BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY
DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

EEE 416 (July 2023)

Microprocessor and Embedded Systems Laboratory

Final Project Report

Section: C1 Group: 04

Visualizing Datapath for Different Data-Processing Instructions of a Complete Single-Cycle Processor

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Signature of Instructor: ____

Academic Honesty Statement:

IMPORTANT! Please carefully read and sign the Academic Honesty Statement, below. Type the student ID and name, and put your signature. ***You will not receive credit for this project experiment unless this statement is signed in the presence of your lab instructor.***

"In signing this statement, We hereby certify that the work on this project is our own and that we have not copied the work of any other students (past or present), and cited all relevant sources while completing this project. We understand that if we fail to honor this agreement, We will each receive a score of ZERO for this project and be subject to failure of this course."

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1 Abstract

A single-cycle microprocessor, also known as a single-cycle CPU, is a type of processor design where each instruction executes in a single clock cycle. Due to the relationship between the control unit of a single cycle processor and the essential building blocks of the data path, it can occasionally become complex. To make it easily visualizable, our project will represent the microarchitecture and operation of a single cycle processor to tackle this challenge and make it simpler to interpret. The control signals will be shown using LED, and the diagram will show how the single cycle processor works. The whole structure will be compact, and this can be used for educational purposes.

2 Introduction

The single-cycle microarchitecture executes an entire instruction in one cycle. It is the fundamental microarchitecture. Despite Undergraduate students frequently struggle to comprehend and grasp the idea of a microarchitecture and the flow of it. The relationship between the control unit of a single cycle processor and the essential building blocks of the data path can occasionally become complex. So, to address this, in this project, we use two LED matrix and microcontroller ESP 32 development board to visually represent the microarchitecture and operation of a single cycle processor to tackle this challenge and make it simpler to visualize and eventually succeeding as a proper demonstration of this fundamental microarchitecture.

3 Design

3.1 Problem Formulation

Undergraduate students frequently struggle to comprehend and grasp the idea of a microarchitecture and the flow of the whole single-cycle microarchitecture. As there are several control signals and variety of data paths, it gets more complex and confusing at times to properly understand. Only theoretical aspects are not always enough for a better understanding of the overall procedure. To address this, a structure can be made showing the data paths gradually and with that visualization progress proper understanding of the process can be attained. This approach can work better for other learning aspects also.

3.1.1 Identification of Scope

A single-cycle microprocessor is a type of processor design where each instruction is executed in a single clock cycle. The Microprocessor and Embedding System is a core course in many renowned Enginering universities of our country under the Electrical and Electronics Engineering. The course might get very complex but if proper visualization can be ensured, the contents will neither get boring but also the students can eagerly participate in the learning process with enthusiasm. To sum up, there is a big opportunity to make it easy and convenient for the students to effectively understand the single-cycle microarchitecture.

3.1.2 Formulation of Problem

The concept of a microarchitecture and the flow of a single-cycle microarchitecture are sometimes difficult for undergraduate students to understand. It can occasionally become difficult to understand due to the multiple control signals and variety of data channels. Sometimes a deeper comprehension of the entire process requires more than just theoretical knowledge. To solve this, a framework that progressively displays the data pathways can be created, and as the visualization advances, a thorough comprehension of the procedure can be reached.

