Addis Ababa University
Addis Ababa Institute of Technology (AAiT)
Department of Electrical and Computer Engineering

Design and analysis of fuzzy logic based controller for flow and level control of cane in Wangi sugar factory

By

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DECLARATION

I, the undersigned declare that this thesis is my original work, and has not been presented for a degree in this or any other university, and all sources of materials used for the thesis have been fully acknowledged.

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Abstract

In a sugar production, flow and the amount of cane fiber carried by cane carrier varies due to non-uniformity of cane supply. The continuous variation of cane fibers flow and the level of cane fiber in chute during the cane juice extraction inversely affect the cane juice extraction efficiency of mill. In this thesis we have developed algorithm for a three input fuzzy controller with an aim to maintain the cane level in chute and flow during cane juice extraction. The developed controller generates signal that required controlling cane carrier motor speed depending upon the value of cane level in chute, quantity of cane on rake carrier and flow rate. The three inputs fuzzy controller is developed and simulated for six cases by using fuzzy logic toolbox of MATLAB.

The performance of the controller is compared in terms of disturbance rejection, transient and steady sate performance.

It is observed from the simulation results that the average overshoot is 0%, rising time is 0.0817 seconds and the settling time is 0.274 seconds with the proposed fuzzy controller while overshoot is 7.62%, rise time is 0.0513 second and settling time is 0.16 seconds with PID controller. Moreover, the robustness and disturbance rejection of the controllers is checked by parameter variation like time constant, delay time & DC gain and giving disturbance signal after settling time respectively. It is further observed that the proposed controller has better disturbance rejection and more robust.

K**eywords**: sugar mill, cane carrier, chute, juice extraction, fuzzy algorithm, fuzzy controller

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ABBREVIATION

VHDL	Very High Speed Integrated Circuits Hardware Description Language
AAiT	Addis Ababa Institute of Technology
AAU	Addis Ababa University
FLC	Fuzzy Logic Controller
NB	Negative Big
NM	Negative Medium
NS	Negative Small
PB	Positive Big
PID	Proportional Integral derivative
PM	Positive Medium
PS	Positive Small
Z	Zero
FPGA	Field Programmable Gate Array
Do	The diameter of roll when measured from the tip of groves
Dg	the length of groves
Ea	armature voltage
Kb	back emf constant (Vs/rad)
La	armature inductance
Ia	armature current
Eb	back emf (v)
W	angular speed (rad/sec)
Θ	angular position of rotor shaft (rad)
Jm	motor moment of inertia
Kf	windage torque coefficient (Nms/rad)

Qi	the inflow rate of cane fiber
Qo	The outflow rate (in m3/sec) of the cane fiber from chute
H	the height of the fiber level of the chute at any time instant.
A	the cross sectional area of the chute
Ke	torque constant of motor (Nm/A)
Ra	armature resistance
CL	capacitance of cane fiber

CHAPTER ONE

INTRODUCTION

1.1 Background

Cane juice extraction is a very important process during sugar making. The supply of cane for processing is very uneven and this uneven supply of cane during juice extraction adversely affects the sugar mill efficiency and causes mill breakdown, stoppage and jamming [2]. The level of cane fiber in Donnelly chute is very crucial. If the level of cane fiber is very low then there may be chances of passing of cane fiber uncrushed from the mill and if the level of cane fiber is very high then there is a chance of breakdown due to heavy load on mill. Therefore, an operator will control the level of cane fiber in Donnelly chute by varying the speed of cane carrier motor. If the level of cane fiber is very low then operator will increase the speed of the cane carrier so that level of cane fiber rise in Donnelly chute and if the level of cane fiber is very high then operator will decrease the speed of the cane carrier so that level of cane fiber falls in Donnelly chute. Because of such type of controlling is not effective and is not good in performance it is better to develop an intelligent three input fuzzy controller which maintains the cane level at desired height in chute during cane crushing by nullifying the variation in cane supply and roll speed and also control the flow of cane. The fuzzy controller for maintaining the cane level in Donnelly chute generates the signal for controlling the speed of motor driving the rake carrier depending upon the cane amount on rake, level of cane in Donnelly chute and flow of cane.

1.2 Statement of problem

The supply of cane for processing is very uneven and this uneven supply of cane during juice extraction adversely affects the sugar mill efficiency and causes mill breakdown, stoppage and jamming. There are many alternative controller design theories that can be used to control the level and flow of cane fiber. Proportional control, PI control, PD control and PID control will be investigate to determine which controller is the best for cane level control. Even though the conventional controller is widely used in industrial process, they have drawback of like:-

- Tuning convectional controller like PID is time consuming.
- only an expert or experienced worker are able to monitor and tune PID
- It is impossible to achieve satisfactory performance when there is no experienced human power
- it is not cost effective
- It is not simple to design and implement
- It is not robust and doesn’t have good dynamic response,
- It has long rise time and large overshoot

For this reason, it is desirable to introduce other type of controller such as artificial fuzzy logic controllers because of these controllers have better performance.

1.3 objectives

1.3.1 General objective

The general objective of this thesis work is to design and analyze fuzzy logic controller for flow and level control of cane in Wangi sugar factory

1.3.2 Specific objective

The specific objective of this thesis work is:

- To study different flow and level control of cane in sugar factory.
- To design fuzzy logic based controller for flow and level of cane in sugar factory.
- To simulate the design of fuzzy logic based controller for flow and level control using MATLAB
- To analyze fuzzy logic based flow and level of cane in sugar manufacturing process.

1.4 Relevance and scope of the Thesis

To have good understanding about fuzzy logic controllers in controlling nonlinear activities like level and flow control of cane, and to study the design of level and flow control of cane and propose implementable design for the future in order to produce cost effective and good cane flow and level control.

1.5 outline of the thesis

This thesis is organized into **five chapters**. The first chapter presents the overview of level and flow control of cane, statement of the problem, relevance and objectives of the study.

In **chapter two**, different literatures, related to level and flow control of cane system, are reviewed. Besides, the basic of fuzzy and PID controllers are also reviewed.

System modeling, designing and analysis are presented in **chapter three**. Simulation and experimental results are presented and discussed in **chapter four**. Finally, **chapter five** presents conclusions and recommendations.

CHAPTER TWO

2.1 LITERATURE REVIEW

One of the basic problems in sugar production industries is cane flow and level controlling system. Level of cane being an important process parameter has to be maintained at the desired level for smooth running of the process and for better quality product. All of the process industries, water treatment plants, and nuclear power plants are contingent upon controlling the level in tank systems. It is vital for engineers work in these plants especially control and mechatronics engineer to have a good understanding to how the chute level controlling system work and how the level control is managed. Most of the control performances in the actual design are usually defined by overshoots, rising time, settling time, steady state error, etc. [1][2]. There are different controlling techniques used to control the level and flow of system like liquid, fluid, fiber, etc. some of them are listed below.

The engineers in the past have used the mathematical model of the system to design a controller based on a linearized model of real control systems, but the problem is that the response of complex and non-linearity of real process is hard to find by applying conventional control techniques (like PID controller) some experiments appearance that the simple PID with constant parameter not achieve response of level chute system [4][5]

Using intelligent system like Fuzzy controller can consider an effective ways to solve this problem Fuzzy controller have a logical of the human behavior in make decision. And as result gives the better performance than convectional controllers.

2.2 Intelligent techniques

Tunyasrirut and Wangnipparnto (2007) have developed a cascade control scheme with fuzzy logic controller in primary (level) loop and conventional PID in secondary (flow) loop in a liquid level control system to control the level of horizontal tank that has diameter 300 mm and 480 mm long. Interface card module in computer and Lab VIEW software program is used for building the cascade controller. The inner loop uses a PID controller for regulating the flow rate of the system and outer loop uses a fuzzy logic controller to control the level. The response time, steady state error, load disturbance and control valve action of cascade control system are tested and compared with the simple controller. The experimental results shows that for the same water level of 50% set point, the rising time noticed with the cascade controller was less than the simple controller about 1750 ms, and has a steady state error less than simple controller of about ±1%. The load disturbance on the plant has no affect when using the cascade controller. The cascade controller that comprises of the PID and the fuzzy logic control improves the dynamic characteristics of the liquid level control system. Limitation is that an increase in settling time of 100 sec is noticed with this method.

Kumar et al (2008) have proposed a cascade control strategy with combined Fuzzy PI and Fuzzy PD in primary loop and conventional PI in secondary loop in a liquid level control system and achieved a settling time of 194 sec and overshoot of 4.5%. A comparative study was carried out to evaluate the real time performance of Fuzzy Proportional-Integral plus Fuzzy Proportional-Derivative (Fuzzy PI + Fuzzy PD) controller with the real time performance of conventional PI controller for a liquid level process. The process considered for this experiment shows highly nonlinear behavior due to equal percentage pneumatic control valve. National Instruments based hardware and software tools (Lab VIEW) were used for precise and accurate acquisition, measurement and control. The real time implementation of the Fuzzy PI + Fuzzy PD controller was carried out in two configurations namely, feedback and cascade. In cascade control configuration, Fuzzy PI + Fuzzy PD controller was implemented in the primary loop. The secondary loop was tuned using the conventional PI controller and the results illustrate that that fuzzy controller perform better in comparison with conventional controller in both the feedback and cascade control configurations. Limitation is that the tuning of controllers becomes a difficult task when fuzzy logic controllers are combined with PI and PD controllers.

Sangeetha et al (2012) have proposed a PID based cascade control scheme for the regulation of level in level control systems through Supervisory Control and Data Acquisition System (SCADA) – Programmable Logic Controller (PLC) – Open Process Control (OPC) interface and a network architecture with no overshoot. The cascade control system was the combination of level (primary process) and flow (secondary) processes. The SCADA was developed with PID controller. The characteristics of the cascade control system have been analyzed through the performance indices, such as peak time, rise time and settling time. The error values such as Integral Square Error (ISE) and Integral Absolute Error (IAE) are also calculated. The performances of cascade control system are validated through number of architectures, such as SCADA, PLC, OPC and internet. The introduction of PLC and National

Instruments NI-OPC server has significantly improved the performance of conventional processes such as level, flow and cascade control systems. However a huge settling time of 107seconds is noticed with this method.[1][2]

In this thesis, fuzzy and PID controller is designed and applied to the cane level and flow control system. Then the fuzzy controller is used to make the system fast and stable.in result a comparison between two controllers was presented.

2.3 Introduction of sugar production Process

In the sugar production the cane is first passed through two sets of rotating knives which converts the cane billets into cane fiber by hammering it by shredder knives. This cane fiber is called prepared cane. The cane fibers are feed to Donnelly chute and cane juice is extracted by crushing fiber in two, three or four rolls of the mill. This process is repeated through sets of five/six mills until last mill is reached [2] [3].

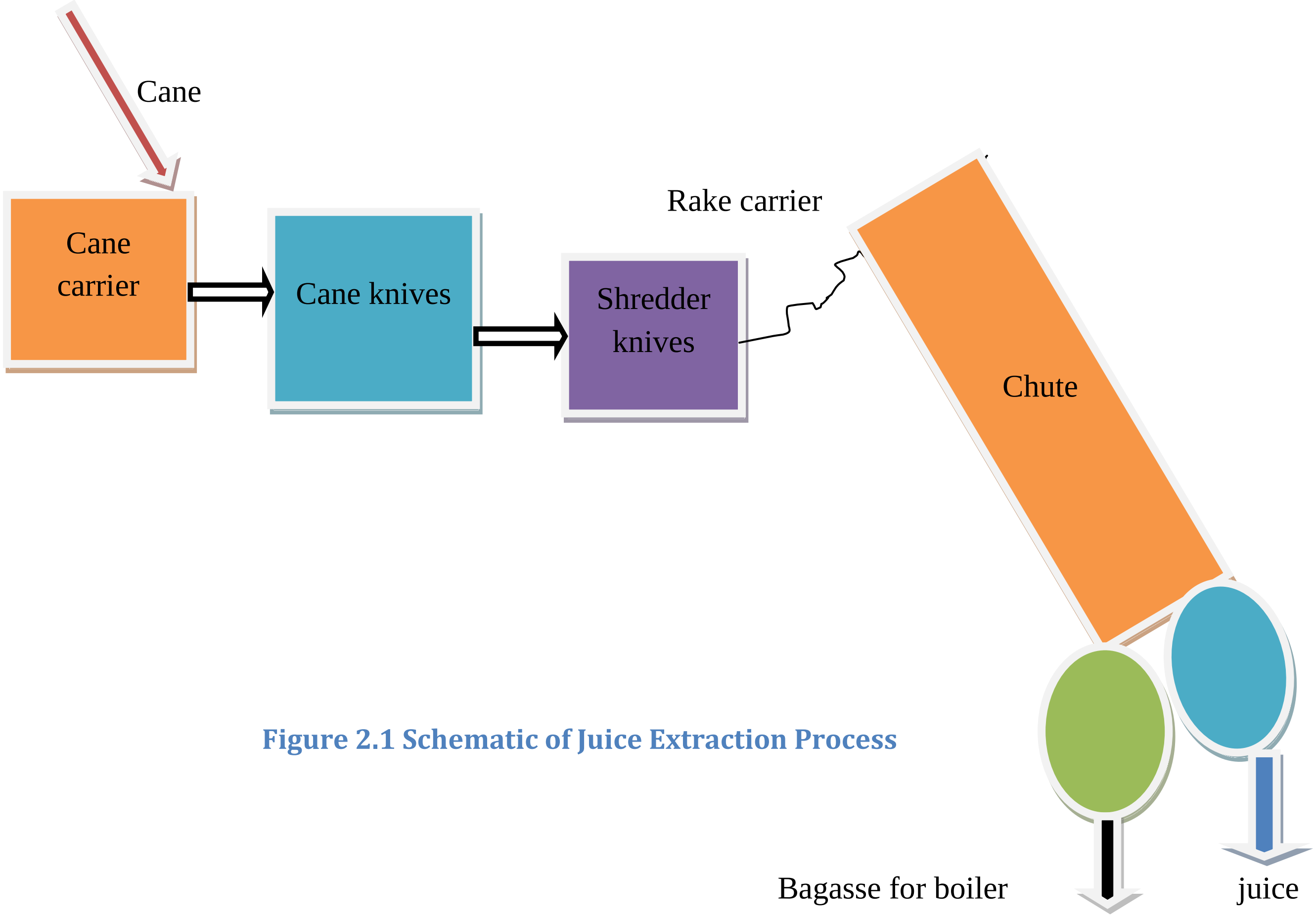


Figure 2.1 Schematic of Juice Extraction Process

If the level of prepared cane is very low then there may be chances of passing of cane uncrushed from the mill and if the level of prepared cane is very high then there is a chance of mill breakdown due to heavy load on mill so the level of cane fiber in Donnelly chute is very crucial. The amount of cane fiber varies due to non-uniformity of cane supply. If the level of cane fiber falls below the desired level then more cane fiber is to be dumped in chute and if the level of cane fiber rises above the desired level the raised level is to be brought back to desired cane level [4].The conventional controller is developed with the help of VHDL [5] and implemented in FPGA [6]. VHDL is one of the most accepted and widely used languages for describing a digital system. In this thesis we developed a controller with an aim of maintaining the cane level and flow at constant height in Donnelly chute using fuzzy logic controller.

