Task 2: Fuzzy Controller System for a Smart Home

Introduction:

As per United Nations (UN) data of world population prospects, for the first time in history, population aged 65 or above outnumbered children under 5 years globally [1][2]. Elderly population welfare is considered to be the responsibility of the state as well as each individual person. This is always a great challenge as they would need support for even their day-to-day routines. The upsurge in technologies enabled verities of possibilities in health care domain for elderly support. European Framework Program has introduced the term ‘Ambient Assisted Living (AAL)’ for their research funding programs. AAL system improves the quality of life of special group of people including elderly and disabled [3]. The main goal of AAL system is to ensure person’s welfare, that is, monitor illnesses, control the provision of fresh food, generate alerts for medical personnel in case of falls or abnormal situations, monitor medication reminders, and enhance social relations by enabling people-to-people communications [3]. Much research is going on in developing smart devices to enable the AAL in more efficient way.

In this coursework, exploring the features and possibilities of Fuzzy Logic Interface to design a home with smart devices for disabled or elderly residence. Fuzzy control system is a mathematical system that analyzes analog input values in terms of logical variables with continuous values in between 0 and 1. The concepts cannot be expressed as true or false, but rather express as partially true or a specific percentage of trueness [4]. Fuzzy logic tries to look at mathematical problems in a way how human brain thinks with uncertainties and vagueness. Ideally a Fuzzy Inferenceface System (FIS) consist of Inputs, Membership functions, Outputs and Rules. Below image shows the Block diagram of fuzzy logic implementation.

Diagram

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*Fig 1: FIS System -----source [6]*

Fuzzier gets the inputs along with its membership function. FIS engine analyzes the inputs and the rules (how the inputs affect outputs). Defuzzification step incorporates the results from FIS engine along with the output variables with corresponding membership functions.

In this coursework, fuzzy logic controller for a smart home is designed in MATLAB. There are many smart devices in current market as part of AAL care. Considered only few of those essential devices in this work. Heater and Automatic Lamps are considered for overall home. Smoke Detector and Smart Oven are designed as the kitchen specific devices. Water Flow Detector and Water Boiler are for bathrooms. Bed Occupancy Detector and Automatic Bed Lamp are for bedroom specifications. TV Ear should be set up adjacent to TV, ideally for living room set ups. And finally, the Corporal sensor is designed as personal care, like to detect a person is ill or not.

The below table is a list of outputs of the FIS system and their corresponding inputs.

|  |  |  |
| --- | --- | --- |
|  | Output | Input |
| 1 | Heater | Room Temperature |
| Humidity |
| 2 | Automatic Lamp | Light |
| Presence of Person |
| 3 | Water Boiler | Room Temperature |
| Water Temperature |
| 4 | Smoke Detector | Presence of Smoke |
| 5 | Water Flow Detector | Moisture |
| 6 | Corporal Sensor | Blood Pressure |
| Heart Rate |
| Body Temperature |
| 7 | Bed Occupancy Detector | Bed Surface Pressure |
| Time Delay |
| 8 | Automatic Bed Lamp | Light |
| Bed Surface Pressure |
| 9 | TV EAR | Surrounding Volume |
| 10 | Smart Oven | Type of Food |
| Quantity of Food |

*Table 1: Output/Input list*

Methodology:

There are two different fuzzy systems available, Mamdani and Sugeno. Mamdani fuzzy system is used in this coursework. There are mainly 3 main steps/components in Mamdani framework.

Diagram

Description automatically generated*source ‘Science Direct – Electrical Load Forecasting 2010’*

1. Fuzzification

Here the crisp input values would be converting into fuzzy linguistic values based on the prior expert knowledge.

1. Fuzzy Inference

In this step, the fuzzy inputs map to the fuzzy outputs. The mapping is done by a set of rules. Rules, based on multiple input variables can be combined using AND (t-norms)/OR (t-conorms) logical operators. All the defined rules will be clipped and aggregated to obtain the specific result set.

