Fuzzy Logic Controller Design and Implementation for Industrial & Domestic Applications

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Abstract: This paper involves the design and implementation of an automated laundry in a firm. The laundry has a washtub having a capacity of about 60 kgs. The design incorporates special hardware to read the data from sensors in the tub like-the detergent should be added depending on the dirt and the weight of the clothes sensed from the tub ; depending on the weight of the material to be washed, the water must come in through the inlet automatically ; the number of wash-cycles will also depend on the dirt and the weight ; The dirt level needs to be checked at the end of each cycle and if the dirt is below a desired value the process needs to be terminated automatically. A computer is to be used to perform the various calculations and to control and monitor all the stages of the project. The software is written to automate the operation employing the concept of fuzzy logic.
Keywords: Fuzzy, Logic, Design, Laundry, Controller

1. Introduction to the laundry system

In industries like textile and paper the raw materials brought in have to be cleaned before use. Even finished products like cloth that has been processed, in the textile industry needs to be washed before usage. Before the advent of industrial revolution, a lot of this washing had to be done manually. This was very difficult since most of these materials like cloth measured yards in length. Thus a lot of labor was involved in this process. But with the introduction of machinery, huge wash-drums could be used for washing the material.

These wash-drums could rotate with heavy loads and obtain effective cleaning. However monitoring of the process was still needed. The amount of water to be added, the detergent to be added, when the process needs to be terminated---all these factors needed to be manually monitored. Thus even though the washing was mechanized, a lot of man-hours were wasted in monitoring the system. Thus, a system is needed which would eliminate the above deficiencies.

However, the dawn of automation, along with the entry of microprocessors and microcontrollers, changed all that. Now a system could be designed which could handle the washing and the monitoring without human intervention. The control of the entire washing can now be programmed into a computer or microcontroller. Sensors measure the dirt, weight and other factors real-time from the washtub and feed this data to the microprocessor. Depending on the information received, the microprocessor decides the flow of control of the washing and when the process needs to be stopped.

1.1Aim of the project

This project involves the design of such an automated laundry. The laundry has a washtub having a capacity of about 60 kgs. The design. requires that

- The design should incorporate special hardware to read the data from sensors in the tub. E.g.: --the detergent should be added depending on the dirt and the weight of the clothes sensed from the tub.
- Depending on the weight of the material to be washed, the water must come in through the inlet automatically.
- The number of wash-cycles will also depend on the dirt and the weight.
- The dirt level needs to be checked at the end of each cycle and if the dirt is below a desired value the process needs to be terminated automatically.
- A computer is to be used to perform the various calculations and to control and monitor all the stages of the project. The software written to automate the operation needs to employ the concept of fuzzy logic.

In the following sections, we describe the concept of fuzzy logic and the design of the controller along with the hardware in detail.

Fuzzy control has emerged as a dynamic and vibrant field of research, particularly in the application of fuzzy set theory. This area finds significant relevance in industrial processes that defy conventional control methods due to the lack of precise quantitative data regarding input-output relationships. Fuzzy control systems, underpinned by fuzzy logic, align more closely with human thought processes and natural language, setting them apart from traditional control systems. In this work, fuzzy logic has been harnessed to introduce a degree of fuzziness into the inputs, specifically related to the level of dirt and the weight of materials designated for washing. This fuzzy input data is then employed to regulate various aspects of the washing process, such as the volume of water entering the washing tub, the quantity of detergent to be dispensed, and the duration of the washing cycles..