3.1.2 Circuit Diagram

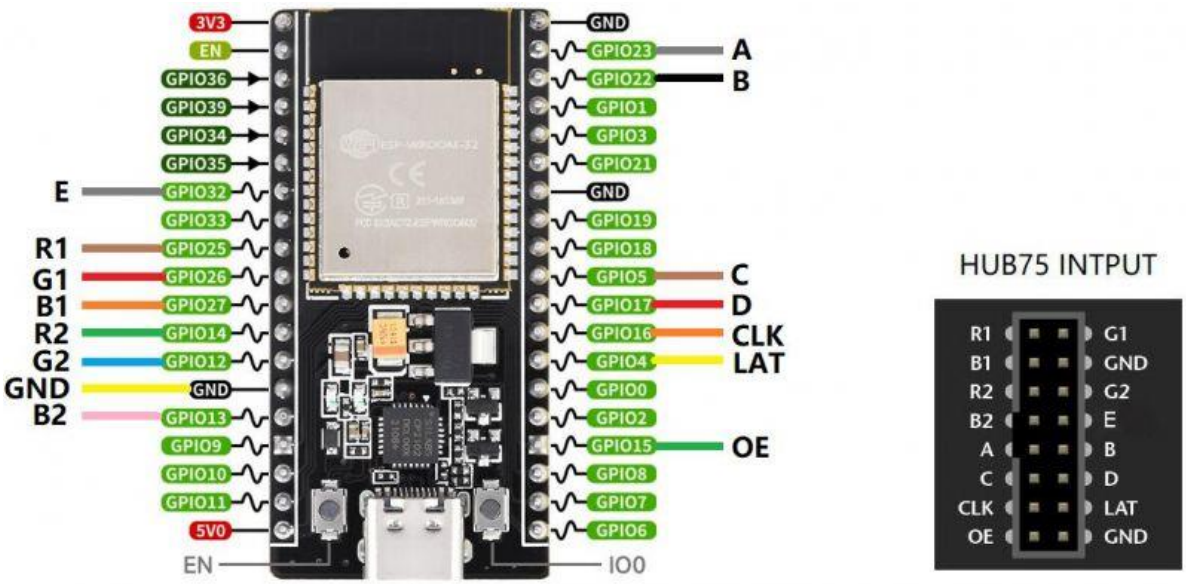


Fig: Interfacing the ESP32 Development board (38 pin) with HUB75 input of the LED display

Fig: Connection of two 64*64 LED display panels

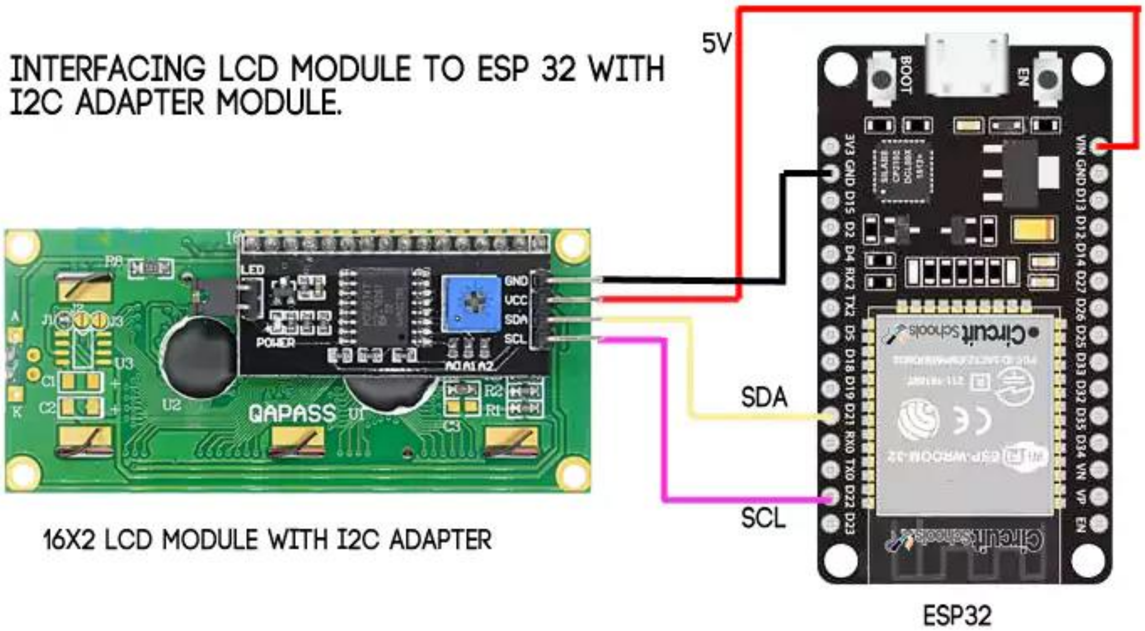


Fig: Interfacing the LCD Module with I2C adapter with the ESP32 Development board (38 pin)