1. Defuzzification

Defuzzification is the process of converting the fuzzy output set into a crisp output value, based on the membership function defined.

The first step in any fuzzy controller design is the design of input variables and their membership functions. Trapezoidal and triangular membership functions are used in this work.

Input Variables and Membership Functions:

1. Room Temperature

Temperature control is essential for any home. Have considered a UK home for this course work. So, the temperature range is considered in between -20 to 40 degree Celsius. In fuzzy system its divided into 5 different values. VL (Very Low), L (Low), M (Medium), H (High) and VH (Very High). VL and VH are trapezoidal function and rest are triangular. Below is the membership function for room temperature and value range is displayed in the table.

|  |  |  |
| --- | --- | --- |
| Membership Function | Range (℃) | Type |
| VL | -20 to -10 | Trapezoid |
| L | -15 to 10 | Triangle |
| M | -5 to 25 | Triangle |
| H | 10 to 35 | Triangle |
| VH | 27 to 40 | Trapezoid |
| *Table 2: Details of Room Temperature MF* | | |

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*Fig 2: Membership function for Room Temperature*

1. Humidity

To maintain a balanced temperature inside home, humidity also considered as considering factor. The range is given from 0 to 100 %. Membership function divided into 5 values VL, L, M, H and VH as shown in table 3 and Fig 2.

|  |  |  |
| --- | --- | --- |
| Membership Function | Range (%) | Type |
| VL | 0 to 20 | Trapezoid |
| L | 10 to 40 | Triangle |
| M | 25 to 75 | Triangle |
| H | 50 to 90 | Triangle |
| VH | 70 to 100 | Trapezoid |
| *Table 3: Details of Humidity MF* | | |

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*Fig 3: Membership function for Humidity*

1. Light

The day light is considered as one of the important factor for controlling automatic lamps in the house. The value ranges in between 0 to 20,000 Lux and the membership function divided into 5 different category as shown below.

|  |  |  |
| --- | --- | --- |
| Membership Function | Range (Lux) | Type |
| VL | 0 to 4000 | Trapezoid |
| L | 2000 to 8000 | Triangle |
| M | 4500 to 12000 | Triangle |
| H | 10000 to 16000 | Triangle |
| VH | 16000 to 20000 | Trapezoid |
| *Table 4: Details of Light MF* | | |

Chart

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*Fig 4: Membership function for Light*

1. Body Temperature

Checking body temperature is critical for maintaining well balanced health conditions for elderly people and disable people. Alerting regular changes from the normal accepted range avoids unnecessary emergencies. Body temperature range is considered as 10 to 40 degree Celsius and divided into 5 different membership value ranges.

|  |  |  |
| --- | --- | --- |
| Membership Function | Range (℃) | Type |
| VL | 10 to 15 | Trapezoid |
| L | 12 to 25 | Triangle |
| M | 18 to 32 | Triangle |
| H | 25 to 38 | Triangle |
| VH | 36 to 40 | Trapezoid |
| *Table 5: Details of Body Temperature MF* | | |

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*Fig 5: Membership function for Body Temperature*

1. Blood Pressure

Blood pressure variations are common in elderly population and its highly risky too. Regular checks on blood pressure and alerting the same is essential. The blood pressure value range is considered between 70 to 140 mmHg and divided into 3 membership functions, L, N and H as shown in the below table.

|  |  |  |
| --- | --- | --- |
| Membership Function | Range (mmHg) | Type |
| L | 70 to 100 | Trapezoid |
| N | 95 to 130 | Triangle |
| H | 125 to 140 | Trapezoid |
| *Table 6: Details of Blood Pressure MF* | | |

Chart, line chart

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*Fig 6: Membership function for Blood Pressure*

1. Heart Rate

Similar to temperature and blood pressure, Heart rate is also important for analyzing whether a person is ill or not. The input range is considered between 20 to 140 bpm (Beats per Minute) and divided into 5 different membership value ranges as shown below.