2. Design of Fuzzy Controller

Designing of fuzzy controller involves development of a fuzzy model of the process, taking into consideration the inputs, outputs and the decision taking logic. Steps involved in developing the process fuzzy model are

Analyzing the Process

The process is analyzed and partitioned into inputs and outputs; also the sequence of operations is considered. Laundry tub has input valves for water inlet, liquid detergent inlet and an output valve for water outflow. The cleaning action is achieved by rotating the tub for which the motor is provided. There is a weight sensor (load cell) for weighing the material to be washed. A dirt sensor (LOR) senses the dirt level of the material loaded in the tub. Sequence of events are :

- The wash tub is loaded with the material to be washed, its weight is noted and sent to the controller.
- The tub is filled with a proportionate amount of water.
- An initial cycle is carried out in which the motor is run for a set amount of time to dislodge dirt from the material. At the end of this cycle the dirt level is measured and sent to the controller. The water in the tub is then emptied.
- The controller processes the weight and dirt inputs and decides whether an additional cycle is necessary; if yes, the motor running time and amount of detergent to be added for the next cycle are determined. If no, the process is terminated.
- The tub is again loaded with water and using the above parameters a fresh cycle is initiated.
- At the end of step 5 the dirt level is again measured and transferred to the controller and the process is repeated from step 4.
- From the above steps we see that the following inputs and outputs are to be considered.

INPUTS : Dirt level & weight of material to be washed.

OUTPUTS : Duration of motor running time & amount of liquid detergent to be added to the material.

The next step involves the conversion of the above inputs into their fuzzy counterparts.

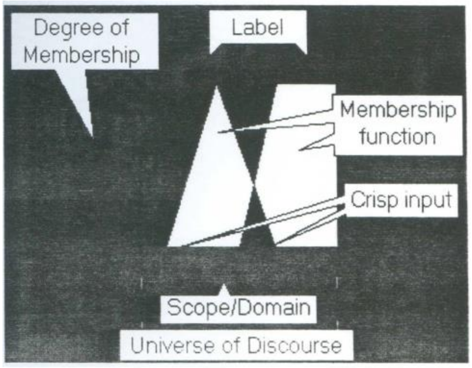

Fig. 1: Fuzzification process

Fuzzification

The initial stage in the fuzzy logic process involves a crucial transformation known as fuzzification. Fuzzification is employed to convert the inherently quantitative nature of crisp inputs into a qualitative framework. This transition trades the exactness of crisp input for enhanced interpretability, enabling the elimination of unnecessary mathematical rigidity. Consequently, crisp inputs are transformed into fuzzy inputs during the fuzzification process. For instance, a crisp input of 78°C might be represented as 'hot' in fuzzy terms, and a speed of 90 mph could be categorized as 'fast'. To accomplish this transformation, membership functions must be established for each input. After the assignment of membership functions, the controller can then take real-time inputs, such as weight, and translate them into fuzzy inputs by utilizing the predefined membership functions. The precise definition of membership functions is a critical aspect of developing an efficient process model. Various factors should be considered when defining membership functions, ensuring their accuracy and relevance.

a) Universe of discourse: It is the range of interest to the application at hand. It is determined by the range of the sensors employed.
b) Domain of membership functions : This is the range of crisp inputs for which the membership function gives non-zero ‘degrees of membership’.
c) Number of membership functions : Here, the number of labels to be used is considered. Selecting too few membership functions may cause the response to be lethargic and the output may tend to oscillate. Again too large a number may fire many rules for small input changes and this may lead to instability. Usually the number of membership functions is an odd number between 3 to 9.
d) Shape of the membership functions : Shape of the membership functions is important because it determines the change in the degree of membership for crisp inputs .The most common shapes are trapezoidal and triangular.
e) Overlap between membership functions : In a fuzzy control system, overlap between membership functions determines system response. A fuzzy system with no overlap is reduced to a system with Boolean logic.

There are some general guidelines for determining overlap between membership functions :

- Overlap is restricted to two labels at a time.
- Sum of the values of the degrees of membership for each crisp input lying within the overlap range should be <= 1.
- There can be no overlap in the range in which the degree of membership of a crisp input is 1.0.

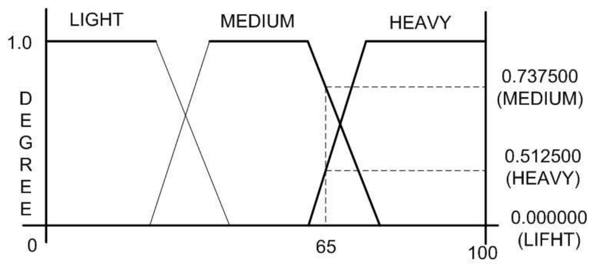

Fig. 2: Fuzzy logic functional representation of the states

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This is in contrast with the rigid and inflexible look up table approach shown below:

Rule Evaluation (Fuzzy Inference)

Rules form the knowledge base of the system. They closely model human reasoning. They replace the need to describe the process by a complex mathematical model. They also reduce the processing requirements to arrive at decisions, eliminating the need to evaluate complex formulae.

