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Design an Expansion Board for Arduino Uno Microcontroller Development Board with Multiple Input and Output

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Abstract: Science, Technology, Engineering and Mathematics (STEM) education plays important role in with technology development towards Industrial Revolution 4.0 (IR4.0). To fulfill this concept in Malaysian Education, The Ministry of Education introduced new subject called *Rekabentuk Teknologi (RBT)* for the primary and secondary school students. Students are exposed to multiple skills through this subject. Arduino Uno is introduced under microprocessor programming topic Form 2. But we can prove that deepness of the teaching is still below par because of the total credit hour and equipment. So, in this paper a new expansion board to teach Arduino Uno is suggested which is suitable for newcomers for the microprocessor programming. This board will include basic component to learn the programming methodology using C++ Language with Arduino Uno. The design also cost effective and suitable for any age of people. This board is including basic Digital Input and Outputs, 7-Segment, RGB LED, Infrared controller, Stepper Motor, Servo Motor, LCD and analogue inputs. Experts can design more than 50 experiment / lab works using these nine modules. Hope the development of this board opens wide area for newcomer to learn microprocessor programming toward create more experts in Malaysia in microprocessor programming.

Keywords: Arduino uno, expansion board, STEM education

1. Introduction

Futurists predict that one third of jobs that exist today could be taken by Smart Technology, Artificial Intelligence, Robotics, and Algorithms (STARA) by 2025 [1]. Speaking at Washington, D.C., economic think tank The American Enterprise Institute, Bill Gates said that within 20 year, a lot of jobs will go away, replaced by software automation which called "software substitution" by Gates [2]. So, Is our younger generation ready for it? Is our education system designed to produce younger generation with STARA and software technology?

Malaysia Education Development Plan 2013-2025 (Pelan Pembangunan Pendidikan Malaysia 2013 – 2015) emphasized STEM education as an agenda in education transformation to develop younger generation to be prepared for challenges in 21-st century [3]. The curriculum in primary and secondary schools were redesigned to help this generation to acquire new knowledge in engineering field especially in coding and programming. But, stimulating interest in this field in our country remains a challenge, as schools often do not have the specialized teachers and funds to buy the hardware and transfer this knowledge to students. So, skill institutions must play their role in transferring their knowledge in coding and programming to school student and teachers through short courses.

After several studies done, we found that microprocessor programming is the easiest and faster method to introduce the basic of STARA to younger generation. By learning microprocessor programming, younger generation will be exposed to hardware and software communication which will lead them to STARA based jobs in the future. Among the many microprocessor, Arduino was chosen for this purpose seems it

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is ease of use, relatively cheap and using C language as for programming. Arduino is also an "open source" device consisting of a hardware unit available in multiple configuration for various technology application [4]. At the same time, Kementerian Pendidikan Malaysia also introducing a single topic for microcontroller and microprocessor subject in Form 2 syllabus [5].

Considering all these issues, CIAST through *Kelab Kakitangan CIAST* (KKC) conduct a basic Microcontroller class for children between 10 to 15 years old to identify the limitation in transferring the microprocessor programming knowledge to younger generation. This course conducted using Arduino Uno R3 board with basic electronic components like breadboard, wires, LED, buzzer and sensors. At the end of three-day course, a survey done to identify the real problem in teaching microcontroller for young people. From the survey we found that the main problem to teach microprocessor programming to young people is: -

(i) Student / participant facing problem to do hardware connection using breadboard. This is because, we are focusing on teaching programming language for microprocessor in order to communicate hardware and software. But the participant spent more time on leaning and understanding the connection of electronic components using breadboard. This issue lead to slow teaching process and unable to compete targeted syllabus.

(ii) After end the course, many electronic components were spoil and missing. This will lead to extra course for next classes to buy those components.

(iii) Even there is a note prepared by the trainer, but there is no proper documented laboratory experiment handbook to cover basic programming for Arduino Uno microprocessor.

So, to overcome these problems, we must identify a proper multifunction expansion board to attached to the existing Arduino Uno Development board. By doing this we can solve problem (i) & (ii). Then a proper Laboratory Experiment Handbook will be developed at end of this research to solve problem (iii).