4 Full Implementation

4.1 Description

There are 6 blocks in a single-cycle processor: program counter, instruction memory, register file, extend, arithmetic logic unit and data memory, and a control unit to control the operation of these blocks. The diagram of a single-cycle microprocessor is shown below-

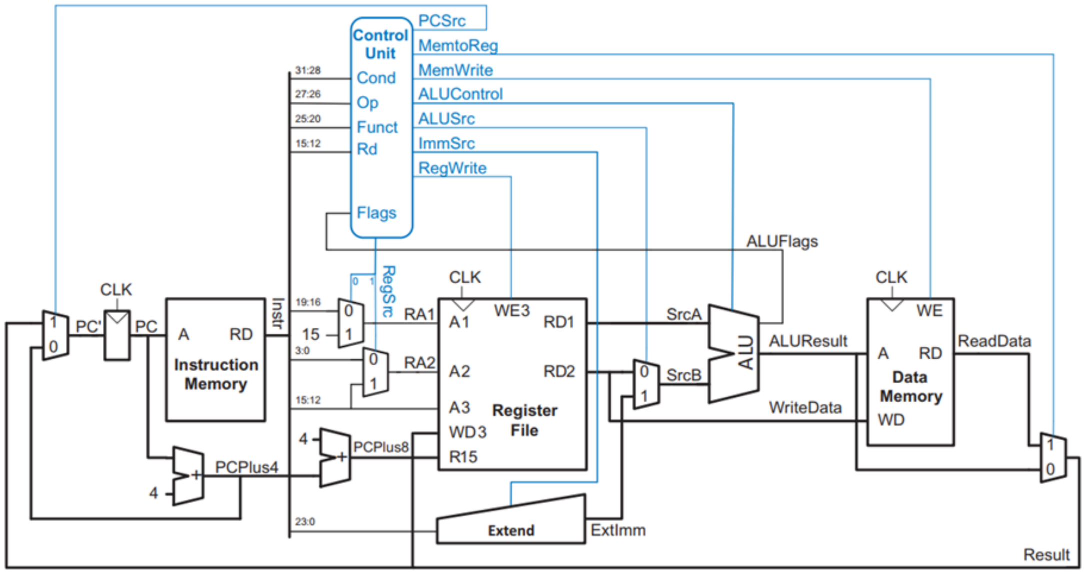


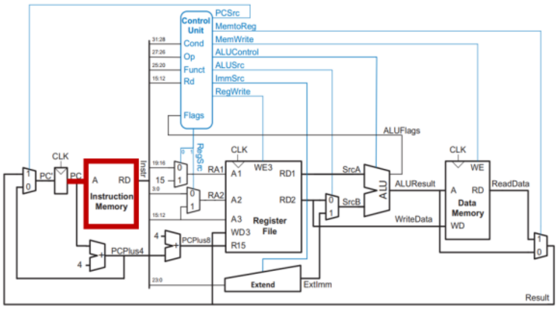
Figure 2: Diagram of a single-cycle processor

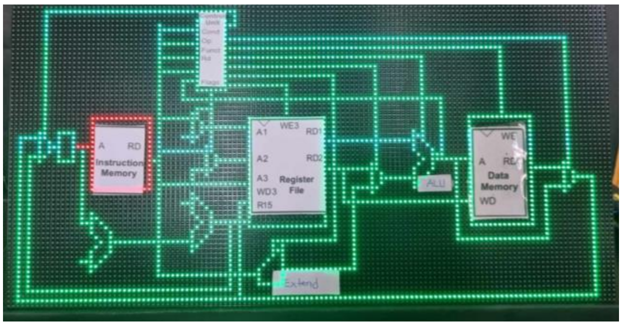
The control signals for different instructions are different from each other, and hence the datapath for instructions are also different. The operation of our circuit is explained for the ADD instruction.