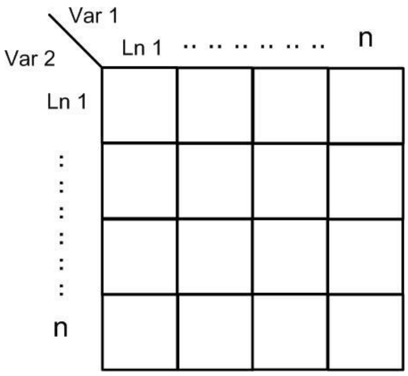

Fig. 3: Rule Base

Rules define the system's common-sense behavior and are expressed using linguistic labels from the membership functions. The standard syntax for rules is as follows:

IF antecedent1 AND antecedent2 AND…..

THEN consequent1 AND consequent2 AND.....

A common method of formulating rules is by using FAM's or Fuzzy Associative Matrices.

MATRIX FOR AMOUNT OF SOAP REQUIRED

WEIGHT \ DIRT LEVEL	Very low	Low	Medium	High	Very high
Light	LESS	LESS	MEDIUM	MEDIUM	MORE
Medium	LESS	MEDIUM	MEDIUM	MORE	MORE
Heavy	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MORE

Fig. 4: Fuzzy Associative Matrices

A sample fuzzy logic used in our system :

"**If** temperature is hot (.46) **AND** soil is 25 dry (.25), **then** water duration is long." Rule Strengths : .25

"**If** temperature is warm (.2) **AND** soil is moist (.75), **then** water duration is medium." Rule Strengths : .2

"**If** temperature is warm (.2) **AND** soil is dry (.25), **then** water duration is long." Rule Strengths : .2

"**If** temperature is hot (.46) **AND** soil is moist (.75), **then** water duration is medium." Rule Strengths : .46

However, the method outlined above is not feasible in case of complex systems with many inputs and outputs. In such cases, the rules which are obvious and those which are vague yet intuitively important are considered. The rules eventually implemented in the inference engine may be far less than the total number of possible combinations. This however does not introduce any substantial errors.

Defuzzification

Defuzzificaton takes the fuzzy outputs obtained from rule evaluation and translates them into crisp outputs. All significant fuzzy outputs (e.g. motor runtime is long, short etc.) are combined into a single, comprehensive result for that output variable (motor runtime). In this process, all the fuzzy outputs modify their respective output membership functions. The choice of membership functions in case of output variables is again very important.

For example having large flat response at the extremities may lead to the membership functions contributing a large weight to the final output. This similar to the effect of a child sitting at one end of a seesaw with the other side empty. Here, we have used the centroidal method and the singleton method of defuzzification, which are the two methods of defuzzification.

Centroidal method : In this method, the output is obtained as follows. The output membership functions are clipped at values determined by rule strengths obtained in rule evaluation. The center of gravity of the area so obtained is then taken as the defuzzified output.

Singleton method : For applications in which processing power is limited and accuracy is not of much concern the singleton method is preferred. Here, the output functions are represented by impulses. These 'singletons' are clipped like in the COG method and centre of gravity is taken as the defuzzified output.

