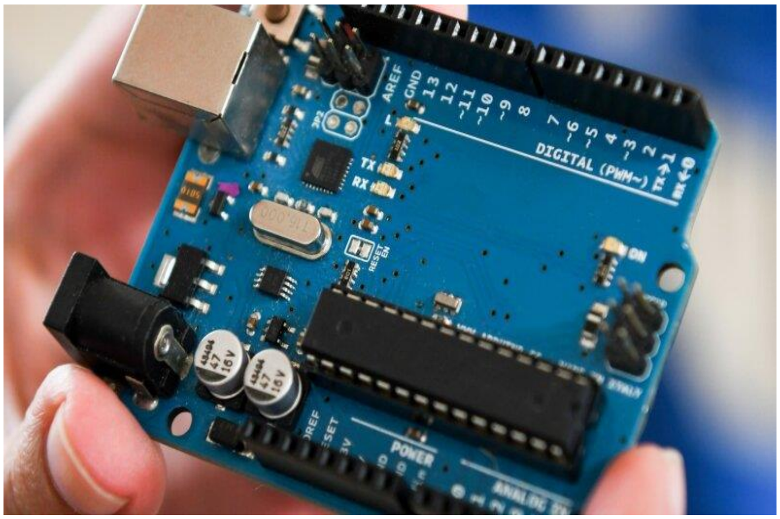

MICROCONTROLLER COMPARISON VIA ENCRYPTION TABLE IMPLEMENTATION

Course ID: CSE331
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1. Main Objective

The objective of this project was to create a 4 -bit encryption system that masks that the output using Boolean Expression. The encryption algorithm was derived from a Truth Table of inputs and its subsequent output. The 4-bit input would be fed into a microcontroller which would then encrypt the output according to the Truth Table using Boolean logic expression and display it via 4 LEDs to signify 4-bits. A total of 16 possible encryption combinations are possible using this 4-bit circuit: from a value of 0 to 15.

This encryption system was programmed in the Arduino IDE using both default C-programming using Arduino Libraries and Register Level Programming. The aim was to monitor the difference between running a program coded in high-level default program using headers and libraries and low-level Register Level Programming and compare their differences of program size, memory occupied, and time taken to execute the program.

The HEX file of the programmed Arduino IDE code was then imported to a circuit schematic designed in Proteus for simulation of the complete system. A virtual terminal was also used monitor the execution.

The encryption system was implemented using two different boards in Proteus: i) Arduino UNO which uses the ATmega328p microcontroller and ii) Arduino Mega 2560 which uses the ATmega2650 microcontroller. Both boards implemented the encryption program in each type of programming to compare the differences of performance and memory to ensure the results are consistent and reliable.

2. General Description

2.1 Arduino UNO R3

Arduino UNO R3 is a microcontroller board based on the ATmega328P microcontroller. It has a 16 MHz ceramic resonator (CSTCE16M0V53-R0), 6 analog inputs, 14 digital input/output pins (of which 6 can be used as PWM outputs), a USB port, a power jack, an ICSP header, and a reset button. It has a clock frequency of 16 MHz, 32 KB of flash memory, and 2 KB of SRAM. The Arduino UNO R3 supports serial communication via USB and interfaces such as UART, SPI, and I2C

It can run programs coded with standard C/C++ libraries and headers created for Arduino on the Arduino IDE. It's simplicity to use, small form factor makes it a popular prototyping board.