2.4 parameters of a 2-roll mil

Two rolls and the chute arrangement used for cane crushing. It has been investigated that the physical structure of mill effect the feed depth at which maximum crushing rate can be achieved [10]. The diameter of roll when measured from the tip of groves is Do and Dg is the length of groves and D is the average diameter of roll.

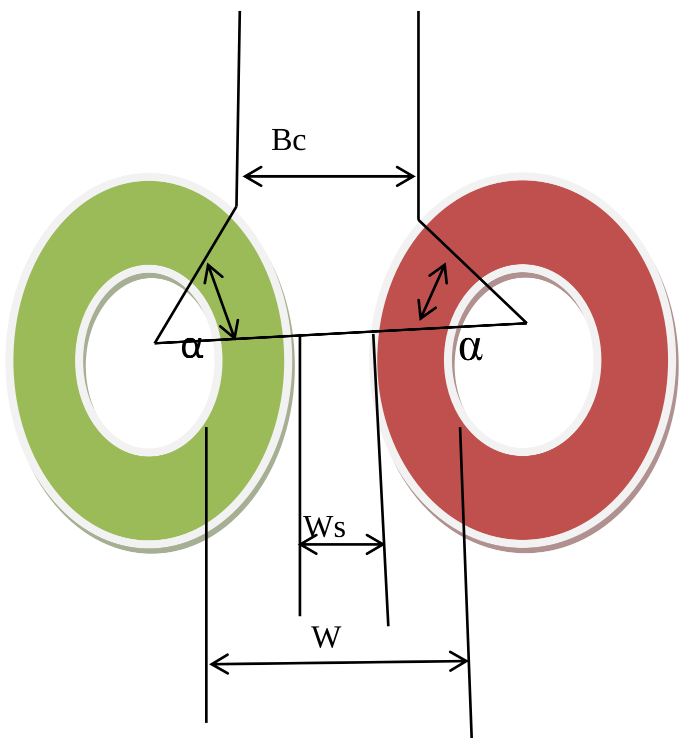


Figure 2.2 two roll and chute arrangement of mill

The mean diameter of roll is given as:

D = D o – Dg……………………………………………………………………………….2.1

Where Do is the outside diameter of roll and Dg is Groove Depth. The opening measured between the two rolls outside diameter is called as nib opening or set opening. The opening measured between the mean diameters of two rolls is called work opening [11] and is given as:

W = Ws + Dg……………………………………………………………………………………2.2

Where Ws is nib opening. The surface speed of roll is given as:

S = (p × D ×N)/60 ………………………………………………………………………………2.3

Where S is surface speed of roll in cm/s and N is roll shaft speed in rpm. The thickness of cane blanket at the feed opening of the mill effects the juice extraction from the mill. The optimum feed depth is investigated and found as follows

Bc = (W+D)/2 …………………………………………………………………………………..2.4

Here Bc is the optimum feed depth in cm [11]. The contact angle is the angle between the line joining the center of the two rolls and the line joining the center of roll to the point where chute touches the roll [12].

The contact angle is given as:

Cos α = (D + W –Bc) / D …...2.5

The scribed volume is the volume of prepared cane passing through the work opening of the mill [12] and is given as:

Ve = Lr × D × S[1 + (W/D) - Cos α) Cos α…………………………………………………….2.6

Where Ve is scribed volume in ($\frac{m^3}{s}$) and Lr is roll length in cm. The average speed of cane blanket at the point where chute touches the rolls is given as

S = S Cos α ……………………………………………………………………………………..2.7

Where Sf is the average speed of cane blanket in cm/s. At the entry of chute the volume of cane passing the entry plane is given as [13]:

Ve = Lr × Bc × S Cos α……………………………………………………...................2.8

The fiber rate is the amount of fiber crushed by mill in one second and it is given as:

Qf = (Qc× f)/ 100……………………………………………………………………………..2.9

Qf is the fiber rate in Kg/s, where **Qc** is cane crushing rate in Kg/s and **f** is the percentage of fiber present in cane.

The prepared cane is carried by cane carrier and dumped in chute. The chute is inclined to horizontal and the angle of inclination and the dimension of chute vary from one mill to other.

The length of chute (L) is 180cm, width (W) is 43.5cm and depth (D) is 183cm. The Roll length (Lr) is 183cm, roll diameter (D) is 200cm and work opening (W) is 11.45cm.

The optimum angle is 61°. The optimum feed depth (Bc) is 43.5cm. It is required to select parameters for a mill which cane crush 2000 tons cane per day (tcd). Allowing about 10% excess crushing, the maximum mill capacity should be 2200 tcd. For achieving 2200 tcd crushing of cane the mill must be able to crush 26.6Kg/s cane [14].

The amount of cane crushed by mill in one second is termed as flow rate and denoted as Qc. We can relate flow rate with cane density and scribed volume as follows:

$Qc = \rho c * Ve$ ……………………………………………………………………………………2.10

Where Ve is scribed volume and ρc is density of cane (350Kg/m^3). The scribed volume is 0.076m^3 /s. The surface speed of roll is 16.6cm/s. The average speed of cane blanket when it touches the roll surface is 9.5cm/s. If the cane crushing rate is 26Kg/s and the fiber percentage in cane is 15% then the fiber rate is 4Kg/s.

The Pressure required to feed mill is given as follows [10]:

$p2=\int_{\beta}^{\alpha} pv\cos\theta \tan(\theta - \beta) d\theta]/(Bc/D)$ …………………………………………………………...2.11

Where p2 is the pressure required at chute exit, pv is the pressure applied to the cane, θ is the angle with which chute is inclined to horizontal, β is the angle with which mill will be feed without the application of external force. β is given as:

$\beta = tan^{-1}\mu$……………………………………………………………………………………2.12

Where μ is the coefficient of friction and its value selected in this application is 0.3. Solving (2. 12) after putting α = 61°, θ=61° and β = 20° then pv is given as

$pv= 36.9\ (100\ Cf - 3.3)^2$…………………………………………………………………..2.13

Where Cf is filling ratio and is given as: $Cf = \gamma$ /1260Kg/m^3)……………………………...2.14

Where γ is called compaction and its value in this application is 52Kg/m^3

The value of Cf is 0.041. The value of the pressure applied to the cane (pv) calculated as 23.6lb/ft^2(0.01152Kg-force/cm^2) and the pressure required at chute exit (p2)is calculated 0.02352Kg-force/cm^2 (2.3KPa). In an open chute, the pressure due to fiber is given as:

$P2 = \rho c\ (\sin\theta - \mu\cos\theta)L$ [15]……………………………………………………………...2.15

Where L is the height of cane in chute and the value of θ in this application is 61°. The height of cane in open chute is 92cm. In order to minimize the failure rate of fiber the cane must be maintained at 90cm in chute.

The cane fiber is assumed to fail in a similar was to soils. The failure ratio in fiber is the ratio of maximum shear stress to shear strength of fiber. A volume of prepared cane contains fiber, air and juice. When fiber is compressed in a pair of roll then air is expressed until fiber contains only fiber and juice. Any further compression of fiber expresses juice. It has been investigated that failure rate of fiber decreases with the increment of pressure applied on fiber at mill opening but beyond certain value the failure rate starts increasing with the increment of pressure. The failure rate is minimum (0.04) when the feed pressure is 2kPa [16][17].

2.5 .controller and interfacing circuits

The prepared cane is dumped in Donnelly chute of height 180cm. The Rake Carrier which carries the prepared cane up to Donnelly chute is of length 800cm, width 150cm and its weight is 500Kg. The rake carrier is run by a motor whose speed can be varied from 17rpm to 116rpm. The amount of prepared cane on rake carrier varies from 500Kg to 1000Kg. This variation of prepared cane can be measured with a load cell. Due to uneven supply of cane billets the level of prepared cane varies in Donnelly chute. This variation of cane level is measured with the help of a light sensor. The two rolls TRF 1 and TRF 2 rotates in anti-clockwise direction with the surface speed in the range from 12cm/s to 16.6cm/s. The steam turbines are used to rotate the rolls in sugar mill. The final product left out after the extraction of juice from the milling train is called bagasse. This bagasse is used as fuel to produce steam and this steam is used to run turbines. In a sugar mill the supply of steam to run turbine is not uniform, therefore the rotational speed of rolls vary. A tachometer can be used to calculate the speed of rolls. The three variables are the weight of prepared cane on rake carrier, flow rate and level of cane in Donnelly chute. A control algorithm is developed in this thesis with an aim of changing the speed of rake carrier depending upon the values of the three variables so that the cane level in Donnelly chute will remain constant.

A. Load Cell – It is used to measure the amount of cane available on rake carrier. Its full capacity is 1500Kg with 10V excitation. The load cell generates 13.3μV/Kg, 13.3mV for 1000Kg and 20mV for 1500Kg. The weight of carrier is 500Kg and the weight of cane will vary from 500Kg to 1000Kg. Therefore, load cell will generate a voltage in the range of 13.3mV to 20mV. A load cell signal conditioning system is designed by using Edraw max software as shown in Fig.2.3

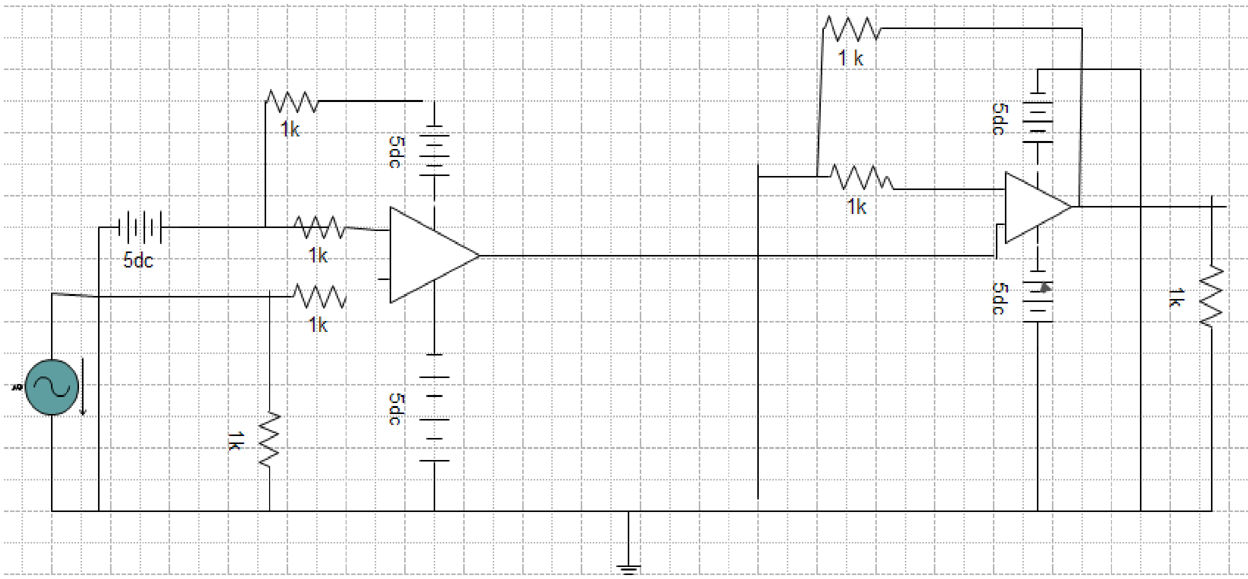


Figure 2.3 load cell signal conditioning system is designed by using Edraw max software

Table 2.1 the digital output corresponding to different load condition on carrier

Carrier weight including cane (Kg)	Output of load cell (mv)	Output of signal conditioning system (v)	Output of ADC (Hex)
1000	13.33	0	00H
1050	13.99	0.261	1BH
1100	14.66	0.509	34H
1150	15.33	0.756	4DH
1200	15.99	1000	66H
1250	16.66	1250	80H
1300	17.32	1490	99H
1350	17.99	1770	B5H
1400	18.66	1980	CBH
1450	19.32	2230	E4H
1500	20.00	2500	FFH

The purpose of signal conditioning system is to change the voltage range 13.3mV-20mV to 0-2.5V. The output of load cell signal conditioning system is connected to an eight bit analog to digital converter (part number 804). The ADC is calibrated to have a step size of 9.77mV. The digital output corresponding to different load condition on carrier is given by Table 1.