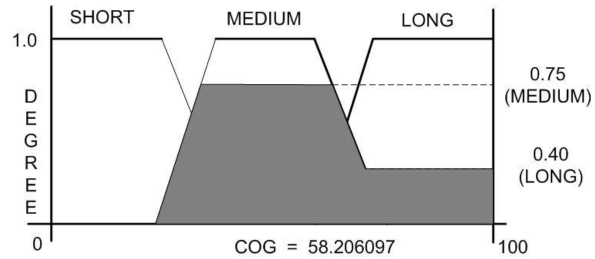

Fig. 6: Defuzzification

Implementation of the design

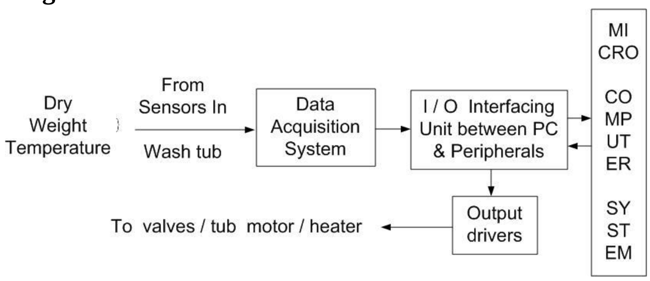

Fig. 7: Working of the laundry system

The system designed is shown above in Fig. 5. The analog signals from the sensors in the washtub are to be converted to digital form by an ADC. An interface unit is to isolate the peripheral devices from the computer system. The processor after having completed the necessary calculations on the data will give the output data and control signals to the interface unit. The output drivers take the signals and help to drive the motors and the valves in the washtub.

4. Selection of the chips, bus architecture & the controlling unit

The chips that were selected to perform the above functions are Data Acquisition ADC 0809, Interface Unit-8255A, Output Drivers-Relays, IC 74l5244-Octal Buffers And Line Drivers, IC 74L5245-Transceiver, IC 74LS138-3 To 8 Line Decoder, IC 74LS04: Hex Inverters, IC 74LS30: 8 -Input NAND Gate, 8253, Controlling Unit - An IBM PC. The details of the chips are given below one by one.

Data Acquisition:

The ADC 0809 is a comprehensive data acquisition solution encapsulated within a single chip, incorporating essential elements of a standard data acquisition system. It comprises an 8-bit Analog-to-Digital (A/D) converter, an 8-channel multiplexer featuring an address input latch, and corresponding control logic. These integrated components offer the fundamental logic needed to establish connections with a variety of microprocessors, minimizing the need for additional processes. This chip is particularly well-suited for applications demanding the coexistence of both analog and digital functions on a unified platform. Operating with a 50-kHz clock, the ADC 0809 typically executes a conversion in 100 microseconds, and a single input conversion can be performed in as little as 50 microseconds. The ADC 0809 boasts high-speed capabilities, impressive accuracy, minimal susceptibility to temperature fluctuations, output conforming to TTL voltage level standards, sustained long-term accuracy and repeatability, all while maintaining low power consumption.

Interface Unit - 8255A:

The 8255A serves as a programmable interface input/output device, facilitating the connection of peripheral equipment to the microprocessor system. System software is responsible for configuring the functions of the 8255A, eliminating the need for external logic components for interfacing with peripheral devices. In scenarios where external circuitry is preferred over the 8255A for processor interfacing, separate drivers become necessary to establish connections with this circuitry. This distinct circuitry lacks programmability akin to the 8255A. Additionally, it was observed that attempting to use the same 8255A for both the input signals from the ADC and the output signals destined for the output drivers led to signal interference. As a result, two separate 8255A chips were employed: one to facilitate the flow of data from the ADC to the processor and another to facilitate data transmission from the *processor to the output drivers.*

OUTPUT DRIVERS---RELAYS

Relays have been used as drivers for the output to isolate the microprocessor from the motor and valve controls. 5 such coils (each ---12V D.C / 150 ohms - 9940B) are used - one each for the following devices : Input valve, Detergent valve, Heater control, Washtub motor, Output valve. In addition to the above main chips the following IC's were also used as drivers and buffers.

IC 74L5244

Octal buffers and Line Drivers. These octal buffers are designed specifically to improve the performance and density of the state memory address drives, clock drives and bus oriented receivers and transmitters.

IC 74L5245

TRANSCEIVER. This chip is used as an octal transceiver featuring non-inverting 3 state bus compatible outputs in both send and receive directions.