|  |  |  |
| --- | --- | --- |
| Membership Function | Range (bpm) | Type |
| VL | 10 to 30 | Trapezoid |
| L | 20 to 70 | Triangle |
| M | 45 to 95 | Triangle |
| H | 70 to 120 | Triangle |
| VH | 100 to 140 | Trapezoid |
| *Table 7: Details of Heart Rate MF* | | |

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*Fig 7: Membership function for Heart Rate*

1. Human Presence

Human presence is an essential input for identifying whether a person is inside the house and control the devices based on that result. In this course work, considered human presence as input for automatic lamps. If a person is there in room, then only the lamp will be ‘on’ considering the light factor along with.

Presence range is defined in between 0 to 100 % and divided into 3 ranges VL, M and VH as shown below.

|  |  |  |
| --- | --- | --- |
| Membership Function | Range (%) | Type |
| VL | 0 to 40 | Triangle |
| M | 10 to 90 | Triangle |
| VH | 50 to 100 | Triangle |
| *Table 8: Details of Human Presence MF* | | |

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*Fig 8: Membership function for presence detector*

1. Moisture

There are changes that the elderly people keep the water taps on unknowingly for a longer period. Identifying moisture content on the floor and alerting the same is critical to avoid accidents. In this work, considered Moisture as input for water flow detector. The value range considered between 0 to 100% and divided into 5 ranges as shown below.

|  |  |  |
| --- | --- | --- |
| Membership Function | Range (%) | Type |
| VL | 0 to 20 | Trapezoid |
| L | 10 to 50 | Triangle |
| M | 25 to 75 | Triangle |
| H | 50 to 90 | Triangle |
| VH | 80 to 100 | Trapezoid |
| *Table 9: Details of Moisture MF* | | |

Diagram

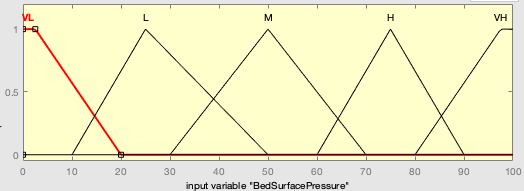
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*Fig 9: Membership function for Moisture*

1. Bed Surface Pressure

Bed surface pressure ideally indicate whether someone is laying on the bed or not. It helps in monitoring people who suffer insomnia. In this coursework, considered bed surface pressure as a key input for the bed occupancy detector device. If the person is not in bed for long time or in bed for long time, an alert will be generated. The input values range between 0 to 100% and divided into 5 membership functions.

|  |  |  |
| --- | --- | --- |
| Membership Function | Range (%) | Type |
| VL | 0 to 20 | Trapezoid |
| L | 10 to 50 | Triangle |
| M | 30 to 70 | Triangle |
| H | 60 to 90 | Triangle |
| VH | 80 to 100 | Trapezoid |
| *Table 10: Details of Bed Surface Pressure MF* | | |



*Fig 10: Membership function for Bed Surface Pressure*

1. Time Delay

Time delay is an import input for Bed Occupancy Detector in this work, as the alert should trigger considering a person’s delay in coming back to bed or getting on from bed. The input restricted into 1 hour. Values range from 0 to 60 minute and divided into 3 membership functions as shown below.

|  |  |  |
| --- | --- | --- |
| Membership Function | Range (minute) | Type |
| L | 0 to 25 | Trapezoid |
| M | 10 to 50 | Triangle |
| H | 30 to 60 | Trapezoid |
| *Table 11: Details of Time Delay MF* | | |

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*Fig 11: Membership function for Time Delay*

1. Smoke

Here smoke in general terms considered any form of CO2, CO or any other toxic gases. It is an important input for smoke detector in kitchen. The value range is considered between 0 to 100% and divided into 5 membership functions as shown below.

|  |  |  |
| --- | --- | --- |
| Membership Function | Range (%) | Type |
| VL | 0 to 20 | Trapezoid |
| L | 10 to 50 | Triangle |
| M | 30 to 70 | Triangle |
| H | 60 to 90 | Triangle |
| VH | 80 to 100 | Trapezoid |
| *Table 12: Details of Smoke MF* | | |