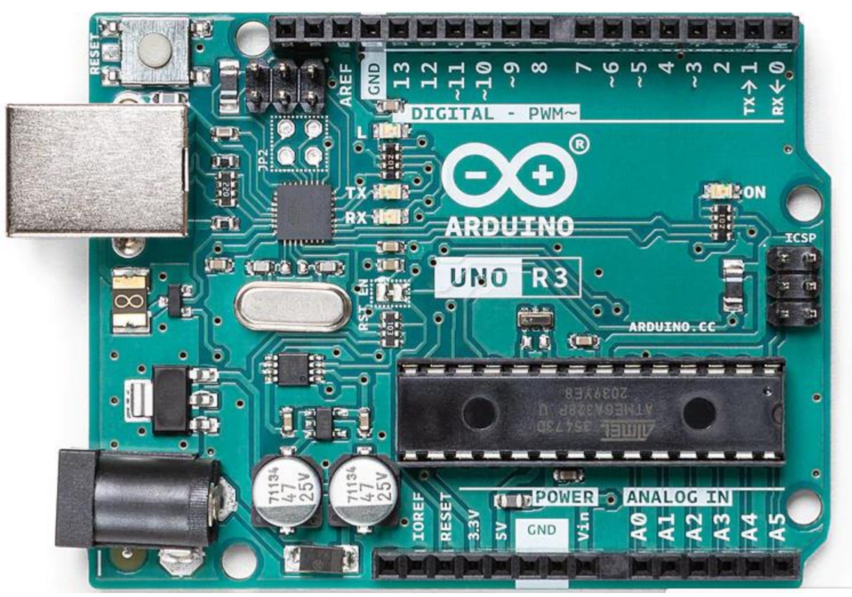

Figure 1: Arduino UNO Rev3

2.2 Arduino Mega 2560

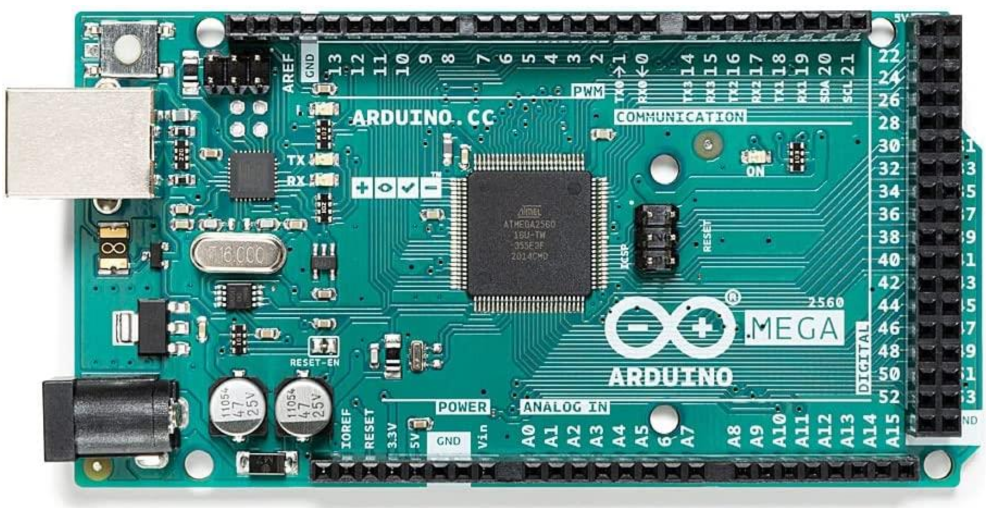

Figure 2: Arduino Mega 2560

The Arduino Mega 2560 is based on the Atmega2560 microcontroller and is used for large projects that require high number of input and output ports. As such the Arduino Mega 2560 contains 54 digital IO pins and 16 analog pins. It also has 15 pins among the digital IO pins that supports PWM. Hence, it can support multiple components at a time to read and output values and data. The Arduino Mega 2560 supports serial communication via USB and interfaces such as UART, SPI, and I2C.To support this, it also contains 256 KB of memory to store large volumes of codes, and 8 KB of SRAM and 4 KB of EEPROM. This also owes to the boards large size. Like the Arduino UNO, the Arduino Mega 2560 has a clock frequency of 16 Mhz.

2.3 Arduino IDE

Figure 3: Arduino IDE

Arduino IDE is an integrated development environment that contains a text editor for writing code on C/C++ to program and develop projects on Arduino boards. The Arduino IDE is designed to be beginner-friendly and provides a simple way to write, compile, and upload code to Arduino boards. It contains a message area, a text console, a toolbar with buttons for common functions and a series of menus. Overall, the IDE provides a user-friendly interface for writing, compiling, and uploading codes to Arduino boards. It has set of libraries and functions that makes using the IDE and connecting code with the boards simple and easy.

Programs written on the Arduino IDE are called sketched and they are uploaded to the board via its upload feature with just one button click.

2.4 Proteus 8 Pro

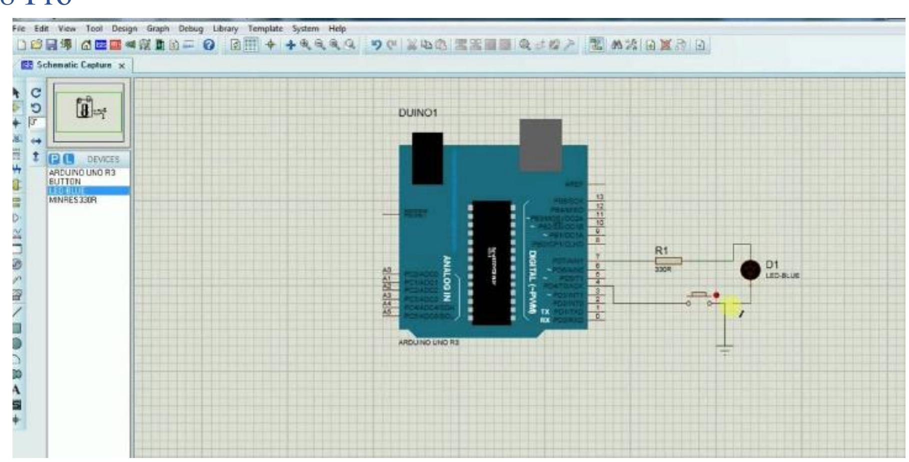

Figure 4: Proteus 8 Pro Interface

Proteus 8 Pro is a comprehensive and versatile tool for electronic circuit design, simulation, and PCB layout. Its intuitive interface, powerful simulation engine, and extensive component library make it a popular choice among electronics enthusiasts and professionals alike.

2.5 Logisim

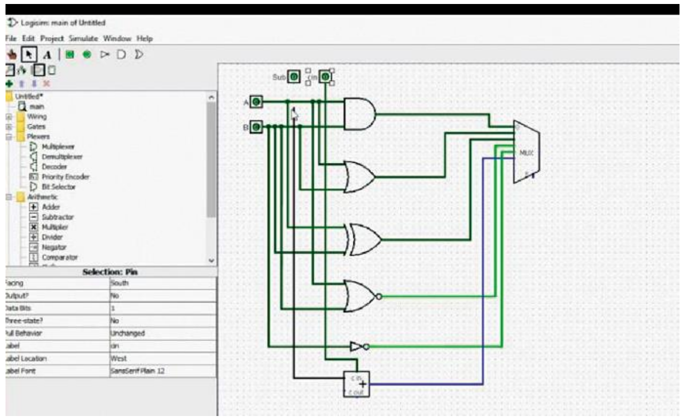

Figure 5: Logisim Interface

Logisim is an open-source program that assists in the design and simulation of logic circuits. The tool can be used to build both straightforward and intricate educational circuits and is intended for use in classrooms. The software contains a large collection of digital components that are widely used circuit design and simulation. It also has a user-friendly interface where components can be dragged and dropped and simulated in real time to see outputs and change inputs.

3. Equipment Used

•Single pole double throw switch:

It is an electrical switch that has one input terminal (pole) and can connect that terminal to one of two output terminals (throws).

•10 kΩ Resistor:

It is an electronic component that provides a resistance of 10,000 ohms to the flow of electric current.

•Red LED:

It is a semiconductor device that emits red light when an electric current is passed through it.

•Arduino UNO REV3:

It is a popular microcontroller board that is widely used in electronics projects and prototyping. It is based on the ATmega328P microcontroller and is part of the Arduino family of boards.

•Arduino Mega 2560:

It is a large and versatile microcontroller board that has a larger flash memory and EEPROM than other Arduino boards. It is based on the ATmega2560 microcontroller and provides similar functionality but in a larger form factor and capacity.

4. Method of Derivation

4.1 Truth Table

Input				Output			
I3	I2	I1	I0	O3	O2	O1	O0
0	0	0	0	1	1	0	1
1	0	0	0	1	1	1	0
0	1	0	0	0	1	1	0
1	1	0	0	1	0	1	0
0	0	1	0	1	0	1	0
1	0	1	0	0	0	0	1
0	1	1	0	0	1	1	0
1	1	1	0	0	0	1	1
0	0	0	1	1	1	0	0
1	0	0	1	0	0	1	1
0	1	0	1	1	1	0	0
1	1	0	1	0	0	0	1
0	0	1	1	1	0	1	1
1	0	1	1	0	0	1	1
0	1	1	1	1	1	1	0
1	1	1	1	1	0	0	0

