CPR machine with a lower cost production but has the same function as the commercial CPR machine.

During the first period of the thesis, the automatic CPR machine will be designed as a prototype to test the function and prove that it is according to the stand of

performing CPR. For the second period, the actual CPR machine will be design for the compatibility with human to show that it is able to work on human.

The results obtained from both periods were successful. The automatic CPR machine is able to work as same as the commercial products but has a lower cost of production.

Even though the automatic CPR machine is able to perform, it still has some limitations due to the equipment used such as a linear actuator and the rubber medical puppet. Future study can be done to eliminate all of the discussion mentioned in this thesis.

In conclusion, the automatic CPR machine is able to help medical staffs to perform CPR on cardiac arrest patients. It has a lower cost of production compared to the commercial products thus Thailand is able to afford the machine. The automatic CPR machine does not mean to replace the manual CPR, it is merely support and help reducing the problems that mostly occurred by human.

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TABLE OF CONTENTS

	Page
ABSTRACT	(iii)
ACKNOWLEDGEMENTS	(v)
LIST OF TABLES	(vii)
LIST OF FIGURES	(ix)
LIST OF SYMBOLS/ABBREVIATIONS	(xii)
CHAPTER 1 INTRODUCTION	
1.1 Statement of the problems	1
1.2 Objectives of the study	4
1.3 Scope of the study	4
CHAPTER 2 REVIEW OF CARDIOPULMONARY RESUSCITATION AND MATERIALS	
2.1 Definition of CPR	5
2.2 Technique of chest compression in CPR	7
2.3 Statistics of cardiac arrest with successful and non-successful CPR	8
2.4 The use of commercial CPR machines and its effects	9
2.5 The automatic CPR machine's materials	10
CHAPTER 3 METHODOLOGY	
3.1 Action Plan	16
3.2 Introduction	16
3.3 Materials	17

3.4 Designing prototype hardware	21
3.5 Assembling the prototype hardware	24
3.6 Designing actual hardware	26
3.7 Building actual hardware	30
CHAPTER 4 EXPERIMENTAL RESULTS	
4.1 Introduction	32
4.2 Hand position	32
4.3 Depth of chest compression	33
4.4 Rate of chest compression	37
4.5 Results of actual automatic CPR machine	37
CHAPTER 5 CONCLUSION	
5.1 Introduction	39
5.2 Discussion	39
5.3 Conclusion	40
REFERENCES	
APPENDICES	
APPENDIX A	50
APPENDIX B	51

LIST OF TABLES

Tables	Page
1 Comparison between three commercial products in United States	2
2 Width of human chest	31
3 Difference in depths of chest compression	34
4 Average depth of chest compression 1	35
5 Average depth of chest compression 2	38
6 Average depth of chest compression 3	39
7 Average depth of chest compression 4	40
8 Total cost of production of CPR machine	43

LIST OF FIGURES

Figures	Page
1 Thumper model 1007	2
2 Lucas 3, v3.1	2
3 Corpuls CPR	2
4 Normal human circulation during cardiac arrest and pure cardiac pump CPR mechanism	6
5 Active decompression with pure thoracic pump CPR mechanism	6
6 Cardiac output with compression rate	7
7 LX800 linear actuator motor	10
8 Arduino Mega 2560	11
9 Motor driver shield MD10 R2	12
10 Ultrasonic sensor HC – SR05	12
11 Ultrasonic sensor HC – SR05 with Arduino board	13
12 Aluminum profiles	14
13 Strength of rubber	14
14 Filaments	17
15 12VDC 5A Adapter	18
16 Corner and 3-way corner brackets	18
17 L and T brackets	19
18 Rubber medical puppet	19
19 Steel rod	19

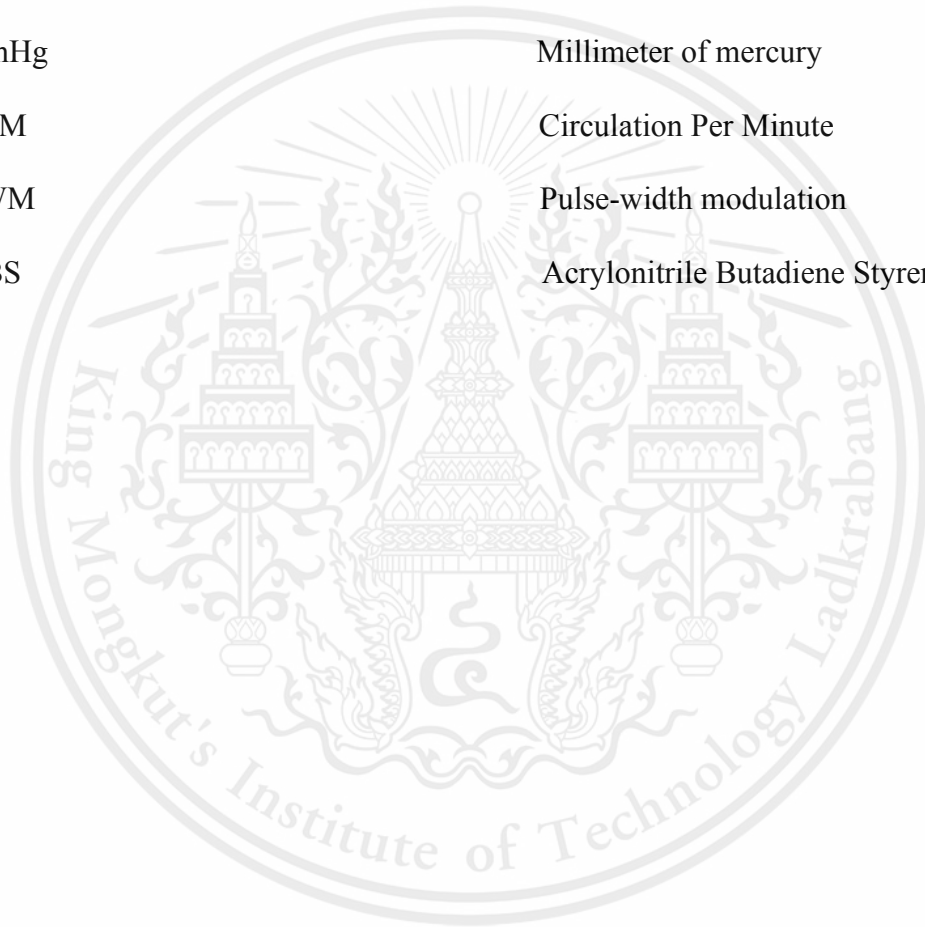
20 3D printer	20
21 GD/CPR 169 Half-body CPR training manikin	21
22 Aluminum profiles prototype	21
23 Attaching linear actuator motor	22
24 Dimension of Attaching	22
25 Assembling with linear actuator motor	23
26 Assembling the motor part with the aluminum profiles prototype	23
27 Assembling the shorter aluminum profiles with the motor	24
28 Actual prototype hardware 1	24
29 Actual prototype hardware 1	25
30 Actual prototype hardware 1	25
31 Base	26
32 Base dimension	26
33 Pillars and dimensions	27
34 Motor holder	28
35 Motor holder dimension	28
36 CPR machine	29
37 Actual CPR machine	30
38 Correct hand position	32
39 Three sets of values from serial monitor 1	33
40 Graph during chest compression from serial plotter 1	35
41 Maximum chest compression	36
42 Initial position	36
43 Graph during chest compression from serial plotter 2	37

44	Three sets of values from serial monitor 2	38
45	Three sets of values from serial monitor 3	39
46	Three sets of values from serial monitor 4	40



LIST OF SYMBOLS/ABBREVIATIONS

Symbols/Abbreviations	Terms
CPR	Cardiopulmonary Resuscitation
VAC	Voltage Alternating Current
mmHg	Millimeter of mercury
CPM	Circulation Per Minute
PWM	Pulse-width modulation
ABS	Acrylonitrile Butadiene Styrene



CHAPTER I

INTRODUCTION

This chapter introduces the overarching themes of this report and places the motivation for the work into context. Thereafter, the rationale and goals defined for the investigation of the project are discussed, followed by a summary of the overall project. Finally, an overview of the dissertation is given on a per-chapter basis.

1.1 Statement of the problems

Cardiopulmonary resuscitation (CPR) is a method to relieve patients from cardiac arrest. It was studied that CPR has to be performed as soon as possible to prevent brain injury from the effect of ischemia and reperfusion [1]. CPR is standardized to have 5 cm for compression depth at the sternum [2] with the force of 10 – 64 kg [3], 100 – 640 N. The rate of CPR should be around 100 – 120 per minute [4]. The person who can perform CPR must be properly trained for, usually medical staffs, when patients or other people have cardiac arrest.

The number of people who have cardiac arrest is highly significant, mostly occurred in elderly or patients who have cardiovascular disease and other underlying disease, while the number of medical staffs or well-trained persons are not sufficient to fulfill the need. Moreover, CPR has some errors that are mostly due to human errors. Even though the persons are well-trained to perform CPR, they still have limitations that can cause severe risks as well. The problems arise when manual CPR performed by human is not appropriately done to patients or people who have cardiac arrest. The position of CPR is not at the correct sternum position on the chest, the depth of the compression is not deep enough to resuscitate the heart, or it is too deep that the heart

cannot resist, the force applied is not strong, or it is too strong in which the sternum rib cannot bare the force, so it becomes broken, and the rate is not sufficient to pump the heart. If the depth, force and rate are not constant, CPR may not give the desired results. To summarize, the problems occurred when inconsistency happens, which is unable to control since they are human being. Therefore, the automatic CPR machine came into idea to eliminate these problems and fulfill the scarce of CPR.

There are many commercial products for the automatic CPR machine in United States such as Thumper model 1007, Lucas 3, version 3.1 and Corpuls CPR. Each has different features and functions with some limitations.

Table 1: Comparison between three commercial products in United States

Features/Products	Thumper model 1007	Lucas 3, v3.1	Corpuls CPR
Pressure	Oxygen 50-90 psi		
Battery		LiPo 3300 mAh, 86Wh	
Power supply: input		100-240 VAC 2.3A	240 VAC
Power supply: output		24VDC 4.2A	12VDC
Compression range	0-80 mm +- 2 mm	45-53 mm +-2 mm	20-60 mm
Compression rate	100-106 cpm	102-120 cpm	80-120 cpm



Figure 1:
Thumper model 1007



Figure 2:
Lucas 3, v3.1



Figure 3:
Corpuls CPR

According to the table, Thumper model 1007 [5] is the only product that operates by using oxygen tank to exert the pressure to push the arm compress on the chest. As it requires the oxygen tank to supply the gas, it is not convenient to move or carry to other places. However, the compression range and rate are based on the standard CPR, and it can be adjustable to fit with person because each person has different body postures.

Lucas 3, version 3.1 operates [6] by either battery or power supply. The battery is made of Lithium polymer, which is rechargeable, and the power supply range is 100 – 240 VAC that is acceptable in Thailand as Thailand has voltage supplied of 220 VAC. Although the compression range and rate are not as wide as Thumper model 1007, it is still in the standard range.

Corpuls CPR [7] operates by power supply of 240 VAC, which exceeds the maximum voltage supplied in Thailand. Thus, it cannot be used in Thailand regardless of the acceptable compression range and rate.

If Thailand wants to import the automatic CPR machine into the country, all commercial products have to include VAT and the total cost of importing will approximately be 60,000 – 100,000 baht. The price does not outweigh the manual CPR since it is not affordable. Therefore, this thesis will design the automatic CPR machine with a lower cost of production to benefit Thai medical staffs.