1.1 The Development Board

There are many microcontroller development boards available in the market for learning process. But, for beginners, Arduino is the best among these boards and selected to be used in this project. Arduino is open-source electronics prototyping platform based on flexible, easy-to-use hardware and software. It's intended for artists, designers, hobbyists, and anyone interested in creating interactive objects or environments [6]. The major benefit for using Arduino in an educational setting that have identified are [7]:

- Easy setup
- Many examples for controlling peripherals – preloaded in the IDE
- Many open source projects to look at
- Work on Windows, Linux and Mac
- Low cost hardware
- Low cost software
- Low maintenance cost
- Student can prototype quickly
- Can be programmed in a C language

Among the many Arduino development boards, Arduino Uno is selected for basic teaching process for the beginners and also declared as the most used and documented board of the whole Arduino family [6]. According to the Arduino website, they recommend Arduino Uno for middle school children. In ther hand, google search trends (Figure 1) among Arduino entry level boards, show that Arduino Uno is the highest search in google which proofs that there are many people show interest in this board compared to other Arduino boards.

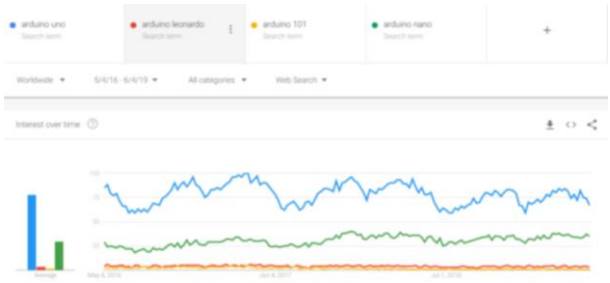

Fig. 1 - Comparison between arduino entry level boards in google search from 2017 to 2019

The Arduino Uno is open-source electronics prototyping platform based on the ATmega 328-P 8-bit microprocessor. The Uno includes 14 digital I/O pins (six of which can produce PWM outputs), 6 analog inputs, a USB connector that provides power and a serial connection to a PC for programming, a power jack for connecting external power, and a reset button [8]. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started. Figure 2 shows the original Arduino Uno Development board (around RM 90). But there are some compatible boards available in the market which is cheaper (about RM 25) and can be used for beginners.

The Arduino Integrated Design Environment (IDE) contains a text editor for composing code, a message area for displaying information during code compilation and upload, a text console, a toolbar with buttons for common functions, and a series of menus. [8].

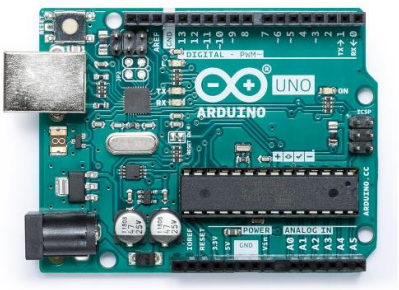

Fig. 2 - Arduino uno R3 development board

1.2 The Course Content

The main purpose of this paper is designing a suitable educational kit to educate beginner with basic programming algorithm using microcontroller which is involving hardware and software. We are focusing on microcontroller programming using C language. But, in other hand we can't ignore the importance of hardware connection. At the end of the course the participant must able to do C programming to control the basic electronic components using Arduino Uno microcontroller.

Embry-Riddle Aeronautical University in Prescot test-run a summer camp for high school students to introduce fundamental concept to them using Arduino based Sparkfun Inventor's kit. The results of student's response confirms the success of the camp as an outreach activity designed to increase student interests in STEM topics [8]. In these summer camp, they use laboratory experiments as in Table 1 to teach the participant the microprocessor programming.

Table 1 - List of sparkfun inventor's kit experiment

Experiment No.	Module Title
1	Blink an LED
2	Control LED Brightness
3	Control RGB LED
4	Control Multiple LEDs
5	Read Push Button
6	Photo Resistor
7	Temperature Sensor
8	A Single Servo
9	Flex Servo
10	Soft Potentiometer
11	Piezo Buzzer
12	Spinning a Motor
13	Relay
14	Shift Register
15	LCD
16	Simon Says Game

Li Xiaoning and Li Zhen suggested 4 main topics to the beginners of Arduino. They chose the content that can mostly reflect the ideas of mechatronics like the interface technology, driver of the motor, distance sensors and the control using software. All these contents are revised to a simplified version, which allow the students to understand these concepts, and the way to use them without caring about the technical details [9].

