Washing Machine Controller using Fuzzy Logic

DL-G04 : Nitant Jain[1], Even Patel[2], and Shashwat Gohel[3]
School of Engineering and Applied Science, Ahmedabad University, Ahmedabad, Gujarat – 380009[1,2,3]

***Abstract*—This project outlines the design and implementation of a washing machine controller using fuzzy logic principles, modeled in Verilog HDL. The system automates key washing processes by utilizing inputs from sensors to classify load size, water level, and detergent level into distinct categories. These categories influence the selection of the wash mode, ensuring an optimal washing cycle tailored to user requirements. The fuzzy logic approach provides dynamic decision-making for determining gentle, normal, or heavy wash cycles based on the sensor data. The project also incorporates a finite state machine (FSM) to manage the sequence of operations, including washing, rinsing, spinning, and draining. The modular design, with individual components for sensor classification and cycle control, ensures flexibility and scalability, making it an efficient solution for modern washing machine automation.**

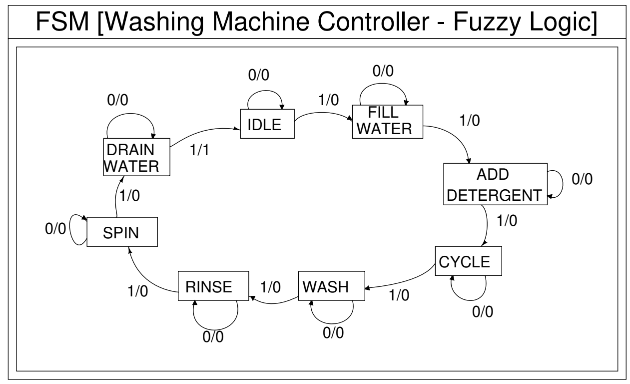

Fig. 1: State Diagram of the FSM

I. Introduction

In this project, we combine the Finite State Machine (FSM) technique and fuzzy logic to design a washing machine controller that automates and optimizes the washing process. The FSM is employed to manage the sequential transition between different operational states: door status, fill water,add detergent, washing, rinsing, spinning, and draining. Each state is executed in a structured and orderly manner to ensure seamless operation.

Fuzzy logic is specifically applied to determine the wash mode (Gentle, Normal, Heavy) based on sensor inputs for load size,door status, water level, and detergent concentration. By categorizing these inputs into fuzzy sets, the system dynamically selects the appropriate wash mode for optimal cleaning. This hybrid approach of FSM and fuzzy logic ensures efficient, user-adaptive performance while maintaining simplicity and modularity in design.

A. *Concept of State Diagram - FSM*

The state diagram illustrates the sequential operation of the washing machine controller, transitioning between various states based on input conditions. Each state represents a specific operation in the washing cycle, controlled by the finite state machine (FSM). Below is a brief explanation of each state:

***IDLE** This is the initial state where the machine awaits user input or checks the readiness of the system, such as ensuring the door is properly closed. No operation is performed in this state.

***CHECK DOOR** In this state, the machine verifies whether the door is securely closed. If the door is open, the system will remain in this state until the issue is resolved.

***FILL WATER** Once the door is checked, the machine transitions to this state to fill the drum with water. The water level is monitored based on sensor inputs, ensuring the correct amount is used for the wash cycle.

***ADD DETERGENT** The detergent is added to the drum in this state. The amount may be determined by the detergent sensor, ensuring proper usage based on the wash load.

***CYCLE** This state initiates the wash cycle. Based on the fuzzy logic wash mode (Gentle, Normal, or Heavy), the motor operates to agitate the clothes for cleaning.

***RINSE** In the rinse state, clean water is added to remove detergent residues from the clothes. This process may involve multiple cycles of filling and draining water.

***SPIN** The spin motor activates to remove excess water from the clothes. The spin speed may vary based on the wash mode selected earlier.

***DRAIN WATER** In this state, the system drains out the water from the drum, preparing the machine for the next cycle or ending the operation.

Each state transition occurs sequentially, with conditions such as sensor inputs and operation completion triggering the movement to the next state. This systematic approach ensures an efficient and automated washing process.