1.2 Objectives of the study

1.2.1 It is to build an automatic CPR machine that can perform like a manual CPR.

1.2.2 It is to reduce the risks and problems that occurred by the manual CPR.

1.2.3 It is to make the automatic CPR machine become inexpensive and affordable in Thailand.

1.3 Scope of the study

1.3.1 Research and decide the main system of the automatic CPR machine

1.3.2 Test the function of the system with the rubber medical puppet

1.3.3 Design the prototype hardware

1.3.4 Assemble the hardware and test the whole system

1.3.5 Design the actual hardware to make it possible for commercial product

CHAPTER II

REVIEW OF CARDIOPULMONARY RESUSCITATION AND MATERIALS

This chapter will discuss the definition of CPR by considering the process and outcome with side effects. The statistics will show the rate of survival and non-survival patients who have cardiac arrest. The advantages and disadvantages of using CPR machine instead of human will be explained to see the benefits. Furthermore, all materials used to build the automatic CPR machine will be summarized to understand the reasons of using.

2.1 Definition of CPR

Cardiopulmonary resuscitation (CPR) is the technique to create blood circulation when the heart is not able to perform, called cardiac arrest. CPR has two mechanisms, which are cardiac pump and thoracic pump [8]. For cardiac pump, during chest compression, the cardiac ventricles between sternum and spine will be extended. This allows blood to flow forward through aortic and pulmonic valves without mitral or tricuspid incompetence [9]. To illustrate, the aortic valve will be opened but the mitral valve will be closed when chest is being compressed.

For thoracic pump, intrathoracic pressure will increase to flow the blood from pulmonary vasculature into periphery. Both mitral and aortic valves will be opened simultaneously during thoracic pump in chest compression [10]. As a result, the left heart will act as a pipe and pulmonary vasculature will consist of the main pumping chamber that fills and empties the blood.

2.1.1 Cardiac pump CPR mechanism

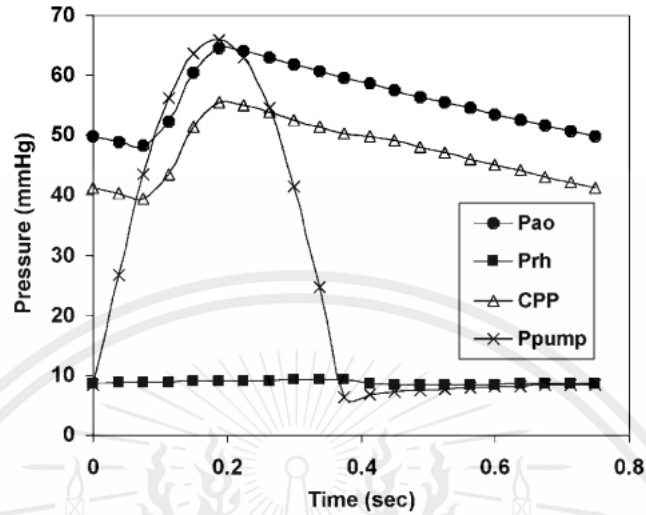


Figure 4: Normal human circulation during cardiac arrest and pure cardiac pump CPR mechanism [8]

The compression rate is 80 per minute with the intrathoracic pressure range of 0 – 60 mmHg in half sinusoidal waveform [11]. This simulation only compressed right and left ventricles of the heart, but it showed the possible chest compression.

2.1.2 Thoracic pump CPR mechanism

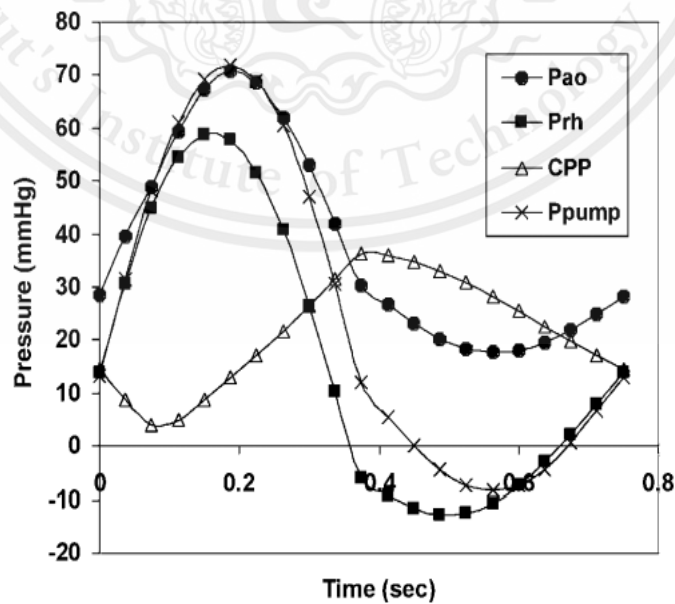


Figure 5: Active decompression with pure thoracic pump CPR mechanism [8]

The compression rate is 80 per minute as well. The intrathoracic pressure on the cardiac ventricles ranges from 0 – 60 mmHg with half sinusoidal waveform. Pneumatic vest stimulates the chest to produce the pulses of chest compression from all sides. Blood flow occurs without the heart squeezing between the sternum and the spine.

2.2 Technique of chest compression in CPR

According to the standard guidelines for CPR, the compression depth should be performed approximately at 4 – 5 cm [8] to allow blood flow. If the depth is less than the standard value, the heart may not response and CPR will not be successful. However, if the depth is more than the standard value, the heart may be deeply compressed that it is not able to allow blood to flow through it.

For the compression rate, the experiment had done to examine the effective rate of CPR [12]. The acceptable value range is between 60 – 120 per minute since there is a plateau within this range.

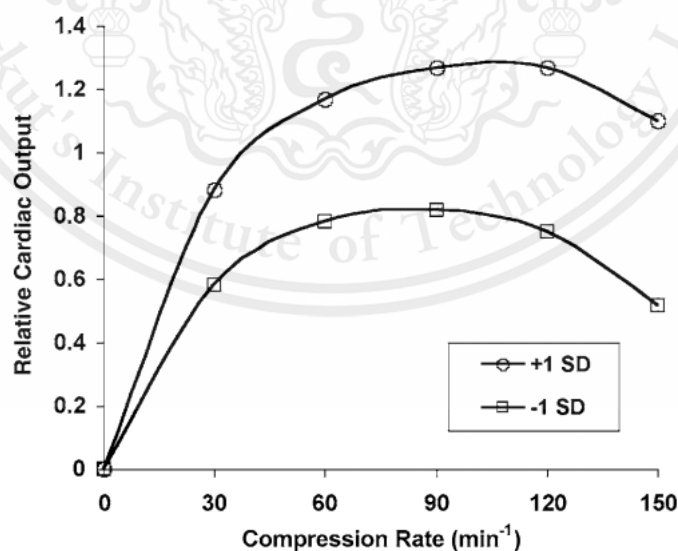


Figure 6: Cardiac output with compression rate [8]

The study of hand position has concluded that the proper position on the chest should be in the middle of the lower half of the sternum [13] because it results in the most effective CPR compared to other positions. If the position is higher than the appropriate position, the aortic and pulmonary arteries will be squeezed and become kinked, which blood circulation will be blocked. On the other hand, if the position is lower than standard position, xiphoid may be pushed to the left lobe of the liver and cause liver laceration. Nevertheless, there is the study to provide the better position for CPR. The compression point should be over the left ventricle since it will exponentially increase the blood flow via facial flush process, but this study has not been proven by peer-reviewed literature [8].

To prioritize the most important factors, the hand position is the most important regarding factor since it will direct the circulation of blood. The second most important variable is the compression depth, which should be around 4 – 5 cm. The compression rate is acceptable in the range of 60 – 120 per minute, so as long as the position and depth are correct, any rate within this range will result in the successful cardiac output.

2.3 Statistics of cardiac arrest with successful and non-successful CPR

Cardiac arrest occurs when the heart suddenly stops functioning. The statistic shows that mortality of cardiac arrest patients is 67% in adults and 5% in children [14]. Based on the study of categorization of survival and death after cardiac arrest [15], most survivors had poor neurological outcome or died for 20%, and non-survivors occurred by unstable CPR for 48%. Brain injury occurs from the effects of ischemia and reperfusion since the blood is not able to flow to supply the oxygen to the brain.

In addition, the research on the global survival rate among adult out-of-hospital cardiac arrest patients who received cardiopulmonary resuscitation showed the

statistics of the survival rate [16]. The average global cardiac arrest among adults is 55 per 100,000 persons a year [17]. However, the survival rate is very low worldwide [18]. This study has concluded that the survival rate is low but increasing when the patients were performed with a good quality of CPR and the use of an automated external defibrillator (AED) [19].

2.4 The use of commercial CPR machines and its effects

The automated CPR machines were expected to improve the outcome of CPR since they are able to maintain stable and constant force, depth and rate during the chest compression. However, CPR machines have not yet succeeded the better performance when compared to manual CPR by human [20]. There is a study based on the utility of CPR machine power that showed the benefits of CPR machine regarding to the narrow space like ambulances and helicopters [21].

Moreover, one study has conducted the literature review to compare the difference between mechanical and manual chest compression when patients have cardiac arrest. The results proved that there is no significant difference between mechanical and manual chest compression, but the suggestion is to apply manual chest compression during the early stage of CPR, then followed by mechanical chest compression at the late stage [22].

Furthermore, there is a study that provide the information to prove that mechanical CPR does not improve the clinical outcome of cardiac arrest patients [23]. This study used Lucas's device to perform CPR on the patients and the results show that there is no significant difference when comparing with manual CPR.

To conclude, the automated CPR machines do not have significant advantage over the manual CPR. They merely provide the stable and constant force, depth and

rate to help medical staffs or persons who perform CPR to improve the outcome during cardiac arrest.

2.5 The automatic CPR machine's materials

2.5.1 Linear actuator motor

In order to build the automatic CPR machine, the main function to operate is the most important factor. In this case, the linear actuator motor is chosen based on its ability to push and pull in linear direction. There are many types of linear actuator motor that are classified by their rate and length. The LX800 linear actuator motor is the most appropriate to apply in the automatic CPR machine because it has the rate of 96mm per 1 second and the force load is around 200 – 300 N.

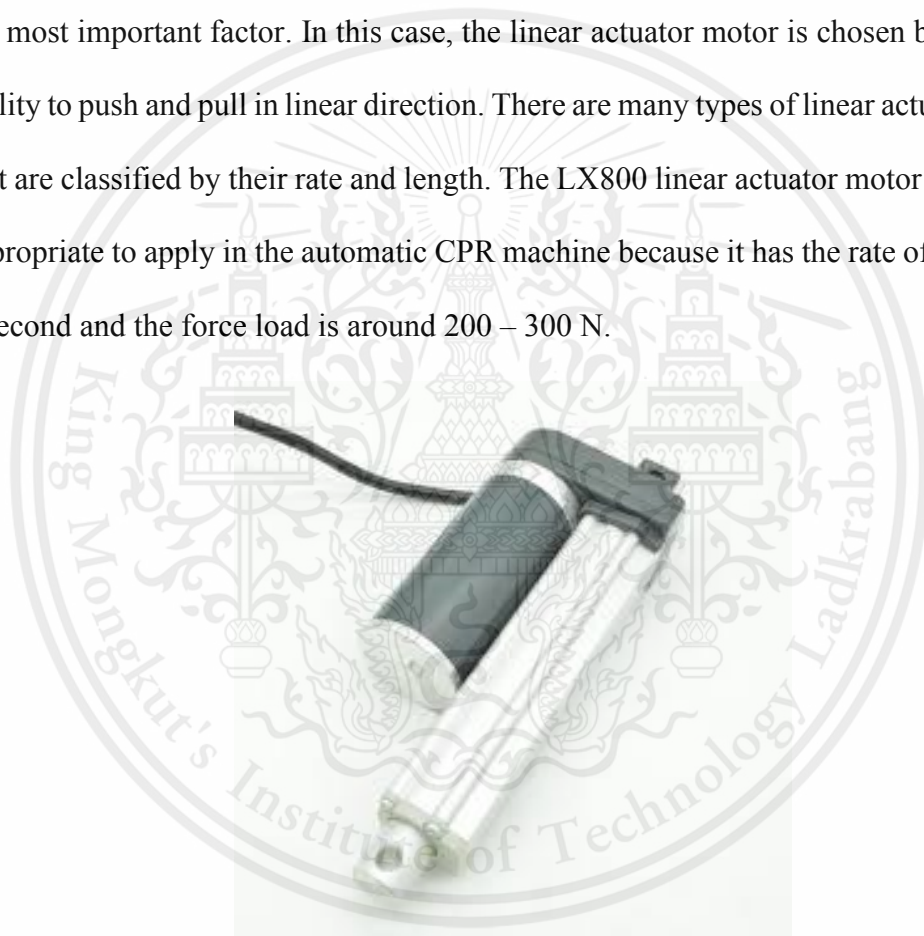


Figure 7: LX800 linear actuator motor [24]

There are still many types of linear actuator motor that could be more suitable to apply in the automatic CPR machine, which could have higher rate and stronger force applied.