<u>Output in LCD display</u>
The LCD display shows the instruction from the beginning of the cycle.

<u>Output in LED</u>
<u>Step-1</u>

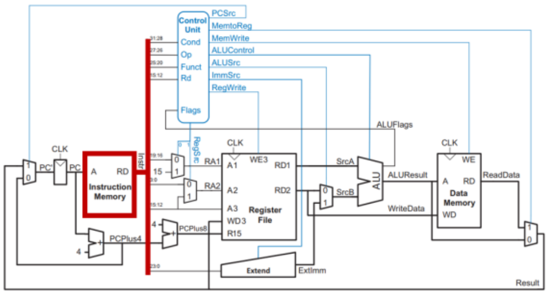
Firstly, the program counter sends a signal to instruction memory indicating which line to execute.

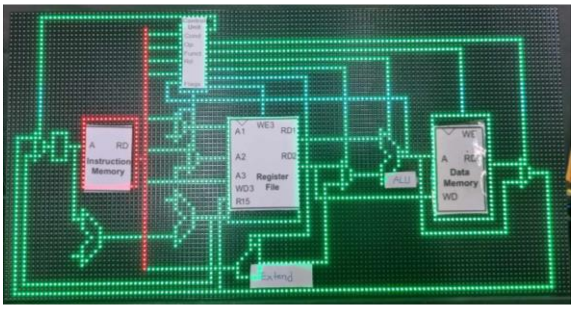




Step-2

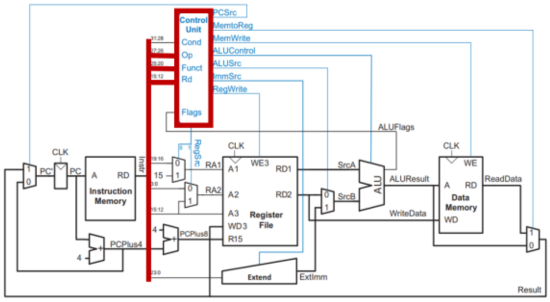
Instruction memory then sends the data to bus.

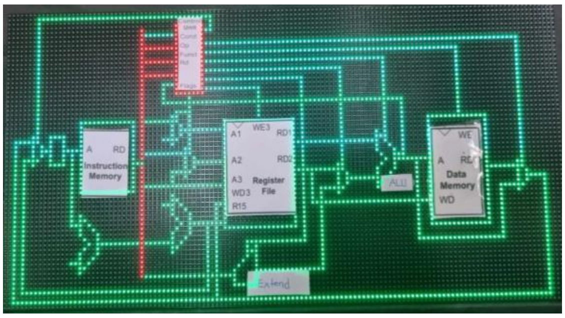




Step-3

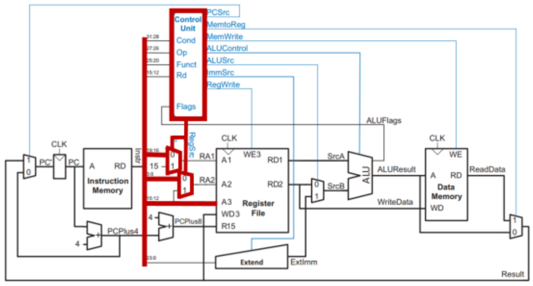
Bus decodes the line to be executed and sends the corresponding Op code, Funct and Rd to the control unit.