Example I – The signal conditioning system generates 1.25V when carrier has 750Kg cane. The simulated output of signal conditioning system is shown. The ADC output is given as follows:

D = Vin/ SS……………………………………………………………………………….2.16

Where Vin = input voltage to ADC = 1.25V

SS = Step size When Vin is 1.25V and SS is 9.77mV then from 2.16 the output of ADC comes to be 128 in decimal or 80H in hexadecimal.

B. Height Sensor – It is used to measure the cane level in chute. A schematic for sensing the height of cane level in chute is shown in Fig.2.5

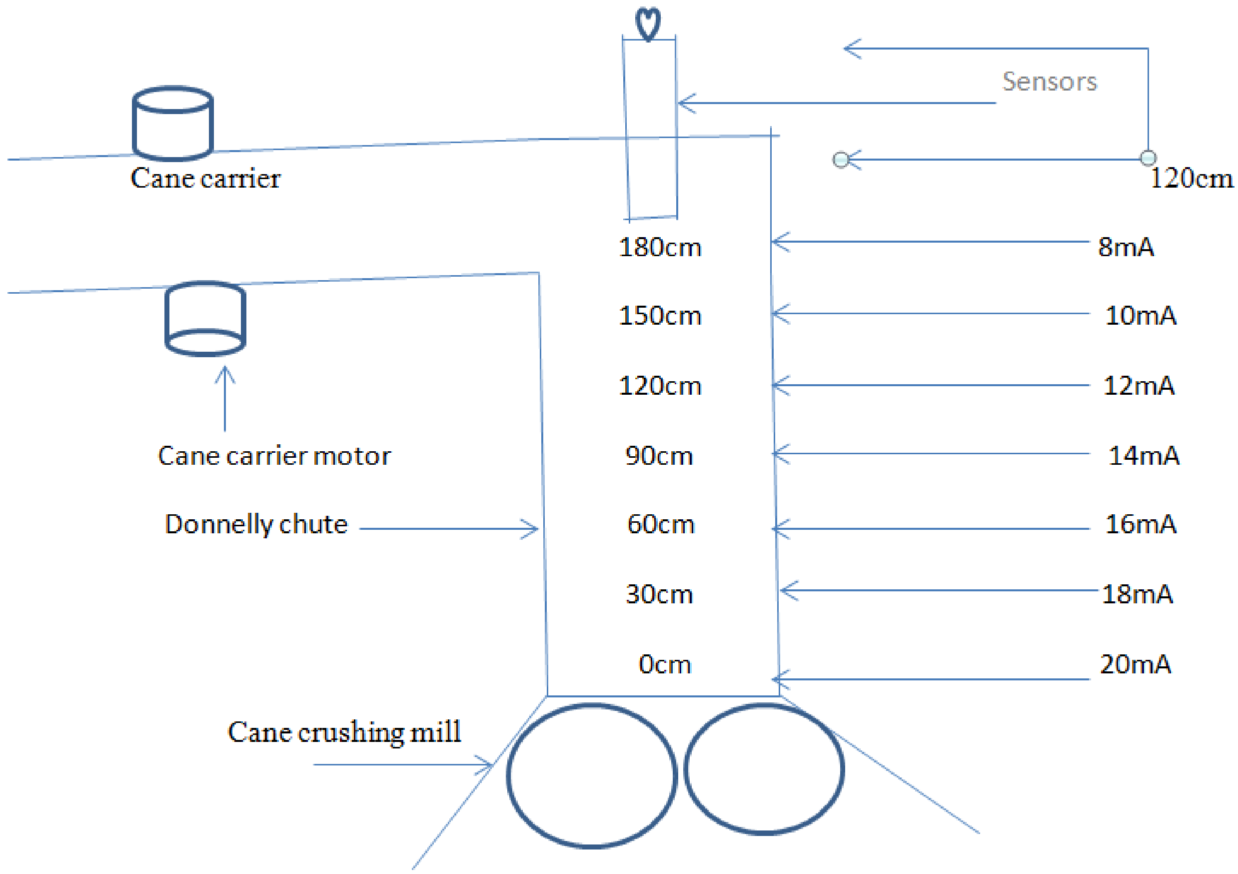


Figure 2.4 schematic for sensing the height of cane level in chute

A light sensor is placed at height of 300cm from the base of chute. When the cane is at the base of chute then sensor will generate 20mA and when the cane is at 180cm height then the sensor will generate 8mA. A height sensing signal conditioning system is designed by using Edraw max software as shown in Fig.2.5

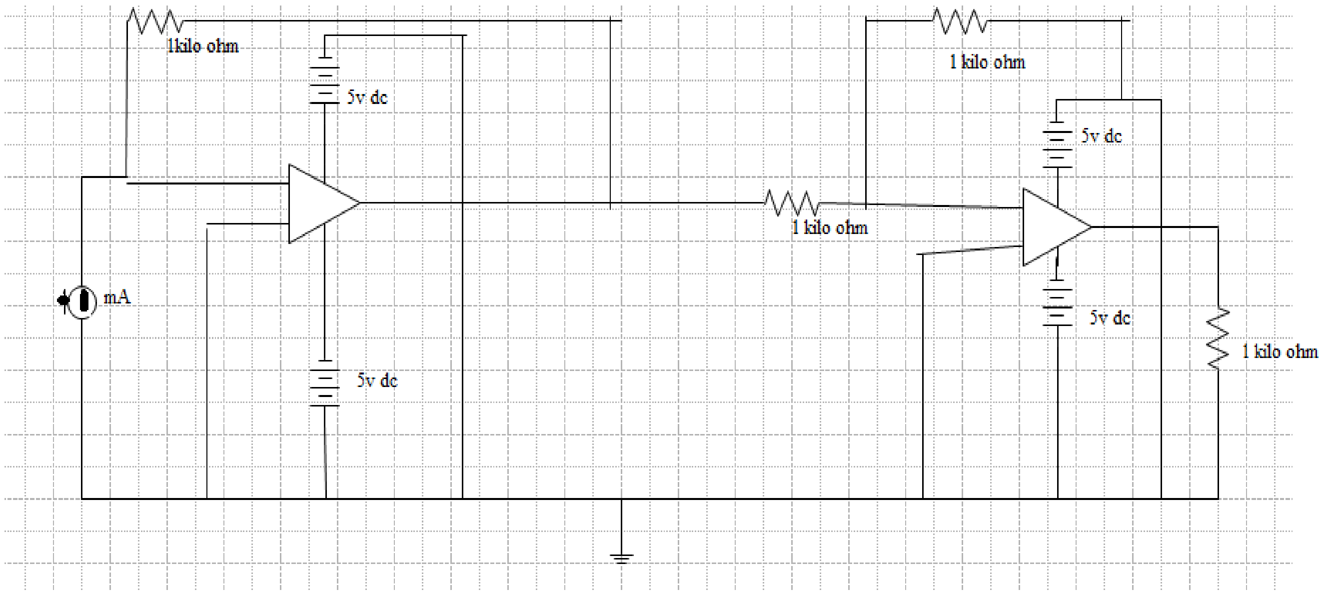


Figure 2.5 height sensing signal conditioning system is designed by using Edraw max software.

Table 2.2 the digital output corresponding to different level of cane fiber in chute

Cane height (cm)	Output of sensors (mA)	Output of signal conditioning(v)	Output of ADC
0cm	20MA	2V	32H
30cm	18MA	1.8V	47H
60cm	16MA	1.6V	5BH
90cm	14MA	1.4V	70H
120cm	12MA	1.2V	84H
150cm	10MA	1V	99H
180cm	8MA	0.8V	ADH

The purpose of height sensing signal conditioning system is the conversion of the current output of height sensor into voltage. The output of height sensor to measure cane level from 0 to 180cm is 20mA to 8mA respectively. The output of conditioning system is from 0.8V to 2V.

The output of photo cell signal conditioning system is connected to an eight bit analog to digital converter (part number 804). The ADC is calibrated to have a step size of 9.77mV. The digital output corresponding to different level of cane in chute

C. Flow sensors:-it is used to measure the flow of cane fiber in the production process .in Wangi sugar factory they use G1/2 Hall Effect flow sensor that sense the flow using unit turbine rotor inside it, whose speed of rotation changes with the different rate of flow. It full capacity is 1250L/min with 5-10vexcitation. The flow sensor generates 48mA for one liter of juice and 60A for 1250 liter of juice. Therefore flow sensor will generate voltage 0.48A to 60A in the present application.it will design using Edraw max software.

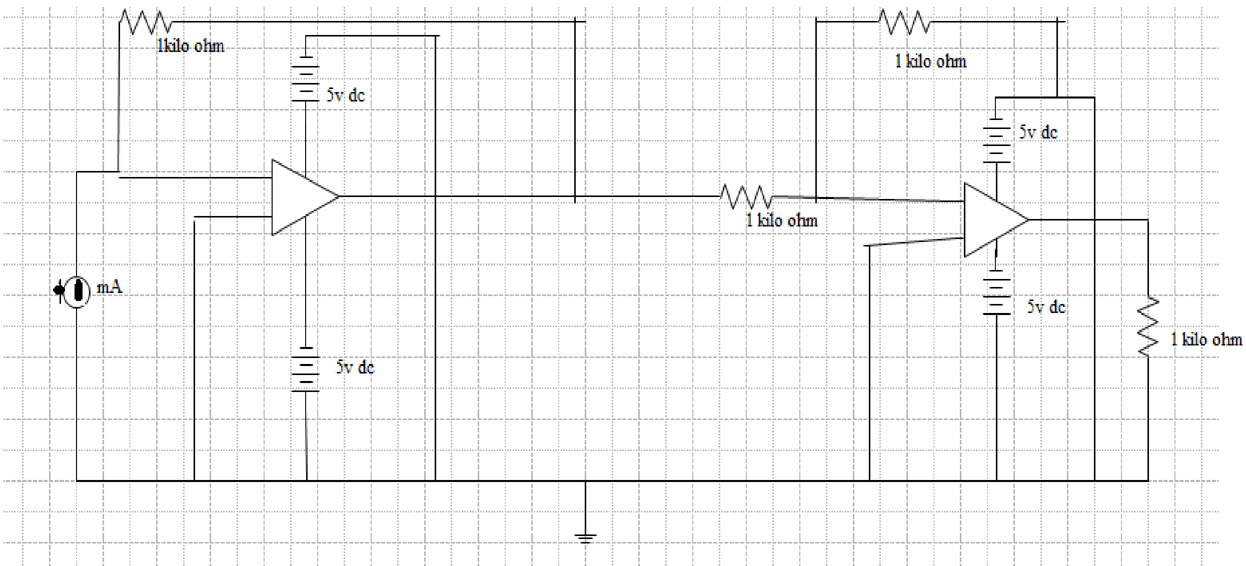


Figure 2.6 flow sensing signal conditioning system is designed by using Edraw max software.

Table 2.3 the digital output corresponding to different flow of cane fibers

S.NO	Flow level of cane fiber(L/min)	Output of flow sensor (A)	Output of signal conditioning (v)	ADC (hex)
1	0	0.48	1.6	A4H
2	312.5	15	1.7	B5H
3	625	30	1.8	B8H
4	937.5	45	1.9	E8H
5	1250	60	2.0	CDH

2.6 Level and flow control of cane in sugar factory

To control the required quality flow and level of cane, the different types of controller like. PI, PID, Fuzzy, Fuzzy PID, feedback linearization and sliding mode controllers are used.

2.6.1 PID Controller

The PID controller is the most common form of feedback. It was an essential element of early governors and it became the standard tool when process control emerged in the 1940s [8-10][13][14]. In process control today, more than 95% of the control loops are of PID type, most loops are actually PI control. PID controllers are today found in all areas where control is used. The controllers come in many different forms. There are standalone systems in boxes for one or a few loops, which are manufactured by the hundred thousand yearly. PID control is an important ingredient of a distributed control system. The controllers are also embedded in many special purpose control systems. PID control is often combined with logic, sequential functions, selectors, and simple function blocks to build the complicated automation systems used for energy production, transportation, and manufacturing. Many sophisticated control strategies, such as model predictive control, are also organized hierarchically. PID control is used at the lowest level; the multivariable controller gives the set points to the controllers at the lower level [16]. PID controllers have survived many changes in technology, from mechanics and pneumatics to microprocessors via electronic tubes, transistors, integrated circuits. The microprocessor has had a dramatic influence on the PID controller. Practically all PID controllers made today are based on microprocessors. This has given opportunities to provide additional features like automatic tuning, gain scheduling, and continuous adaptation [8].

2.6.1.1 Algorithm of PID controller

A PID controller continuously calculates an error value as the difference between a desired set point and a measured process variable. The controller attempts to minimize the error over time by adjustment of a control variable, such as the level of cane in chute, a weight of cane, [8] [9]

$$U(t) = kpe(t) + ki\int_0^{\tau} e(\tau)d\tau + kd\frac{de(t)}{dt} \qquad \text{2.17}$$

Where kb, kd and ki all non-negative, denote the coefficients for the proportional, integral and derivative terms, respectively (sometimes denoted P, I, and D).

Proportional term: accounts for present values of the error. Because a non-zero error is required to drive it, a proportional controller generally operates with a so-called steady state error. Steady-state error (SSE) is proportional to the process gain and inversely proportional to proportional gain. SSE may be mitigated by adding a compensating bias term to the set point or output, or corrected dynamically by adding an integral term [15].

The proportion gain is given by

$P_{out} = K_p$……………………………………………………………2.18

Integral term accounts for past values of the error. The contribution from the integral term is proportional to both the magnitude of the error and the duration of the error.