B. *Concept of State Table*

TABLE I: State Transition Table from FSM Diagram

Present State	Next State	Input	Output
IDLE	IDLE	0	0
IDLE	FILL WATER	1	0
FILL WATER	FILL WATER	0	0
FILL WATER	ADD DETERGENT	1	0
ADD DETERGENT	ADD DETERGENT	0	0
ADD DETERGENT	CYCLE	1	0
CYCLE	CYCLE	0	0
CYCLE	WASH	1	0
WASH	WASH	0	0
WASH	RINSE	1	0
RINSE	RINSE	0	0
RINSE	SPIN	1	0
SPIN	SPIN	0	0
SPIN	DRAIN WATER	1	0
DRAIN WATER	IDLE	1	1

C. *Concept of Fuzzy Logic*

Fuzzy logic is a computational approach that handles imprecision and uncertainty by modeling reasoning similar to human decision-making. Unlike traditional binary logic, which categorizes inputs strictly as true (1) or false (0), fuzzy logic uses degrees of truth, allowing inputs to take a range of values between 0 and 1. This flexibility makes it particularly well-suited for applications like washing machines, where decisions are influenced by imprecise inputs such as load size, water level, and detergent concentration.

D. *Role of Fuzzy Logic in the Washing Machine Controller*

In our washing machine controller, fuzzy logic is applied to determine the appropriate wash mode based on sensor inputs. The wash mode adjusts the machine's operation (Gentle, Normal, or Heavy) to optimize washing efficiency and adapt to varying conditions.

1) *Key Features of Fuzzy Logic in the Project:*:

Input Variables:

- **Load Size:** Categorized as Small, Medium, or Large.
- **Water Level:** Categorized as Low, Medium, or High.
- **Detergent Level:** Categorized as Light, Medium, or Heavy.

These inputs are measured by sensors and mapped to a 2-bit value (00, 01, or 10) based on thresholds:

- **00** represents the lowest range (e.g., Small, Low, or Light).
- **01** represents a medium range (e.g., Medium).
- **10** represents the highest range (e.g., Large, High, or Heavy).

Output Variable: **Wash Mode:** The machine's washing intensity, with the following possible values:

- **00** - Gentle
- **01** - Normal
- **10** - Heavy

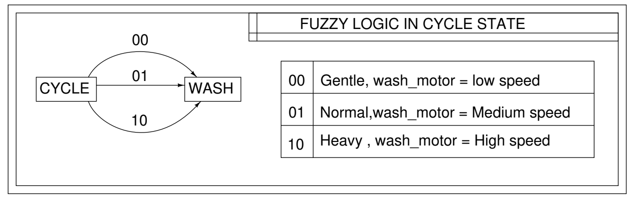

Fig. 2: Fuzzy Logic diagram for the cycle

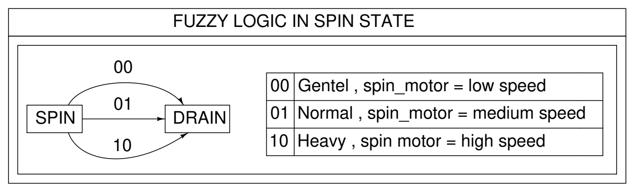

Fig. 3: Fuzzy Logic diagram for the spin

Logic Implementation: The fuzzy logic algorithm uses a simple rule-based approach to map the inputs to the wash mode:

- If Load Size is Large (10) or Detergent Level is Heavy (10), the wash mode is set to Heavy (10).
- If Load Size is Medium (01) or Water Level is Medium (01), the wash mode is set to Normal (01).
- If none of the above conditions are met, the wash mode is set to Gentle (00).

Range of Values: Each input sensor takes an 8-bit value, ranging from 0 to 255. This range is divided into three categories using thresholds:

- **Low:** Below 85 (approximately 33% of the full range).
- **Medium:** Between 85 and 170 (approximately 33%-66% of the range).
- **High:** Above 170 (greater than 66% of the range).

E. *Design Of Washing Machine using fuzzy in Verilog*

1) *Flowchart* :

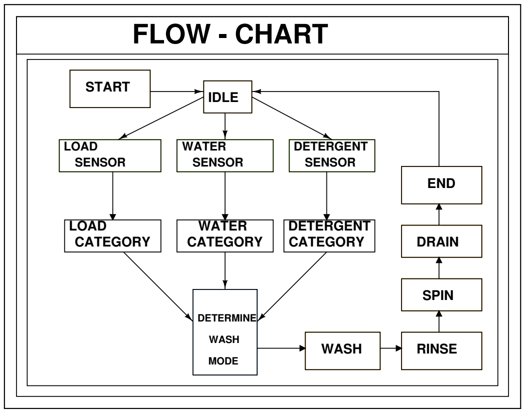

Fig. 4: Flowchart depicting sequential steps taken

2) *Pseudo Code:*

MODULE: LOAD SIZE

```
INPUT: load_sensor (8-bit)
OUTPUT: load_category (2-bit)

IF load_sensor < 85:
    load_category = 00  // Small
ELSE IF load_sensor < 170:
    load_category = 01  // Medium
OTHERWISE:
    load_category = 10  // Large
END IF
```