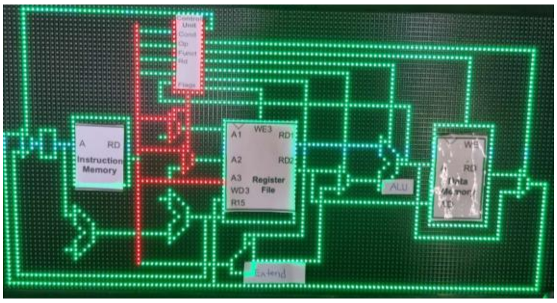




Step-4

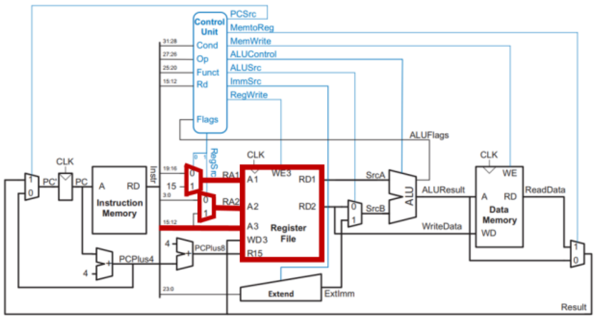
Bus sends the address of source and destination registers to the corresponding multiplexers. Control unit sends selection bits (RegSrc) to multiplexers.





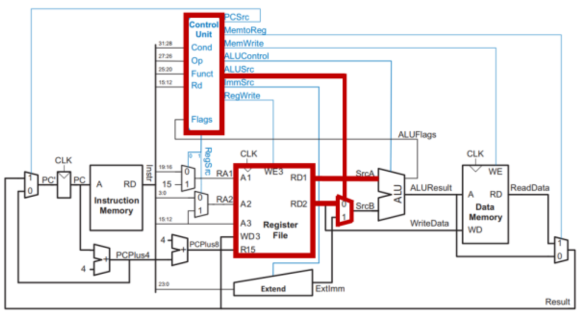
Step-5

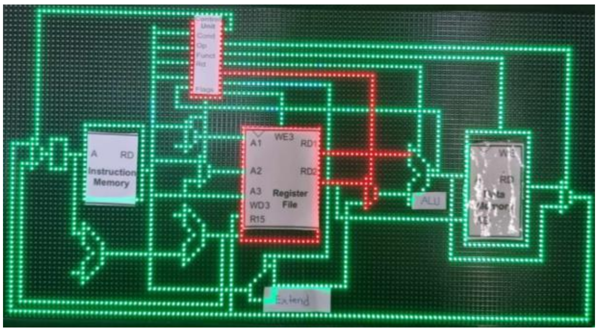
Multiplexers send the address of source registers to register file and register file extracts the value from the registers.



Step-6

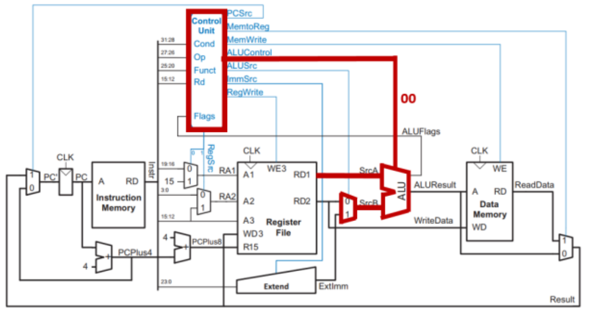
Register file sends the values extracted from the registers to multiplexer before arithmetic logic unit (RD2) and arithmetic logic unit (RD1). To activate the input line from register file, control unit sends signal (ALUSrc) to the multiplexer before arithmetic logic unit.