The integral in a PID controller is the sum of the instantaneous error over time and gives the accumulated offset that should have been corrected previously. The accumulated error is then multiplied by the integral gain and added to the controller output. The integral term is given by:

The integral term accelerates the movement of the process towards set point and eliminates the residual steady-state error that occurs with a pure proportional controller. However, since the integral term responds to accumulated errors from the past, it can cause the present value to overshoot the set point value [15].

The integral term is given by

$I_{out} = ki\int_0^\tau e(\tau)d\tau$……………………………………………………………………………2.19

Derivative term accounts for possible future values of the error, based on its current rate of change. The derivative of the process error is calculated by determining the slope of the error over time and multiplying this rate of change by the derivative gain.

The PID Based flow and level control of cane is the contribution of the derivative term to the overall control action is termed the derivative gain, Kd [15]

The derivative term is given by:

$D_{out} = Kd\frac{de(t)}{dt}$……………………………………………………………………………….2.20

Derivative action predicts system behavior and thus improves settling time and stability of the system. An ideal derivative is not causal, so that implementations of PID controllers include an additional low pass filtering for the derivative term, to limit the high level of cane and weight [15]. As a PID controller relies only on the measured process variable, not on knowledge of the underlying process, it is broadly applicable. By tuning the two parameters of the model, a PID controller can deal with specific process requirements. The response of the controller can be described in terms of its responsiveness to an error, the degree to which the system overshoot set point, and the degree of any system oscillation. The use of the PID algorithm does not guarantee optimal control of the system or even its stability [8]. Some applications may require using only one or two terms to provide the appropriate system control. This is achieved by setting the other parameters to zero. A PID controller will be called a PI, PD, P or I controller in the absence of the respective control actions. PI controllers are fairly common, since derivative action is sensitive to measurement noise, whereas the absence of an integral term may prevent the system from reaching its target value [14][15].

The PID controller algorithm that operates as a position algorithm is shown in the following

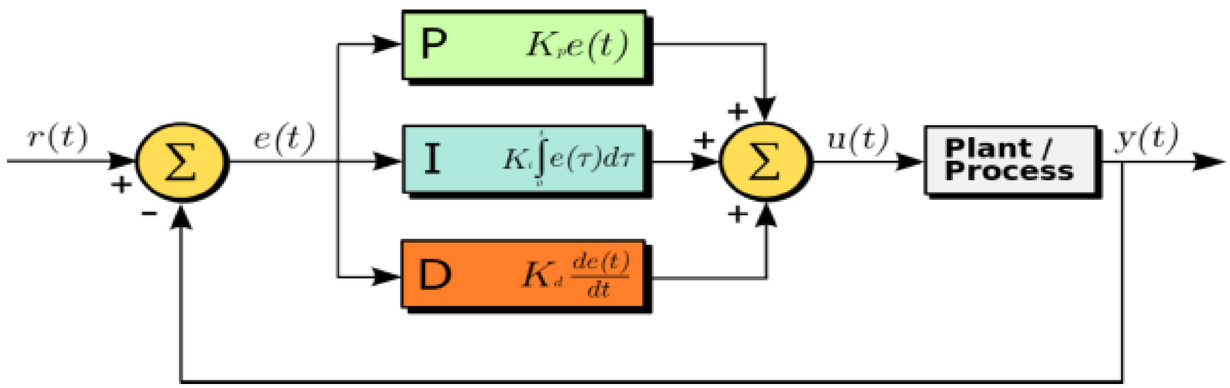


Figure 2.7 closed loop system control using PID controller

PID based flow and level control have two inputs where, u (t) and e (t) denotes the control and error signals of the system. The corresponding PID controller transfer function Gc (s) is given as

$$Gc(s) = Kp + \frac{Ki}{s} + Kd\, s \qquad \text{2.21}$$

2.6.1.2 Limitation of PID controller

While PID controllers are applicable to many control problems, and often perform satisfactorily without any improvements or only coarse tuning, they can perform poorly in some applications, and do not in general provide optimal control [15]. The fundamental difficulty with PID control is that it is a feedback control system, with constant parameters, and no direct knowledge of the process, and thus overall performance is reactive and a compromise.

PID controllers, when used alone, can give poor performance when the PID loop gains must be reduced so that the control system does not overshoot, oscillate or hunt about the control set point value. They also have difficulties in the presence of non-linearity's do not react to changing process behavior (say, the process changes after it has warmed up), and have lag in responding to large disturbances [15].

The most significant improvement is to incorporate feed-forward control with knowledge about the system, and using the PID only to control error. Alternatively, PIDs can be modified in more minor ways, such as by changing the parameters (either gain scheduling in different use cases or adaptively modifying them based on performance), improving measurement (higher sampling rate, precision, and accuracy, and low-pass filtering if necessary), or cascading multiple PID controllers [15].

2.7 Fuzzy logic controller

Fuzzy logic is a branch of artificial intelligence that deals with reasoning algorithms used to emulate human thinking and decision making in machines. These algorithms are used in applications where process data cannot be represented in binary form. For example, the statements “the air feels cool” and “he is young” are not discrete statements. Fuzzy logic interprets vague statements like these so that they make logical sense. In the case of the cool air, a PLC with fuzzy logic capabilities would interpret both the level of coolness and its relationship to warmth to ascertain that “cool” means somewhere between hot and cold. In straight binary logic, hot would be one discrete value (e.g., logic 1) and cold would be the other (e.g., logic 0), leaving no value to represent a cool temperature [17].

In contrast to binary logic, fuzzy logic can be thought of as gray logic, which creates a way to express in-between data values. Fuzzy logic associates a grade, or level, with a data range, giving it a value of 1 at its maximum and 0 at its minimum [17-21]. Fuzzy logic requires knowledge in order to reason. This knowledge is provided by a person who knows the process or machine (the expert), is stored in the fuzzy system. For example, if the temperature rises in a temperature regulated batch system, the expert may say that the steam valve needs to be turned clockwise a “little bit.” A fuzzy system may interpret this expression as a 10-degree clockwise rotation that closes the current valve opening by 5%. As the name implies, a description such as a “little bit” is a fuzzy description, meaning that it does not have a definite value [17 Around the 1920s, independent of Bertrand Russell, a Polish logician named Jan Lukasiewicz started working on multivalued logic, which created fractional binary values between logic 1 and logic 0.

CHAPTER THREE

3.1 MATERIALS AND METHODS

This chapter deals with the materials and the methods used in accomplishing the thesis. The materials used are digital computer and MATLAB/SIMULINK software. Modeling, designing and analyzing are the methods used. The following sections present each of these in detail

3.1.1 Modeling sugar production process

A mathematical model represents some behavior of a real-world system of interest which can often gain improved understanding of that system through the analysis of the model. Furthermore, in the process of building the model, certain factors are most important in the system, and how different parts of the system are related. Second category is to predict or simulate. It is expensive, impractical, or impossible to experiment directly with the system. Modeling is an important task to be carried out in such situations and based on the mathematical model, computer simulations can be performed before implementing the same on hardware.

A reasonable trade off exists between accuracy, cost and flexibility. Increasing the accuracy of a model generally increases cost and decreases flexibility. The goal in creating a model is usually to obtain a sufficiently accurate and flexible model at a low cost.

The first step in the analysis and design of the control system is mathematical modeling of the different components. The transfer function method is widely used in designing control systems. After proper assumptions and approximations are made to linearize the mathematical equations describing the components, transfer functions are obtained. Thus, using these transfer functions, the sugar production process is modeled for level and flow control.

Figure 3.1 shows the overall system block diagram. Before designing the flow and level control system, the appropriate model for each component should be obtained [28].

3.2 overall system block diagram

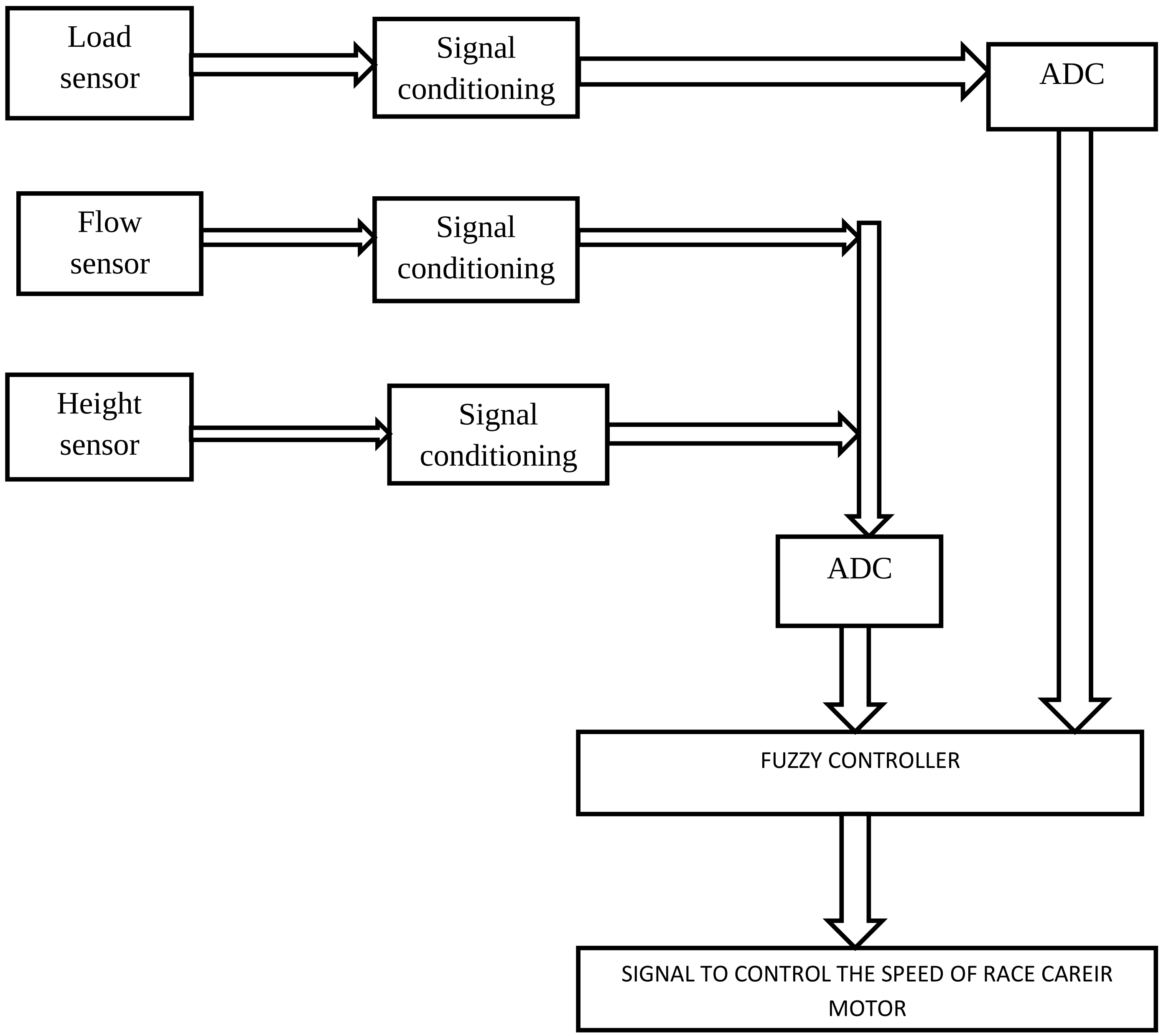


Figure 3.1.General Block diagram of fuzzy logic based flow and level control

3.3 mathematical Model of cane fiber flow out (Qo)

In the process of controlling the level and flow of cane there should be mathematical model that express the relation of variable in the system. So in our case to determine the inflow of cane fiber the system model is as shown below.

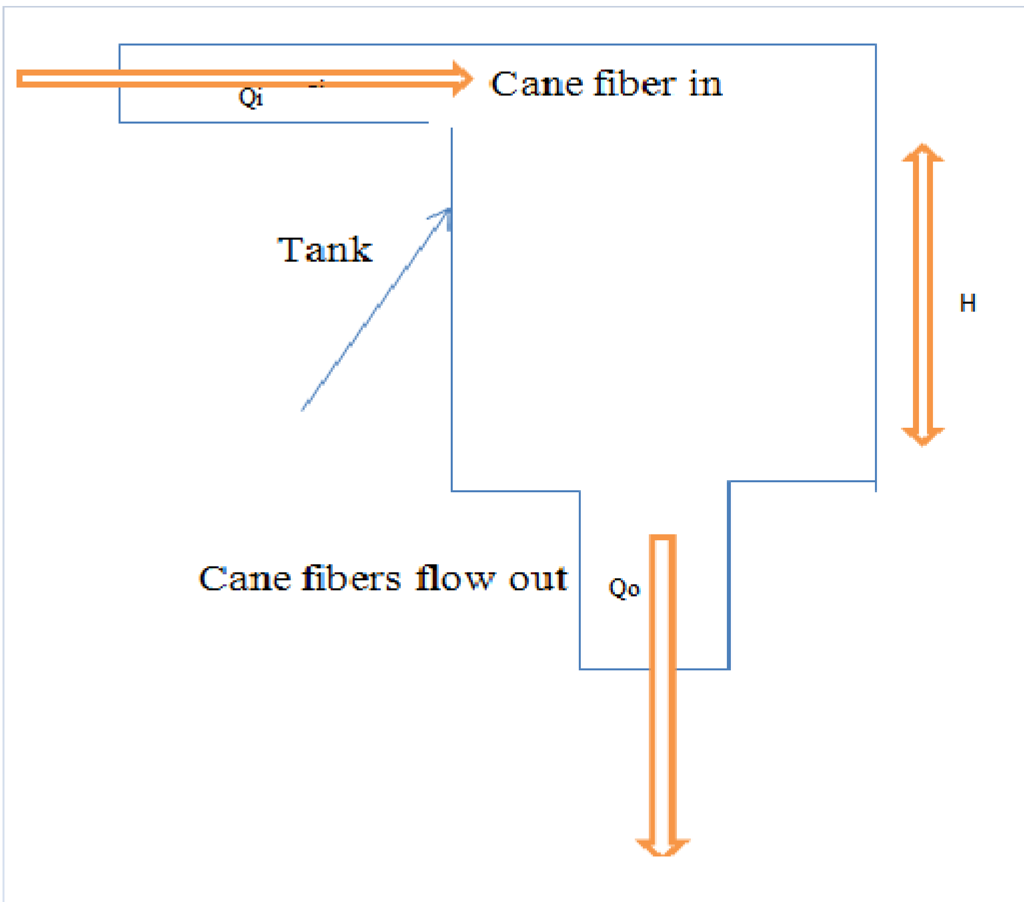


Figure 3.2 modeling of cane fiber flowing out of chute

In steady state condition, both **Qi** and **Qo** are same, and the height of the fiber level of the chute will be constant.

