BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

EEE 304 (January 2023)

Digital Electronics Laboratory

Final Project Report

Section: C2 Group: 03

SmartServe: Designing an Intelligent and Interactive Vending Machine System

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"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

Vending machines are ubiquitous in our society, providing us with a convenient way to purchase a variety of goods. The goal of this project is to design an intelligent and interactive vending machine system. The system is implemented using a finite-state machine (FSM) on a field-programmable gate array (FPGA). The FSM controls the operation of the vending machine, including accepting coins, dispensing items, and providing feedback to the user. The system has been successfully implemented and tested. It can dispense a variety of items, accept coins of different denominations, and provide feedback to the user in the form of lights. The results of this project demonstrate the feasibility of designing an interactive vending machine system using a FSM on an FPGA.

2 Introduction

Public places including airports, railway and bus stations, school and other educational institutions, commercial places, such as office buildings, hospitals, and shopping malls, often have a diverse population with varying preferences and dietary needs. Operating a traditional store or cafeteria within the above mentioned places can have some limitations such as:

1. High Labor and Maintenance Cost
2. Limited Operating Hours
3. Lack of Convenience and Speed
4. Higher Risk of Theft or Vandalism
5. Higher Inventory Space

Automated self-service machines or Vending machines that can dispense various products, typically snacks, beverages, or other small items can be a solution corresponding to the issue stated. **The basic goal of this project is to design the control unit of a classic Vending Machine with a synchronous sequential circuit (FSM).** Designing a finite state machine (FSM) for a vending machine on an FPGA is a hard engineering problem because of the following reasons:

- The vending machine needs to be able to handle a variety of inputs, such as coins of different denominations, button presses, and sensor readings. This can make the FSM state diagram complex and difficult to manage.
- The vending machine needs to be able to operate in real time, so the FSM must be implemented efficiently in hardware. This can be challenging, especially if the vending machine needs to handle a large number of states.
- The vending machine needs to be reliable and fault-tolerant. This means that the FSM must be designed in a way that can handle unexpected input conditions and hardware failures.

Some other possible solutions to the problem of operating a traditional store or cafeteria in public places:

1. **Automated micro markets:** These are small, self-service convenience stores that are equipped with self-checkout machines. They offer a wider variety of products than vending machines, and they can be restocked and maintained remotely.
2. **Kiosks:** These are small, stand-alone units that offer a limited selection of products and services. They can be used to sell food, drinks, snacks, tickets, or other items.

It is important to note that none of these solutions are without their own limitations. Automated micro markets can be expensive to install and maintain, and kiosks can be vandalized or stolen.

3 Design

3.1 Problem Formulation

3.1.1 Identification of Scope

The scopes of out project includes the following:

1. **Designing the state machine:** The state machine will be responsible for controlling the operation of the vending machine. It will need to be able to handle a variety of inputs, such as coin insertion and button presses. It will also need to be able to output a variety of signals, such as display the system states or the illumination of a lights.
2. **Implementing the state machine:** The state machine can be implemented in a variety of ways, such as using hardware logic, software, or a combination of the two. We chose to implement the FSM in Verilog and deploy it in a FPGA.
3. **Testing the state machine:** The state machine must be tested to ensure that it is working correctly. This can be done using a variety of methods, such as simulation or physical testing.

3.1.2 Literature Review

Recent works on vending machines have focused more on the user interface side than on engineering the hardware. **"Smart vending machines in the era of internet of things"** by Solano et al. (2017) introduces a new approach for mobile proximity payment for unattended point of sales. The basic idea is to have a digital representation of a vending machine on the Internet and be able to order products from a smartphone in a fully contactless way, i.e. without interacting with the vending machine. **"IOT Based Smart Vending Machine for Bangladesh"** by Alam et al. (2019) puts forward the design a IoT enabled service of a vending machine which will be operated through a mobile application and bKash (digital payment system of Bangladesh) with the incorporation of cloud computing which aims to be cost effective and less time consuming and yet user friendly.

3.1.3 Formulation of Problem

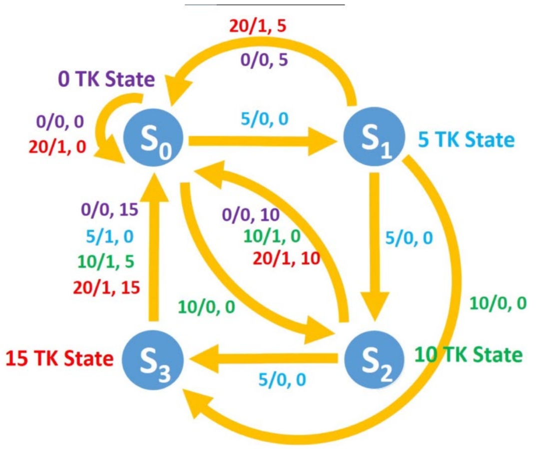
The following are some of the specific problems that need to be solved in order to design and implement the FSM:

1. What are the different states that the vending machine can be in?
2. What are the inputs and outputs for each state?
3. How can the state transition table be designed?
4. How can the FSM be implemented in Verilog?
5. How can the FSM be deployed in a FPGA?
6. How can the FSM be tested?