2.5.2 Arduino mega 2560

Arduino mega 2560 is a microcontroller board that can receive and send the signal via digital and analog input or output as well as pulse-width modulation (PWM). The Arduino program is very convenient to conduct the code to control the motor to move according to the value set. In this case, the value to adjust depends on the value of delay in the Arduino program.

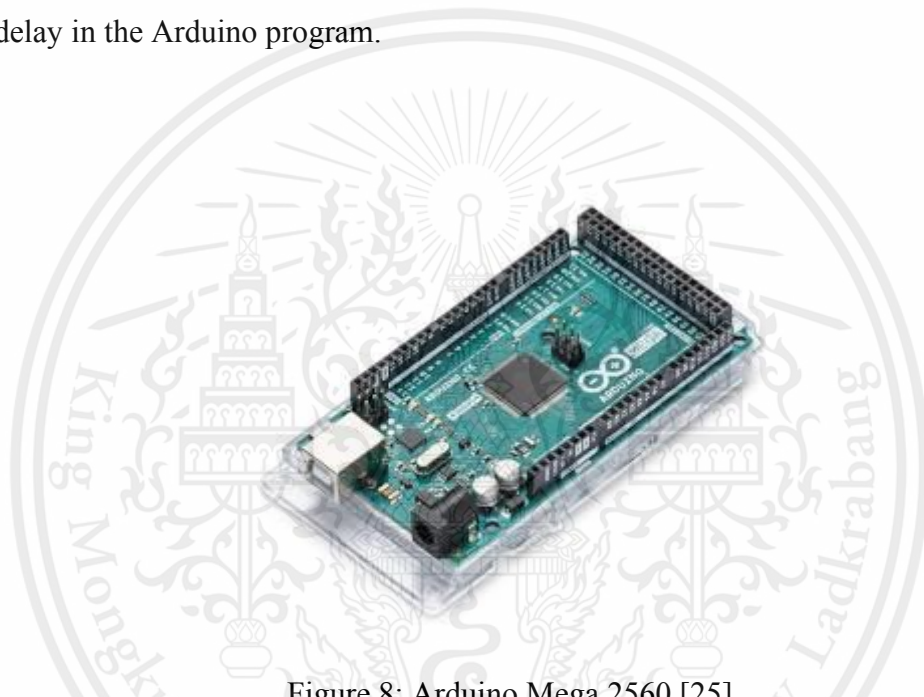


Figure 8: Arduino Mega 2560 [25]

However, Arduino Uno board is similar to the Arduino Mega board. Arduino Uno board is merely smaller in size than Arduino Mega board, but their functions are the same. The difference is in the Arduino program when choosing board, the board will not be the same.

2.5.3 Motor driver shield MD10 R2

Motor driver is the control board that connects to the input power supply and the output board as well as converting AC voltage to DC voltage. Power supply in Thailand is 220 VAC, which is largely exceeded the power needed for Arduino Mega board. Thus, the motor driver will limit the range of voltage and current to pass through.

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Figure 9: Motor driver shield MD10 R2 [26]

This type of the motor driver will give the current up to 10 A and 7 – 30 DC voltage. The recommended voltage range supplied to Arduino Mega board is 7 – 12 V. Therefore, this motor driver is suitable with the Arduino Mega board.

2.5.4 Ultrasonic sensor HC – SR05

Ultrasonic is the sensor to detect the distance between the sensor and the objects by sound pulses. In this case, the ultrasonic sensor will detect the distance between the linear actuator motor and the rubber medical puppet. The sensor will be connected to the Arduino Mega board and controlled by Arduino program.



Figure 10: Ultrasonic sensor HC – SR05 [27]

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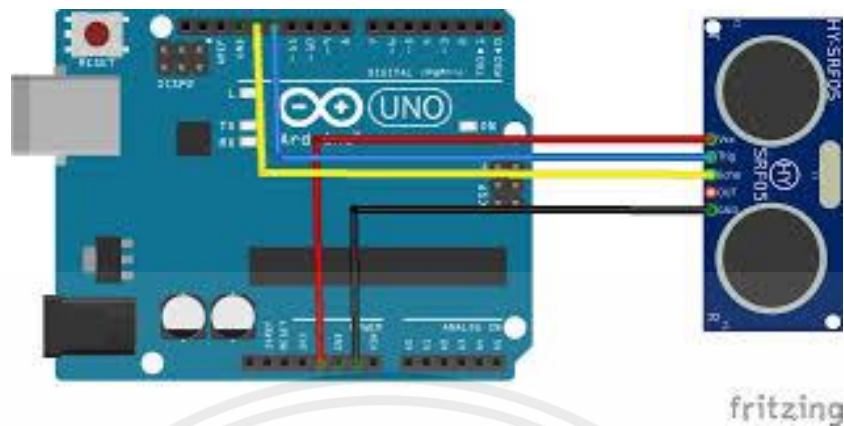


Figure 11: Ultrasonic sensor HC – SR05 with Arduino board [28]

The ultrasonic has two pins to detect the distance. The first pin is a trigger pin (Trig) that triggers the ultrasonic sound pulses. The second pin is an echo pin that creates the pulses when the reflected sound signal is received back. The time taken for transmitted signal to be detected represents the length of the pulses. Both of them are directly proportional to one another [29].

2.5.5 Aluminum profiles

The prototype of the automatic CPR machine will be structured by aluminum profiles in order to test for the strength of the hardware. The reason of using aluminum profiles is because it can resist the corrosion and it is a lightweight material that has medium to high strength forms, the typical yield values are approximately 30,000 lbf/in² [30]. Moreover, the strength of the aluminum profiles will increase in low temperature, which is opposite to the steel that becomes brittle in low temperature.



Figure 12: Aluminum profiles [31]

The aluminum profiles have many shapes and sizes. In the automatic CPR machine, V slot aluminum profiles are used to connect together with the connecting brackets as it allows the linear guide rail for adjusting its length. T slot will not allow linear guide rail to occur [32].

2.5.6 Rubber

Rubber is the material that is elastic and viscous. It can resist the shear and stress force.

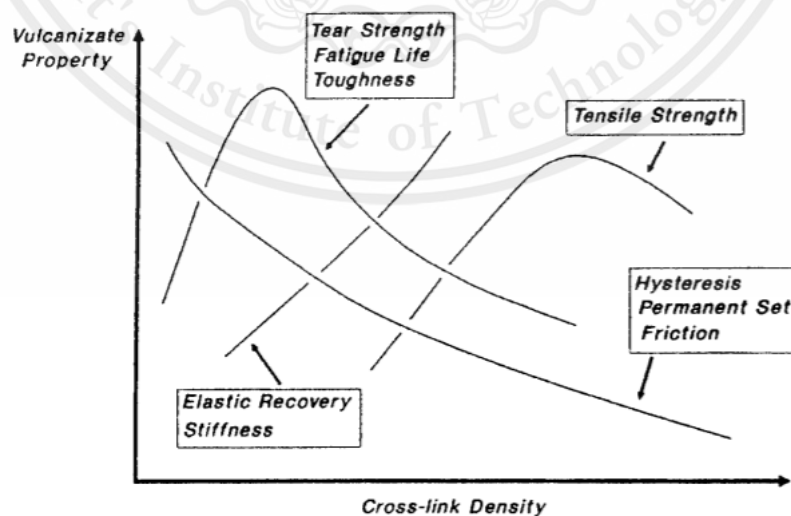


Figure 13: Strength of rubber [33]

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For the linear actuator motor to compress on the chest, the surface of the motor should not be too hard because it can break the rib of the patients. In addition, rubber will prevent the slippery of motor and fix it in the stable position. Thus, the chest compression will be softly pushed with the still position all the time.



CHAPTER III METHODOLOGY

3.1 Action Plan

Action Plan for the automatic CPR machine																								
Month	January				February				March				April				May				June			
Week	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
State the main function																								
Test the function																								
Design prototype hardware																								
Assemble hardware to test																								
Design and build actual hardware																								

3.2 Introduction

This chapter will demonstrate and explain the methodology in detail, including figures, graphs and data analysis. The step of each process will be discussed in this chapter as well.

3.3 Materials

The materials used are discussed in the previous chapter. In this chapter, the materials are classified as software components and hardware equipment. Research equipment and instrument are also included in this chapter.

3.3.1 Software components

3.3.1.1 Arduino Mega board

3.3.1.2 Motor driver shield MD10 R2

3.3.1.3 Ultrasonic sensor HC – SR05

3.3.2 Hardware equipment

3.3.2.1 LX800 linear actuator motor

3.3.2.2 Aluminum profiles

3.3.2.3 Rubber

3.3.3 Research equipment

3.3.3.1 ABS Filaments



Figure 14: Filaments [34]

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Filaments are used to print out plastic objects to hold the linear actuator motor. The strength of the plastic filaments is very strong that it will not be broken when motor is working.

3.3.3.2 12VDC 5A Adapter



Figure 15: 12VDC 5A Adapter [35]

3.3.3.3 Brackets

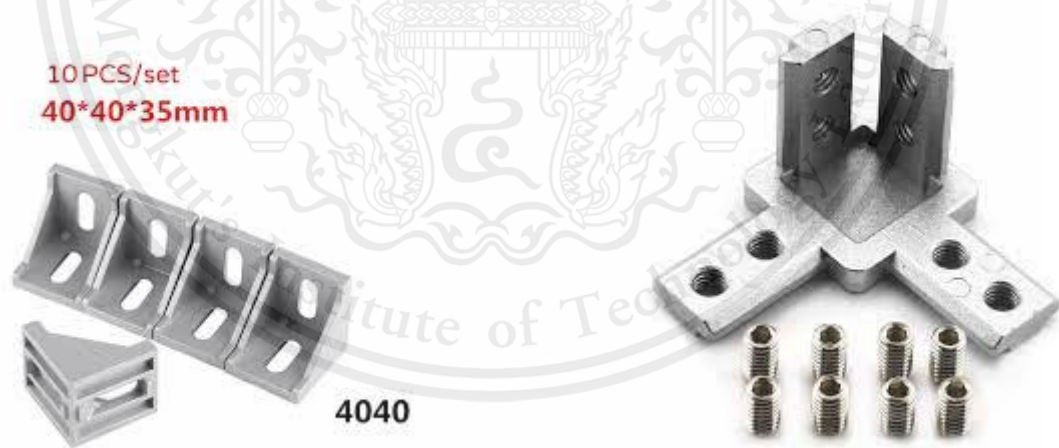


Figure 16: Corner and 3-way corner brackets [36]



Figure 17: L and T brackets [37]

The brackets will connect and join all the aluminum profiles together. This increases the total strength of aluminum profiles when assembling.

3.3.3.4 Rubber medical puppet



Figure 18: Rubber medical puppet

3.3.3.5 Steel Rod



Figure 19: Steel rod [38]

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Steel rod is used to attach the motor with two attaching plastic objects on the aluminum profiles. The diameter of the steel rod is 8 mm. which is the same as the diameter of the hole on the motor. The length of the steel rod is 7 cm, which is sufficient to connect two attaching plastic objects and motor together.