Table 2 - Content of course suggest by Li Xioming and Li Zhen

Lecture	Content	
	In Presentation	***In Experiments***
1	Introduction to Arduino - Hardware interface - Software structure - Preparation	- Connect to PC - Install IDE - "Hello World"
2	Interface Technology - Digital Input / Output (I/O) - Analog Input - PWM	- Flash on Board - Adjust LED's brightness Swith controlled LED - Light Controlled LED
3	Motors - Drives a DC Motor - Control a servomotor	- Control a servomotor
4	Sensors - Ultra-sonic distance measurement - Line detector	- Radar sound alarm

After considering the free online resources and the availability of components in Malaysia, nine modules are suggested to be included in our Arduino Beginner course. The modules are as in Table 3.

Table 3 - List of modules to be include in Arduino beginner's course

No	Modul e Title
Modul 1	Digital Input & Output
Modul 2	Multiple Digital Input
Modul 3	7-Segment Display
Modul 4	Analog Input
Modul 5	PWM & Buzzer
Modul 6	Stepper Motor
Modul 7	Servo Motor
Modul 8	IR Receiver
Modul 9	LCD Display

1.3 The Expansion Board

As mentioned above, many students facing problem in doing external connection to integrate the hardware / electronic component to the Development Board and computer. On top of that, the teachers are also facing with the lost and malfunction of the components due to wrong connection. To avoid this problem, we need a proper expansion board which can attached to the Arduino development board which can avoid extra works for the participant. There are several boards in the market but not all the boards are compatible with our course outline.

1.4 Maker Uno

Maker Uno is a Malaysia product design by Cytron Technologies Sdn. Bhd. is shown in figure 3. This is an Arduino compatible board which includes the processor and build-in electronic components as follows:

- 12 unit of programmable indicator LED
- 1 Unit of programmable push button
- 1 Unit of piezo buzzer

Fig. 3 - Maker uno board by Cytron T0echnologies Sdn. Bhd.

This board has a complete educational material in their website which is related to Malaysia Education System especially for *Rekabentuk Teknologi* subject in form 2 [10]. But, build-in components are very limited compare to our course outline. Student / participants still need to do extra wiring and connection for some topics. The advantage of this board is, we do not need to get an external Arduino development board and the educational material is complete for basic courses. But it does not covers additional components such as analogue input, motor, 7-segment, LCD and so on.

1.5 Multifunction Expansion Board

This board is available in online shopping websites which is comes from China. It is fully compatible with Arduino UNO R3 interfaces. Providing Arduino beginners basic experimental module. A board integrates various modules function. Provide all the module code library files, all tested and can be used directly. This board includes: -

- 2 unit of LED
- 2 unit of push button
- 1 unit of potentiometer
- 1 Unit of buzzer
- LM35D temperature sensor
- DHT11 temperature & humidity sensor
- IR receiver module

This board (as shown in Figure 4) has many I/O but still not meets our course content. LCD, 7-segment LED and motors are not included. At the same time educational material for this board also unavailable. This will make the teaching process more difficult.

Fig. 4 - Multifunction expansion board

After considering all these issues, we decide to design a new expansion board with complete components as mentioned in Table 3 with educational material. Only this solution will help teachers to conduct a basic Arduino course with easy.

2. Methodology

This research divided into two parts, first is developing an Arduino UNO expansion board, then preparing educational material / laboratory experiment to cover the suggested topic. First, the circuit was developed and tested for each module. The Arduino Uno only has 14 Digital Input / Output, 6 Analogue Input. Out of 14 digital I/O, port D0 is declared as data receiver and port D01 is declared as data receiver. Now we have balance 12 Digital I/O D02 to D13. From these 12 I/O, port D03, D05, D06, D09, D10, D11 and D12 can used as well for Pulse Width Modulation (PWM). So, this information is used to decide the ports in developing the expansion board.

First process to design circuit for each module and test it using online software and actual test using breadboard and components. There are many online simulation software available for test the electronic circuits. For this research, we used Autodesk Tinker-Cad (www.tinkercad.com/circuits) online simulation software to test all the circuits. Then, all these circuits are tested using actual components and Arduino Uno Development Board.

Module 1 consist of two LED connected to digital pin D12 and D13 and declared as general-purpose LEDs which can be used for all the modules. Then two push buttons connected to digital pin D02 and D03 as shown in Figure 5. These two push buttons are connected as *pull-down resistor*.

For Module 2, 8 light emitting diode (LED) is connected to 8 digital pins (D04 to D11) and grounded using Jumper pin 1 (JP1) as shown in Figure 6. Another 2 LEDs connected to digital pin D12 and D13 and grounded directly to GND as in Module 1 also can be used in this module to get total of 10 LED. So, by connecting jumper 1, participant can write programs to control ten LEDs.