Table 1: Truth Table for Input and Output

4.2 Karnaugh Map

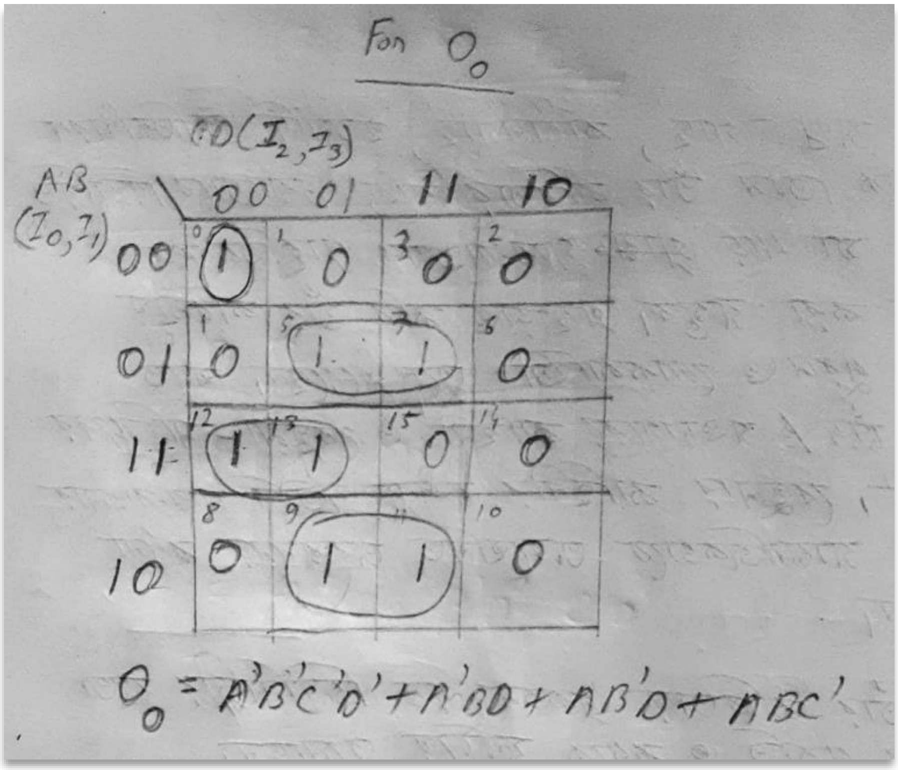

Figure 6: Kmap Derivation for O0

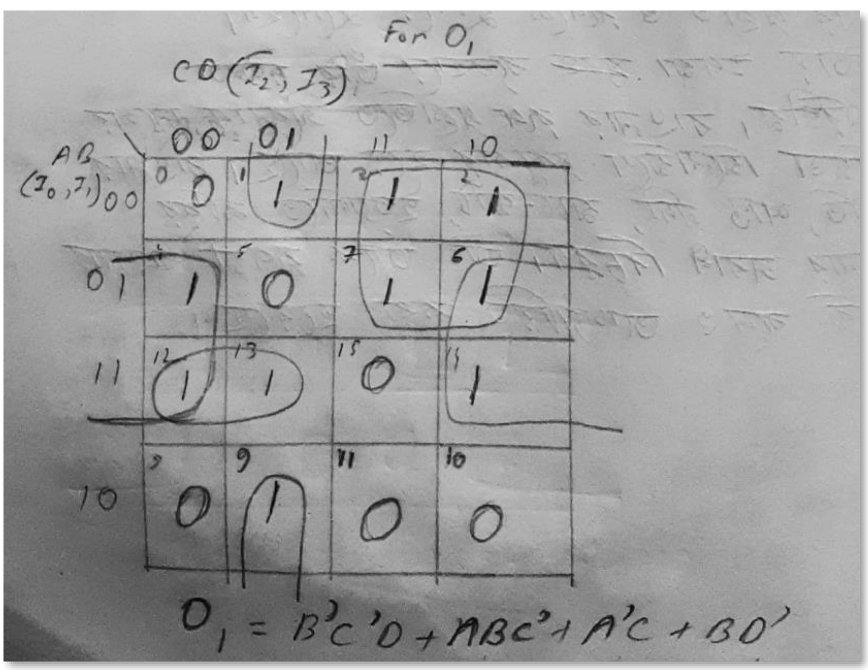

Figure 7: Kmap Derivation for O1

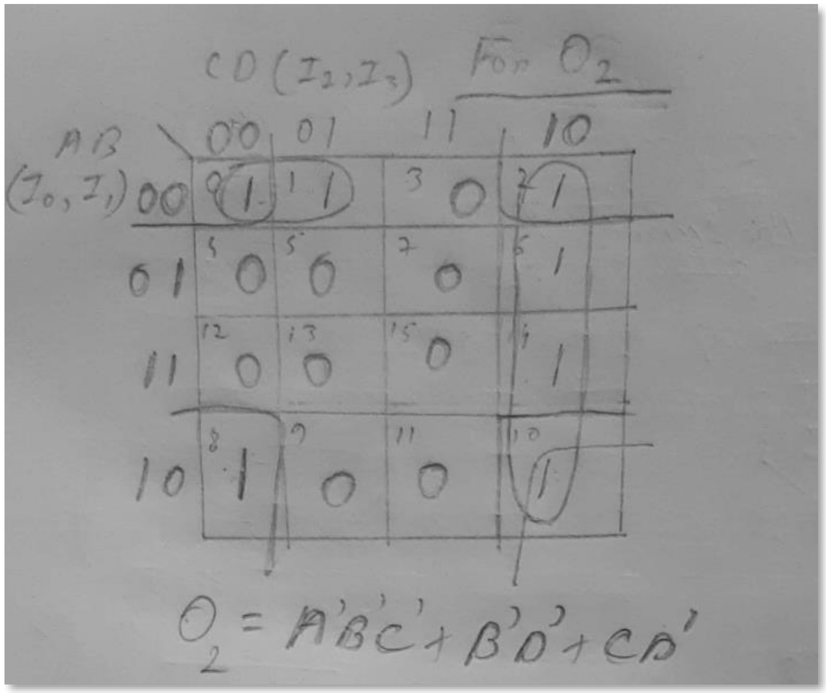

Figure 8: Kmap Derivation for O2

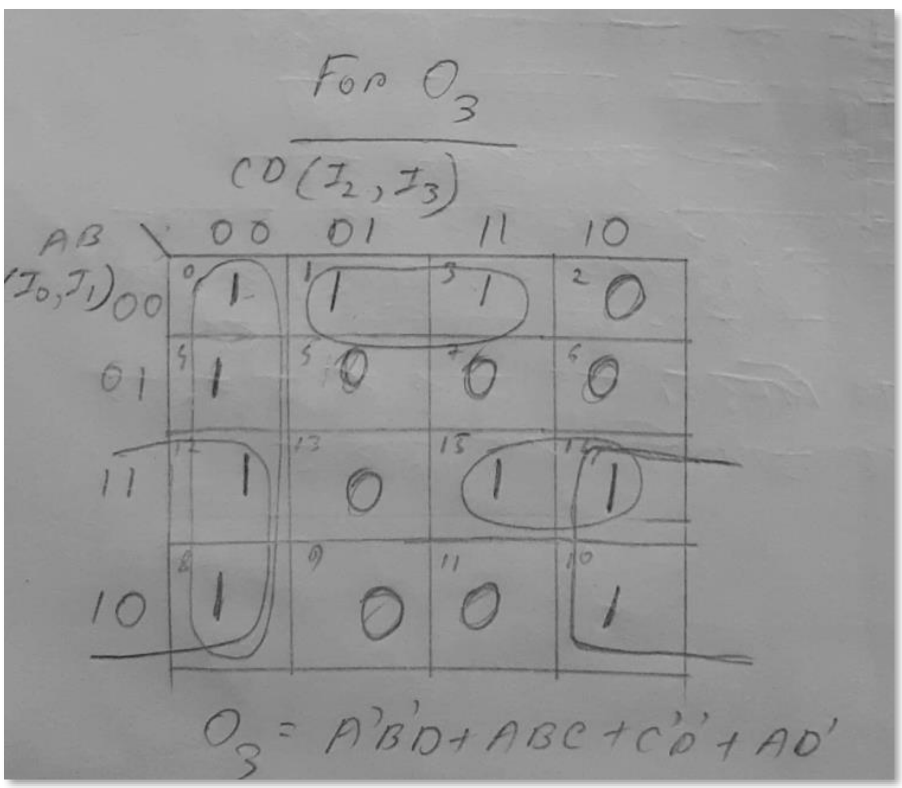

Figure 9: Kmap Derivation for O3

4.3 Derived Boolean Output Expression from Karnaugh Map

The Final Derived Expression for each output from the Kmaps is:

i) O0 = I0’I1’I2’I3’ + I0’I1I3 + I0I1’I3 + I0I1I2’

ii) O1 = I1’I2’I3 + I0I1I2’ + I0’I2 + I1I3’

iii) O2 = I0’I1’I2’ + I1’+I3’ + I2I3’

iv) O3 = I0’I1’I3 + I0I1I2 + I2’I3’ + I0I3’