3.3.4 Research instrument

3.3.4.1 3D printer

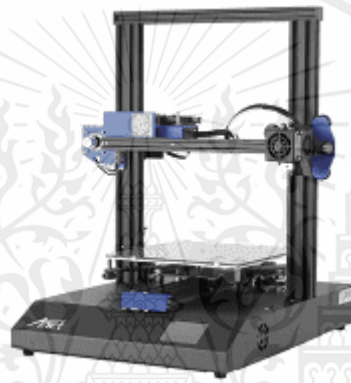


Figure 20: 3D printer [39]

The 3D printer will melt the ABS filaments to deform into new structure according to the design on the Autodesk Inventor program. The dimension should exceed the actual value since the ABS filaments has its own diameter, usually around 1.75 mm to 3 mm [40]. Thus, the dimension in the program will not be exactly the same as the actual printed out objects.

3.3.4.2 GD/CPR 169 Half-body CPR training manikin



Figure 21: GD/CPR 169 Half-body CPR training manikin

The GD/CPR 169 Half-body CPR training manikin will detect the correct hand position and the correct cardiac compression. If hand position is correct, top green light will light up. If cardiac compression is correct, middle green light will light up.

3.4 Designing prototype hardware

The prototype hardware is designed by Autodesk Inventor program to give an illustration of the real prototype. First and foremost, aluminum profiles are connected to form a box, which has the size according to the rubber medical puppet. In this case, the rubber medical puppet has its width of 40 cm.

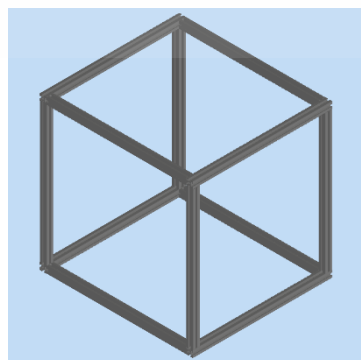


Figure 22: Aluminum profiles prototype

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Secondly, the attaching linear actuator motor is designed with the thickness of 2 cm. Each attaching has its space according to the width of the motor, which is 4 cm.

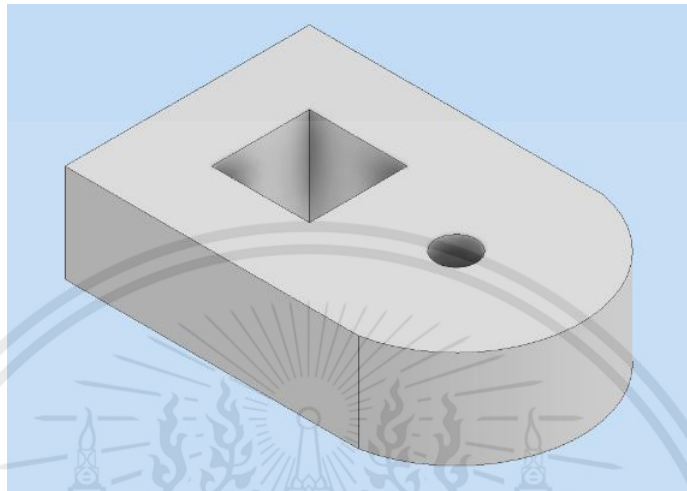


Figure 23: Attaching linear actuator motor

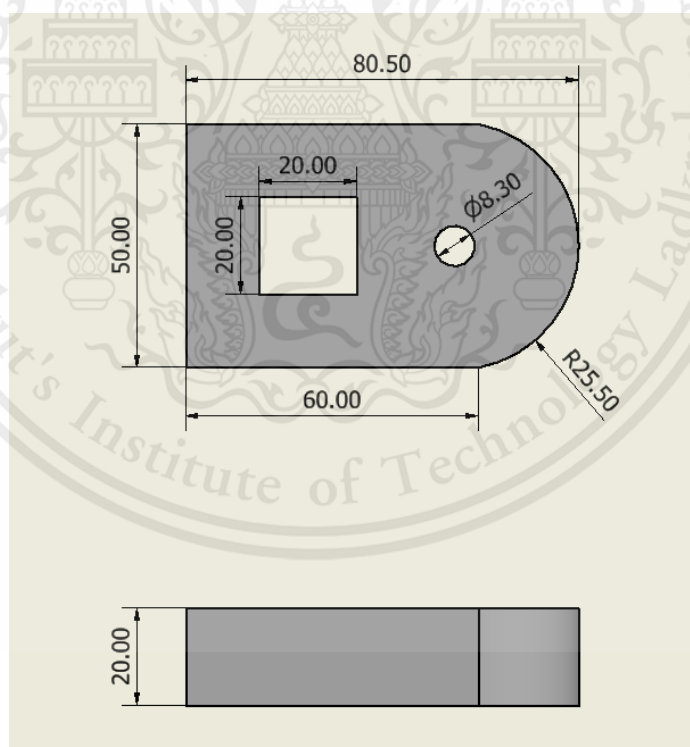


Figure 24: Dimension of Attaching

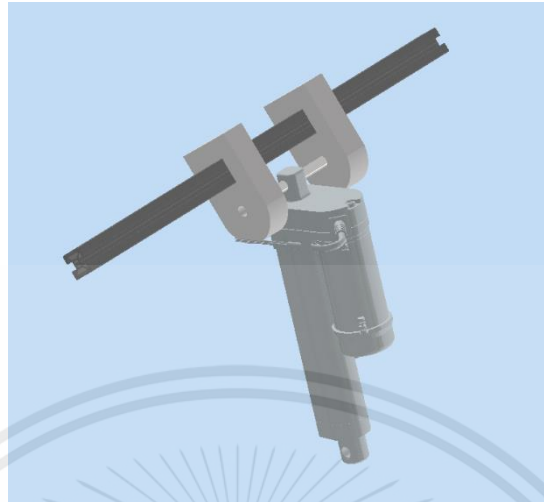


Figure 25: Assembling with linear actuator motor

Thirdly, assembling the motor part with the aluminum profiles prototype. The position of the motor is based on the sternum of the rubber medical puppet, which is approximately 10 cm.

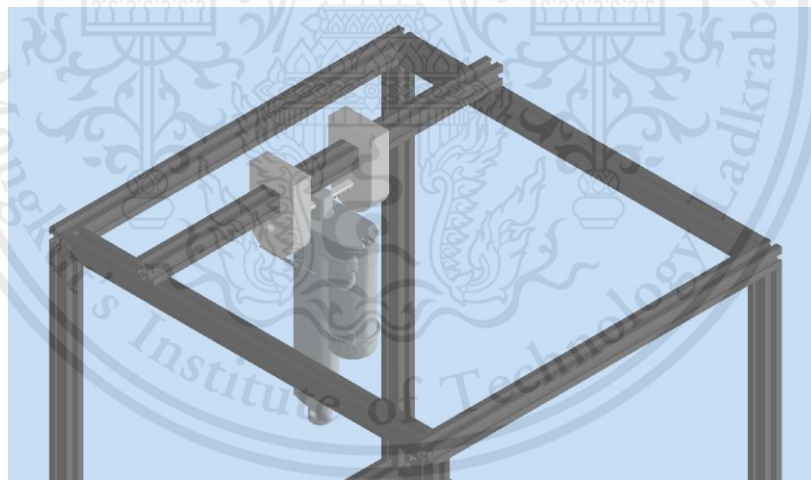


Figure 26: Assembling the motor part with the aluminum profiles prototype

Lastly, in order to prevent the motor from moving after chest compression due to resistant force from the puppet, shorter aluminum profiles are designed to lock both side of the motor to stop moving. However, the assembly of the motor and aluminum profiles prototype has to be altered into the different axis as the motor cannot move parallelly to the shorter aluminum profiles.

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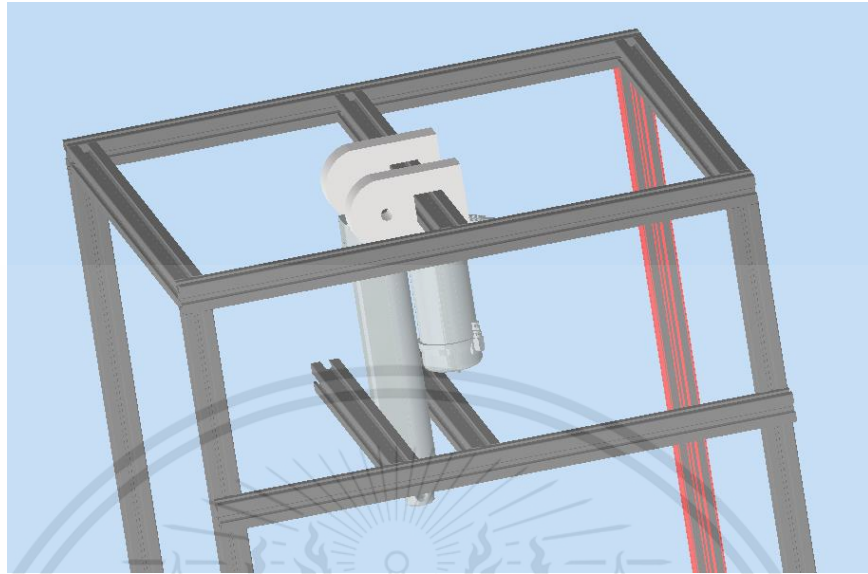


Figure 27: Assembling the shorter aluminum profiles with the motor

3.5 Assembling the prototype hardware

According to the design of the prototype, aluminum profiles were ordered to assemble, and the actual prototype is able to illustrate as similar as the design prototype.

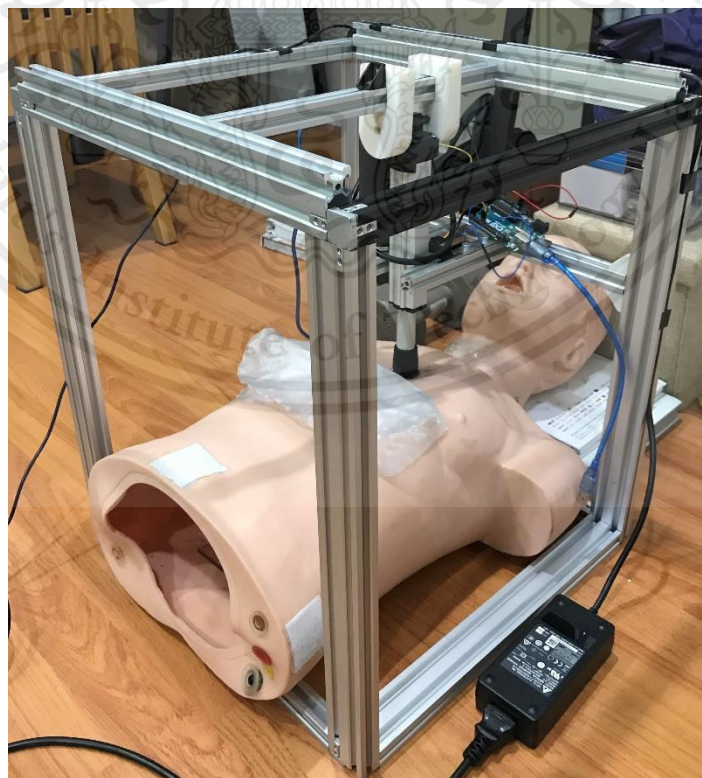


Figure 28: Actual prototype hardware 1

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Figure 29: Actual prototype hardware 2



Figure 30: Actual prototype hardware 3

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Secondly, two pillars are designed in order to attach with the base and connect with the motor holder. The first pillar will allow the horizontal adjustment and the second pillar will allow the vertical adjustment for changing the position of the motor when the size of human is varied. The height of both pillars is 30 cm, and the diameter is 40 cm.