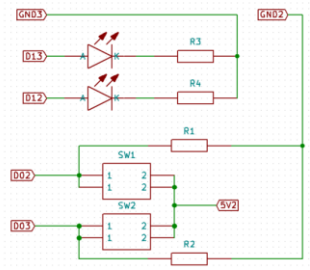

Fig. 5 - Circuit for module 1 - general purpose LED and push button

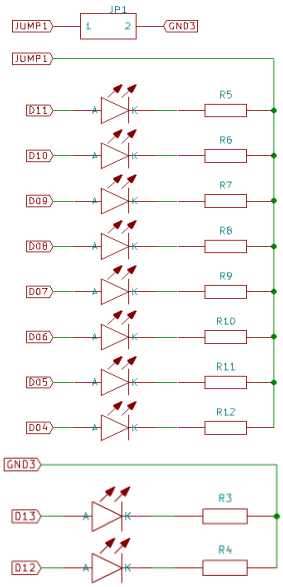

Fig. 6 - Circuit for module 2 – 8 LED connected in parallel

Module 3 consist of a single 7-segment display which is connected to digital pin D04 to D11 as shown in Figure 7. This 7-segment display is grounded through jumper 2 (JP2). So, by connecting JP2, participant can do programming using 7-segment display.

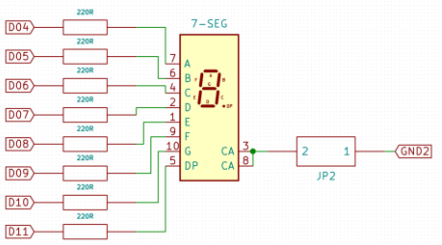

Fig. 7 - Circuit for module 3 - 7-segment display

Module 4 is based on analogue input. There are 6 analogue input pins in Arduino Uno, but for this paper, only 4 inputs are used. Two inputs are used for two unit of 10K potentiometer and one for temperature sensor (LM35) and one for light dependent resistor (LDR). The circuit is shown in Figure 8.

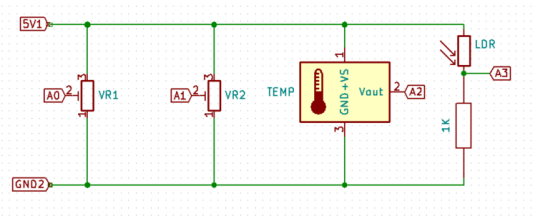

Fig. 8 - Circuit for module 4-analogue input

Module 5 consist of one unit of RGB (Red, Green & Blue) LED and one unit of buzzer. RGB LED is connected to digital pin D09, D10 dan D11. Buzzer is connected to digital pin D08. Both RGB LED and buzzer is grounded through jumper JP#.

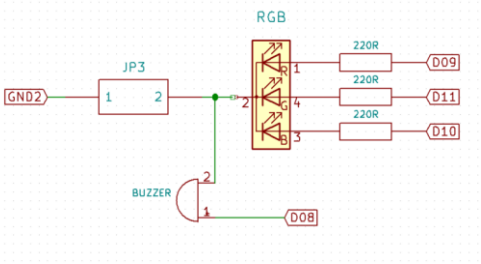

Fig. 9 - Circuit for module 5 - RGB LED and buzzer

Module 6 is a stepper motor control. This stepper motor is controlled by Darlington Transistor ULN2003. Pin IN1, IN2, IN3 and I4 from ULN2003 is connected to digital pin D04, D05, D06 and D07 respectively. The ground and 5V of stepper motor are connected through jumper JP4 and jumper JP5 as shown in figure 10. The stepper motor comes separately, and the participant need to connect it to 5-pin male connector. The switching sequence of the stepper motor is shown in Table 4.

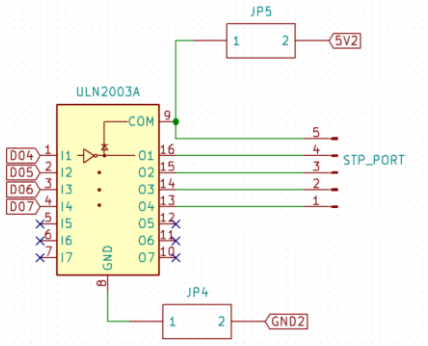

Fig. 10 - Circuit for module 6 - stepper motor

Table 4 - Switching sequence of stepper motor

Wire Color	Clockwise (1 – 2 Phase)							
	1	2	3	4	5	6	7	8
4 – Orange	1	1						1
3 – Yellow		1	1	1				
2 – Pink				1	1	1		
1 – Blue						1	1	1

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Module 7 is consisting of one unit of micro servo motor. The input of servo motor is connected to digital port D09 and the ground and 5V is connected through jumper 6(JP6) and jumper 7(JP7). The circuit is as shown in Figure 11.