5. Circuit Diagram with Values of Electrical Components

5.1 Logisim Circuit

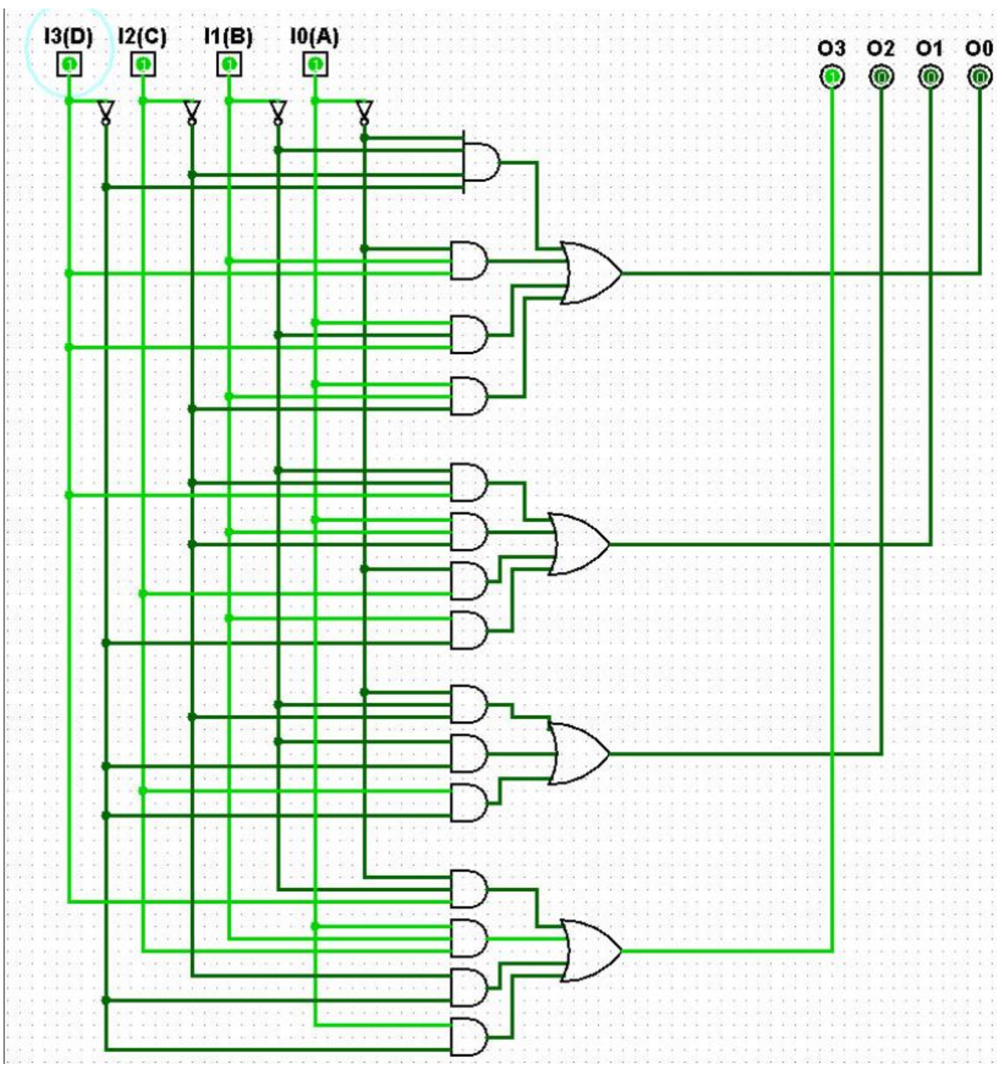

Figure 10: Logisim Simulation

5.2 Proteus Circuit

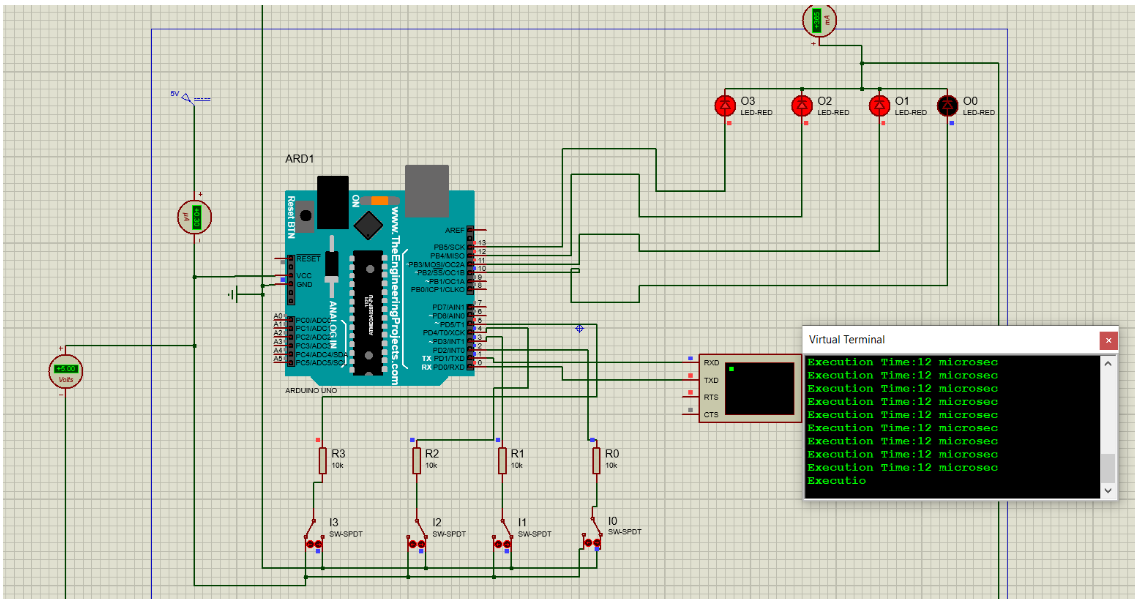

Figure 11: Proteus Simulation Demo for Arduino Uno

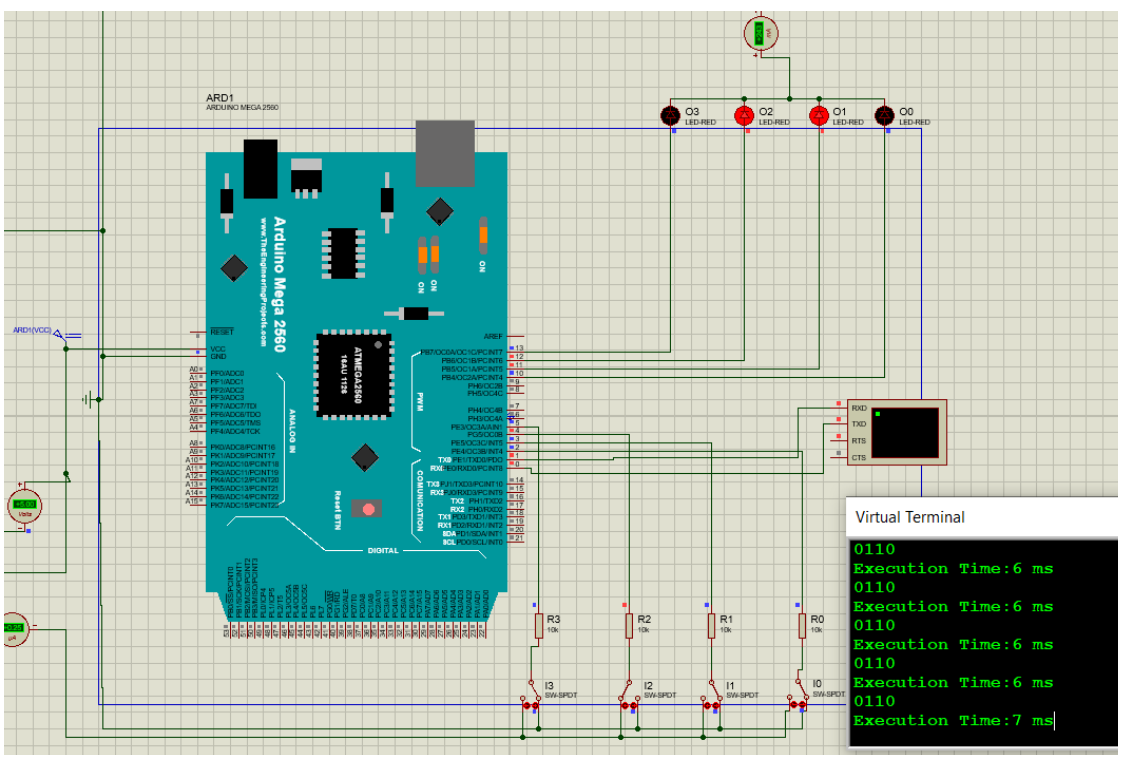

Figure 12: Proteus Simulation Demo for Arduino Mega 2560

6. Circuit Operation Principles

For our circuit operation the output equation from the Kmap is as follows:

O0 = I0'I1'I2'I3' + I0'I1I3 + I0I1'I3 + I0I1I2'

O1 = I1'I2'I3 + I0I1I2' + I0'I2 + I1I3'

O2 = I0'I1'I2' + I1'+I3' + I2I3'

O3 = I0'I1'I3 + I0I1I2 + I2'I3' + I0I3'

As a demo to test whether these expression is correct for our input bits, we designed a logic circuit on Logisim and simulated using four input and output bits and using the help AND, OR, and NOT gates to achieve the output equations.

Then, with the help of Proteus 8 Professional software, we built our main Hardware Circuit.We have used the following components:

Arduino Uno: We have used an Arduino Uno Model as our first board to test.
We will connect the Vcc pin of Arduino to a power supply of 5V. And we will connect the ground pin of the Arduino to a Ground component.

Arduino Mega: Used as the second board to test and compare. Connection of Vcc is same as with Arduino Uno.

Resistors: We have used a total of 4 resistors of 10k Ohms. These are connected with the SPDT switches.

Single Pole Double Throw Switches: We used four of these Switches with our Arduino Digital pins. They are arranged as follows:

Arduino UNO Digital Pin No. 2 --------- SPDT Switch I0
Arduino UNO Digital Pin No. 3 --------- SPDT Switch I1
Arduino UNO Digital Pin No. 4 --------- SPDT Switch I2
Arduino UNO Digital Pin No. 5 --------- SPDT Switch I3

The Resistors are connected in series with the pins and SPDT switches while the other pole of the switches is connected to the GND. Hence, one side of the switch acts as open while the other acts as closed and provides current flow and power to the pins.