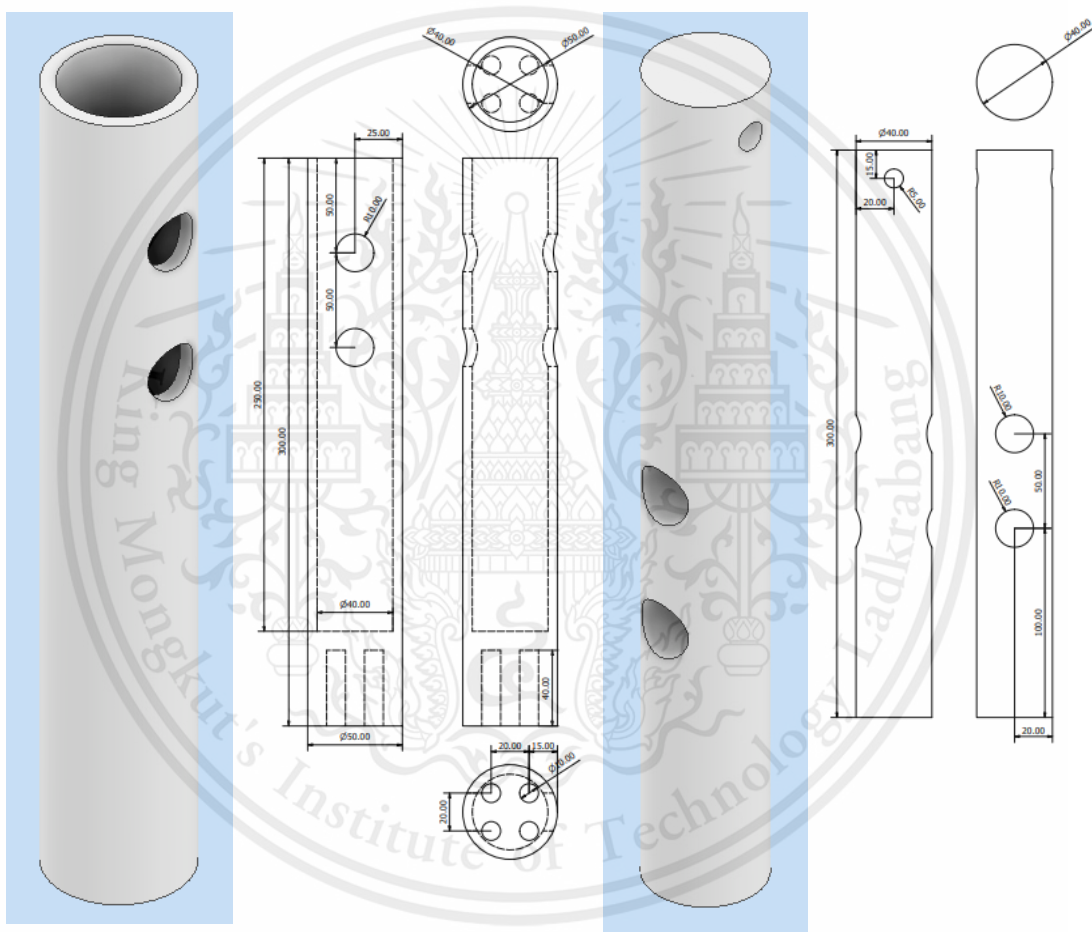


Figure 33: Pillars and dimensions

Both pillars need to be strong and tolerant because they need to balance the machine to be stable. Thus, the size and weight must be suitable to bear the force. The material used should be appropriate as well, otherwise the pillars can break apart due to the resistant force from the motor.

Thirdly, the motor holder is design to hold the motor and keep all microcontroller devices. The size of the holder should allow the motor to be in the correct hand position and the holder must be strong and tolerant to bear the motor force.

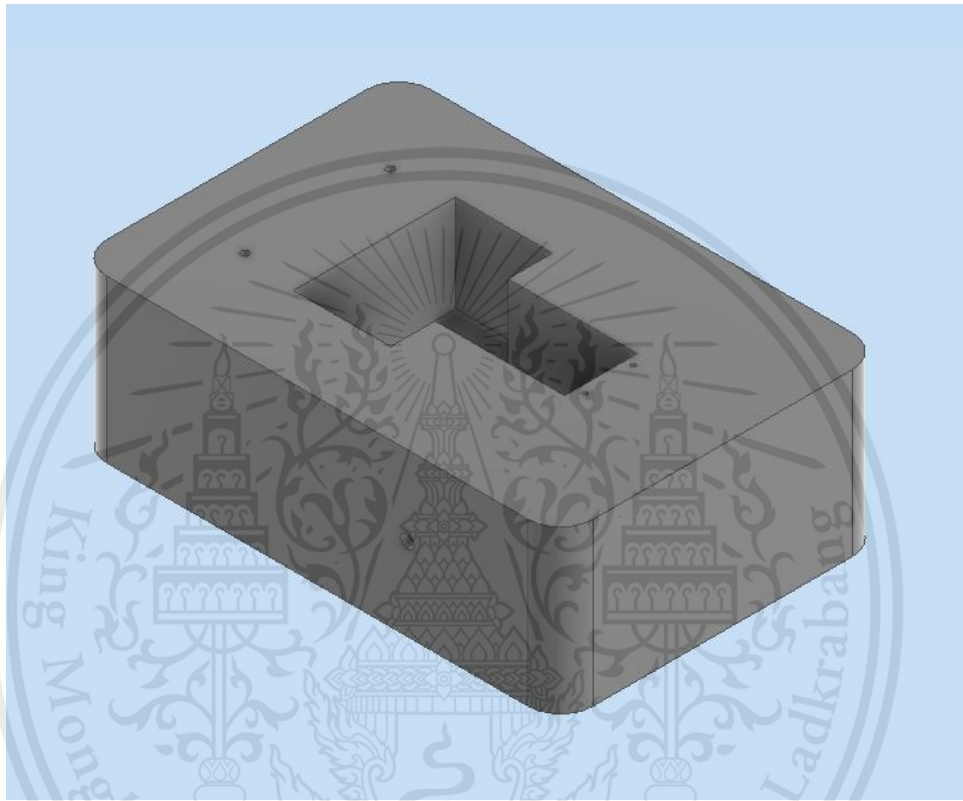


Figure 34: Motor holder

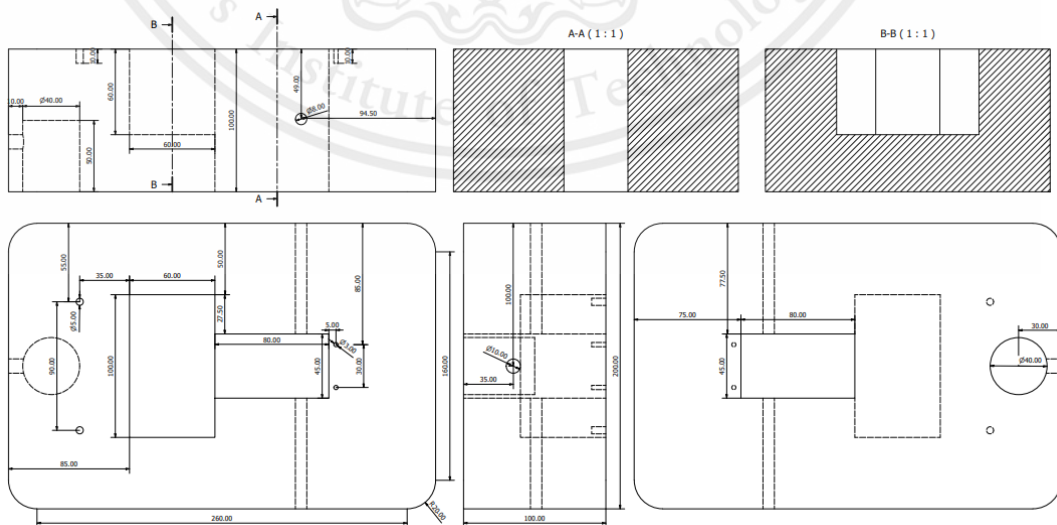


Figure 35: Motor holder dimension

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Lastly, at the top of the motor holder will have the handle for people to carry the machine and a hole for keeping the microcontroller devices. After assembling all the design parts, the automatic CPR machine will be like a C-shape.

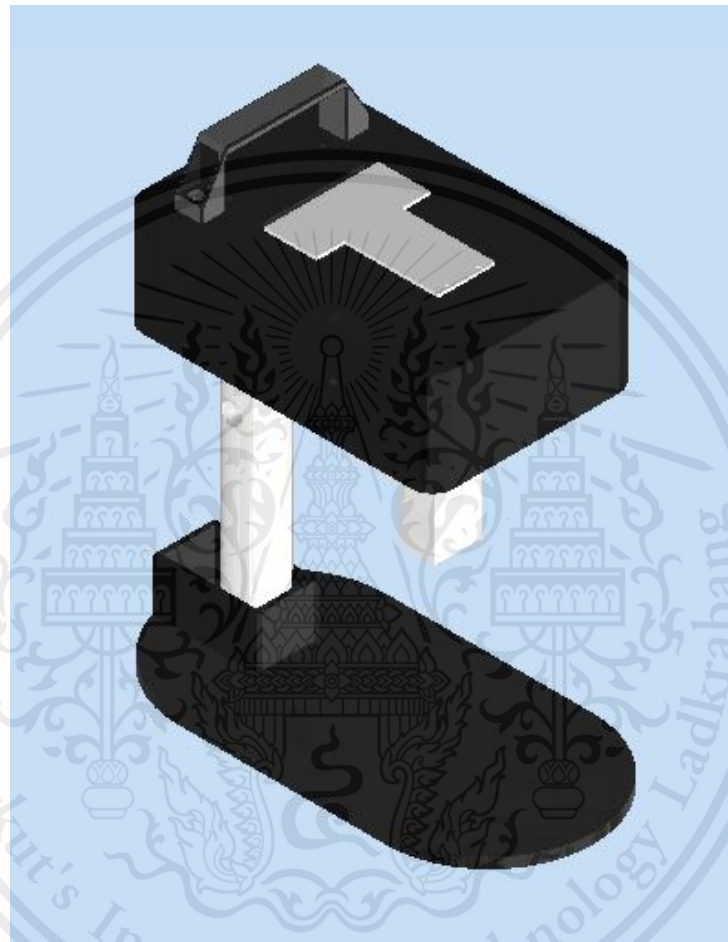


Figure 36: CPR machine

According to the design in the program, the machine should be compatible with the rubber medical puppet. After designing, the actual hardware will be printed out to assemble in the next process. Most of the materials will be plastic and aluminum alloy since the machine requires high strength and tolerant force. Plastic will provide strength but lower in weight and the aluminum alloy will provide the stability to prevent the machine from collapsing.

3.7 Building actual hardware

The materials used are plastic and aluminum as mentioned. It was successfully built according to the design given.



Figure 37: Actual CPR machine

According to the research, the width of average human chest is approximately 23 – 25cm. It means that the motor should be away from the pillar by 11 – 13cm. Therefore, the width between the motor and the chest is adjustable with the range of +6cm. In addition, the height of the pillar is 15cm and it can be changed according to the size of the human. In this case, the range of the height is +4cm.

Table 2: Width of human chest [41]

	Normal subjects			Cystic fibrosis patients		
	Males	Females	All	Males	Females	All
Patients, n	14	14	28	13	17	30
Arm length, cm	55.9±3.0	50.1±1.3	53.0±3.7	52.8±2.4 [†]	48.4±2.2 [‡]	50.3±3.1 [†]
Leg length, cm	101.4±3.8	91.5±2.1	96.4±5.8	95.7±5.6 [†]	88.7±4.0 [‡]	91.7±5.8 [†]
Biacromial distance, cm	40.1±2.3	34.9±1.3	37.5±3.2	38.0±2.1 [†]	33.8±1.7	35.7±2.8 [†]
Pelvis width, cm	25.5±1.3	23.1±1.1	24.3±1.7	25.8±1.4	23.8±1.8	24.7±1.9
AP _{RC_U} , cm	16.2±1.2	13.6±1.3	14.9±1.8	18.7±1.5 [†]	15.7±1.8 [†]	17.0±2.2 [†]
AP _{RC_L} , cm	12.7±1.3	10.4±1.0	11.5±1.6	13.6±0.9 [‡]	11.7±1.3 [†]	12.5±1.5 [†]
LA _{RC} , cm	25.6±2.0	21.7±1.3	23.7±2.6	24.6±1.7	22.8±1.5	23.6±1.8
Sternum length, cm	17.2±1.3	16.1±1.8	16.7±1.7	16.5±1.4	15.4±1.2	15.9±1.4 [‡]

Data presented as group mean ± SD. [†]Between-group comparison based on Mann-Whitney two-sample statistic, all other comparisons based on two-sample t test. [‡]P<0.005 versus normal subjects; [†]P<0.05. AP_{RC_L} Diameter of the anteroposterior lower rib cage at the level of xiphisternum; AP_{RC_U} Diameter of the anteroposterior upper rib cage at the level of manubrium; BMI Body mass index; LA_{RC} Lateral diameter of the rib cage at the level of xiphisternum

CHAPTER IV

EXPERIMENTAL RESULTS

4.1 Introduction

In this project, the purpose of studying is to build the automatic CPR machine that performs like a manual CPR to reduce the problems occurred by human and eliminate the costs of importing the devices into Thailand. Therefore, the automatic CPR machine must be able to compress the chest at the correct position for 3 – 5 cm with the rate of 80 – 120 per minute.