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*Fig 12: Membership function for Smoke*

1. Type of Food

Designing a smart oven for kitchen appliance requires the information regarding the type of food that should be heated. The input values range between 0 to 100% and divided into 3 different membership functions like ‘Raw’, ‘Half-Cooked’ and ‘Fully-Cooked’ as shown below.

|  |  |  |
| --- | --- | --- |
| Membership Function | Range (%) | Type |
| Raw | 0 to 40 | Triangle |
| Half-Cooked | 20 to 90 | Triangle |
| Fully-Cooked | 70 to 100 | Triangle |
| *Table 13: Details of Type of Food MF* | | |

Line chart

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*Fig 13: Membership function for Type of Food*

1. Quantity of Food

Similar to type of food, quantity of food is also an essential input for the smart oven. The value range considered between 0 to 100% and divided into 3 membership functions like ‘Little’, ‘Medium’ and ‘Large’ as shown below.

|  |  |  |
| --- | --- | --- |
| Membership Function | Range (%) | Type |
| Little | 0 to 40 | Triangle |
| Medium | 20 to 90 | Triangle |
| Large | 70 to 100 | Triangle |
| *Table 13: Details of Quantity of Food MF* | | |

Chart, line chart

Description automatically generated

*Fig 13: Membership function for Quantity*

*of Food*

1. Water Temperature

Since water temperature differs with atmospheric temperature, while designing water boiler, considered water temperature as a key input. The input value ranges between 0 to 70 Degree Celsius and divided into 5 different membership functions as shown below.

|  |  |  |
| --- | --- | --- |
| Membership Function | Range (℃) | Type |
| VL | 0 to 15 | Trapezoid |
| L | 10 to 30 | Triangle |
| M | 20 to 50 | Triangle |
| H | 35 to 65 | Triangle |
| VH | 60 to 70 | Trapezoid |
| *Table 15: Details of Water Temperature MF* | | |

Diagram

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*Fig 15: Membership function for Water Temperature*

1. Surrounding Volume

Adjusting the volume of TV or any other devices like that, automatically is a good help for the elderly or disabled people. In this course work considered Surrounding Volume as input so that based on that the TV volume can be controlled. The value range considered between 0 to 40 decibel and divided into 5 different membership functions as shown below.

|  |  |  |
| --- | --- | --- |
| Membership Function | Range (db) | Type |
| VL | 0 to 8 | Trapezoid |
| L | 5 to 20 | Triangle |
| M | 10 to 30 | Triangle |
| H | 25 to 35 | Triangle |
| VH | 33 to 40 | Trapezoid |
| *Table 16: Details of Surrounding Volume MF* | | |

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*Fig 16: Membership function for Surrounding Volume*

Once the input variables are created, next step in FIS design is to design output variables and their membership functions. As shown in *table 1* designed 10 different output variables for smart home in this coursework. The output variables can be considered as the smart devices installed in the flat, in a general way.

Output Variables and Membership functions:

1. Heater

Heater is the device which controls the overall temperature of the home based on the room temperature and the humidity. The value range considered in between 0 to 10 as the heater output scale and divided into 5 membership functions (VL, L, M, H and VH) as shown below.

|  |  |  |
| --- | --- | --- |
| Membership Function | Range | Type |
| VL | 0 to 2.5 | Trapezoid |
| L | 1 to 5 | Triangle |
| M | 2.5 to 7.5 | Triangle |
| H | 5 to 8 | Triangle |
| VH | 7 to 10 | Trapezoid |
| *Table 17: Details of Heater MF* | | |

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*Fig 17: Membership function for Heater*

1. Automatic Lamp

Switching on and off the lamps automatically, by detecting the presence of a person in a room and the day light available, is always a smart design especially for energy savers. The lamp value ranges between 0 to 20,000 Lux and divided into 5 different membership functions as shown below.