LEDs: We have connected Four LEDs to the Digital Pins of Arduino to receive Output through those Pins. They are arranged in such way:

Arduino UNO Digital Pin No. 10 --------- LED O0
Arduino UNO Digital Pin No. 11 --------- LED O1
Arduino UNO Digital Pin No. 12 --------- LED O2
Arduino UNO Digital Pin No. 13 --------- LED O3

Finally, a Virtual Terminal is used to monitor the execution time to compare performance between Register Level Programming and C-programming. This execution time is analyzed in the Results Analysis section. The Hex file exported from Arduino IDE for both types of programming is imported on the board and simulated.

7. Program Flow Chart

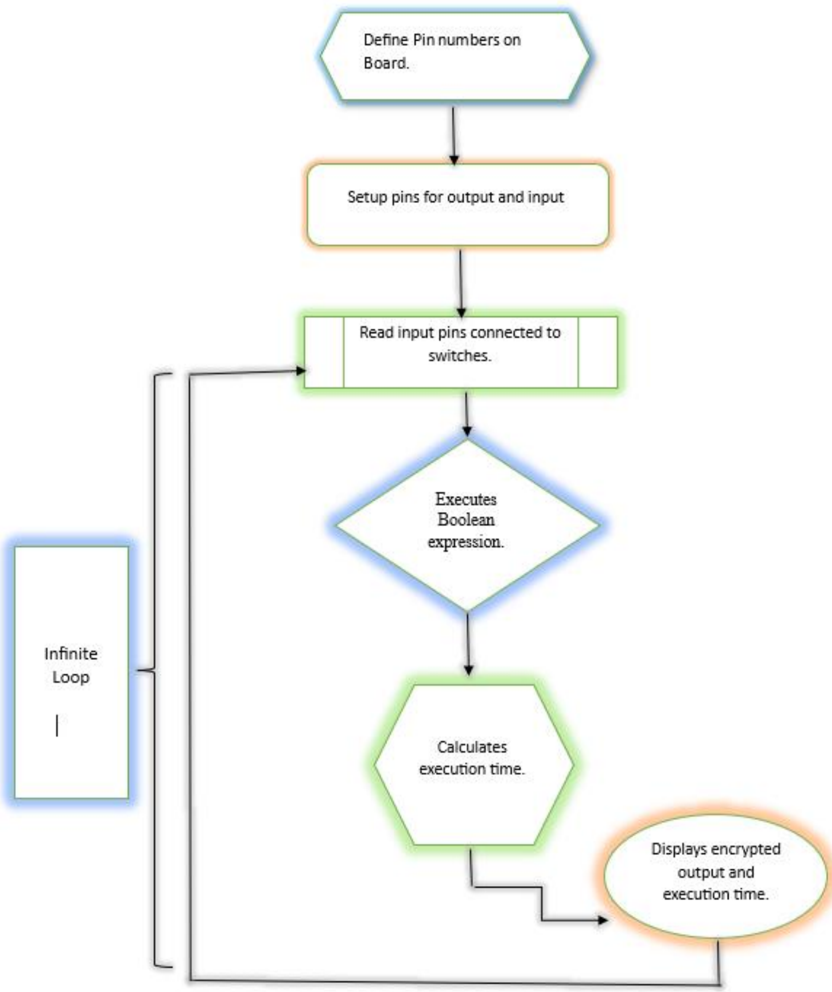

Figure 13: Program Loop Flowchart

8. Arduino Program

8.1 Arduino Program for both Arduino UNO R3 and Mega using Arduino Libraries:

```
/// output LED variable declaration
int O0LED = 10; /// variable for O0 LED connected to pin 10
int O1LED = 11; /// variable for O1 LED connected to pin 11
int O2LED = 12; // variable for O2 LED connected to pin 12
int O3LED = 13; //variable for O3 LED connected to pin 13
/// switch input variable declaration
int I0Switch = 2; /// variable for switch O0 connected to pin 2
int I1Switch = 3; /// variable for switch O1 connected to pin 3
int I2Switch = 4; /// variable for switch O2 connected to pin 4
int I3Switch = 5; /// variable for switch O3 connected to pin 5
unsigned long startTime;
unsigned long endTime;

void setup()
{
// sets Switches as input
pinMode(I0Switch,INPUT);
pinMode(I1Switch,INPUT);
pinMode(I2Switch,INPUT);
pinMode(I3Switch,INPUT);
// sets LEDs as output
pinMode(O0LED,OUTPUT);
pinMode(O1LED,OUTPUT);
pinMode(O2LED,OUTPUT);
pinMode(O3LED,OUTPUT);
Serial.begin(9600);

}

void loop()
{
startTime = millis();
boolean I0State = digitalRead(I0Switch);
boolean I1State = digitalRead(I1Switch);
boolean I2State = digitalRead(I2Switch);
boolean I3State = digitalRead(I3Switch);
boolean O0State;
boolean O1State;
boolean O2State;
boolean O3State;
```

```
// Kmap Equation Logic
O0State= (!I0State & !I1State & !I2State & !I3State)|(!I0State & I1State & I3State)|(I0State & !I1State &
I3State)|(I0State & I1State& !I2State);
O1State= (!I1State & !I2State & I3State)|(I0State & I1State & !I2State)|(!I0State & I2State)|(I1State &
!I3State);
O2State= (!I0State & !I1State & !I2State)|(!I1State & !I3State)|(I2State & !I3State);
O3State= (!I0State & !I1State & I3State)|(I0State & I1State & I2State)|(!I2State & !I3State)|(I0State &
!I3State);

digitalWrite(O0LED,O0State);
digitalWrite(O1LED,O1State);
digitalWrite(O2LED,O2State);
digitalWrite(O3LED,O3State);
Serial.print(O3State);
Serial.print(O2State);
Serial.print(O1State);
Serial.println(O0State);
endTime = millis();
Serial.print("Execution Time:");
Serial.print(endTime-startTime);
Serial.println(" ms");
// delay(1000);
}
```