4.2 Hand position

The results showed that the linear actuator motor is able to compress the chest at the correct position on the rubber medical puppet. The top green light represents the correct hand position as mentioned in methodology chapter.

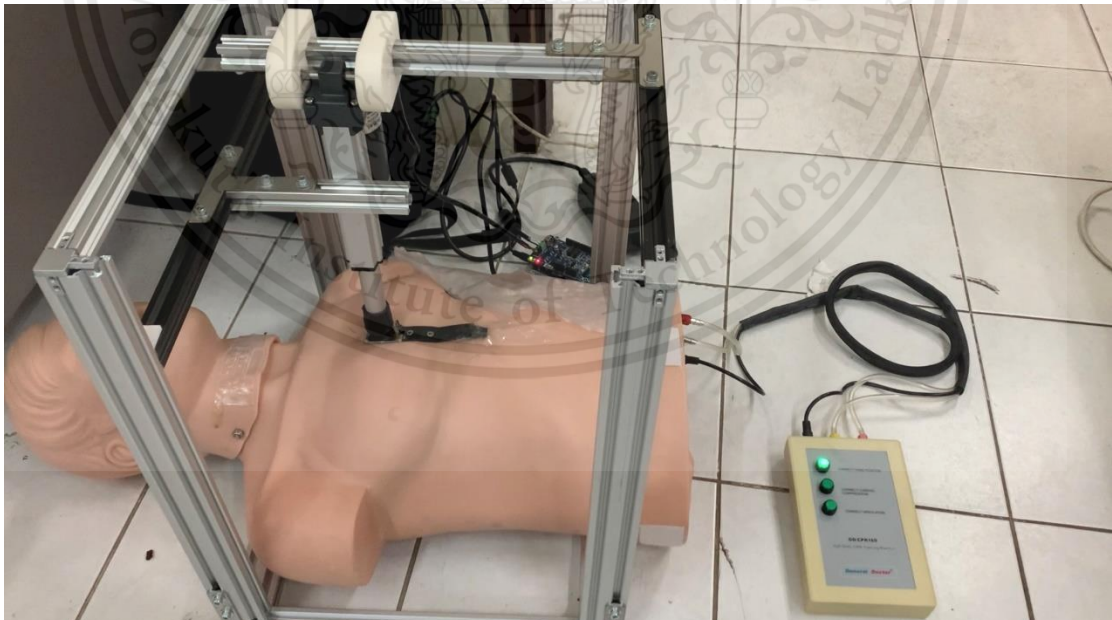


Figure 38: Correct hand position

4.3 Depth of chest compression

The depth of chest compression is measured by using the ultrasonic sensor as mentioned. The unit measurement is millimeter, and the result values are obtained via serial monitor and plotter.

The results were taken three rounds to calculate for the average depth, which is the difference between initial and maximum compressed position.

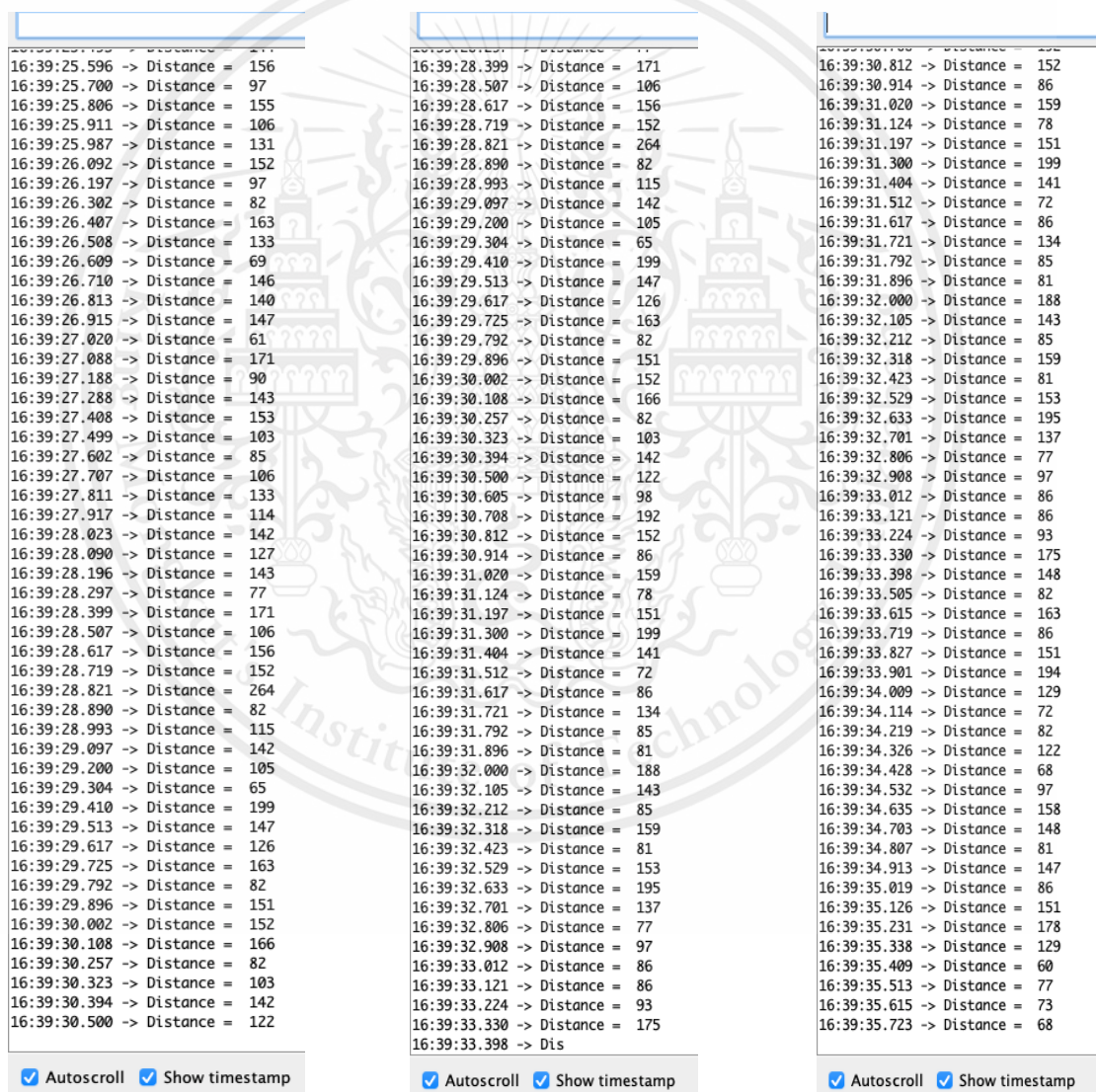


Figure 39: Three sets of values from serial monitor 1

Table 3: Difference in depths of chest compression

Round 1		Round 2		Round 3		Average	
Compression	Relaxation	Compression	Relaxation	Compression	Relaxation	Compression	Relaxation
152	97	142	115	129	77		
55		27		52		45	
143	90	134	86	178	151		
53		48		27		42	
133	85	188	143	134	86		
48		45		48		47	
106	75	195	153	199	151		
31		42		48		40	
115	82	97	77	151	86		
33		20		65		39	
151	82	147	126	122	82		
69		21		40		43	
142	82	122	98	129	72		
60		24		66		50	
142	114	122	82	148	82		
28		40		66		44	
163	126	105	65	137	97		
37		40		40		39	
143	77	115	82	178	151		
66		33		27		42	

Table 4: Average depth of chest compression 1

No.	1	2	3	4	5	6	7	8	9	10	Average
Values	45	42	47	40	39	43	50	44	39	42	43

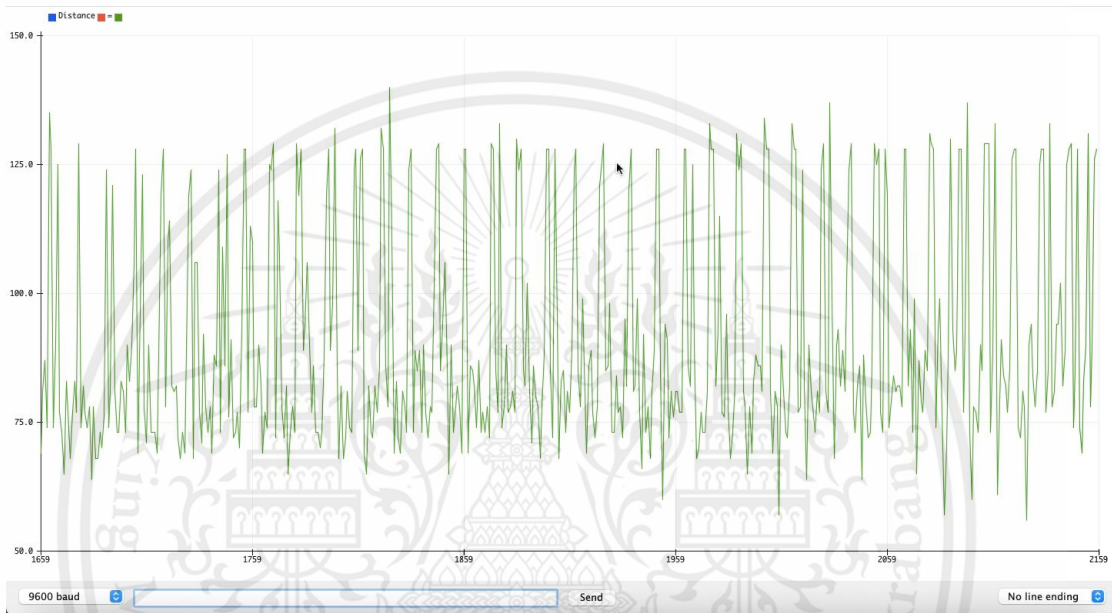


Figure 40: Graph during chest compression from serial plotter 1

According to the results, the average depth of chest compression is approximately 43 mm, which converts to 4.3 cm. This value is acceptable since it is within the standard range. However, improvement on the depth is still needed to be studied because the values were not stable but varied. Therefore, this problems will be further discussed in the chapter of discussion.