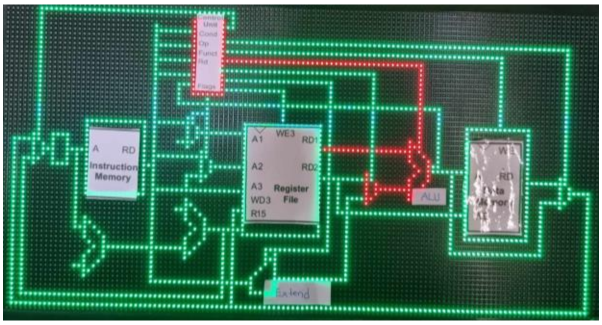




Step-7

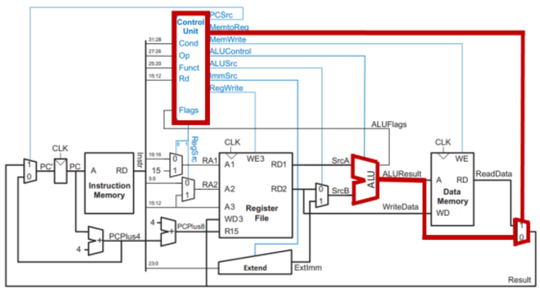
The values to be added are added in arithmetic logic unit in this step. For ADD operation, control unit sends ‘00’ (ALUControl) to arithmetic logic unit

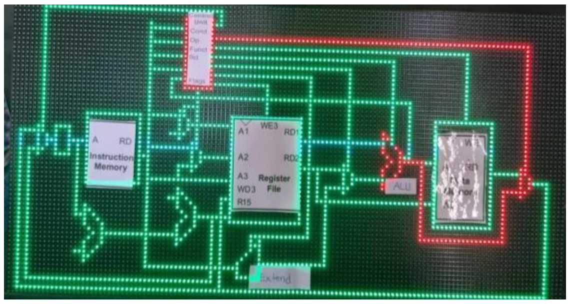




Step-8

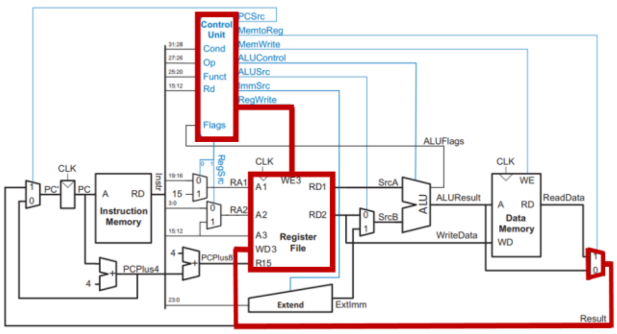
Arithmetic logic unit sends the sum (output of the ALU) to the multiplexer after data memory and control unit sends ‘0’ to multiplexer to select the input coming from arithmetic logic unit.

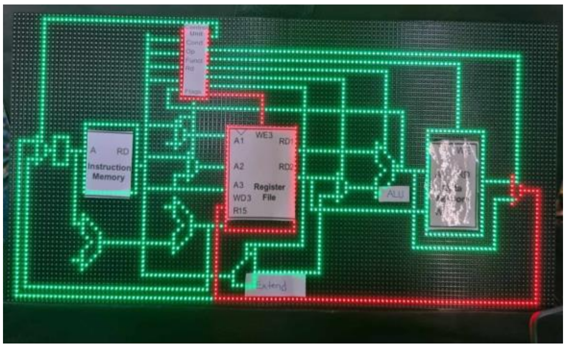




Step-9

Finally, the multiplexer sends the value to register file and control unit sends ‘1’ (RegWrite) to register file to enable writing operation in destination register. Register file stores the sum in the destination register.





5 Design Analysis and Evaluation

5.1 Novelty

Our goal for this project was to design a device that would help undergraduate/college students understand the datapath of a single-cycle processor for different instructions.
Our project is unique. There are no available devices that help us visualize the datapath for a single-cycle processor in the market. We used two 64x64 LED matrix and coded the entire single cycle processor onto it. Then for different instructions such as (ADD, MOV, STR), we implemented our own code to visualize their datapaths. We used existing libraries in Arduino, but the codes we constructed for all the different instructions are unique and are an original contribution.