8.2 Arduino Program for both Arduino UNO R3 and Mega using Register Programming:

```
unsigned long startTime;
unsigned long endTime;

void setup()
{

// sets Switches as input
DDRD &= ~(1 << 2); // sets PORTD bit 2 as input
DDRD &= ~(1 << 3); // sets PORTD bit 3 as input
DDRD &= ~(1 << 4); // sets PORTD bit 4 as input
DDRD &= ~(1 << 5); // sets PORTD bit 5 as input
// sets LEDs as output
DDRB |= (1 << 2); // sets PORTB bit 2 as output
DDRB |= (1 << 3); // sets PORTB bit 3 as output
DDRB |= (1 << 4); // sets PORTB bit 4 as output
DDRB |= (1 << 5); // sets PORTB bit 5 as output;
Serial.begin(9600);
}
```

```
void loop()
{
startTime = micros();
// read the switch states
bool I0State = (PIND & (1 << 2)) != 0;
bool I1State = (PIND & (1 << 3)) != 0;
bool I2State = (PIND & (1 << 4)) != 0;
bool I3State = (PIND & (1 << 5)) != 0;

// calculate the LED states
bool O0State = (!I0State & !I1State & !I2State & !I3State) |
(!I0State & I1State & I3State) |
(I0State & !I1State & I3State) |
(I0State & I1State & !I2State);
bool O1State = (!I1State & !I2State & I3State) |
(I0State & I1State & !I2State) |
(!I0State & I2State) |
(I1State & !I3State);
bool O2State = (!I0State & !I1State & !I2State) |
(!I1State & I3State) |
(I2State & I3State);
bool O3State = (!I0State & !I1State & I3State) |
(I0State & I1State & I2State) |
(!I2State & I3State) |
(I0State & !I3State);

// write the LED states
PORTB |= (O0State << 2); // sets PORTB bit 2 to the value of O0State
PORTB |= (O1State << 3); // sets PORTB bit 3 to the value of O1State
PORTB |= (O2State << 4); // sets PORTB bit 4 to the value of O2State
PORTB |= (O3State << 5); // sets PORTB bit 5 to the value of O3State;
endTime = micros();
Serial.print("Execution Time:");
Serial.print(endTime-startTime);
Serial.println(" microsec");
}
```

8.3 Hex Code

8.3.1 Hex Codes generated for use on Arduino UNO R3

Arduino Library and C programming Hex Code:

```
:100000000C9462000C948A000C948A000C948A0070
:100010000C948A000C948A000C948A000C948A0038
:100020000C948A000C948A000C948A000C948A0028
:100030000C948A000C948A000C948A000C948A0018
:100040000C94C3020C948A000C9433030C940D039B
:100050000C948A000C948A000C948A000C948A00F8
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:100070002A0000000000250028002B0000000000DE
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:100160000895809 1B0008F7DF9CFCF93DF93282F32
:1001700030E0F901E255FF4F8491F901E656FF4F57
:10018000D491F901EA57FF4FC491CC23A1F081111A
:100190000E948C00EC2FF0E0EE0FFF1FE458FF4FA1
```

```
:1001A000A591B491EC91ED2381E090E009F480E019
:1001B000DF91CF91089580E090E0FACF1F93CF9325
:1001C000DF93282F30E0F901E255FF4F8491F901C8
:1001D000E656FF4FD491F901EA57FF4FC491CC2363
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:10032000981731F0828DE80FF11D858D90E00895CA
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:10034000805C9F4F821B91098F73992708958BE3DF
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:10036000089580E090E0892B29F00E94A701811177
```

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:10039000848FA689B7892C93A089B1898C918370A9

:1003A00080648C93938D848D981306C00288F389A2

:1003B000E02D80818F7D80830895EF92FF920F93CF

:1003C0001F93CF93DF93EC0181E0888F9B8D8C8D01

:1003D00098131AC0E889F989808185FF15C09FB7F5

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:1008C0001D23122B172B21E0B5016C297D29672BE5

:1008D00009F020E02323122BA82AB92A21E0AB2813

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:100920000E94DE006B2D8CE00E94DE006D2F8DE0BA
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:100940000E94BC02812F90E00E94BC026C2F70E0DC
:1009500090E080E04AE00E94570282E191E00E942C
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:100970003901B0913A012FBF80932A0190932B0146
:10098000A0932C01B0932D0185E191E00E944A02D1
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:10011000EF92FF920F931F93CF93DF936C017B01BC

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:1007500090E09587848784EC90E09787868780EC8B
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:1007700090E0958B848B86EC90E0978B868B118E26
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8.3.2 Hex Code generated for use on Arduino Mega 2560

Arduino Library and C programming Hex Code:

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:100050000C9466010C9466010C9466010C940404E3
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:100240000000000000000000000000000000012118B
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:10026000000000000000000000005B0611241FBECFEF5D