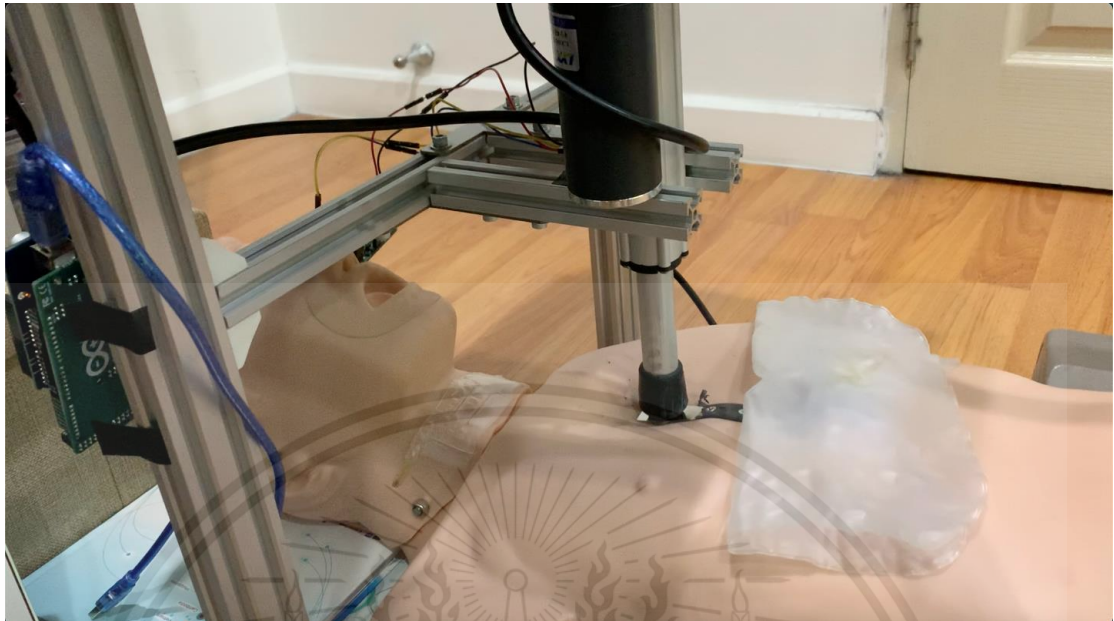


Figure 41: Maximum chest compression



Figure 42: Initial position

4.4 Rate of chest compression

Based on the quality of the linear actuator motor, the rate of chest compression is limited since it has an inversely proportional relationship to the depth of chest compression. The motor could merely give the rate of 75 – 87 CPM, but the desired rate of chest compression should be 80 – 120 CPM. Even though the rates obtained are acceptable, they are still needed to be improved through further experiment.

According to the research done, the rate of chest compression is not as significant as the depth of the chest compression. Thus, the prototype automatic CPR machine will focus more on the depth and later, the rate will be considered.

4.5 Results of actual automatic CPR machine

4.5.1 Depth of chest compression

The actual CPR machine is more stable than the prototype since the rubber medical puppet did not move when compressing, which gives more obvious graph to observe the difference.

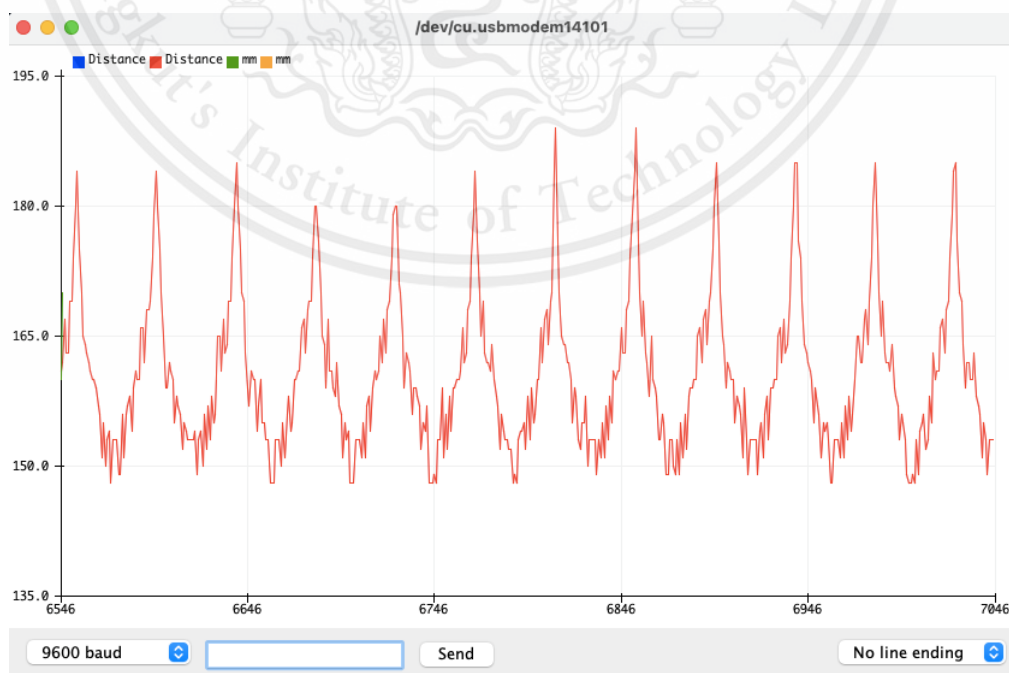


Figure 43: Graph during chest compression from serial plotter 2

This material is reserved for educational use only, not allowed for commercial use.

16:47:35.423 -> Distance: 161 mm 16:47:36.227 -> Distance: 158 mm 16:47:37.061 -> Distance: 163 mm
16:47:35.423 -> Distance: 162 mm 16:47:36.261 -> Distance: 163 mm 16:47:37.061 -> Distance: 164 mm
16:47:35.457 -> Distance: 158 mm 16:47:36.261 -> Distance: 163 mm 16:47:37.097 -> Distance: 164 mm
16:47:35.457 -> Distance: 159 mm 16:47:36.295 -> Distance: 164 mm 16:47:37.097 -> Distance: 165 mm
16:47:35.493 -> Distance: 159 mm 16:47:36.295 -> Distance: 165 mm 16:47:37.134 -> Distance: 173 mm
16:47:35.493 -> Distance: 168 mm 16:47:36.329 -> Distance: 173 mm 16:47:37.134 -> Distance: 170 mm
16:47:35.529 -> Distance: 165 mm 16:47:36.329 -> Distance: 170 mm 16:47:37.168 -> Distance: 167 mm
16:47:35.529 -> Distance: 170 mm 16:47:36.363 -> Distance: 166 mm 16:47:37.168 -> Distance: 167 mm
16:47:35.564 -> Distance: 170 mm 16:47:36.363 -> Distance: 167 mm 16:47:37.205 -> Distance: 167 mm
16:47:35.564 -> Distance: 167 mm 16:47:36.397 -> Distance: 167 mm 16:47:37.242 -> Distance: 177 mm
16:47:35.599 -> Distance: 167 mm 16:47:36.434 -> Distance: 177 mm 16:47:37.242 -> Distance: 190 mm
16:47:35.599 -> Distance: 177 mm 16:47:36.434 -> Distance: 182 mm 16:47:37.278 -> Distance: 196 mm
16:47:35.633 -> Distance: 182 mm 16:47:36.468 -> Distance: 192 mm 16:47:37.278 -> Distance: 210 mm
16:47:35.633 -> Distance: 187 mm 16:47:36.468 -> Distance: 201 mm 16:47:37.313 -> Distance: 218 mm
16:47:35.667 -> Distance: 183 mm 16:47:36.504 -> Distance: 222 mm 16:47:37.313 -> Distance: 210 mm
16:47:35.702 -> Distance: 222 mm 16:47:36.504 -> Distance: 206 mm 16:47:37.351 -> Distance: 192 mm
16:47:35.702 -> Distance: 236 mm 16:47:36.538 -> Distance: 184 mm 16:47:37.351 -> Distance: 182 mm
16:47:35.739 -> Distance: 188 mm 16:47:36.538 -> Distance: 179 mm 16:47:37.385 -> Distance: 172 mm
16:47:35.739 -> Distance: 183 mm 16:47:36.576 -> Distance: 176 mm 16:47:37.423 -> Distance: 162 mm
16:47:35.775 -> Distance: 178 mm 16:47:36.576 -> Distance: 163 mm 16:47:37.423 -> Distance: 161 mm
16:47:35.775 -> Distance: 168 mm 16:47:36.611 -> Distance: 167 mm 16:47:37.423 -> Distance: 161 mm
16:47:35.812 -> Distance: 163 mm 16:47:36.611 -> Distance: 166 mm 16:47:37.459 -> Distance: 160 mm
16:47:35.812 -> Distance: 166 mm 16:47:36.648 -> Distance: 165 mm 16:47:37.459 -> Distance: 164 mm
16:47:35.847 -> Distance: 166 mm 16:47:36.648 -> Distance: 164 mm 16:47:37.493 -> Distance: 159 mm
16:47:35.847 -> Distance: 164 mm 16:47:36.683 -> Distance: 159 mm 16:47:37.493 -> Distance: 159 mm
16:47:35.884 -> Distance: 159 mm 16:47:36.683 -> Distance: 162 mm 16:47:37.528 -> Distance: 161 mm
16:47:35.884 -> Distance: 159 mm 16:47:36.720 -> Distance: 161 mm 16:47:37.528 -> Distance: 160 mm
16:47:35.919 -> Distance: 158 mm 16:47:36.720 -> Distance: 160 mm 16:47:37.561 -> Distance: 155 mm

Figure 44: Three sets of values from serial monitor 2

Table 5: Average depth of chest compression 2

	Maximum compression (mm)	Initial position (mm)	Depth (mm)
	222	182	40
	201	158	43
	196	159	37
Average	206	166	40

According to this table, the average depth is about 40mm or 4.0cm with the rate of 81 CPM.

16:47:31.840 -> Distance: 162 mm	16:35:41.416 -> Distance: 155 mm	16:35:35.800 -> Distance: 160 mm
16:47:31.840 -> Distance: 165 mm	16:35:41.416 -> Distance: 154 mm	16:35:35.800 -> Distance: 155 mm
16:47:31.876 -> Distance: 160 mm	16:35:41.453 -> Distance: 153 mm	16:35:35.834 -> Distance: 154 mm
16:47:31.876 -> Distance: 155 mm	16:35:41.453 -> Distance: 152 mm	16:35:35.834 -> Distance: 158 mm
16:47:31.914 -> Distance: 154 mm	16:35:41.487 -> Distance: 148 mm	16:35:35.871 -> Distance: 157 mm
16:47:31.914 -> Distance: 162 mm	16:35:41.487 -> Distance: 149 mm	16:35:35.871 -> Distance: 152 mm
16:47:31.947 -> Distance: 160 mm	16:35:41.520 -> Distance: 152 mm	16:35:35.905 -> Distance: 152 mm
16:47:31.947 -> Distance: 155 mm	16:35:41.520 -> Distance: 152 mm	16:35:35.905 -> Distance: 152 mm
16:47:31.981 -> Distance: 160 mm	16:35:41.557 -> Distance: 152 mm	16:35:35.938 -> Distance: 152 mm
16:47:32.016 -> Distance: 154 mm	16:35:41.557 -> Distance: 153 mm	16:35:35.976 -> Distance: 148 mm
16:47:32.016 -> Distance: 158 mm	16:35:41.594 -> Distance: 158 mm	16:35:35.976 -> Distance: 154 mm
16:47:32.051 -> Distance: 157 mm	16:35:41.594 -> Distance: 155 mm	16:35:36.010 -> Distance: 154 mm
16:47:32.051 -> Distance: 157 mm	16:35:41.628 -> Distance: 159 mm	16:35:36.010 -> Distance: 159 mm
16:47:32.088 -> Distance: 157 mm	16:35:41.662 -> Distance: 156 mm	16:35:36.044 -> Distance: 155 mm
16:47:32.088 -> Distance: 162 mm	16:35:41.662 -> Distance: 157 mm	16:35:36.044 -> Distance: 157 mm
16:47:32.122 -> Distance: 159 mm	16:35:41.696 -> Distance: 162 mm	16:35:36.079 -> Distance: 157 mm
16:47:32.122 -> Distance: 154 mm	16:35:41.696 -> Distance: 158 mm	16:35:36.079 -> Distance: 158 mm
16:47:32.157 -> Distance: 155 mm	16:35:41.729 -> Distance: 155 mm	16:35:36.116 -> Distance: 156 mm
16:47:32.157 -> Distance: 155 mm	16:35:41.729 -> Distance: 156 mm	16:35:36.116 -> Distance: 155 mm
16:47:32.190 -> Distance: 160 mm	16:35:41.763 -> Distance: 161 mm	16:35:36.149 -> Distance: 160 mm
16:47:32.190 -> Distance: 166 mm	16:35:41.797 -> Distance: 161 mm	16:35:36.149 -> Distance: 161 mm
16:47:32.223 -> Distance: 158 mm	16:35:41.797 -> Distance: 161 mm	16:35:36.187 -> Distance: 165 mm
16:47:32.258 -> Distance: 164 mm	16:35:41.834 -> Distance: 167 mm	16:35:36.187 -> Distance: 162 mm
16:47:32.258 -> Distance: 163 mm	16:35:41.834 -> Distance: 163 mm	16:35:36.220 -> Distance: 167 mm
16:47:32.292 -> Distance: 164 mm	16:35:41.870 -> Distance: 163 mm	16:35:36.255 -> Distance: 167 mm
16:47:32.292 -> Distance: 164 mm	16:35:41.870 -> Distance: 169 mm	16:35:36.255 -> Distance: 163 mm
16:47:32.326 -> Distance: 173 mm	16:35:41.903 -> Distance: 169 mm	16:35:36.290 -> Distance: 173 mm
16:47:32.326 -> Distance: 173 mm	16:35:41.903 -> Distance: 169 mm	16:35:36.290 -> Distance: 173 mm

Figure 45: Three sets of values from serial monitor 3

Table 6: Average depth of chest compression 3

	Maximum compression (mm)	Initial position (mm)	Depth (mm)
	173	154	19
	169	148	21
	173	148	25
Average	171	150	21

According to this table, the average depth is about 21mm or 2.1cm with the rate of 95 CPM.