IC 74LS138

3 to 8 line decoder. This chip is used for selecting the 8255's and the ADC. FEATURES-demultiplexing capability, multiple input enable for easy use expansion and ideal for memory chip select decoding.

IC 74LSO4

HEX INVERTERS, FEATURES - chip select generator six independent gates.

IC 74LS30

8 -INPUT NAND GATE, FEATURES

A single 8-input NAND gate card select generator.

In the *8253*, which is a LSI peripheral is designed to permit easy implementation of timer and counter functions in a microcomputer system. 8253 is used to give a clock signal to the ADC. The clock signal of the ISA is divided by 2 by a D-Flip Flop which is then given to the 8253 where is divided by 10. This clock frequency of 416.5 kHz is then given to the ADC.

In the *controlling unit*, which is the IBM PC, the PC forms the central controlling unit. It monitors the conditions and actuates the wash cycles as per requirement. The minimum requirements for the laundry control system are a 16 or 32-bit processor, 2-4 MB of system memory, video monitor, hard disk drive of 100 to 200 MB and most importantly expansion slots for interfacing the card. The algorithm that implements the fuzzy logic required for the system resides on the PC. The PC receives the specific conditions as inputs from the card. It then applies the rules, based on the algorithms written, on the data. This process is called fuzzification. The output is obtained and converted to a form useable by the rest of the system. This is called defuzzification. It then outputs this data to the card for initializing the wash cycle and / or controlling the different parameters for the wash cycle. The advantages of using a PC over a microcontroller are:

- Any modification to the system can be carried out by just changing the software in the PC as against having to physically burn software into the microcontroller EPROM.
- Just by using a single PC, more than 1 laundry can be controlled simultaneously which is not possible in the case of the microcontroller.
- Because of the graphical display provided by the PC, monitoring and control of the system is easier than in the case of a microcontroller.

PC expansion bus architecture type ISA (Industry Standard Architecture)

The card in the system connects to the PC through an ISA slots. The system motherboard features a 52-way direct-edge connector, which directly interfaces with the motherboard. The connector is divided into two sides, denoted as A (comprising lines A1 to A31) and B (consisting of lines B1 to B31). On side A of the connector, you will find a grouping of address and data lines, while side B accommodates the control bus lines and power rails. Notably, all signal lines within the slot adhere to TTL compatibility standards. The clock that is used to synchronize the ISA bus transfers is the BCLK or bus clock. The ISA is based on the 8 MHz version of the 80286-based IBM PC/AT. In later machines the BCLK speed is upto 8.33 MHz.

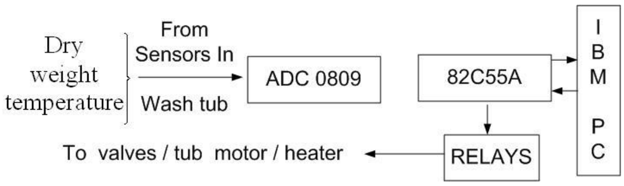

Fig. 6: The add-on card

Choice of ISA over PCI : PCI provides many advantages over ISA in terms of both speed of data transfer and size of data bytes. However, any device also needs to include arbitration mechanism. This has to be implemented in VLSI to compensate for the higher speed of PCI. This increases the complexity in implementing the card. Hence the device could be kept only as large as to accommodate the essential components. Also, in a laundry system, time is usually of the order of minutes .or hours. So the speed provided by ISA is more than adequate for our applications.

The above card is used as an interface between the PC and the laundry. It contains an ADC 0809 chip to translate sensor readings into voltages and circuitry to drive relays that control external devices like motor, inlet valve etc. The card is designed to plug into a free 8-bit ISA slot on a PC. The onboard circuitry can be divided into the following sections:

- Address decode / chip select logic
- Data bus buffer and address latch
- Clock generator and control for ADC
- Control and interfacing for relays.