3.2 Design Method

3.2.1 Method 1: Using Mealy

State Diagram for 20 TK:



State Diagram for 20TK

State Table and equations for 20 TK:

Truth Table

Present State	New State				Output							
	Y1Y2				z				c1c2			
y1y2	(w1w2)				(w1w2)				(w1w2)			
	00	01	10	11	00	01	10	11	00	01	10	11
00	00	01	10	00	0	0	0	1	00	00	00	00
01	01	10	11	00	0	0	0	1	00	00	00	01
10	10	11	00	00	0	0	1	1	00	00	00	10
11	11	00	00	00	0	1	1	1	00	00	01	11

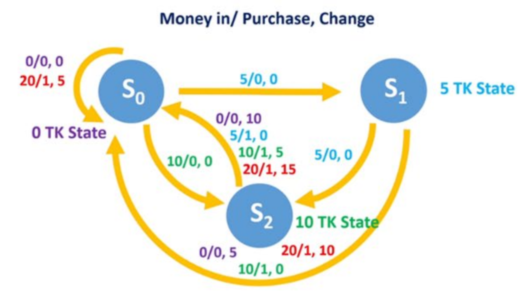
	00	01	11	10
00	0	0	0	1
01	0	1	0	1
11	1	0	0	0
10	1	1	0	0

	00	01	11	10
00	0	1	0	0
01	1	0	0	1
11	1	0	0	0
10	0	1	0	0

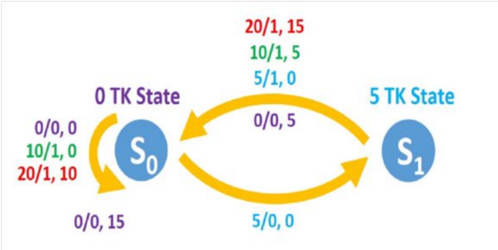
Fig: K-map for Y1 and Y2

$$Y_1 = \bar{y}_1 w_1 \bar{w}_2 + \bar{y}_1 y_2 \bar{w}_1 w_2 + y_1 \bar{y}_2 \bar{w}_1 + y_1 \bar{w}_1 \bar{w}_2$$
$$Y_2 = \bar{y}_2 \bar{w}_1 w_2 + \bar{y}_1 y_2 \bar{w}_2 + y_2 \bar{w}_1 \bar{w}_2$$

State Table for 15 and 10 TK:



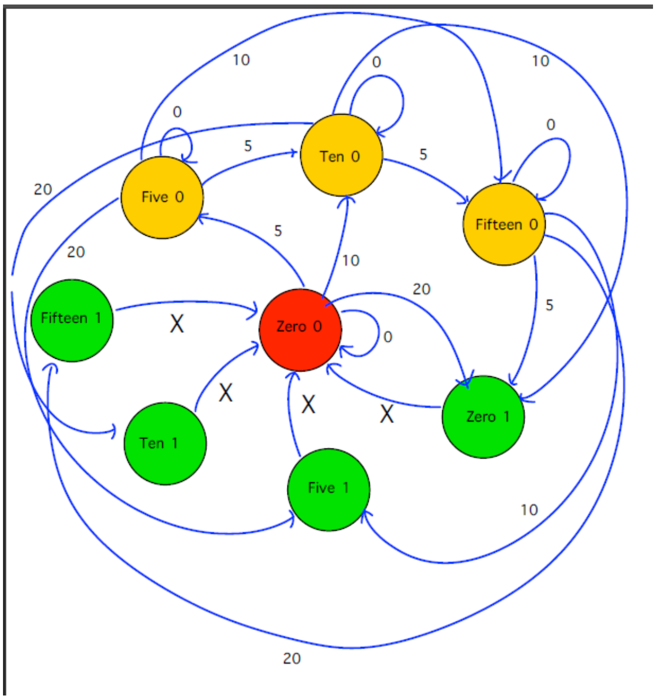
State Diagram for 15 taka



State Diagram for 10TK

3.2.2 Method 2: Using Moore

State Diagram for 20 TK:



State Table for 20 TK:

	Taka Input			
Present state	0	5	10	20
000	000	001	010	011
001	001	010	011	101
010	010	011	101	110
011	011	100	110	111
1xx	000			

State Diagram for 15 TK:

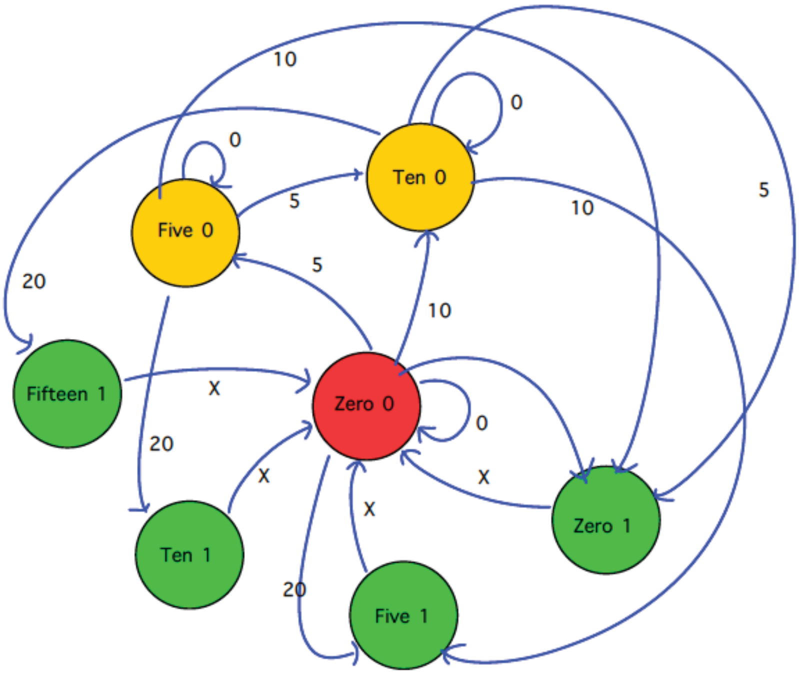
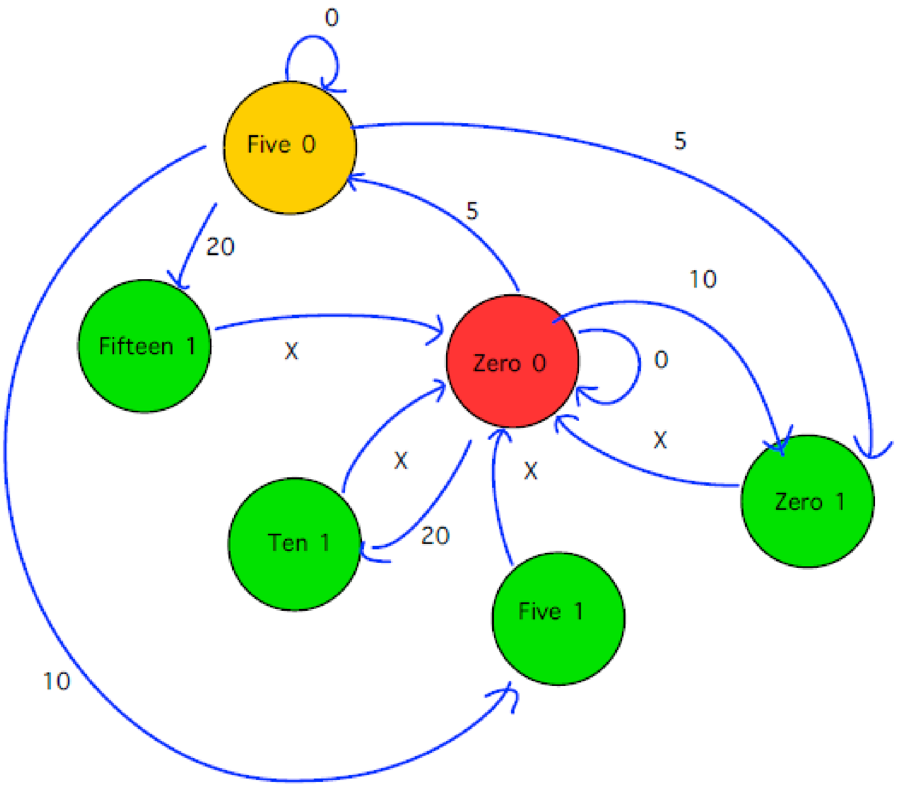


Fig: FSM State Diagram fot Tk. 15 items

State Table for 15 TK:

	Taka Input			
Present state	0	5	10	20
000	000	001	010	101
001	001	010	100	110
010	010	100	101	111
011	-	-	-	-
1xx	000			

State Diagram for 10 TK:



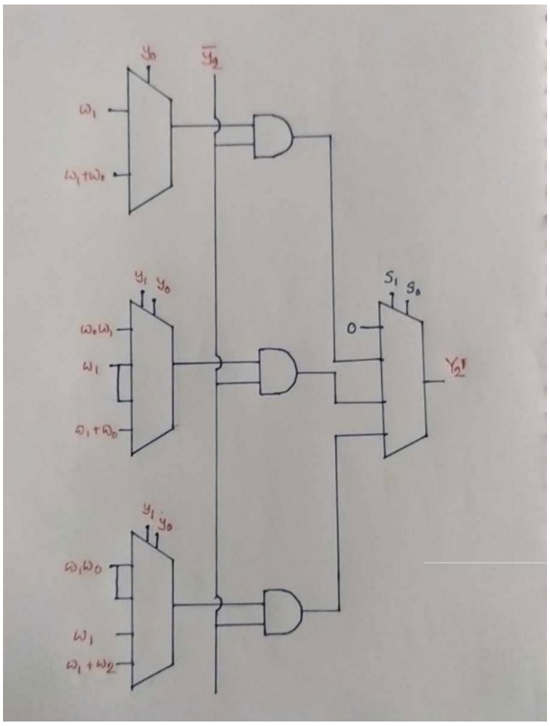
State Table for 10 TK:

	Taka Input			
Present state	0	5	10	20
000	000	001	100	110
001	001	100	101	111
010	-	-	-	-
011	-	-	-	-
1xx	000			

State Table for Overall Output/ Cash reserve/ Cash Return:

States	output	cash_reserve	cash _return
000	0	0	0
001	0	5	0
010	0	10	0
011	0	15	0
100	1	0	0
101	1	0	5
110	1	0	10
111	1	0	15

Overall Circuit:



$$
\begin{aligned}
Y_2 = \bar{y_2} \cdot [\bar{s_1} s_0 \cdot (y_0 w_1 + y_0 w_0 + \bar{y_0} w_1) \\
+ s_1 \bar{s_0} \cdot (\bar{y_1} \bar{y_0} w_0 w_1 + (y_1 \hat{} y_0) w_1 + y_1 y_0 w_1 + y_1 y_0 w_2) \\
+ s_1 s_0 \cdot (\bar{y_1} w_1 w_0 + y_1 \bar{y_0} w_1 + y_1 \bar{y_0} w_1 + y_1 y_0 w_1 + y_1 y_0 w_0)]
\end{aligned}
$$

3.2.3 Choosing Moore Over Mealy

- As in Mealy machine output depends on present output, while changing the selection of product a garbage value is shown in posedge clock.
- In comparison, in Moore machine output does not depend on present input, hence no disturbance is seen.