MODULE: WATER LEVEL

```
INPUT: water_sensor (8-bit)
OUTPUT: water_category (2-bit)

IF water_sensor < 85:
    water_category = 00  // Low
ELSE IF water_sensor < 170:
    water_category = 01  // Medium
OTHERWISE:
    water_category = 10  // High
END IF
```

MODULE: DETERGENT LEVEL

```
INPUT: detergent_sensor (8-bit)
OUTPUT: detergent_category (2-bit)

IF detergent_sensor < 85:
    detergent_category = 00  // Light
ELSE IF detergent_sensor < 170:
    detergent_category = 01  // Medium
OTHERWISE:
    detergent_category = 10  // Heavy
END IF
```

MODULE: WASH MODE

```
INPUT: load_category (2-bit),
    water_category (2-bit),
    detergent_category (2-bit)
OUTPUT: wash_mode (2-bit)

IF load_category == 10 OR
    detergent_category == 10:
    wash_mode = 10  // Heavy
ELSE IF load_category == 01 OR
    water_category == 01:
    wash_mode = 01  // Normal
OTHERWISE:
    wash_mode = 00  // Gentle
END IF
```

MODULE: CYCLE CONTROL

```
INPUT: clk, rst, wash_mode (2-bit)
OUTPUT: wash_motor, rinse_valve,
    spin_motor, drain_valve (1-bit each)

DEFINE STATES: IDLE, WASH, RINSE, SPIN,
    DRAIN
SET initial state to IDLE

ON every clock signal:
    IF rst is active:
        current_state = IDLE
    ELSE:
        current_state = next_state
    END IF

STATE LOGIC:
RESET all outputs (wash_motor,
    rinse_valve, spin_motor, drain_valve
    = 0)
DEFAULT next_state = current_state

SWITCH current_state:
    CASE IDLE:
        next_state = WASH
    CASE WASH:
        wash_motor = 1
        next_state = RINSE
    CASE RINSE:
        rinse_valve = 1
        next_state = SPIN
    CASE SPIN:
        spin_motor = 1
        next_state = DRAIN
    CASE DRAIN:
        drain_valve = 1
        next_state = IDLE
END SWITCH
```

F. *Verification - GUI Design and Implementation*

We had implemented a washing machine controller with a graphical user interface (GUI) designed using Python's tkinter library just for the verification purposes. The system uses fuzzy logic to categorize inputs and determine the appropriate wash mode. This tool is primarily aimed at simulating and visualizing the decision-making process of a washing machine based on sensor inputs such as load, water, and detergent levels.