This logic is responsible for selecting onboard chips when they are addressed. It is composed of a 7404 inverter and a 7430 NAND gate and a 74138 3-8 line decoder. The inverter and NAND gate decode the upper A9-A5 address lines on the ISA bus. Hence, the NAND gate output goes low whenever A9-A7 is high and A6 and A5 are low. The software for operating the laundry has been written to make the operation as user friendly as possible. The user initially has to choose the details about a particular wash cycle from menus, which are displayed, on screen. At any stage during the wash the user can abort the current cycle and leave the process. There are 2 main types of washing program modes : -AUTOMATIC wash & MANUAL wash.

5. Operation of the system

Basics steps to be carried before operating the automated laundry

The user has to connect the wires from the sensors in the washtub to the ADC inputs on the card.

The 5 relays need to be connected to the various valves, the motor in the washtub and the heater control.

The user has to insert the designed PCB card into a free ISA slot of the computer.

The software needed to automate the process has to be loaded into the computer

The Two Main Washing Modes

The software for operating the laundry has been written to make the operation as user friendly as possible. The user initially has to choose the details about a particular wash cycle from menus, which are displayed, on screen. At any stage during the wash the user can abort the current cycle and leave the process.

There are 2 main types of washing programs, viz., AUTOMATIC wash and the MANUAL wash.

Automatic Wash Program

The automatic wash is designed for users who leave the computer to decide when the washing process needs to be terminated depending on the fuzzy algorithm. In this program every batch of clothes added into the tub is soaked for default 30 mins after addition of soap. Users wanting to add extra soak time (in case the weight of a batch of clothes is more or the dirt content is more) can do so by specifying the same in the menus shown before the start of the wash. An option to heat the water is also available in this program. This option can again be selected in the menu before the start of the program.

Default Cycle

Depending on the weight of the clothes, the amount of water and detergent to be added is determined by the fuzzy algorithms. The motor in the tub turns on for some default time The clothes are then soaked for a default 30 mins plus any extra soak time the user may have entered. The dirt is measured at the end of this cycle after which the water is automatically emptied from the tub.

Main Cycles

The computer then adds fresh water again depending on the weight. The detergent is then automatically added depending on the weight and the dirt of the clothes. The water is then heated depending on the option entered by the user. The computer then determines the time for performing the washing operation again using fuzzy algorithms based on dirt and weight. The motor turns on for this time and again after the end of calculated time the dirt is measured and water emptied. These MAIN CYCLES are repeatedly performed till the dirt level falls below a certain value after which the user is informed that the process is complete.

Manual Wash Program

The manual wash program has been designed for users who do not want the computer to decide the time for the washing to be performed. Thus this program is selected by users in situations where time is of essence and perhaps the complete cleanliness of clothes is secondary. In this program, to save time, soaking of the clothes and heating of the water is not carried out. Before the beginning of the wash, the user is asked to enter the time for which he wants the process to be carried out. There is no default cycle in this process. The water and detergent enter the tub depending on the weight of the clothes. The motor is turned on for the time specified by the user. After the process is over the water is drained and the user is informed about it.

Using The Software

On running the software for the laundry the user is first asked whether he wants to go ahead with the washing process or not. On deciding to exit the process the user is taken out of the system. The user also has the facility of changing the settings for flow rates of the valves from the same menu. On entering the main washing screen the user is asked about which washing mode he wants to go for : Automatic mode or Manual mode

Automatic Mode

If he selects the automatic mode, he is asked to enter the temperature for the water to be heated from a menu shown on the screen. The menu shows a temperature ranging from room temperature to very hot water. Next he is asked whether he wants to add extra soak time. The user is given a menu ranging from 15 mins to 90 mins for selecting extra time. The user is then presented with a screen showing a summary of the options he has selected. For e.g., if the user has selected automatic mode then the summary screen will show the values of temperature and soaking time selected by the user. He will also be asked if he is sure about the parameters he has selected before the process is started. On saying “no” he will be again taken to the first screen to select the washing mode and the entire process will be repeated.

Manual Mode

On selecting the manual mode, the user will only be asked to enter the time for which he wants the process to be carried out. He will be shown the menu for a time ranging from 15mins to 45 mins. After this the user is again shown a summary screen like in the automatic mode from where he can start the process or again return back to the main screen.