3.3 Circuit Diagram

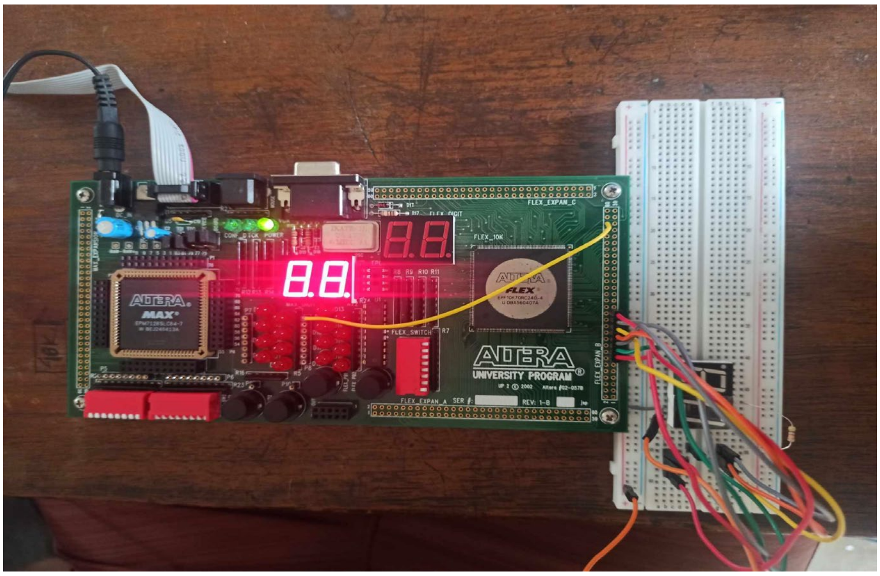
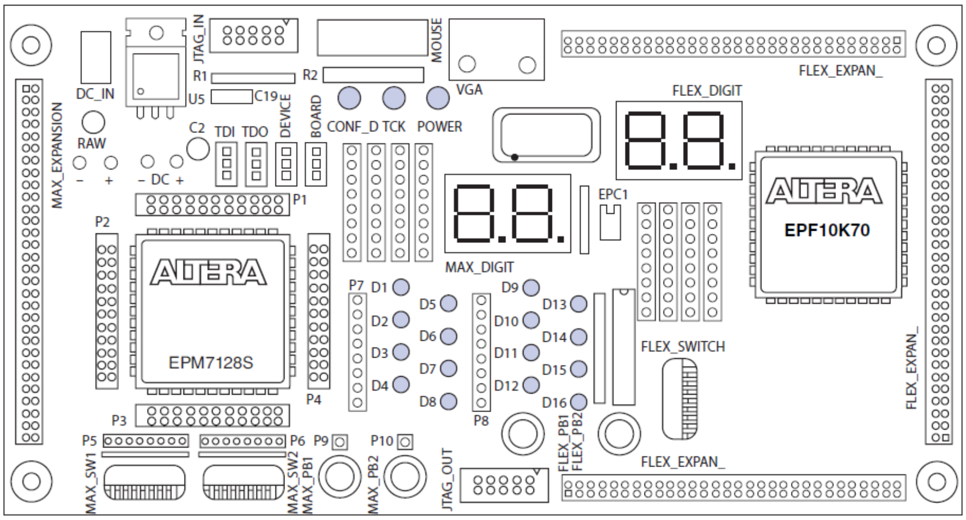
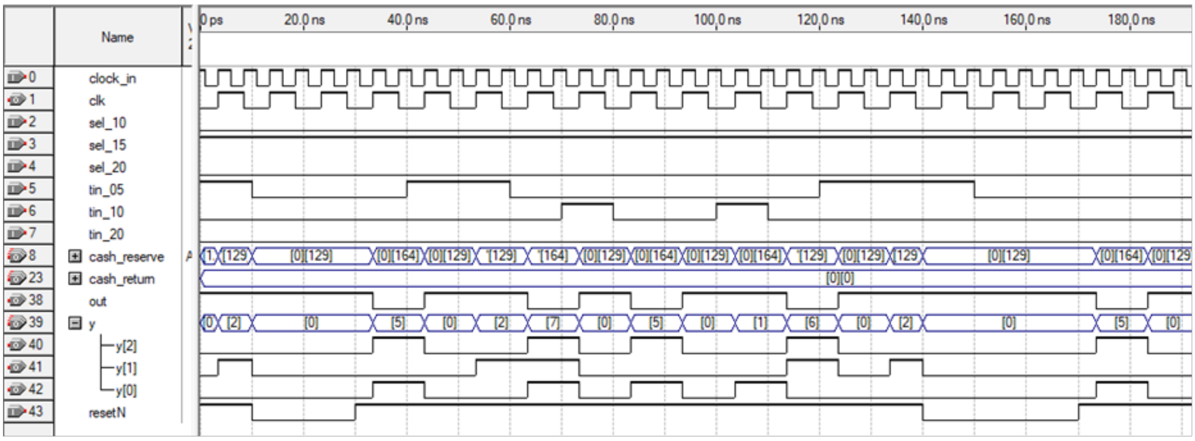