16:35:37.448 -> Distance: 158 mm	16:47:29.353 -> Distance: 195 mm	16:35:45.896 -> Distance: 165 mm
16:35:37.448 -> Distance: 153 mm	16:47:29.353 -> Distance: 177 mm	16:35:45.896 -> Distance: 174 mm
16:35:37.483 -> Distance: 152 mm	16:47:29.390 -> Distance: 172 mm	16:35:45.930 -> Distance: 179 mm
16:35:37.483 -> Distance: 152 mm	16:47:29.390 -> Distance: 167 mm	16:35:45.930 -> Distance: 184 mm
16:35:37.517 -> Distance: 153 mm	16:47:29.424 -> Distance: 166 mm	16:35:45.963 -> Distance: 179 mm
16:35:37.517 -> Distance: 152 mm	16:47:29.424 -> Distance: 165 mm	16:35:45.963 -> Distance: 171 mm
16:35:37.552 -> Distance: 152 mm	16:47:29.458 -> Distance: 160 mm	16:35:45.997 -> Distance: 166 mm
16:35:37.552 -> Distance: 157 mm	16:47:29.458 -> Distance: 163 mm	16:35:45.997 -> Distance: 169 mm
16:35:37.585 -> Distance: 153 mm	16:47:29.492 -> Distance: 158 mm	16:35:46.031 -> Distance: 164 mm
16:35:37.621 -> Distance: 159 mm	16:47:29.525 -> Distance: 166 mm	16:35:46.065 -> Distance: 163 mm
16:35:37.621 -> Distance: 155 mm	16:47:29.525 -> Distance: 160 mm	16:35:46.065 -> Distance: 158 mm
16:35:37.656 -> Distance: 160 mm	16:47:29.559 -> Distance: 155 mm	16:35:46.099 -> Distance: 161 mm
16:35:37.656 -> Distance: 157 mm	16:47:29.559 -> Distance: 159 mm	16:35:46.099 -> Distance: 165 mm
16:35:37.693 -> Distance: 162 mm	16:47:29.592 -> Distance: 162 mm	16:35:46.134 -> Distance: 160 mm
16:35:37.693 -> Distance: 158 mm	16:47:29.592 -> Distance: 157 mm	16:35:46.134 -> Distance: 159 mm
16:35:37.728 -> Distance: 163 mm	16:47:29.626 -> Distance: 157 mm	16:35:46.171 -> Distance: 155 mm
16:35:37.728 -> Distance: 159 mm	16:47:29.626 -> Distance: 161 mm	16:35:46.171 -> Distance: 157 mm
16:35:37.762 -> Distance: 160 mm	16:47:29.660 -> Distance: 161 mm	16:35:46.205 -> Distance: 156 mm
16:35:37.762 -> Distance: 161 mm	16:47:29.694 -> Distance: 157 mm	16:35:46.205 -> Distance: 155 mm
16:35:37.796 -> Distance: 161 mm	16:47:29.694 -> Distance: 157 mm	16:35:46.239 -> Distance: 150 mm
16:35:37.796 -> Distance: 166 mm	16:47:29.728 -> Distance: 162 mm	16:35:46.239 -> Distance: 153 mm
16:35:37.831 -> Distance: 162 mm	16:47:29.728 -> Distance: 162 mm	16:35:46.273 -> Distance: 153 mm
16:35:37.866 -> Distance: 163 mm	16:47:29.766 -> Distance: 158 mm	16:35:46.309 -> Distance: 149 mm
16:35:37.866 -> Distance: 168 mm	16:47:29.766 -> Distance: 155 mm	16:35:46.309 -> Distance: 148 mm
16:35:37.902 -> Distance: 165 mm	16:47:29.799 -> Distance: 160 mm	16:35:46.343 -> Distance: 148 mm
16:35:37.902 -> Distance: 174 mm	16:47:29.799 -> Distance: 165 mm	16:35:46.343 -> Distance: 153 mm
16:35:37.938 -> Distance: 179 mm	16:47:29.833 -> Distance: 162 mm	16:35:46.376 -> Distance: 149 mm
16:35:37.938 -> Distance: 184	16:47:29.833 -> Distanc	

Figure 46: Three sets of values from serial monitor 4

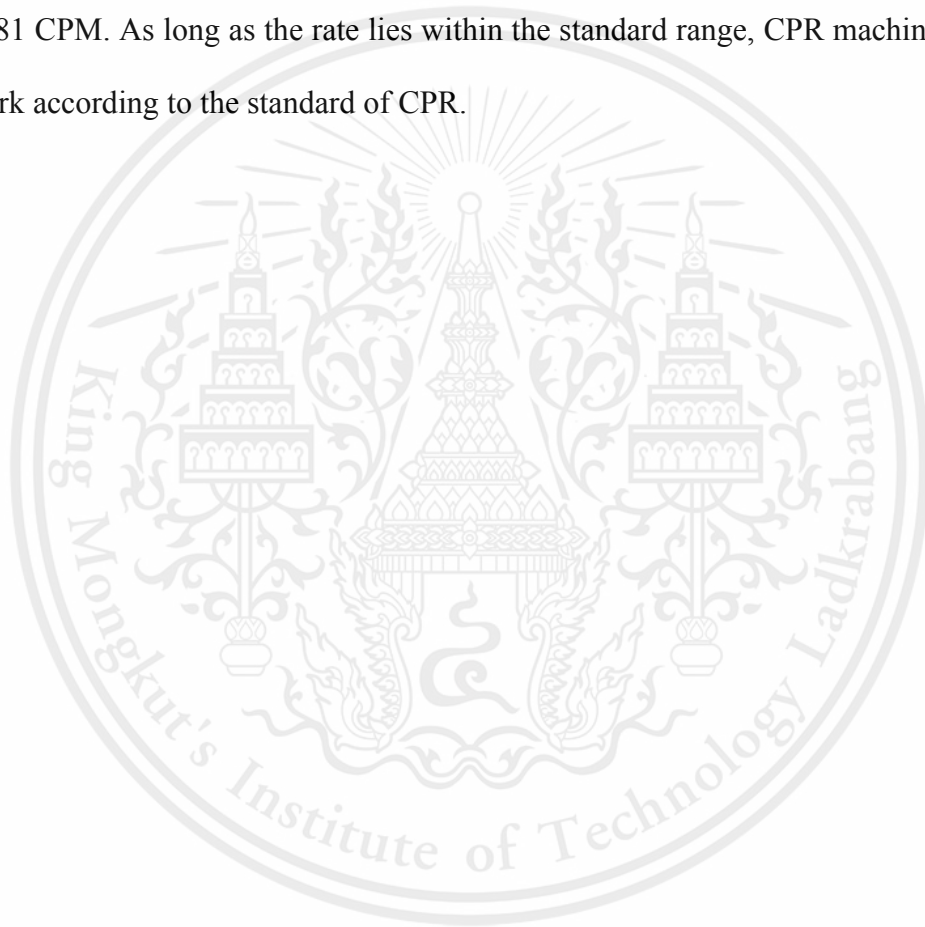
Table 7: Average depth of chest compression 4

	Maximum compression (mm)	Initial position (mm)	Depth (mm)
	184	152	32
	195	155	40
	179	148	31
Average	186	152	34

According to this table, the average depth is about 34mm or 3.4cm with the rate of 89 CPM.

4.5.2 Rate of chest compression

The rate of chest compression is 81 CPM at the depth of 4.0cm, 89 CPM at 3.4cm and 95 CPM at 2.1cm. These values are acceptable according to the research, but they can be improved further. In this thesis, the depth of chest compression is more significant than the rate of compression. Hence, the depth will be 4.0cm with the rate of 81 CPM. As long as the rate lies within the standard range, CPR machine is able to work according to the standard of CPR.



CHAPTER V

CONCLUSION

5.1 Introduction

In this chapter, the discussion and conclusion will be discussed and summarized for further understanding of the development of automatic CPR machine and its actual purpose of this machine.

5.2 Discussion

The automatic CPR machine has some limitations due to the quality of the motor, the depth and the rate. The linear actuator motor is not able to give the sufficient values for both depth and rate of chest compression. Other motor might be considered in the next process of this project.

The depth of the chest compression is inversely proportional to the rate of compression. It means that when increasing the depth of the compression, the rate will be lower. Thus, the finding of the optimum range for both depth and rate could be the solution for the CPR prototype machine.

Moreover, the rubber medical puppet has a limitation about its weight as well. The weight of the puppet is significantly lower than the weight of human being, so the force applied by the motor will be able to cause the puppet to move because there is insufficient resistant force applied back to the motor. Therefore, the stability of the rubber medical puppet is not constant.

For further study in the future, a better linear actuator motor can be considered with the concerning of its price and the design of the CPR machine can be adjusted to be more compatible with the patients.

5.3 Conclusion

In conclusion, the prototype of this CPR machine shows that it can perform CPR with the lower cost of production compared to the commercial products and with the rate of 81 CPM and depth of 4.0cm.

Table 8: Total cost of production of CPR machine

Materials	Price (Baht)
Linear actuator motor	2,500
Microcontroller devices	1,000
Hardware	6,500
Total	10,000

However, more studies are still needed to be done to improve it further. The automatic CPR machine is not developed in order to replace the manual CPR. It is developed to help human to perform CPR and reduce the problems that might occur during the process.

With more studies on improving CPR machine, it will be able to develop into a commercial product and sell to many hospitals. Consequently, this could help saving many more lives in Thailand if the automatic CPR machine is successful.

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APPENDIX A

ARDUINO CODE FOR LINEAR ACTUATOR MOTOR

```
// PWM is connected to pin 11 on motor driver.

const int pinPwm = 11;

// DIR is connected to pin 12 on motor driver.

const int pinDir = 12;

int currentPosition = 0;

// The setup routine runs once when you press reset.

void setup() {

  // Initialize the PWM and DIR pins as digital outputs.

  pinMode(pinPwm, OUTPUT);

  pinMode(pinDir, OUTPUT);

  Serial.begin(9600);

}

// The loop routine runs over and over again forever.

void loop() {

  digitalWrite(pinPwm, HIGH);

  digitalWrite(pinDir, LOW);

  delay(400); //Rate 82

  digitalWrite(pinPwm, HIGH);

  digitalWrite(pinDir, HIGH);

  delay(400); //Rate 82

}
```

APPENDIX B

ARDUINO CODE FOR ULTRASONIC SENSOR

```
#include <UltrasonicSensor.h>
```

```
UltrasonicSensor ultrasonic(13, 12);
```

```
void setup()
```

```
{  
  Serial.begin(9600);  
}
```

```
void loop()
```

```
{  
  int distance = ultrasonic.distanceInMillimeters();  
  Serial.print("Distance: ");  
  Serial.print(distance);  
  Serial.println(" mm");  
}
```