3.3.1 RESISTANCE OF FIBER LEVEL SYSTEM

The resistance for fiber flow in such a pipe or restriction is defined as the change in the level difference to a unit change in flow rate; that

$$\text{Resistance} = \frac{changeleveldifference(m)}{changeinflowrate(m^3/s)}$$

$$R = \frac{\Delta H}{\Delta Q} \qquad 3.1$$

3.3.2 CAPACITANCE OF FIBER-LEVEL SYSTEMS

The capacitance of a fiber is defined to be the change in quantity of stored fiber necessary to cause a unity change in the potential (head). The potential (head) is the quantity that includes the energy level of the system.

$$\frac{change\text{liquid stored }(m^3)}{changein\text{ head ,m)}} \qquad 3.2$$

Capacitance (C) is nothing but is cross sectional area (A) of the chute.

- Rate of change of fiber volume in chute = flow in – flow out

$$\frac{\text{dv}}{\text{dt}} = QI - QO \qquad 3.3$$

Since volume is (area x height)

$$\frac{\text{d(A*h)}}{\text{dt}} = \text{QI - QO} \qquad 3.4$$

$$\frac{\text{Ad(h)}}{\text{dt}} = \text{QI - QO} \qquad 3.5$$

And cross sectional area can be replaced by capacitance

$$\frac{\text{CdH}}{\text{dt}} = \text{QI - QO} \qquad 3.6$$

Where the resistance R may be written as

$$R = \frac{dH}{dQ} = \frac{H}{Qi} \qquad 3.7$$

Then rearranging the equation (8) we get

$$\frac{H}{R} = \text{Qi} \qquad 3.8$$

Substitute equation (9) in equation (7), we get

$$\frac{\text{CdH}}{\text{dt}} = \frac{\text{H}}{\text{R}} - Qo \qquad 3.9$$

After simplifying above equation the equation (10) becomes

$\frac{\text{R Cdh}}{\text{dt}} - \text{H} = \text{-RQo}$……………………………………………………………………………………………3.10

Taking Laplace transform considering initial conditions to zero

RC SH(s)-H(s) = - RQ(s)……………………………………………………………………3. 11

The transfer function can be obtained as

$$\frac{H(s)}{Qo(s)} = \frac{R}{(RCS+1)}$$ ………………………………………………………………3. 12

Where,

C=capacitance of cane fiber

R = radius of roller in chute

3.4 Mathematical model of cane fiber flow in (Qi)

Consider the single chute shown below

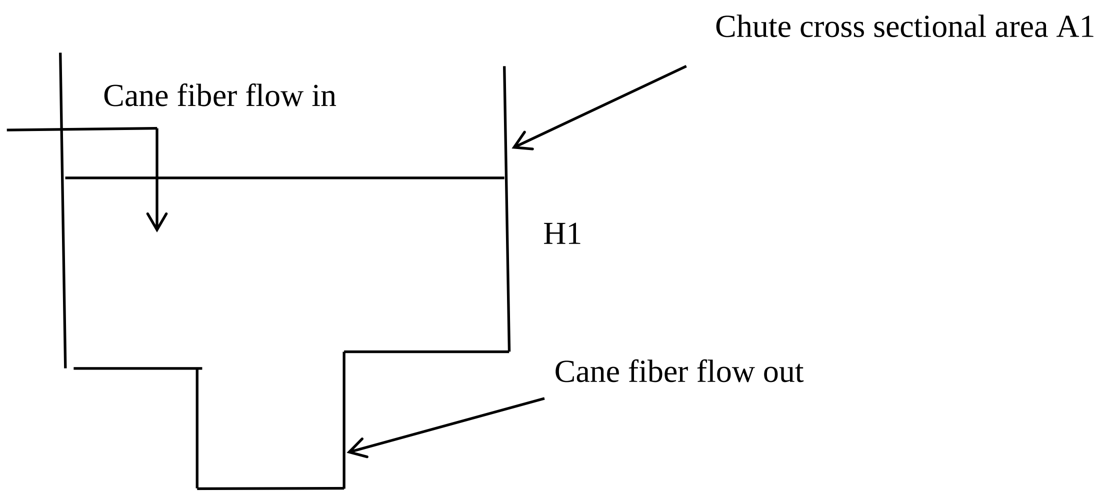


Figure 3.3 Mathematical model of cane fiber flow considering valve B

The system flow model is determined by relating the flow into the tank to that leaving via valve

Qi - Qb = rate of change of cane level volume

$$\text{Qi} - \text{Qb} = \frac{dV_1}{dt} = A\,\frac{dH_1}{dt}$$ ………………………………………………………………3.13

Where,

A = cross sectional area of chute

V1= volume of cane in chute (V)

Qi = flow in rate

Qb = flow rate out of valve B

If valve B is assumed to behave like a standard sharp edged orifice, then the flow through valve B will be related to the fluid level in the chute, H , by the expression

Qb =Cdb*ab$\sqrt{2gH1}$……………………………………………………………………...3.14

Where,

a= cross sectional area of the orifice. Represents the dimensions of valve B and the flow channel in which it is mounted.

Cdb = discharge coefficient of valve B.

g = gravitational constant = 0.98 m/sec

Assumes **Cdb** is a constant and, therefore, that **Qb** is proportional to the square root of the level **H** for all possible operating condition

In a practical valve the flow rate **Qb** will be some general nonlinear function of level **H**

Qb =f (H1)……………………………………………………………………………..3.15

Combining equation 3.12 and 3.14 gives,

A $\frac{dH_1}{dt} + f(H1) = Qi$……………………………………………………………………...3.16

The system model, equation 3.15 is a first order differential equation relating input flow rate Qi, to the output cane fiber level, H1

In order to make it useful for control systems purposes, it must be linear equation by considering small variations about a desired operating level of cane in the chute.

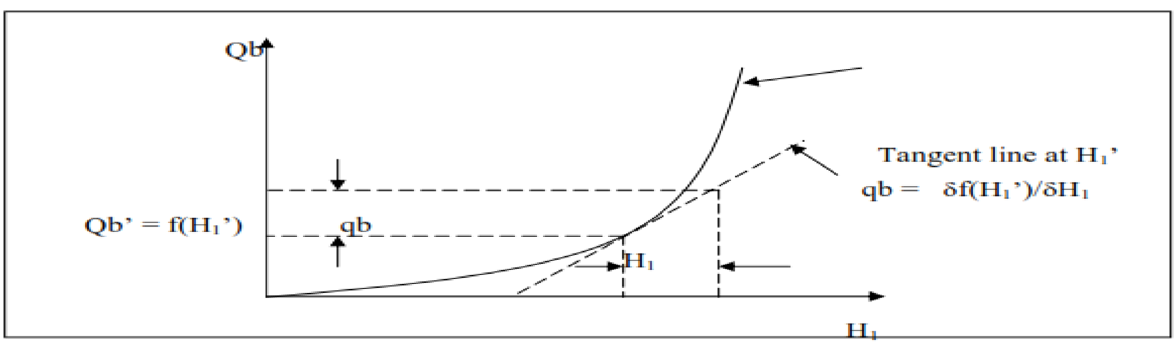


Figure 3.4: Linearization of the cane level in operating system

Let, H1 = H1' + h1

H1' is the normal operating level and is a constant **H** is small change about that level. Then, for small variations of h1 about H', can approximate the function f (H) by the straight line tangent at H1'. Let the inflow Qi consist of a steady component Qi' plus a small change qi, then if Q'b is the steady state outflow corresponding to Qb, and then we can rewrite equation 3.13 as:

$\frac{A\,dH_1}{dt} + Q'b + qb = Q'i + qi$……………………………………………………………..3.17

This can be rewritten, with reference to figure 3.13 as,

$\frac{A\,dH_1}{dt} + f(H'1) + h1 * D = Q'i + qi$……………………………………………………….3.18

Where the coefficient is the slope of the valve characteristics at the level H'1

D $=\frac{\delta f(H'_1)}{\delta H_1}$………………………………………………………………………..3.19

When the level is constant, with qi=0 and h=0, then equation 3.5 gives the steady state relation for flow and level,

f (H1') = Qi'…………………………………………………………………………....3,20

Subtracting equation 3.15 from equation 3.13 and then rearranging gives the linear; first order differential equation for the single tank system,

$\frac{A\,dH_1}{dt} + h * D = qi$……………………………………………………......................3.21

Where kb $=D^{-1} = \frac{1}{D}$ *where* D $=\frac{1}{Kb}$, the time constant T = $\frac{A}{D}$

$\frac{T*D\,dH_1}{dt}$ + h1*$\frac{1}{Kb}$ = qi …………………………………………………………………..3.22

(T*$\frac{1}{Kb}\frac{dH_1}{dt}$) +h1 $\frac{1}{Kb} = qi$…………………………………………………………………3.23

$\frac{1}{Kb}$ [($T\frac{dH_1}{dt}$) + h1] $= qi$……………………………………………………………...3.24

$T\frac{dH_1}{dt} + h1 = Kb * qi$………………………………………………………………………3.25

Taking Laplace transforms gives the single chute system transfer function,

[T.sH_1] + h1 = Kb*qi

H_1 [Ts + 1] = kb*qi

$\frac{H(s)}{qi(s)} = \frac{kb}{Ts+1}$…………………………………………………………………………..3.26

3.5 Mathematical model of flow sensors

The linear relationship between height of chute and flow speed of cane fiber is relate as follow even though behavior of sensing element itself may be nonlinear [37][38]

We relate physical height of chute H(s) and reading of sensors flow rate qo(s) as follow.

H(s) = Ks*w(s) + b(s) ……………………………………………………………………………3.27

In handling digital level sensors measurement the electronics are adjusted so that the gain Ks is unity and bias **bs** is zero. In in our case the control loop more likely to have **qo** that range over 48mA to 60mA where these limit corresponding to expected range of flow variation

8mA= ks*60A+bs………………………………………………………………………......3.28

20mA= ks*48mA+bs……………………………………………………………………..3.29

Ks = 0.41, Using these

8mA= 0.41*48+bs

Bs=7.76

Then the sensors response is the first order without delay so that bias is controlled and zero [38]

$$\frac{H(s)}{w(s)} = \frac{ks}{Ts+1} \ldots\ldots\ldots 3.30$$

3.6 Cane fiber flow capacitance

Increasing in the volume of juice and cane fiber is required to produce unit increase in pressure And the capacitance of the juice is calculated by

$$CL=\frac{changeinvolume}{changeinpressure} \ldots\ldots 3.31$$

And the pressure of the juice is calculated by

P=ρ *g* H……………………………………………………………………………...3.32

Where ρ = is the density of juice (350Kg/m^3)

g =is the gravitational acceleration (9.8 m/s^2)

And H =$\frac{\text{change in volume}}{Areaofchute}$

Because of CL = $\frac{\text{change in volume}}{\text{pressure}}$ substituting equation 3.31 and rearranging then gain

$$CL = \frac{A}{\rho * g} \ldots\ldots 3.33$$

Using the data of density of cane juice 350Kg/m^3 and area of chute is calculated by using diameter of chute 2 meters.