6. Details About The Graphical Display

On starting the process, the user will be shown the washtub. The main washtub is seen with the input valve, output valve, heater, detergent valve and the motor. The glowing of a particular device informs the user that it is in use now-for e.g., whenever the motor unit is seen glowing in the graphical display, the user knows that the motor is now in use in the tub-this is similar for the valves and the heater. The upper rectangular box indicates to the user about what is happening instantaneously in the system. It indicates the sensing of weight, dirt etc and also about the times for which a particular operation is carried out. The box also shows the action that is taken at each step in the process. The rectangular box on the lower left corner shows the graphs from which the defuzzified values of water amount, detergent amount and wash time are calculated instantaneously. The lower middle box shows the values of dirt, temperature and weight that are sensed. Whenever the user wants to terminate the operation. he can 90 so by pressing the "**escape**" key on the keyboard. On doing so a question is popped in the lower right box on the screen about whether he is sure about his decision. Saying yes will terminate the process, i.e., the washtub will be emptied of the water and the user is taken out of the system.

ALGORITHM

C language is used to write the code that forms the fuzzy processor.

1) START.
2) Initialize variables and structures holding membership function forms.
3) Display menus to user to select wash mode as automatic or manual, soak time and temperature water must be heated to. Store these choices in program variables.
4) Show graphical process display on screen.
5) Read weight of material loaded in tub.
6) Determine amount of water for washes based on fuzzy processing of weight of material. Allow this water into tub by inlet valve.
7) Check if manual or automatic mode is selected. If manual is selected, go to step 8 else go to step 11 .
8) Since manual mode is selected, determine amount of soap to be added by fuzzy processing of weight of material. Allow this amount of soap into tub by means of soap valve.
9) Turn motor on for an amount of time selected by user through menus in initial phase; then turn it off.
10) Empty tub and intimate user that the process is over. Go to step 24.
11) Since automatic mode is selected, start default cycle.
12) Determine amount of soap to be added to tub by fuzzy processing of weight of material. Add the soap to the tub.
13) Turn motor on for default number of cycles.
14) Now soak material for 30 mins plus whatever time user has selected as extra soak time through menus in initial phase.
15) Measure dirt level of material in tub. If dirt level is less than 30, go to step next step else go to step 18.
16) Intimate user that material needs no further cleaning and process is over.
17) Empty tub and Go to step 24.
18) Another cycle is required for further washing. Determine soap amount and wash time for next cycle by fuzzifying dirt level and weight of material into fuzzy labels, evaluating rules on fuzzy labels to get rule strengths and defuzzifying rule strengths.
19) Empty tub and fill fresh water.
20) Fill amount of soap, which was determined in step 18.
21) Read current temperature of water and compare with temperature specified by user. If current water temperature is lower than specified temperature, heat water till it reaches specified temperature by turning heater on.
22) Turn motor on for wash time that was determined in step 18. Go to step 15.
23) Display in how many cycles wash was completed.
24) Clear graphics display and exit to system.
25) STOP.

7. Conclusions

An fuzzy logic controller was designed & implemented for a laundry system and was functioning at it best. In conclusion, the development and implementation of Fuzzy Logic Controllers (FLCs) mark a significant stride in enhancing control systems for both industrial and domestic applications. FLCs offer a versatile approach to handle complex and nonlinear systems, providing precise and adaptive control. The adaptability of Fuzzy Logic Controllers to real-world conditions makes them suitable for a wide range of applications, from industrial processes to home automation. Through this project, the potential of Fuzzy Logic Controllers has been explored and demonstrated, showcasing their effectiveness in optimizing processes, conserving energy, and improving overall system performance. Industrial sectors can benefit from increased efficiency and reduced operational costs, while in the domestic realm, FLCs can enhance comfort, convenience, and energy conservation. Furthermore, the project highlights the importance of refining Fuzzy Logic Controller designs to suit specific application requirements, considering factors such as system complexity, environmental conditions, and user preferences. As technology continues to advance, Fuzzy Logic Controllers are poised to play a pivotal role in shaping the future of automation and control, ultimately providing smarter and more efficient solutions for industrial and domestic environments.

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