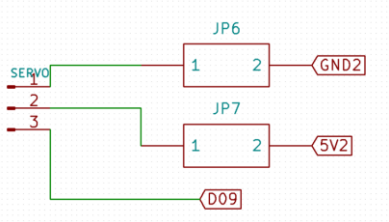

Fig. 11 - Circuit for module 7 - servo motor

Module 8 is an infrared receiver (IR) connected to digital port D08 and the ground and 5V is connected through jumper 6(JP6) and jumper 7(JP7). This IR sensor comes with a remote controller, but also can use any remote controller using infrared transmitter.

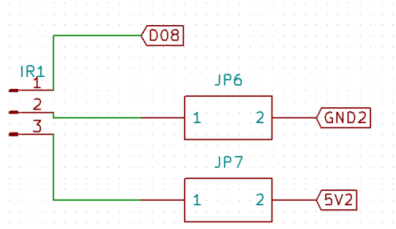

Fig. 12 - Circuit for module 8 - infrared receiver

The last module, Module 9 is a module for Liquid Crystal Display (LCD Display). LCD data input is connected to digital port D04 to D07. Enable and RS is connected to port D10 and D11 respectively. 5V power source is connected through jumper JP9 and grounded with jumper JP8 as shown in figure 13.

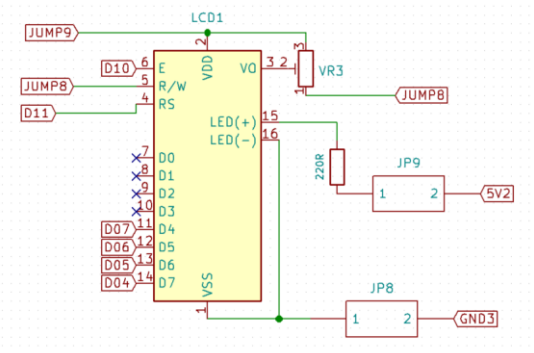

Fig. 13 - Circuit for module 9 - LCD display

Once all the circuit drawn and tested, it combined into one single circuit and converted into PCB mode use KiCAD software. The PCB layout is shown in Figure 14.

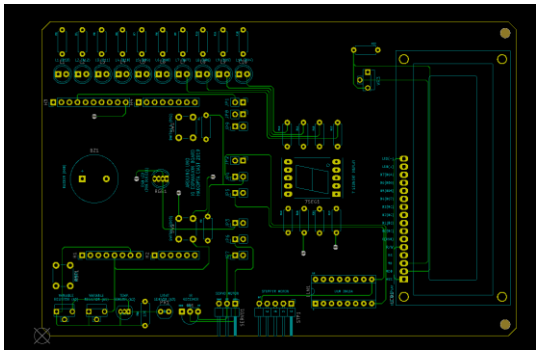

Fig. 14 - PCB layout for the expansion board

Finally, 3D model for the expansion board has been generated as the following figure.

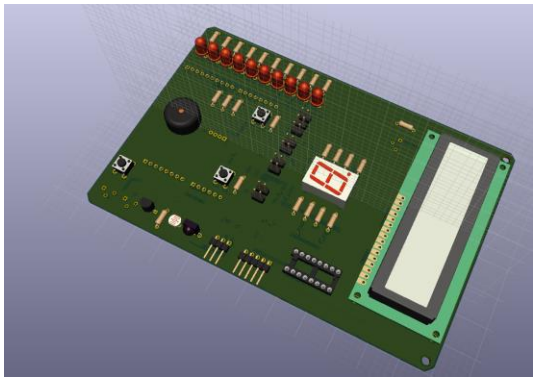

Fig. 15 - 3D model for the expansion board

The final design converted into *Gerber* file and sent to print the printed circuit board (PCB). Once PCB is ready then the components are soldered to make complete expansion board as shown in figure 16.