|  |  |  |
| --- | --- | --- |
| Membership Function | Range (Lux) | Type |
| VL | 0 to 4500 | Trapezoid |
| L | 2000 to 8000 | Triangle |
| M | 4500 to 12000 | Triangle |
| H | 10000 to 16000 | Triangle |
| VH | 15500 to 20000 | Trapezoid |
| *Table 18: Details of Automatic Lamp MF* | | |

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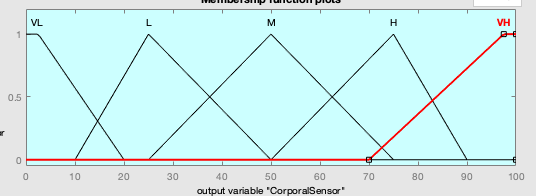
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*Fig 18: Membership function for Automatic Lamp*

1. Corporal Detector

Corporal Detector or illness detector can be considered as the most essential device that should be added in elderly support. It will take inputs as body temperature, blood pressure and heart rate and alerts any unusual variations from the normal rage. It helps the carers to identify if the person is ill or not. The detector values range from 0 to 100% and divided into 5 different membership functions as shown below.

|  |  |  |
| --- | --- | --- |
| Membership Function | Range (%) | Type |
| VL | 0 to 20 | Trapezoid |
| L | 10 to 50 | Triangle |
| M | 25 to 75 | Triangle |
| H | 50 to 90 | Triangle |
| VH | 70 to 100 | Trapezoid |
| *Table 19: Details of Corporal Detector MF* | | |



*Fig 19: Membership function for Corporal*

*Detector*

1. Water Flow Detector

Water flow detector can be placed in bathroom or in kitchen. It detects the overflow of water and identifies whether the tap is kept on for longer period or not by detecting the moisture content on the floor. The value range between 0 to 10 and divided into 5 membership functions as shown below.

|  |  |  |
| --- | --- | --- |
| Membership Function | Range | Type |
| VL | 0 to 2 | Trapezoid |
| L | 1 to 5 | Triangle |
| M | 3 to 7 | Triangle |
| H | 5 to 9 | Triangle |
| VH | 8 to 10 | Trapezoid |
| *Table 20: Details of water flow Detector MF* | | |

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*Fig 20: Membership function for water flow*

*Detector*

1. Bed Occupancy Detector

Bed occupancy detector is a small device, that can be placed below the bedsheet. It allows to identify whether a person is there in bed or not. It’s a key device that can be installed for elderly support as we may alert the carer if the person is not return to bed after a certain period of time or if a person did not get up from bed after a certain amount of time. The value ranges from 0 to 100% and divided into 5 membership functions as shown below.

|  |  |  |
| --- | --- | --- |
| Membership Function | Range (%) | Type |
| VL | 0 to 20 | Trapezoid |
| L | 10 to 50 | Triangle |
| M | 30 to 70 | Triangle |
| H | 60 to 90 | Triangle |
| VH | 80 to 100 | Trapezoid |
| *Table 21: Details of Bed Occupancy Detector MF* | | |

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*Fig 21: Membership function for Bed Occupancy Detector*

1. Smoke Detector

Smoke detector detects the presence of smoke content in the surrounding and alerts it. The values range from 0 to 8 and divided into 5 membership functions as shown below.

|  |  |  |
| --- | --- | --- |
| Membership Function | Range | Type |
| VL | 0 to 2 | Trapezoid |
| L | 1 to 3 | Triangle |
| M | 2 to 5 | Triangle |
| H | 4 to 7.5 | Triangle |
| VH | 6.5 to 8 | Trapezoid |
| *Table 22: Details of smoke Detector MF* | | |

Chart, line chart

Description automatically generated

*Fig 22: Membership function for smoke*

*Detector*

1. Water Boiler

Water Boiler is the device to maintain the water temperature in bathroom. It considers the atmospheric temperature and water temperature to decide the water heating rate. Getting hot water for bathroom needs is essential for elderly and disabled population. The output scale range between 0 to 10 and divided into 5 membership functions.