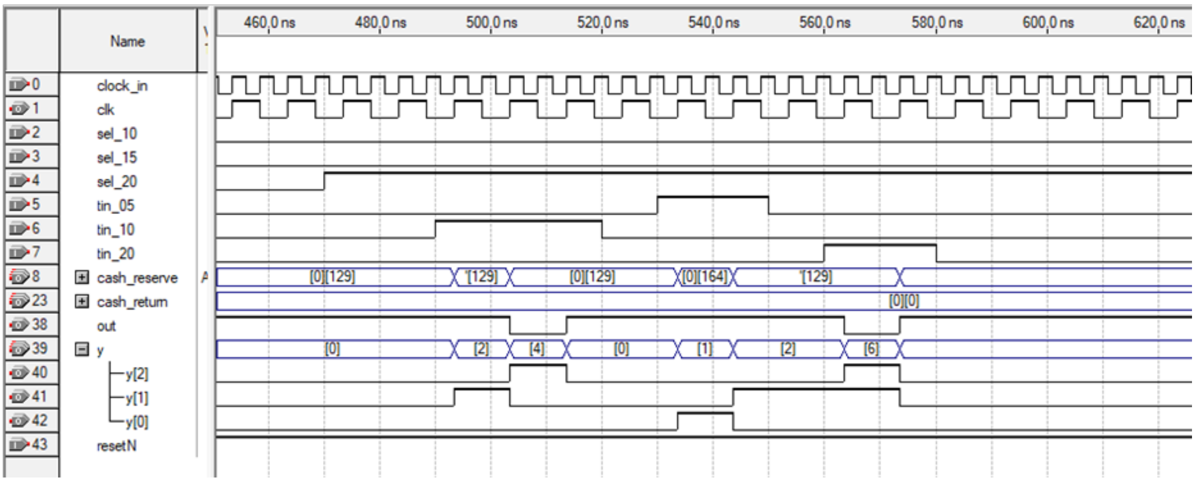
Figure 1. UP2 Education Board Block Diagram



3.4 Simulation Model

Verilog Vector Waveform:





3.5 Full Source Code of Firmware

```
module vending(clock_in, clk, y, sel_10, sel_15, sel_20, tin_05, tin_10, tin_20,
out, cash_return, cash_reserve);

input clock_in; // input clock on FPGA
input sel_10, sel_15, sel_20;       // Product Price Selector
input tin_05, tin_10, tin_20;       // Input money

output reg clk; // output clock after dividing the input clock by divisor
reg[27:0] counter=28'd0;
parameter DIVISOR = 28'd100000000; // change value here
//parameter DIVISOR = 28'd2; // change value here

// The frequency of the output clk_out
always @(posedge clock_in)
begin
 counter <= counter + 28'd1;
 if(counter>=(DIVISOR-1))
    counter <= 28'd0;
 clk <= (counter<DIVISOR/2)?1'b1:1'b0;
end

output reg [2:0] y;
output out;
output [13:0]cash_reserve, cash_return;
wire [1:0] w;
reg [2:0] Yn;

// PARAMETERS for states
parameter [2:0] zero_0 = 3'b000,
                five_0 = 3'b001,
                ten_0 = 3'b010,
                fifteen_0 = 3'b011,
                zero_1 = 3'b100,
                five_1 = 3'b101,
                ten_1 = 3'b110,
                fifteen_1 = 3'b111;

// PARAMETERS for output 7 segment Displays
parameter [6:0] zero = 7'b0000001,
                one = 7'b1001111,
```