5.2 Design Considerations (PO(c))

There were a multitude of aspects we had to take into consideration while designing our project. As previously mentioned, there were no such available devices that showcased the datapath for a single-cycle processor. Therefore, we did not have any template to base our project on. We decided to use 2 LED matrix (64x64) to help visualize the datapath. Single-cycle processor consists of many different blocks such as instruction memory, control unit, register file, ALU, MUX, extend, data memory. We provided them distinct shapes so the viewer can easily discriminate between all the different blocks. A LCD display would show the corresponding assembly language instruction corresponding to the datapath shown on the LED matrix.

5.3 Limitations of Tools (PO(e))

Our project showcases the datapath of the single-cycle processor on the LED matrix and the corresponding assembly instruction on the LCD display. We wanted to connect both the LCD display and the LED matrix using only one ESP32. But trying to run both using a singular microcontroller produced erroneous results. Our first assumption was that the disturbance on datapath shown on LED matrix while connecting both lcd and LED was because they both had to share SCL (GPIO 22) of the ESP32. This was later debunked as the LED matrix showed no disturbances while both were connected, if we didn't implement the code to display in the lcd. This problem was left solved and so we decided to use two different microcontrollers (ESP32), one for the LCD and the other for the LED matrix.

5.4 Impact Assessment (PO(f))

The concept of a microarchitecture and the flow of a single-cycle microarchitecture are sometimes difficult for undergraduate students to understand. It can occasionally become difficult to understand due to the multiple control signals and variety of datapaths. Sometimes a deeper comprehension of the entire process requires more than just theoretical knowledge. Our project can easily be put into practice in different universities where they offer the course “Microprocessor and Embedding System”. This project will provide assistance to students learning how the single-cycle processors work when covering this particular topic.

6 Reflection on Individual and Team work (PO(i))

6.1 Individual Contribution of Each Member

The entire workload of the project was evenly distributed between all 4 group members.
We were all involved in the process of formulating the design of our project, adding different components to achieve a robust structure that conveys our main goal of providing a way to visualize datapaths of a single-cycle processor. Everybody was present at the acquisition of the required components and material. The next step was to construct all the blocks and then map them to the LED matrix accordingly. After that we implemented the datapath of different instructions such as MOV, ADD, SUB, STR and simultaneously displayed the corresponding assembly language instruction on the LCD where we took equal responsibility for completing the tasks.

6.2 Mode of TeamWork

Initially our work mode was of a collaborative nature as we all were involved in formulating the design and acquiring different components. Mapping different instructions in the LED matrix required division of labor among us, changing the mode of work into a cooperative one. Then we reverted back to collaborative mode to finish assembling and providing the whole project with a firm hardware structure.

6.3 Log Book of Project Implementation

Date	Milestone achieved	Team Role	Comments
Week 1	Project Group Formed		GO TEAM!
Date	**Milestone achieved**	**Team Role**	**Comments**
Week 6	Project Assigned	Researched multiple fruitful projects.Submitted best 3 projects. Was assigned the current one	Good discussions on projects.
Date	**Milestone achieved**	**Team Role**	**Comments**
Week 7	Finalised Project Structure	Researched hardwares to implement project. Went to extraordinary measures to find compatible hardware.	The markets were fresh out of LED Matrices.
Date	**Milestone achieved**	**Team Role**	**Comments**
Week 8	Assembled Hardware Setup and Finalised Algorithm	Implemented desired hardware setup and ran some codes for the project	LED Matrix and ESP32 Setup proved difficult and frustrating.
Date	**Milestone achieved**	**Team Role**	**Comments**
Week 9	Setup Initial Single Cycle Processor Visualization	The initial visualization was implemented using LED Matrix and ESP32	Team's motivation and efficiency shot up from here.
Date	**Milestone achieved**	**Team Role**	**Comments**
Week 10	Project Update	Briefed course teachers on our setup and plans for implementation. They approved.	Teachers were awesome and helpful.
Date	**Milestone achieved**	**Team Role**	**Comments**
Week 11	Implemented Visualization for Different Operations	Studied and implemented visualization for LDR,STR operation.	Team worked efficiently.
Date	**Milestone achieved**	**Team Role**	**Comments**
Week 12	Implemented Visualization for Different Operations	Studied and implemented visualization for BRANCH, MOV, ADD, SUB operation.	Team had to work under presure due to labtests and CTs.
Date	**Milestone achieved**	**Team Role**	**Comments**
Week 13	Implemented ASSEMBLY Display and Ran Final Tests	Setup hardware and implemented code to display corresponding ASSEMBLY commands on the LCD.	Team had to work under presure due to labtquiz and CTs.
Date	**Milestone achieved**	**Team Role**	**Comments**
Week 14	Project Submission	Project submitted successfully.	Yay!