Gentle Wash mode

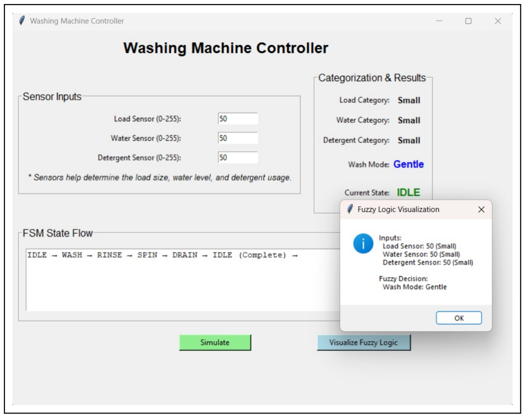

Fig. 5: Diagram depicting gentle wash mode

Normal Wash mode

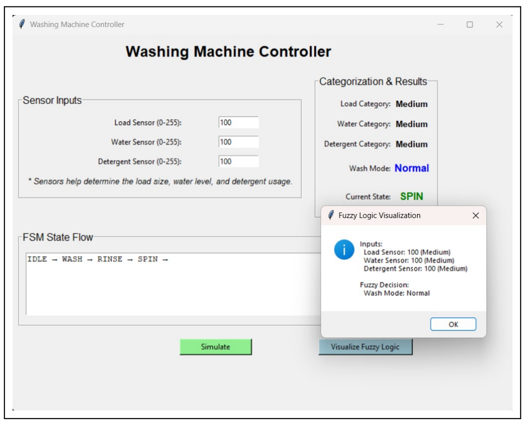

Fig. 6: Diagram depicting normal wash mode

Heavy Wash mode

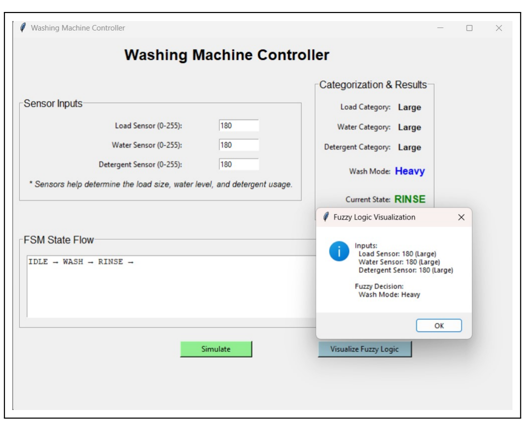

Fig. 7: Diagram depicting heavy wash mode

II. Results and Discussion

The washing machine controller was also implemented and simulated using the Verilog HDL successfully. The simulation results show that the design is correct for each one of the modules as well as the incorporation of the fuzzy logic decision-making algorithm. The following is the detailed analysis of the simulation outcome.

A. *Simulation Results*

The simulation proved the feasibility of the washing machine controller when subjected to different test scenarios. These were; load size, water level, detergent level, wash mode selection and cycle control modules were tested aside from their validation.

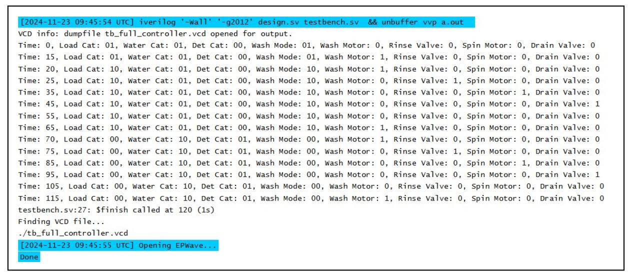

Fig. 8: Timing diagram representing different states transition

B. *Graphical Representation*

The timing diagram obtained after simulation is given below for better understanding. It shows how the controller reacts and which control signals are activated at the right time due to the fuzzy logic implementation.

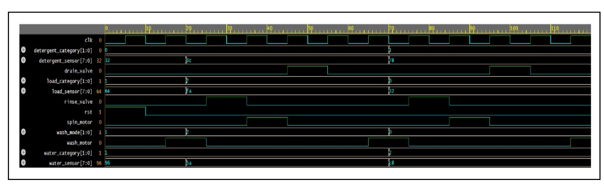

Fig. 9: Simulation Waveform representing different parameters activation graph

III. CONCLUSION

A. Key Learnings:

In this project, we implemented a washing machine system controller using fuzzy logic. The primary learning included the knowledge and the concepts of fuzzy logic, its utility in decision-making methods, and its potential to deal with uncertainties. By leveraging fuzzy sets and membership functions, we were able to layout a smart system that adjusts washing parameters like water motor speed, wash time, and detergent quantity based on inputs together with dirt degree, load length, and fabric kind.

B. Future Scopes:

The washing machine controller using fuzzy logic can be further optimized and improved in several ways:

- When Integrated with the technology of Iot , it can be made to operate from a remote distance also.
- Incorporation of machine learning techniques to fine-tune fuzzy rules and membership functions based of the user's opinion and user satisfaction.
- Can include more levels like Fabric quality , Dirt Level, and many various other.
- Development of an adaptive fuzzy logic system that learns and automatically changes itself over time for enhanced performance.

C. Applications:

The fuzzy logic-based washing machine controller has a wide range of practical applications:

- **Household Appliances:** Enhances user convenience by automating washing parameters and delivering optimal cleaning performance.
- **Industrial Washing Systems:** Provides a large scale control , improving efficiency and even reducing the wasteage of the resources.
- **Energy Efficiency:** Contributes to sustainable practices by optimizing water and detergent usage based on load requirements.
- **Customizable Control:** Offers tailored washing experiences for different fabric types and user preferences, ensuring gentle handling and improved results.

IV. ACKNOWLEDGMENT

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