|  |  |  |
| --- | --- | --- |
| Membership Function | Range | Type |
| VL | 0 to 2 | Trapezoid |
| L | 1 to 5 | Triangle |
| M | 3 to 7 | Triangle |
| H | 6 to 9 | Triangle |
| VH | 8 to 10 | Trapezoid |
| *Table 23: Details of Boiler MF* | | |

Chart, line chart

Description automatically generated

*Fig 23: Membership function for Boiler*

1. Smart Oven

Based on the type of food and quantity of food, the oven deices automatically the time require to heat up the food. The output scale varies between 0 to 60 minutes and divided into 5 different membership functions as shown below.

|  |  |  |
| --- | --- | --- |
| Membership Function | Range (Minute) | Type |
| VL | 0 to 10 | Triangle |
| L | 5 to 20 | Triangle |
| M | 10 to 40 | Triangle |
| H | 20 to 50 | Triangle |
| VH | 40 to 60 | Triangle |
| *Table 24: Details of Oven MF* | | |

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*Fig 24: Membership function for Oven*

1. Automatic Bed Lamp

Automatic Bed lamp turn on when a person gets up from bed in the nighttime. It will be helpful for elderly people especially as it can avoid unnecessary accidents. It considered the bed surface pressure and Light as inputs and turns on accordingly. The values range between 0 to 10000 lux and divided into 5 membership functions.

|  |  |  |
| --- | --- | --- |
| Membership Function | Range (Lux) | Type |
| VL | 0 to 2500 | Trapezoid |
| L | 1000 to 5000 | Triangle |
| M | 2500 to 7500 | Triangle |
| H | 5000 to 9000 | Triangle |
| VH | 7000 to 10000 | Trapezoid |
| *Table 25: Details of Automatic Bed Lamp MF* | | |

Diagram

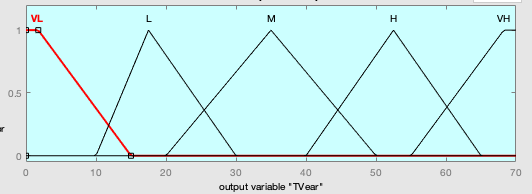
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*Fig 25: Membership function for Bed lamp*

1. TV Ear

TV Ear is a smart device which would automatically adjusts the volume of the TV according to the surrounding volume. The output TV volume ranges between 0 to 70 decibel and divided into 5 membership functions.

|  |  |  |
| --- | --- | --- |
| Membership Function | Range (db) | Type |
| VL | 0 to 15 | Trapezoid |
| L | 10 to 30 | Triangle |
| M | 20 to 50 | Triangle |
| H | 40 to 65 | Triangle |
| VH | 55 to 70 | Trapezoid |
| *Table 26: Details of Automatic TV Ear MF* | | |



*Fig 26: Membership function for TV Ear*

The FIS Engine:

The main component of a fuzzy control system is it’s FIS engine. It can be called as the brain of the control system. FIS engine maps the inputs to outputs in the form of rules. Well defined rules improve the efficiency of the system. Below is the Mamdani FIS system designed for this coursework.

Diagram

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*Fig 27: FIS system*

Below are the set of rules defined for each output variable and surface plot.

1. Heater

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Humidity | VL | L | M | H | VH |
| Temperature |  |  |  |  |  |
| VL | VH | VH | H | H | H |
| L | H | H | H | M | M |
| M | M | M | M | M | L |
| H | L | L | L | L | L |
| VH | VL | VL | VL | VL | VL |
| *Table 27: Heater rules* | | | |  |  |

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*Fig 28: Temperature, Humidity vs Heater*

1. Automatic Lamp

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Presence | VL | L | M | H | VH |
| Light |  |  |  |  |  |
| VL | VL | VL | H | VH | VH |
| L | VL | L | H | H | H |
| M | VL | L | H | H | L |
| H | VL | L | M | L | L |
| VH | VL | L | M | VL | VL |
| *Table 28: Automatic Lamp rules* | | | |  |  |