7 Communication to External Stakeholders (PO(j))

7.1 Executive Summary

A microprocessor is an electronic device that executes the tasks of the central processing unit in a computer. There are different architectures of processors. A single-cycle microprocessor is a type of processor design where each instruction is fetched, decoded, executed, and the result stored all within a single clock cycle. There are several blocks in processor architecture. To execute an instruction, the use of every block is not required. Datapath of an instruction refers to the path that a processor follows to execute that specific instruction. The datapath of every instruction is different from others. In this project, we visualized the datapath of different instructions of a single-cycle microprocessor in LED matrix panel. The goal of this project is to achieve better understanding of the microarchitecture and instruction cycles of single-cycle microprocessors. This project can also be used in future for teaching purposes.

7.2 User Manual

Two LED matrix panels are used to visualize the instruction cycle of single-cycle microprocessor and an LCD display shows the corresponding instruction in assembly language. These two outputs are controlled by a microcontroller (ESP-32 dev board). A switched mode power supply (SMPS) is used for the supply of the LED matrix panels. No external user input is required to visualize the processor datapaths. The LED matrix panel shows the instruction cycles of the processor on loop and the corresponding assembly code appears in the LCD display.

8 Project Management and Cost Analysis (PO(k))

*This section is mandatory to write if the course outcomes address PO(k) Read the PO Statement in the website first, before writing this section (*Program Outcomes and Program Educational Objectives | Department of EEE, BUET*) . If not needed, remove this entire section. If needed, DO NOT Change the title of this section.*

8.1 Bill of Materials

Components	**Cost (Tk. Per unit)**
ESP 32 Dev board (38 pin)	800
LED panel	2000
Switched mode power supply	900
LCD display	460
Structure and miscellaneous overhead	1500

8.2 Calculation of Per Unit Cost of Prototype

Components	Quantity	Cost (Tk. Per unit)	Cost (Total)
ESP 32 Dev Board	1	800	800
LED Matrix Panel	2	2000	4000
Switched Mode Power Supply	1	900	900
LCD display	1	460	460

Structure and Miscellaneous Overhead	-	1500	1500
Total Cost			**7560**
Cost Per Member			1890

8.3 Timeline of Project Implementation

Timeline	Progress
Week 6	Project Assigned
Week 7	Finalized Project Structure
Week 8	Assembled hardware setup and finalized algorithm
Week 9	Setup initial single cycle processor visualization
Week 10	Developed a few instructions for visualization
Week 11	Implemented visualization for different operations
Week 12	Implemented assembly display and ran final tests

9 Future Work

The biggest drawback of our project is the use of two ESP32, one for the LED screen and another for the LCD one. There are a few instructions that our project is missing, and we are only capable of showing our code in an infinite loop. Further work is required to create a user interface so we can only view the instruction we want to.

10 References

- https://www.circuitschools.com/interfacing-16x2-lcd-module-with-esp32-with-and-without-i2c/?fbclid=IwAR1SXnwuzfOeIbRRPZtAe69jwHGajmTidegC9nIqLZVURAm2q96QmY9ItZo

- https://www.waveshare.com/wiki/RGB-Matrix-P3-64x64?fbclid=IwAR3mHo6NqsroI69KENnQi5vh-3ygSMBO6GQOB44v6gsuyPR48IqPVVLyy40