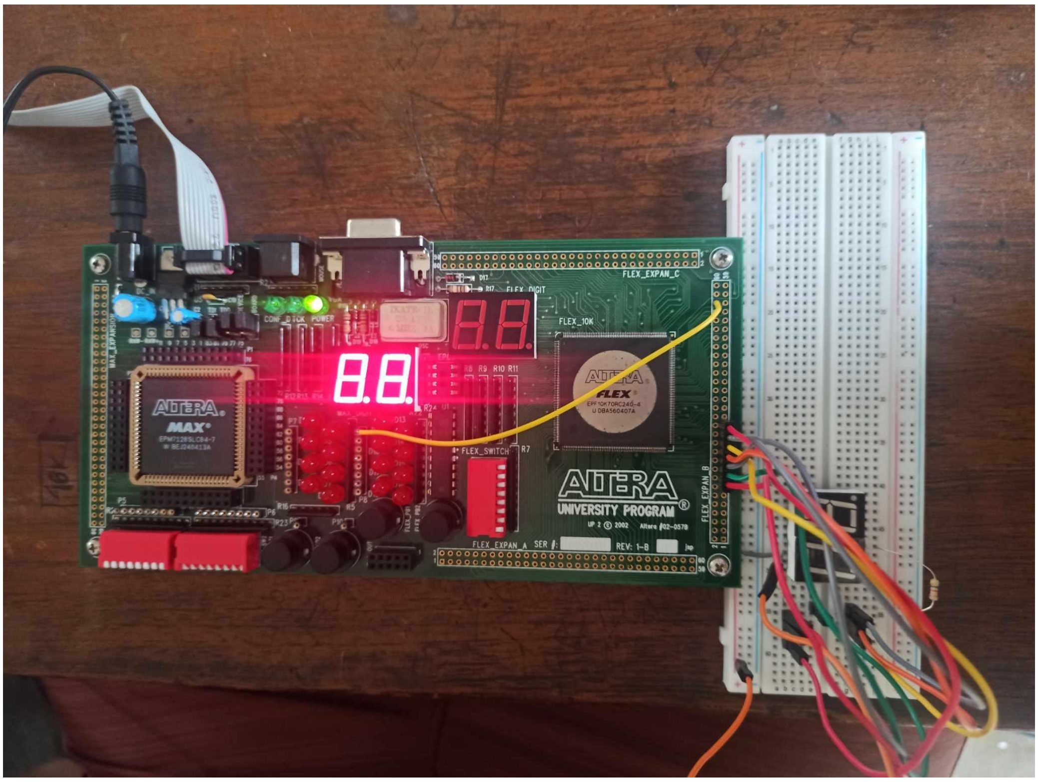
```
                two = 7'b0010010,
                three = 7'b0000110,
                four = 7'b1001100,
                five = 7'b0100100,
                six = 7'b0100000,
                seven = 7'b0001111,
                eight = 7'b0000000,
                nine = 7'b0000100;

// Encoding Input Amounts
assign w[1] = ~tin_10;
assign w[0] = ~tin_05;

always @(w,y, sel_10, sel_15, sel_20)
begin
    // For 20 Taka Product
    if(sel_20)
    begin
        case(y)
        zero_0:
            if(w==2'b00)   Yn = zero_0;            // 0 taka input
            else if (w==2'b01) Yn = five_0;         // 5 taka niput
            else if (w==2'b10)  Yn = ten_0;        // 10 taka input
            else    Yn = zero_1;                   // 20 taka input

        five_0:
            if(w==2'b00)   Yn = five_0;            // 0 taka input
            else if (w==2'b01) Yn = ten_0;         // 5 taka niput
            else if (w==2'b10)  Yn = fifteen_0;       // 10 taka input
            else    Yn = five_1;                   // 20 taka input

        ten_0:
            if(w==2'b00)   Yn = ten_0;            // 0 taka input
            else if (w==2'b01) Yn = fifteen_0;          // 5 taka niput
            else if (w==2'b10)  Yn = zero_1;       // 10 taka input
            else    Yn = ten_1;                   // 20 taka input

        fifteen_0:
            if(w==2'b00)   Yn = fifteen_0;            // 0 taka input
            else if (w==2'b01) Yn = zero_1;         // 5 taka niput
            else if (w==2'b10)  Yn = five_1;       // 10 taka input
            else    Yn = fifteen_1;                 // 20 taka input
```

```
        default: Yn = zero_0;

        endcase
    end

    // For 15 Taka Product
    else if (sel_15)
    begin
        case (y)
        zero_0:
            if(w==2'b00)    Yn = zero_0;              // 0 taka input
            else if (w==2'b01) Yn = five_0;            // 5 taka niput
            else if (w==2'b10)  Yn = ten_0;          // 10 taka input
            else    Yn = five_1;                     // 20 taka input

        five_0:
            if(w==2'b00)    Yn = five_0;              // 0 taka input
            else if (w==2'b01) Yn = ten_0;            // 5 taka niput
            else if (w==2'b10)  Yn = zero_1;          // 10 taka input
            else    Yn = ten_1;                      // 20 taka input

        ten_0:
            if(w==2'b00)    Yn = ten_0;              // 0 taka input
            else if (w==2'b01) Yn = zero_1;            // 5 taka niput
            else if (w==2'b10)  Yn = five_1;          // 10 taka input
            else    Yn = fifteen_1;                    // 20 taka input

        default: Yn = zero_0;

        endcase
    end

    // For 10 Taka Product
    else if (sel_10)
    begin
        case (y)
        zero_0:
            if(w==2'b00)    Yn = zero_0;              // 0 taka input
            else if (w==2'b01) Yn = five_0;            // 5 taka niput
            else if (w==2'b10)  Yn = zero_1;          // 10 taka input
            else    Yn = ten_1;                      // 20 taka input
```

```
        five_0:
            if(w==2'b00)   Yn = five_0;            // 0 taka input
            else if (w==2'b01) Yn = zero_1;         // 5 taka niput
            else if (w==2'b10)  Yn = five_1;       // 10 taka input
            else     Yn = fifteen_1;                 // 20 taka input

        default: Yn = zero_0;

        endcase
    end

    // If No Product Is Selected
    else
    Yn = zero_0;

end

// Sequential Block
always @(posedge clk)
        y <= Yn;


// Output
// Output
assign out = ~ y[2];
// assign cash_return[13:7] = y[2]?  (y[1]? one:zero): zero;
// assign cash_return[6:0] = y[2]? (y[0]? five:zero): zero;

// assign cash_reserve[13:7] = (~ y[2])? (y[1]? one:zero): zero;
// assign cash_reserve[6:0] = (~ y[2])? (y[0]? five:zero): zero;


assign cash_reserve[13:7] = (y[1]? one:zero);
assign cash_reserve[6:0] = (y[0]? five:zero);

endmodule
```