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*Fig 29: Light, Human Presence vs Automatic Lamp*

1. Corporal Detector

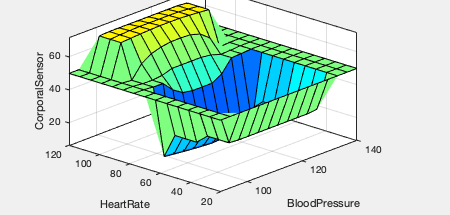
Here there are 3 inputs in the design, for the visualization simplicity, plotting the output against combination of two inputs.

Chart, surface chart

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*Fig 30: Blood Pressure, Body Temp vs Corporal Detector Fig 31: Heart rate, Body Temp vs Corporal Detector*

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*Fig 32: Blood Pressure, Heart rate vs Corporal Detector Fig 33: Corporal Detector rules*

1. Water Flow Detector

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Moisture | VL | L | M | H | VH |
| Water Flow Detector | VL | L | M | H | VH |
| *Table 29: Water Flow Detector Rules* | | |  |  |  |

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*Fig 34: Moisture vs Water Flow Detector*

1. Bed Occupancy Detector

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Bed Surface Pressure | VL | L | M | H | VH |
| Time Delay |  |  |  |  |  |
| VL | L | L | M | M | VL |
| L | L | L | M | M | VL |
| M | M | L | L | L | L |
| H | H | H | M | M | L |
| VH | VH | H | H | M | VL |
| *Table 30: Bed Occupancy Detector rules* | | | |  |  |

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*Fig 35: Bed surface pressure, Time delay vs*

*Bed occupancy detector*

1. Smoke Detector

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Smoke | VL | L | M | H | VH |
| Smoke Detector | VL | L | M | H | VH |
| *Table 31: Smoke Detector Rules* | | |  |  |  |

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*Fig 36: Smoke vs Smoke Detector*

1. Smart Oven

|  |  |  |  |
| --- | --- | --- | --- |
| Type of Food | Raw | Half-Cooked | Fully-Cooked |
| Quantity of Food |  |  |  |
| Little | VL | L | H |
| Medium | L | M | VH |
| Large | H | H | VH |
| Table 32: Oven Rules | | |  |

Chart, surface chart

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*Fig 37: Type of Food, Quantity vs Oven*

1. Water Boiler

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Room Temp | VL | L | M | H | VH |
| Water Temp |  |  |  |  |  |
| VL | VH | VH | H | H | M |
| L | VH | H | M | M | L |
| M | H | H | M | L | L |
| H | L | L | L | L | L |
| VH | VL | VL | VL | VL | VL |
| *Table 33: Boiler rules* | | | |  |  |

Chart, surface chart

Description automatically generated

*Fig 38: Room Temp, Water Temp vs Boiler*

1. Automatic Bed Lamp

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Light | VL | L | M | H | VH |
| Bed Surface Pressure |  |  |  |  |  |
| VL | VH | H | M | L | VL |
| L | VH | H | M | M | L |
| M | H | M | M | L | L |
| H | L | L | L | L | L |
| VH | VL | VL | VL | VL | VL |
| *Table 34: Automatic Bed Lamp rules* | | | |  |  |

Chart, surface chart

Description automatically generated

*Fig 39: Light, Bed Surface Pressure vs Bed Lamp*

1. TV Ear

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Surrounding Volume | VL | L | M | H | VH |
| TV Ear | VL | L | M | H | VH |
| *Table 35: TV Ear Rules* | | |  |  |  |

Chart, line chart

Description automatically generated

*Fig 40: Surrounding Volume vs TV Ear*

Overall, there defined 118 rules for this system. Once the rules are clearly defined in the FIS system, rules would be get aggregated for the prefect results. The weight for each rule is considered 1 in this work. An overview of rules can be shown in the below figure.

Table

Description automatically generated

*Fig 41: Aggregated rules*

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