$A = \frac{\pi(D^2)}{4}$then $A = \frac{\pi(2^2)}{4} = 3.14m^2$

Then $CL = \frac{A}{\rho * g} = \frac{3.14}{\frac{350Kg}{m^3} * 9.8\ m/s^2} = 0.05kg/s$

$\frac{h(s)}{qi(s)} = \frac{Kb}{Ts+1} = \frac{1}{0.01s+1}$ Where let T=0.01s and $\frac{h(s)}{q0(s)} = \frac{R}{RCs+1} = \frac{1}{0.05s+1}$ Where CL= 0.05kg/s , $\frac{h(s)}{w(s)} = \frac{Ks}{Ts+1} = \frac{1}{1.57s+1}$, the time T is the time needed by juice to flow and Where T=$\frac{A}{D} = \frac{3.14}{2} = 1.57\ second$ where the value of ks and kb is unity for this model considering that every electronics is calibrated so that their gain is unity

3.7 Mathematical model of serially excited Dc motor

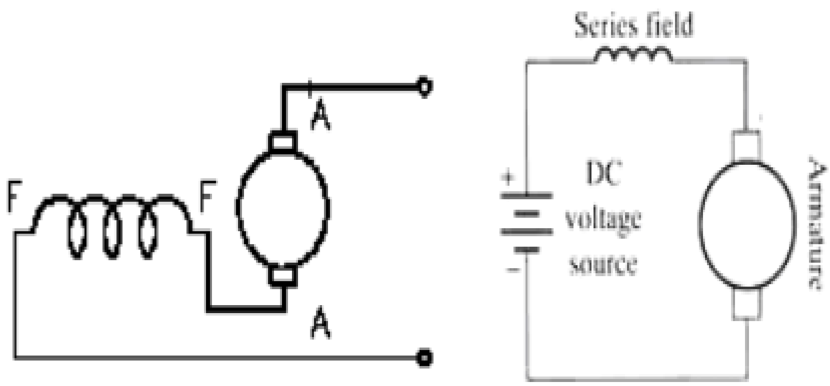


Figure 3.5 filed and armature component connected to supply of dc motor

The voltage supply is divided between stator and rotor circuits and a common current flow through the field and armature coils current ia

Vin =Va +Vf…………………………………………………………………………...3.34

Im =If =Ia……………………………………………………………………………3.35

Applying Kirchhoff's law around the electrical loop,

$Vin(s) = La\frac{dia}{dt} + Lf\frac{dif}{dt}$ + Ia Ra +If Rf + EMF…………………………………………………3.36

$(La\frac{dia}{dt} + Lf\frac{dif}{dt})$ + Ia (RF + Ra) + Kb ia w =Vin(s)……………………………………………3.37

Vin(s) =ia($La\frac{d}{dt} + Lf\frac{d}{dt}$) +ia (Rf+ Ra) + L mutual*ia*ws……………………………………3.38

Tm = Kt ia^2 = T load+b w + J$\frac{dw}{dt}$……………………………………………………...3.39

Under steady state condition induction (L=0) gives

Vin(s) =Rf Ia + Ra Ia + EMF……………………………………………………..3.40

Vin(s) =Ia(Rf + Ra) + EMF……………………………………………………….3.41

The torque developed in the rotor is

Tm =K*∅*I where ∅ = Kf * if……………………………………………………….3.42

Tm=Kt*ia^2 ….3.43

The back EMF, also, can be expressed as

EMF =Kb*∅ * wn =Kb (Kf*ia) wn………………………………………………….3.44

Substituting, we have the armature current given by:

Ia =$\frac{vin(s)}{Ra+Rf+Kb\ wn}$ And the developed torque given by……………………………...3.45

T=$\frac{vin^2 kt}{(Ra+Rf+Kt\ wn)}$2……………………………………………………………….3.46

Based on this equation, if input voltage **Vin** is kept constant, then the output angular speed is almost inversely proportional to the square root of the torque, therefore a high torque is obtained at low speed and low torque is obtained at high speed.

3.8 Parameters of cane carry motor and its Simulink block diagram

1. Armature resistance (Ra) =25 ohm
2. Armature inductance (La) = 0.5H
3. Torque constant (kb) = 3N.M/A
4. Friction viscous gain (kf) = 6.5N.M.s
5. Rotor inertia (J) = 0.5kg.m^2

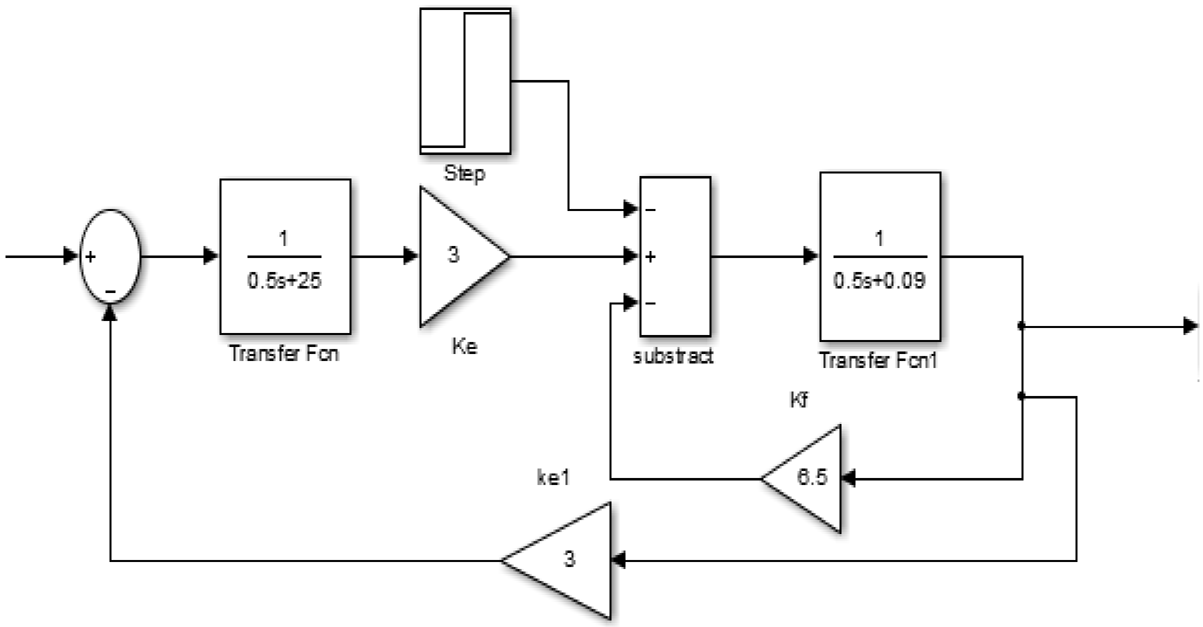


Figure 3.6. Simulink block of serially excited dc motor structure

The developed fuzzy controller can be implemented in analog voltage for controlling the opening of solenoid valve. The solenoid valve will control the speed of turbine that controlled dc cane carrier motor. The developed fuzzy controller can be implemented in FPGA, and integrated with the microcontroller to generate the voltage for controlling the opening of solenoid valve. The solenoid valve will control the control speed of turbine controlled cane carrier motor

3.9 Overall system control block diagram

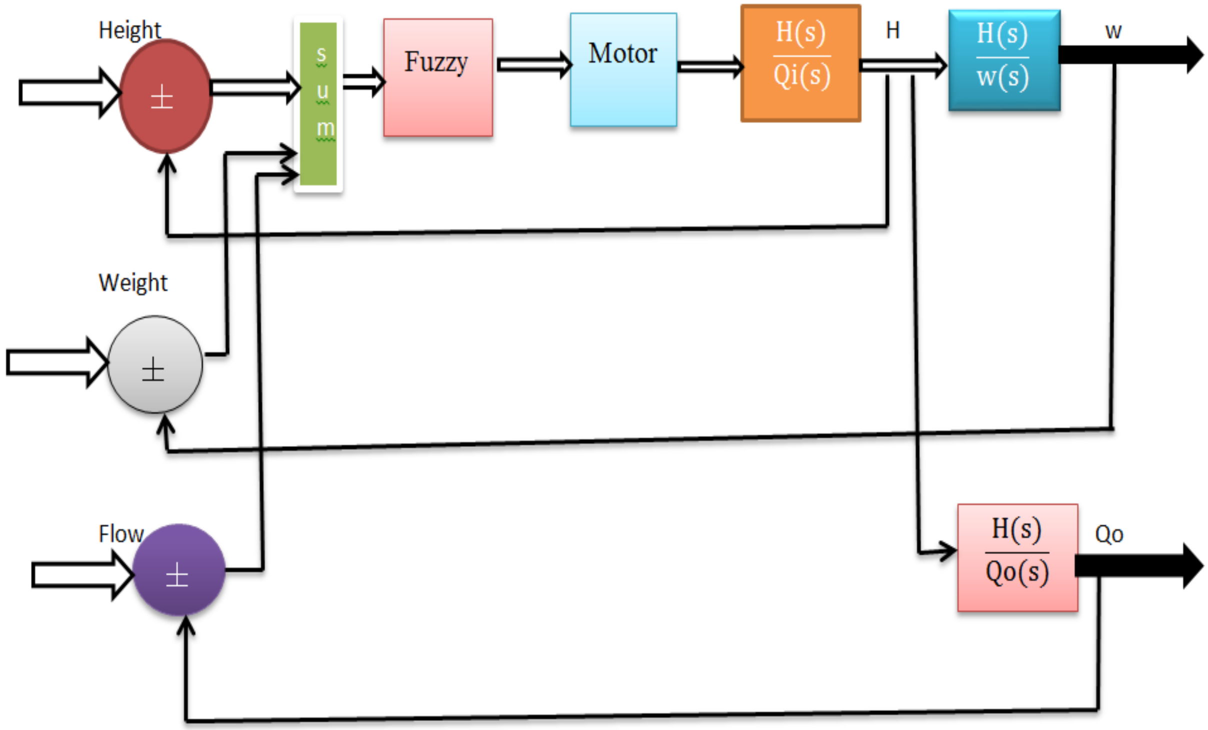


Figure 3.7 over all block diagram of controlling system

In the above block diagram there are different mathematical model used. those are height, weight, and flow of cane fiber are an input for system, while output flow rate and speed of cane carrier motor.

CHAPTER FOUR

AN INTELLIGENT CONTROLLER

4.1 Introduction

According to the oxford dictionary, the word intelligent is derived from intellect, which is the faculty of knowing, reasoning and understanding. Intelligent behavior is therefore the ability to reason, plan and learn, which is in turn requires access to knowledge.

Artificial intelligent (AI) is a by-product of the information technology (IT) revolution and is an attempt to replace human intelligent with machine intelligence. An artificial intelligent control system combines the techniques from the field of AI with those of control engineering to design autonomous system that can sense, reason, and plan, learn and act in an intelligent manner. Such a system should be able to achieve sustained desired behavior under conditions of uncertainty, which include:

(1) Uncertainty in plant models
(2) Unpredictable environmental changes
(3) Incomplete, inconsistent or unreliable sensor information
(4) Actuator mal function.

The term ‘‘intelligent control’’ has a more general meaning and addresses more general control problems. That is, it may refer to systems which cannot be adequately described by a differential/difference equations framework but require other mathematical models, as for example, discrete event system models. More often, it treats control problems, where a qualitative model is available and the control strategy is formulated and executed on the basis of a set of linguistic rules. Overall, intelligent control techniques can be applied to ordinary systems and more important to systems whose complexity defines conventional control method.

4.2 Fundamentals of Fuzzy Systems

4.2.1 Logic

Logic is the science of reasoning. Symbolic or mathematical logic has turned out to be powerful computational paradigm. Not only symbolic logic help in the description of events in the real world but has also turn out to be an effective tool for inferring or deducing information from a given set of facts.

4.2.2 Fuzzy versus crisp

Consider the query "Is water colorless?" The answer to this is a definite yes/true or no/false as warranted by the situation. If "yes/true" is accorded a value of 1 and "no/false" is accorded value of 0, this statement results in a 0/1 type situation. Such logic which demands a binary (0/1) type of handling is termed crisp in the domain of fuzzy set theory. Thus statement such as "temperature is 32 ^{0}C", "the running time of program is 4 seconds" are examples of crisp situations.

On the other hand consider the statement, "is Abebe honest?" The answers to this query need not to be definite "yes" or "no". Considering the degree to which one know Abebe, a variety of answers spanning a range such as "extremely honest", "extremely dishonest", "honest at times", "very honest" could be generated. If for instance, "extremely honest" were to be accorded a value of 1, at the high end of spectrum of value "extremely dishonest" a value of 0 at the low end of the spectrum then "honest at the times" and "very honest" could be assigned value of 0.4 and 0.85respectively. So the situation is that it can accept values between 0 and 1. Such a Situation is termed as fuzzy.

4.2.3 Fuzzy logic

An objective of fuzzy logic has been to make computers think like people. Fuzzy logic can deal with the vagueness intrinsic to human thinking and natural language and recognizes that its nature is different from randomness. Using fuzzy logic algorithms could enable machines to understand and respond to vague human concepts such as hot, cold, large, small, etc. It also could provide a relatively simple approach to reach definite conclusions from imprecise information.

Almost every application, including embedded control applications, could reap some benefits from fuzzy logic. Its incorporation in embedded systems could lead to enhanced performance, increased simplicity and productivity, reduced cost and time to- market, along with other benefits. Fuzzy logic has the advantage of modeling complex, nonlinear problems linguistically rather than mathematically and using natural language processing (computing with words). The use of fuzzy logic requires, however, the knowledge of a human expert to create an algorithm that mimics his/her expertise and thinking. Also, studying the stability of a fuzzy system is a demanding task. [49]

4.2.4 FUZZY SET THEORY

Classical sets

A set is defined as a collection of objects that may share certain characteristics. For example, one may define a set of positive integers, a set of students with passing grades, and a set of honest politicians. Each individual object is referred to as an element or member of the set. In a classical set an object x is either a member of a given set A (expressed as $x \in A$) or not a member (expressed as $x \notin A$); partial membership is not allowed.

There are numerous ways to define a set:

■ One may specify the properties of its elements. For example,

A = {x|x is an odd number <10}

■ One may list all the members of the set. For example,

A = {1, 3, 5, 7, 9}

■ One may use a formula to define the set. For example,

A = {xi = xi + 1, i = 1... 5, where xi = 1}

■ the set could also be defined as the result of a logical operation. For example,

A = {x|x is an element that belongs to B OR C}

Membership function

■ a membership function, μ, can be used to define a set.

$\mu A(x) = 1$ if $x \in A$, and

$\mu A(x) = 0$ if $x \notin A$ for all values of x.

Let all the numbers under consideration, i.e. the universe of discourse, be defined as

{1, 2, 3, 4, 5, 6, 7, 8, 9, 10}.

Then, the set of odd numbers can be expressed as

{(1,1), (2,0), (3,1), (4,0), (5,1), (6,0), (7,1), (8,0), (9,1), (10,0)}.