4 Implementation

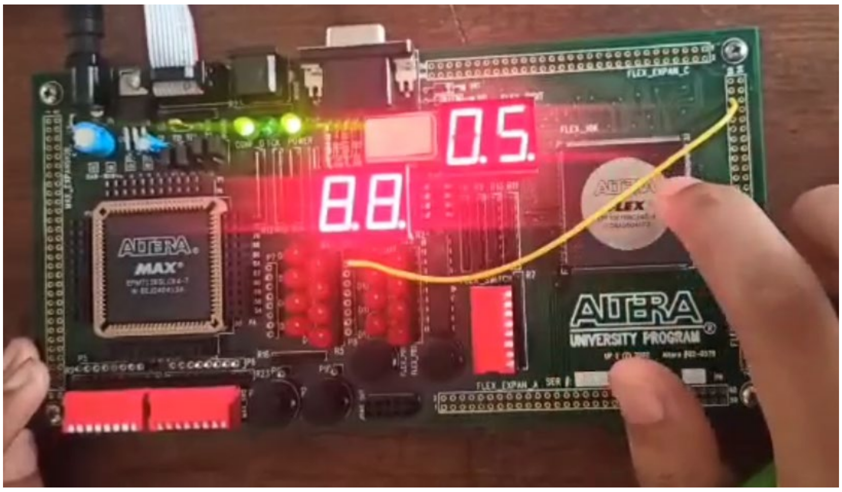
4.1 Description



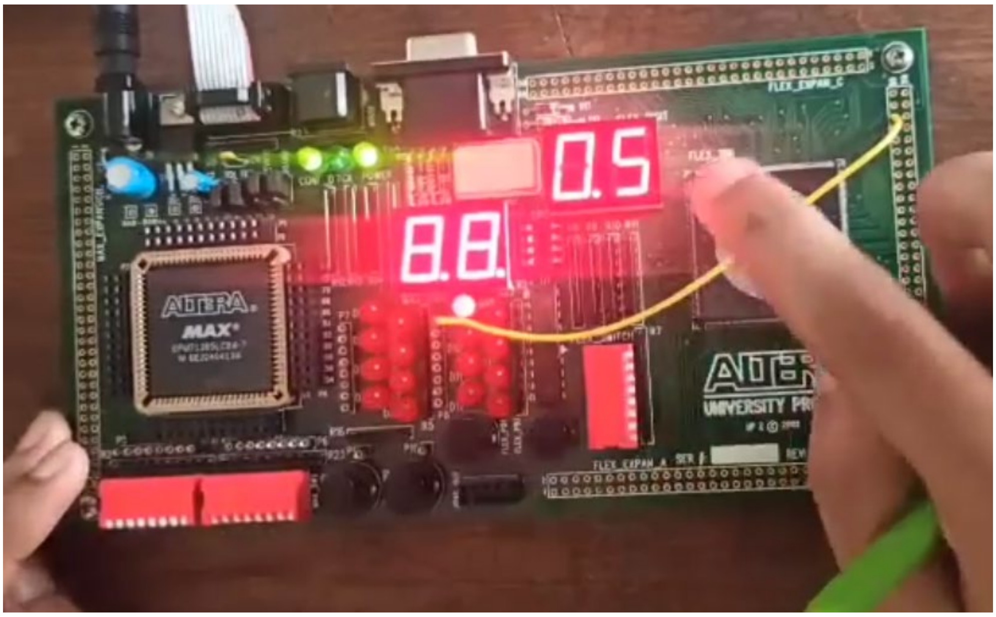
Here we incorporated 3 Flex Switches to associate product value and FLEX PB1, FLEX PB2 to provide input. An led (D13) was used to show the output and 2 7 segment displays were used to show cash reserve/ cash back amount.

4.2 Experiment and Data Collection

Providing 5 TK input:



Providing 5+10+10 TK:



4.3 Result Analysis

From the above figures, we can see that, when selection of product is 20 TK and input is not exceeding 20 TK, the D13 led light is off and display shows current reserve. As soon as, overall input exceeds 20 TK, the led turns on and the displays show cash to be returned.

5 Design Analysis and Evaluation

5.1 Design Considerations

5.1.1 Considerations to public health and safety

Safe operation:

This Vending machine control circuit does not contain any hazardous power source or any component that has to be disposed carefully. Also the circuit operates on low voltage hence the whole design assures safety.

5.1.2 Considerations to environment

Energy Efficient:

This vending machine runs on a rechargeable battery. Battery can be charged through Solar Power during day and can operate 24/7. As this uses renewable energy, it is environment friendly.

5.1.3 Considerations to cultural and societal needs

Regional Preferences:

Selection of products are based on regional tastes and preferences. People from different regions have their own unique style of taste and cooking techniques. Keeping that in mind we select our snacks and beverages.

Cultural Preference:

Food taste also changes with change of culture. Food from one place may be culturally inappropriate for another group of people.We have to make sure foods are culturally appropriate.