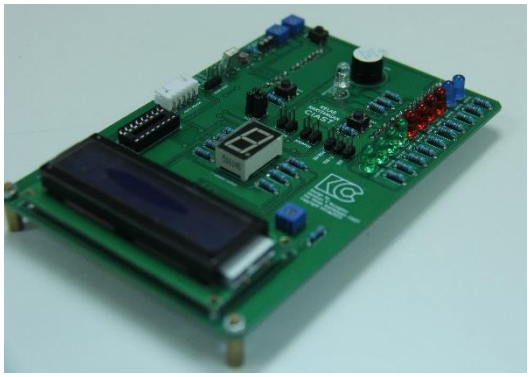

Fig. 16 - Complete expansion board for arduino uno

4. Result & Discussion

After the completion, each component tested for the functionality and properties. A simple program is written to test each component according to the modules. Table 5 shows jumper pin configuration for the appropriate modules /

components. Connecting wrong jumper or more than delegated jumpers can lead to power shortage and unstable of result. This board is using 5V input source from computer USB port. So, input voltage is limited, and all the different components are controlled by different jumpers.

Table 5 - Jumper pin connection for the components

Component	Jumper (JPx)								
	1	2	3	4	5	6	7	8	9
Blue LED (2)									
Green LED (4)	●								
Red LED (4)	●								
Switch 1 & 2									
Potentiometer 1									
Potentiometer 2									
Temperature Sensor									
LDR									
7-Segment		●							
Buzzer			●						
RGB LED			●						
Stepper Motor				●	●				
Servo Motor						●	●		
IR Receiver						●	●		
LCD Display								●	●

Before testing the components, the software to write C language is installed in the computer. This is an open source program which can be downloaded from Arduino official website (https://www.arduino.cc/en/Main/Software). Current version as of May 2019 is Arduino 1.8.9. The software can be used either in online mode or desktop mode. For the online mode user can use it online without install in their PC. The most recommended mode id desktop mode. If we are using compatible Arduino board, then another additional software needs to install in the PC to recognize the USB port. This software can be downloaded from the following URL:
http://www.wch.cn/download/CH341SER_EXE.html

All the nine modules were tested accordingly to determine the full function of the new developed expansion board.

Module 1 Output (No Jumper needs):
When press switch, LED L1 is HIGH, and
When press switch, LED L2 is HIGH.

Module 2 Output (Jumper JP1)
LED L3 to L10 is blinking.

Module 3 Output (Jumper JP2)
7-Segment is rotating.

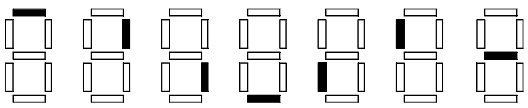

Fig. 17 - 7-Segment rotation mode

Module 4 Output (No jumper needs)

This module will give the output value for two potentiometers, a temperature sensor and LDR. The value is depending on the signal received by these components.

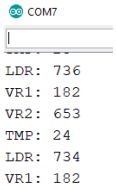

Fig. 18 - Analogue reading in serial monitor

Module 5 Output (Jumper JP3 connected)
This module will give the output in RGB LED dan buzzer. It will flash three colors in RGB LED then a beep sound in buzzer.

Module 6 Output (Jumper JP4 & JP5 is connected)
This module will test the function of stepper motor. It rotates Stepper motor 180º.

Module 7 Output (Jumper JP6 & JP7)
This module will rotates the servo motor based on potentiometer's reading which connected to analogue pin A0.

Module 8 Output (Jumper JP6 & JP7)
This module gives output of IR controller. The output of IR sensor can be seen in the serial windows.

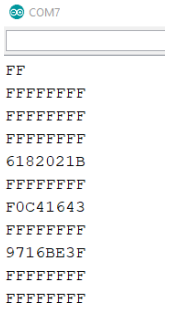

Fig. 19 - Output for remote controller in serial monitor

Module 9 Output (Jumper JP8 & JP9)
This program will show display in LCD screen as follow: -

Welcome
Arduino is Easy

5. Conclusion and Suggestion

This new expansion board is suitable for newcomers who wants to learn microcontroller programming. Primary school children can use scratch programming to learn basic microcontroller. Secondary or higher-level student can use C++ languages to write the microcontroller program.

It is recommended that this board and suggested lab experiments are evaluated by Malaysian Education Ministry or TVET institutions to determine the depth of the knowledge that should be transferred to the newcomers for the microcontroller programming. The board size still can be reduced using surface-mount (SMD) components. By doing this we can design cheaper and small size boards.

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