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:100D680000000000ED02570284023A03B502930224
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:0A0D8800696D653A00206D730000EC
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Register Level Programming Hex Code:

```
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9 Result Analysis and Comparison Among The Boards Used

9.1 Hardware Comparison Among Boards Used

Hardware Specifications	Arduino UNO R3	Arduino Mega 2560
Power	5V	5V
Microcontroller Used	ATmega328p	ATmega2560
Flash Memory	32KB	256KB
EEPROM	1KB	4KB
Clock Frequency	16 MHz	16 MHz
PWM Pins	6	15
Analog Pins	6	16
Digital Pins	14	54
SRAM	2 KB	8KB

Table 2: Hardware Specification of Arduino UNO R3 and Arduino Mega 2560

9.2 Power Consumption Comparison

Input Bits	Output Bits	Current(mA	Voltage(V)	Power(mW)
0000	1101	365	5	1825
1000	1110	365	5	1825
0100	0110	243	5	1215
1100	1010	243	5	1215
0010	1010	243	5	1215
1010	0001	122	5	610
0110	0110	243	5	1215
1110	0011	243	5	1215
0001	1100	243	5	1215
1001	0011	243	5	1215
0101	1100	243	5	1215
1101	0001	122	5	610
0011	1011	365	5	1825
1011	0011	243	5	1215
0111	1110	365	5	1825
1111	1000	122	5	610

Table 3: Current, Voltage and Power use for Arduino UNO R3

Input Bits	Output Bits	Current(mA	Voltage(V)	Power(mW)
0000	1101	365	5	1825
1000	1110	365	5	1825
0100	0110	243	5	1215
1100	1010	243	5	1215
0010	1010	243	5	1215
1010	0001	122	5	610
0110	0110	243	5	1215
1110	0011	243	5	1215
0001	1100	243	5	1215
1001	0011	243	5	1215
0101	1100	243	5	1215
1101	0001	122	5	610
0011	1011	365	5	1825
1011	0011	243	5	1215
0111	1110	365	5	1825
1111	1000	122	5	610

Table 4: Current, Voltage, and Power use for Arduino Mega 2560

Both Arduino UNO R3 and Mega show the same current draw, voltage, and Power consumption since both use the same number of components and resistors connected to it and both have same 5V power input via DC Generator. Increasing supplied power increases the current drawn.

9.3 Memory Size and Execution Time Comparison

	Arduino UNO R3		***Arduino Mega 2560***	
	Default C Programming	**Register Level Programming**	**Default C Programming**	**Register Level Programming**
Program Memory Size	2750 bytes	2060 bytes	3474 bytes	2392 bytes
Local Variable Size Left	1832 bytes	1826 bytes	7976 bytes	7970 bytes
Global Variable Size	216 bytes	222 bytes	216 bytes	222 bytes
Program Execution Time	6 milliseconds	12 microsec	6 milliseconds	12 microsec

Table 5: Program memory size, Variable Size and Program Execution Time using Arduino Uno and Mega

The program when used with Arduino UNO R3 uses 2750 bytes in default programming and 2060 bytes in Register Level Programming, out of a maximum of 32256 bytes. Hence uses only 8.52% of memory and 6.38% of memory, respectively. From a maximum of 2048 bytes for variable size, both types of programming use 216 bytes for Global Variables, allocating 1832 bytes for local variables when coded with default coding language, and uses 222 bytes for Global Variables and leaves 1826 for Local Variables when Register Level Programming is used.

When used with Arduino Mega 2560, the default programming takes up 3474 bytes out of 253952 bytes which is only 1.3% of the maximum program memory size. When the program is run with Register Level Programming, it uses 2392 bytes out of 253952, 0.94% of maximum memory. It also uses 222 bytes of variable memory for Global variable out of a maximum of 8192 bytes, leaving 7970 bytes for local variables, for Register Programming, and 216 bytes of Global Variable leaving 7975 for local variables.

Moreover, Program Execution Time for both boards was significantly faster when Register Level Programming is used than when C programming is used. The code executes in 6 milliseconds when run by when default C programming and 12 microseconds when default C programming is used. About 500 times faster. Here program execution time means the time between switch reading to LED lighting output.

10 Conclusion

Comparing results show that using Register Level Programming occupies less memory and has much shorter execution time. Hence, a program coded with Register Level Programming will have a smaller program memory and executes faster than default C programming. This trend is consistent when tried on a second board, i.e., Arduino Mega 2560.

This is because when we code with registers, we directly manipulate the registers, pins, and ports of the microcontroller, this gives better control and optimization of the hardware and allows us to directly access the hardware components. We have more control and access of memory manipulation and can directly use memory addresses in our code. Whereas, using the default IDE programming uses pre-built functions, commands, and built-in libraries that then access the registers, ports, memory addresses. Hence, there is a layer of abstraction that needs to be passed through which increases memory usage and execution time of the code.

The trade-off is that using default C-programming is much easier to code for due to its massive libraries and functions. On the other hand, Register Level Programming is complex and requires good knowledge of the board's specifications being used as well as register and memory manipulation. But the program will be smaller and faster by a wide margin.

Since both boards shows that the program size occupies lesser memory and has faster execution time in Register Level Programming than in default C programming, it can be concluded that the data and results of this project is reliable.

11 Questions and Answers

11.1 Arduino UNO

1. What is the clock frequency of the microcontroller used?

Answer: 16 MHz is the clock frequency of the microcontroller.

2. What is the data bus width of the microcontroller used?

Answer: The data bus width of the microcontroller used is 8 bit.

3. What is the size of your hex file generated?

Answer: For default programming- 8KB, for Register Level Programming- 6KB

4. Can the project be implemented by using interrupt?

Answer: Yes, since Arduino UNO pins support interrupt use. External Interrupt are supported on digital pin 2 and 3 while Pin Change interrupt are supported on any of the 20 pins, A0-A5 and D0-D13.

5. Is the main routine required to be an infinite loop? Provide an explanation in favor of your answer.

Answer: Yes, the main routine is required to be an infinite loop. Since we need to continuously provide input using switches and monitor the output accordingly as well as monitor the execution time continuously, for each input and output. Without an infinite loop, the program would run once and then terminate.

6. Is there any difference between level triggered and edge triggered operation for the given project?

Answer: Since we are using SPDT switch, one terminal connects to ground and the other connects to input pins. There is no difference between level trigger and edge trigger in this project. The toggling switch provides either an ON-1(ON/HIGH) signal or ON-2 (OFF/LOW) signal.

7. Is the project referring to encryption or decryption from input to output?

Answer: The project refers to an encryption circuit from input to output where an encryption algorithm is applied to a given piece of information. Here, input of 4 bits corresponds to a unique 4-bit output, encrypting the original input.

11.2 Arduino Mega 2560

1. What is the clock frequency of the microcontroller used?

Answer: 16 MHz is the clock frequency of the microcontroller.

2. What is the data bus width of the microcontroller used?

Answer: The data bus width of the microcontroller used is 8 bit.

3. What is the size of your hex file generated?

Answer: For default programming- 10KB, for Register Level Programming- 7KB

4. Can the project be implemented by using interrupt?

Answer: Yes, since Arduino Mega 2560 pins support interrupt use. It supports up to 6 external interrupt on digital pin 2,3,18,19,20,21. Like UNO, Pin Change Interrupt can be implemented on all pins.

5. Is the main routine required to be an infinite loop? Provide an explanation in favor of your answer.

Answer: Yes, the main routine is required to be an infinite loop. Since we need to continuously provide input using switches and monitor the output accordingly as well as monitor the execution time continuously, for each input and output. Without an infinite loop, the program would run once and then terminate.

6. Is there any difference between level triggered and edge triggered operation for the given project?

Answer: Since we are using SPDT switch, one terminal connects to ground and the other connects to input pins. There is no difference between level trigger and edge trigger in this project. The toggling switch provides either an ON-1(ON/HIGH) signal or ON-2 (OFF/LOW) signal.

7. Is the project referring to encryption or decryption from input to output?

Answer: The project refers to an encryption circuit from input to output where an encryption algorithm is applied to a given piece of information. Here, input of 4 bits corresponds to a unique 4-bit output, encrypting the original input.

References

1. Materials provided by Dr. Dihan Md. Nuruddin Hassan.
2. Tinkercad + Arduino Lesson 4: Blink an LED (DDR and PORT registers) - YouTube
3. How to Use Serial Monitor in Proteus 8 | Easy | Virtual Terminal - YouTube
4. Arduino register control, timers and interruptions (electronoobs.com)
5. Arduino Uno Vs Nano Vs Mega, Pinout, and technical Specifications (electroniclinic.com)
6. Differentiate between arduino uno and arduino mega - Semiconductor for You (semiconductorforu.com)
7. Arduino Comparison Guide - SparkFun Learn

Resources:

Video demonstration link:
https://drive.google.com/file/d/1sUdUpIl7NXBqEe95HPFNuKMlCz6V3Wx8/view?usp=sharing

Project Resources:

https://drive.google.com/drive/folders/1SYawO___AWZa99ASQvjJ-EGcxW-FM7Hb?usp=sharing