5.2 Impact Assessment

5.2.1 Assessment of Societal and Cultural Issues

Social responsibility: Demonstrating social responsibility by sourcing products from ethical suppliers, supporting fair labor practices. Foods supply are taken in after strict monitoring and following all the labor act and consumer laws.

5.2.2 Assessment of Health and Safety Issues

Food Security: In regions with limited access to affordable, nutritious food, vending machines can serve as valuable resources. Area where people are busy with their work like corporate areas don't have enough time to pick nutritious food. For them vending machine can be a quick solution and way to go stationery shop.

5.2.3 Assessment of Legal Issues

Consumer Protection Law & Taxation: We maintain all the consumer protection laws and tax payment as per the running acts. We keep all our transactions clear and make a public report at the end of every 6 month which is accessible to all.

5.3 Sustainability and Environmental Impact Evaluation

Evaluation of Sustainability:

All the materials of the vending machine are sustainable. As it uses the best parts and components from tech giants like INTEL.

Evaluation of Impact of Design in Societal Context:

As the vending machine is designed for all age groups and people with special needs this plays an exemplary role in society.

Evaluation of Impact of Design in Environmental Context:

This vending machine is designed as environment friendly. It draws power from a rechargeable battery which is charged from Solar Power.

5.4 Ethical Issues

1. **Price Manipulation:**
   Issue: Some vending machines can have price markups, taking advantage of customers.
   Mitigation: Implement transparent pricing policies and ensure prices are clearly displayed on the machine.

2. **Data Privacy:**
   Issue: Vending machines that collect customer data may raise privacy concerns.
   Mitigation: Clearly communicate data collection practices, obtain consent, and anonymize collected data to protect customer privacy.

3. **Supply Chain Ethics**:
   Issue: Ethical concerns can arise in the sourcing and production of vending machine products.
   Mitigation: Encourage vendors to adopt ethical sourcing practices and prioritize products from responsible suppliers.

6 Reflection on Individual and Team work

6.1 Individual Contribution of Each Member

Student ID	Contribution
1906177	Implementation of the code in FPGA
1906178	Designing the Moore and Mealy FSM
1906191	Designing State Table and Expressions using Kmap
1906195	Implementing the code

6.2 Mode of TeamWork

Our project team consists of four dedicated individuals who not only work diligently but also know how to create a vibrant and enjoyable work environment. Our working procedure is a harmonious blend of productivity and camaraderie.

We start our workdays with a brief team huddle, setting clear goals and priorities. As we dive into our tasks, we maintain open lines of communication, supporting each other's progress and sharing insights. Collaboration is at the core of our approach, and we often brainstorm ideas collectively, leveraging the diverse perspectives of our team members.

6.3 Diversity Statement of Team

Our team is a diversified team. We came from different cultural backgrounds. In our team one of our members is from Ethnic group CHAK. Others came from different areas of the country. So we have a cultural mixup in our team.

6.4 Log Book of Project Implementation

Date	Milestone Achieved	Individual Role	Team Role	Comment
July 7	Implementation of Mealy Machine	1906178- Design of FSM and Verilog 1906177 – Deriving Equations using Kmap 1906191- Calculation of No, of IC'c Needed		
August 8	Design of Moore Machine	1906195 – Design of State Diagram and State Table		
August 27	Collecting FPGA	1906177, 1906195 – Using the FPGA To upload a random code and checkin the i/o pins of the board		
September 7	Finalizing the project	Everyone		

7 Communication

7.1 Executive Summary

Innovative Vending Machine Project Redefines Convenience

We are excited to introduce our groundbreaking Vending Machine project, set to revolutionize convenience for all. Our state-of-the-art vending machine combines cutting-edge technology with user-centric design.

This vending machine offers an array of products, from snacks to beverages, in an intuitive and efficient manner. Equipped with contactless payment options, real-time inventory monitoring, and sustainability features, it delivers a modern and eco-conscious experience.

Join us in embracing the future of vending with this exceptional project. Convenience, accessibility, and sustainability - it's all within reach.

7.2 User Manual

Our Vending Machine project is a very user-friendly device. From children to elderly people all can use this device. This vending machine has push buttons for price input and touch switches for product selection. You will have to first select your product then proceed for payment. Our payment method takes taka 5, 10, 20. After you pay the vending machine will show the remaining taka and also refundable taka based on the state. After full payment you will get your product. As you can see this is really simple to operate.

8 Project Management and Cost Analysis

8.1 Bill of Materials

- Bill of Materials

Component	Cost
Altera UP2 Development Kit	-
7 segment displays X 2	50
Resistors and Wires	20

9 Future Work

Future work for a vending machine project can encompass various areas of improvement and expansion. Here are some potential avenues for future development:

1. Product Diversification: Expand the range of products offered to cater to diverse customer preferences, including healthier snack options, fresh food, and specialty beverages.

2. Customization and Personalization: Implement technology that allows customers to personalize their orders, such as adjusting portion sizes, flavors, or dietary preferences.

3. Enhanced Payment Options: Integrate cutting-edge payment solutions, including mobile wallets, cryptocurrencies, and contactless payment methods, to enhance user convenience.

4. IoT and Data Analytics: Utilize Internet of Things (IoT) sensors to collect real-time data on machine usage and inventory levels, enabling predictive maintenance and optimized restocking.