Where each member of the universe of discourse is associated with a membership value in the form (#, μ). The numbers 1, 3, 5, 7, and 9 are associated with μ = 1because they form the set of odd numbers extracted from the universe of discourse. This method of defining a set can be easily extended to define a fuzzy set by allowing partial membership.

Universal Set

The set that consists of all the elements of interest for a particular application (the universe of discourse) is referred to as the universal set. It is the mother of all sets; any set that is not a universal set is a subset. One may write $A \subset I$ to mean that a set A (any set) is actually a subset of the universal set I.

4.2.5 Set Operations

Sets can be manipulated through numerous operations such as the complement, union, intersection, subtraction, and Cartesian product. These will be defined and explained in the following sections.

Complement

The Complement or Absolute Complement of a given set A is denoted by $\bar{A}$. It is defined by $\bar{A}$ = {x |$x \in I$ and $x \notin A$}.If the membership function of set A is μA(x) and that of $\bar{A}$ is $\mu\bar{A}$(x), then one can write $\mu\bar{A}$(x) = 1 – μA(x).

Union

The ***Union*** of sets A and B is defined by

$A \cup B$= { x|$x \in A$ or $x \in B$}.

Intersection

The ***Intersection*** of sets A and B is defined by

$A \cap B$= {x|$x \in$ Aandx $\in$ B}.

Let A = {1, 2, 3, 4, 5, 6} and B = {2, 4, 6, 8, 10}, then

$A \cap B$= {2, 4, 6}.

Cartesian product

The Cartesian product of sets A and B is defined as A × B {(a,b)| $a \in A$, $b \in B$}.

4.2.7 Determination of Membership Functions

Discrete and continuous membership functions of a fuzzy set are intended to capture a person's thinking. Fuzzy membership functions can still be determined subjectively in practical problems based on an expert's opinion. In such a situation one can think of membership functions as a technique to formalize empirical problem solving that is based on experience rather than the knowledge of theory. The expert's way of thinking can be captured either directly or through a special algorithm.

Such determination could become more focused by physical measurements if the need arises. Available frequency histograms and other probability data can also help in constructing the membership function. It is important, however, to note that membership function values, or grades of membership are not probabilities and they do not have to add to 1. Membership construction can be further simplified by selecting their form from the smaller family of the commonly used ones, such as

4.2.8 Fuzzy Sets Properties

Empty fuzzy set

A fuzzy set is referred to as empty if and only if the value of the membership function is zero for all possible members under consideration. In a short hand form this statement would read

$A=\varnothing$ if $\mu A\ (x)=0\ \forall\ x\in X$.(if and $\forall$ are short hand forms for if and only if and for all values of, respectively).

Universal fuzzy Set

A fuzzy set is universal if and only if the value of the membership function is one for all members under consideration.

4.2.9 Operations on Fuzzy Sets

Logic Operations

The three basic logic operations on classical (crisp) sets were introduced in Section3.3. The definitions of sets were generalized leading to fuzzy sets upon which similar operations can be performed. The generalizations of operations on sets to operations on fuzzy sets are not unique. The ones introduced here are referred to as the standard fuzzy set operations. They are the operations most commonly used in engineering applications.

Complement

The absolute complement of a fuzzy set A is denoted by $\bar{A}$ and its membership function is defined by:

$\mu\bar{A}(x) = 1 - \mu A(x)$ for all $x\in X$.

Union

The union of two fuzzy sets A and B is a fuzzy set whose membership function is defined by

$\mu A\cup B\ (x) = \max\ [\mu A(x), \mu B(x)]$

Intersection

The intersection of two fuzzy sets A and B is a fuzzy set whose membership function is defined by $\mu\ A\cap B\ (x) = \min\ [\mu A(x), \mu B(x)$

Algebraic Operations on Fuzzy Sets

Cartesian multiplication

The Cartesian multiplication of two sets A and B is a fuzzy set C such that

$C = A \times B$

$= \{\mu C\ (x)/\ (a, b)\ |a \in A,\ b \in B,\ \mu C(c) = \min\ [\mu A\ (a),\ \mu B\ (b)]$

Let A = 0.2/3 + 1/5 + 0.5/7, and

B = 0.8/2 + 0.3/6.

Then,

A × B = min[0.2,0.8]/(3,2) + min[0.2,0.3]/(3,6) + min[1,0.8]/(5,2) + min[1,0.3]/(5,6) + min[0.5,0.8]/(7,2) + min[0.5,0.3]/(7,6)

= 0.2/(3,2) + 0.2/(3,6) + 0.8/(5,2) + 0.3/(5,6) + 0.5/(7,2) + 0.3/(7,6).

Algebraic multiplication

The algebraic product of two fuzzy sets A and B leads to a fuzzy set C such that

$AB = \{\mu A\ (a),\ \mu B\ (b)/x|x \in A,\ x \in B\}$.

Let A = 0.2/3 + 1/5 + 0.5/7, and

B = 0.1/3 + 0.3/7 + 0.2/8.

Then, AB = (0.2)(0.1)/3 + (1)(0)/5 + (0.5)(0.3)/7 + (0)(0.2)/8

= 0.02/3 + 0.15/7

As pointed out earlier, a fuzzy set A can be expressed as a linguistic concept such ashot, cold, young, old, etc. The result of using nested linguistic modifiers such as very,very very, etc. can be expressed using A^{α}

4.2.10 Fuzzification

Fuzzification is the operation of transforming a crisp set to a fuzzy set, or a fuzzy set to a fuzzier set. The operation translates crisp input or measured values into linguistic concepts. This, in a way, is similar to what people may do in numerous situations to reach a decision. For example, if one is told that the temperature is going to be 10 °C, one translates this crisp input value into a linguistic concept such as mild, cold, or warm according to one's inclination, then reaches a decision about the need to wear jacket or not. If one fails to fuzzify (for example, due to lack of familiarity with the Celsius temperature scale) then the decision process cannot continue or a possibly erroneous decision would be reached. So, you have been fuzzifying all along (without knowing it) whenever you made correct decisions.

A common fuzzification algorithm of a set A = {μi/xi|xi ∈ x} is performed by keeping μi constant and transforming xi to a fuzzy set that depicts the expression about xi, K(xi). The fuzzy set K(xi) is referred to as the kernel of fuzzification.

Fuzzified set A is expressed as

$\sim A = \mu_1 K(x_1) + \mu_2 K(x_2) + \ldots + \mu_n K(x_n)$

Where the symbol ~ means fuzzified.

4.2.11 Classical Reasoning

In classical binary logic, reasoning is based on two complementary mechanisms: deduction (modus ponens) and induction (modus tollens). Deduction is used to obtain conclusions by means of forward inference and induction is used to deduce causes by means of backward inference. The two mechanisms are contrasted in Table 3.2. In that table *A* and *B* are crisp sets and the symbol → means implies.

Table 4.1 Deduction and Induction

	Deduction	Induction
Rule	IF x is A →y is B	IF x is A→y is B
Premise	X is A	Y is not B
Conclusion	Y is B	X is not A

In other words, given the rule: IF x is A, THEN y is B and the observation that “x is A”, one concludes by deduction that: “y is B”. In mathematical shorthand:

$(p \wedge (p \rightarrow q)) \rightarrow q$

Given the same rule but the observation that “y is not B”, one concludes by induction that: “x is not A”. In mathematical shorthand:

$(q \wedge (p \rightarrow q)) \rightarrow p$

4.2.12 Fuzzy Reasoning

Fuzzy reasoning is based on inference rules of the form IF <premise>, THEN <consequence>as is the case in classical logic, but fuzzy sets, rather than crisp sets, are used. Fuzzy sets define linguistic variables and hence fuzzy inference rules can model a system linguistically. Fuzzy algorithms are mathematically equivalent to fuzzy relations and fuzzy inference is equivalent to fuzzy composition.

There are numerous ways that have been put forward to express an inference rule.

A direct, simple inference rule takes the form:

IF *x* is *A*, THEN *y* is *B*

Where *A and B* are fuzzy sets.

If the number of rules is large it becomes more convenient to employ a fuzzy relations approach. The IF/THEN rules are converted to fuzzy relations, and then fuzzy composition is used to infer conclusions. The conversion from IF/THEN rules to fuzzy relations could be defined in more than one way. A simple method is given by:

$R = A \rightarrow B = A \times B$

An inference rule could have more than one proposition. For example, a rule of inference with two propositions would take the form: if x is A, and y is B, then z is C where A, B, and C are fuzzy subsets of X, Y, and Z, respectively.

The rule may be written as:

$A \text{ and } B \rightarrow C$

A fuzzy algorithm has several rules, such as

Rule 1: IF *x* is A_1, THEN *y* is B_1

Rule 2: IF *x* is A_2, THEN *y* is B_2

.

.

.

Rule n: IF *x* is *An*, THEN *y* is *Bn*

The rules can be also written as

$A_1 \rightarrow B_1$

$A_2 \rightarrow B_2$

.

.

.

$A_n \rightarrow B_n$

This n-rule system can be converted to n relations: $R_1, R_2, \ldots, R_n$. These relations can be combined into one relation, *R*, using fuzzy intersection operations or fuzzy union operations depending on how the rules are perceived to be connected.

$R = R_1 \cup R_2 \ldots \cup R_n$, or

$R1 = R_1 \cap R_2 \ldots \cap R_n$

The difference in the way the rules are perceived to be related would obviously lead to different results.

4.2.13 Fuzzy Logic Controller and Design

Basic block diagram of fuzzy logic controller is as shown under.

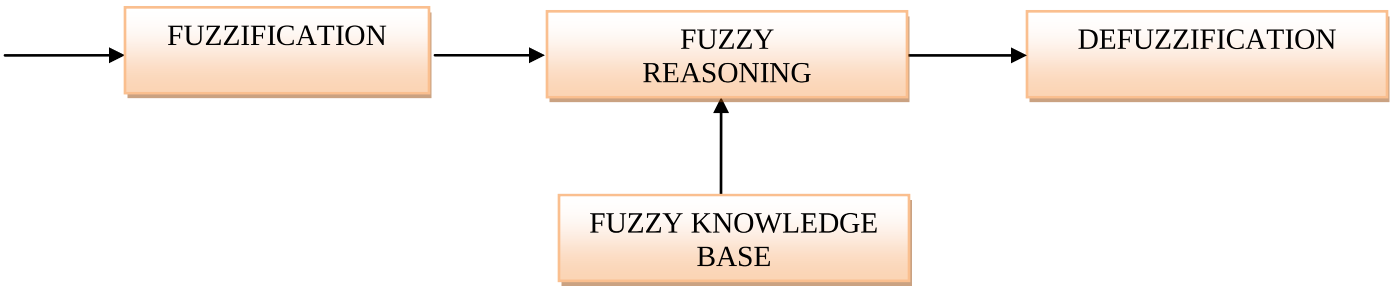


Figure 4.1 Basic structure of fuzzy logic controller.

The main building units of an FLC are a fuzzification unit, a fuzzy logic reasoning unit, a knowledge base, and a defuzzification unit. Defuzzification is the process of converting inferred fuzzy control actions into a crisp control action.

In the design of an FLC system it is assumed that:

- ■ a solution exists.
- ■ the input and output variables can be observed and measured.
- ■ an adequate solution (not necessarily an optimum one) is acceptable.
- ■ a linguistic model can be created based on the knowledge of a human expert.

Fuzzy modeling is the method of describing the characteristics of a system using fuzzy inference rules. The method has a distinguishing feature in that it can express linguistically complex nonlinear systems. It is however, very hard to identify the rules and tune the membership functions of the fuzzy reasoning. Fuzzy controllers are normally built with the use of fuzzy rules. These fuzzy rules are obtained either from domain experts or by observing the people *who are currently doing the control. The membership functions for the fuzzy sets will be derived from the information available from the domain experts and/or observed control actions. The building of such rules and membership functions require tuning. That **is,** performance of the controller must be measured and the membership functions and rules adjusted based upon the performance.

The basic configuration of Fuzzy Logic Controller (FLC) consists of four main parts

(i) Fuzzification

(ii) Knowledge base

(iii) Decision-making logic and

(iv) Defuzzificatian

The functions of the above modules are described below.

(i) The Fuzzification:

(a) Measure the values of input variables

(b) Performs a scale mapping that transforms the range of values of input variables into corresponding universe of discourse.

(c) Performs the function of fuzzification that converts input into suitable linguistic values, which may be, **viewed** labels of fuzzy sets.

(ii) The Knowledge Base:

It consists of data base and linguistic control rule base.

(a) The database provides necessary definitions, which are used to define linguistic control rules and fuzzy data, manipulation in an, FLC.

(b) The rule base characterizes the control goals and control policy of the domain experts by means of set of linguistic control rules.

(iii) The Decision Making Logic:

It is the kernel of an FLC; it has the capability of simulating human decision making based on fuzzy concepts and of inferring fuzzy control actions employing fuzzy implication and the rules of inference in fuzzy logic.

(iv) The Defuzzification:

(a) A scale mapping which converts the range of values of input variables into corresponding universe of discourse.

(b) Defuzzification, which yields a non-fuzzy, control action from an inferred fuzzy control action.

Fuzzy logic controllers are not dependent on accurate mathematical models. This is particularly useful in power system applications where large systems are difficult to model. It is also relevant to smaller applications with significant non-linearity’s in the system.

Fuzzy logic controllers are based on heuristics and therefore able to incorporate human intuition and experience.

There are numerous ways to build and implement a fuzzy logic system. It can either be based on a fuzzy logic development shell or built using software programming languages such as C++ or even Java.

4.3 Modeling and Analysis of fuzzy controller

The basic idea behind fuzzy logic control is to incorporate the experience of a human operator in the design of a controller in controlling a process whose input-output relationship is described by a collection of fuzzy control rules (e.g. IF-THEN rules) involving linguistic variables.

A number of assumptions are implicit in a fuzzy control system design. Six basic assumptions are commonly made whenever a fuzzy rule-based control policy is selected [40][28].

i. The plant is observable and controllable: state, input, and output variables are usually available for observation and measurement or computation.

ii. There exists a body of knowledge comprised of a set of linguistic rules, engineering common sense, intuition, or a set of input–output measurements data from which rules can be extracted.

iii. A solution exists.

iv. The control engineer is looking for a good enough ''solution, not necessarily the optimum one.

v. The controller will be designed within an acceptable range of precision.

vi. The problems of stability and optimality are not addressed explicitly; such issues are still open problems in fuzzy controller design.

4.4 Fuzzy inference system

Three input parameters selected for the fuzzy controller are 'HEIGHT', 'WEIGHT' and FLOW LEVEL. Input parameter 'HEIGHT' is the measured value for level of cane fiber in Donnelly Chute in centimeters; input parameter 'WEIGHT' is the measured value for the weight of cane in cane carrier in Kilograms. The input parameters flow used to measure the flow of cane fiber in L/min .The output parameter selected for this design is 'SPEED' which is the speed of the carrier motor in rpm. The universe of discourse of input parameter 'HEIGHT' is in the range 0 to 180cm .The universe of discourse of the input parameter. 'HEIGHT' is fuzzified into seven triangular linguistic variables and input parameters weight is fuzzified in to eleven triangular linguistic variables and input parameters flow is fuzzified in to three triangular linguistic variables . All member ship function is drown as follow.

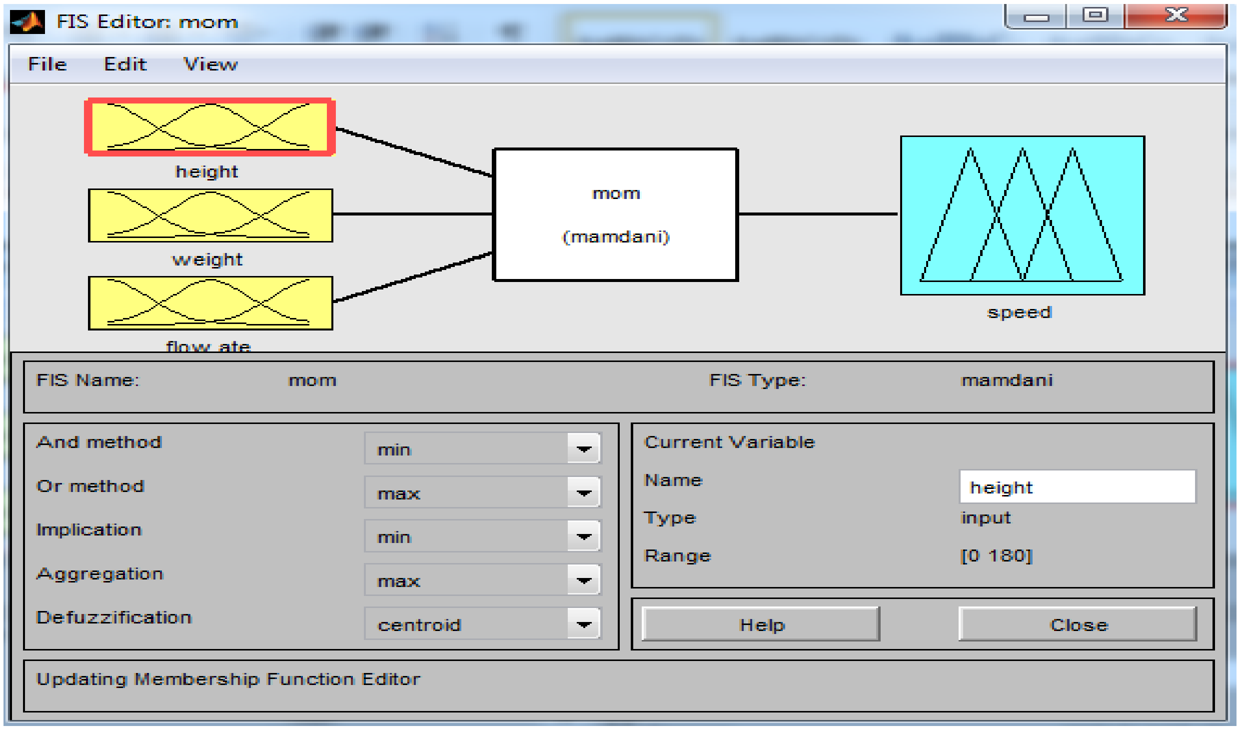


Figure 4.2.FIS representation of general system

The universe of discourse of input parameter 'HEIGHT' is in the range 0 to 180cm and it is fuzzified into seven triangular linguistic variables. It has been calculated that the level of cane in the chute should be maintained at 90cm for proper feeding of prepared cane in the mill. Therefore during the selection of membership function it is decided that the 90cm height of cane in chute must possess membership value 1 for linguistic variable JR (Just Right).

Table 4.2:- the fuzzification of input variable height in to seven linguistic variables

Symbol	Range	Description
EL	[0 30]	Extremely low
VL	[0 30 60]	Very low
L	[30 60 90]	Low
JR	[60 90 120]	Just right
H	[90 120 150]	High
VH	[120 150 180]	Very high
EH	[150 180]	Extremely high

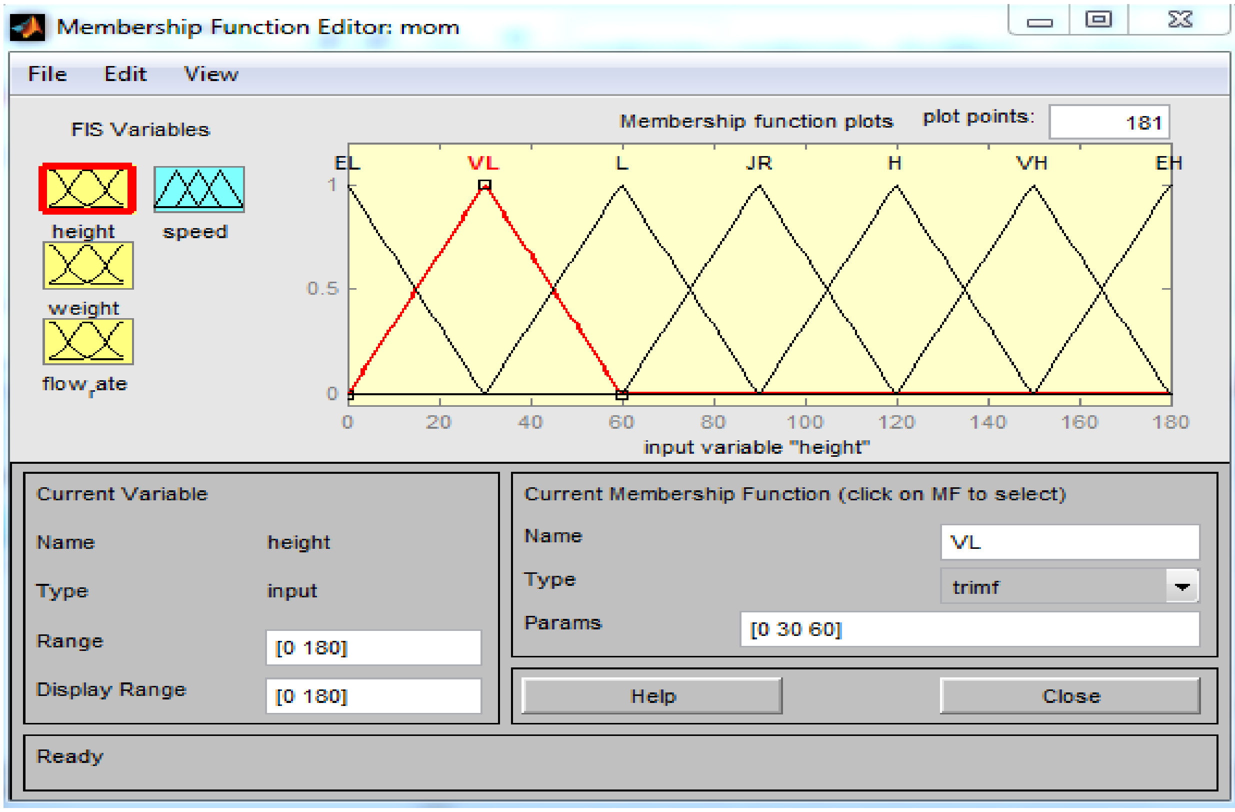


Figure 4.3 FIS representation of input variable height

The universe of discourse of input parameter 'WEIGHT' is in the range 500Kg to 1000Kg and it is fuzzified into eleven triangular linguistic variables as follows:

Table 4.3:- the fuzzification of input variable weight in to eleven linguistic variables

Symbol	Range	Description
SL	[1000 1050]	Super low
UL	[1000 1050 1100]	Ultra low
EL	[1050 1100 1150]	Extreme low
VL	[1100 1150 1200]	Very low
L	[1150 1200 1250]	Low
JR	[1200 1250 1300]	Just right
H	[1250 1300 1350]	high
VH	[1300 1350 1400]	Very high
EH	[1350 1400 1450]	Extreme high
UH	[1400 1450 1500]	Ultra high
SH	[1450 1500]	Super high

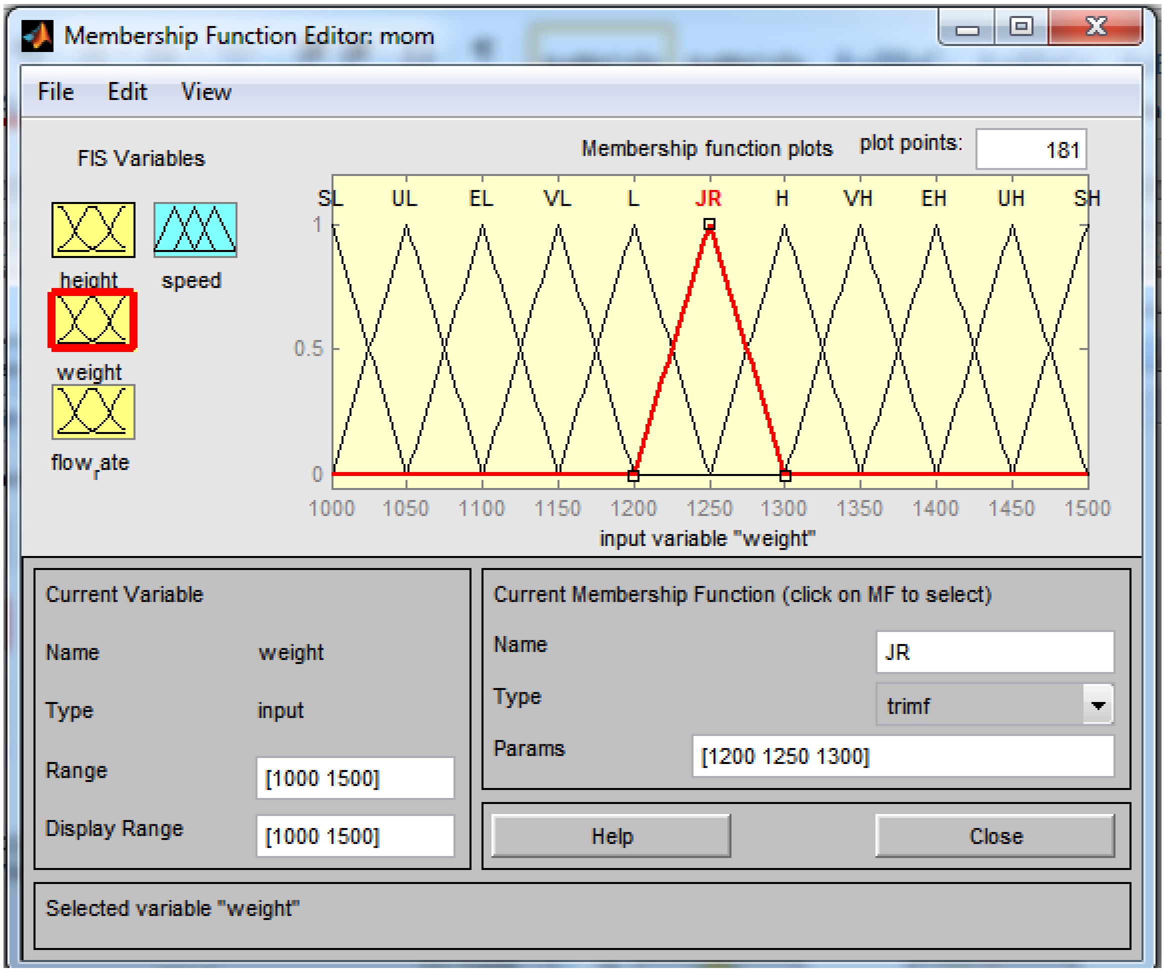


Figure 4.4 FIS representation of input variable weight

The universe of discourse of output parameter 'SPEED' is in the range 17RPM to 116RPM. And it is fuzzified into seven triangular linguistic variables as follows

Table 4.4:- the fuzzification of output variable speed in to seven linguistic variables

Symbol	Range	Description
EL	[17 17 29.5]	Extremely low
VL	[17 29.5 42]	Very low
L	[29.5 42 54.5]	Low
JR	[42 54.5 67]	Just right
H	[54.5 67 79.5]	High
VH	[67 79.5 92]	Very high
EH	[79.5 92 104.5]	Extreme high
UH	[92 104.5 115.5]	Ultra high
SH	[104.5 115.5]	Super high

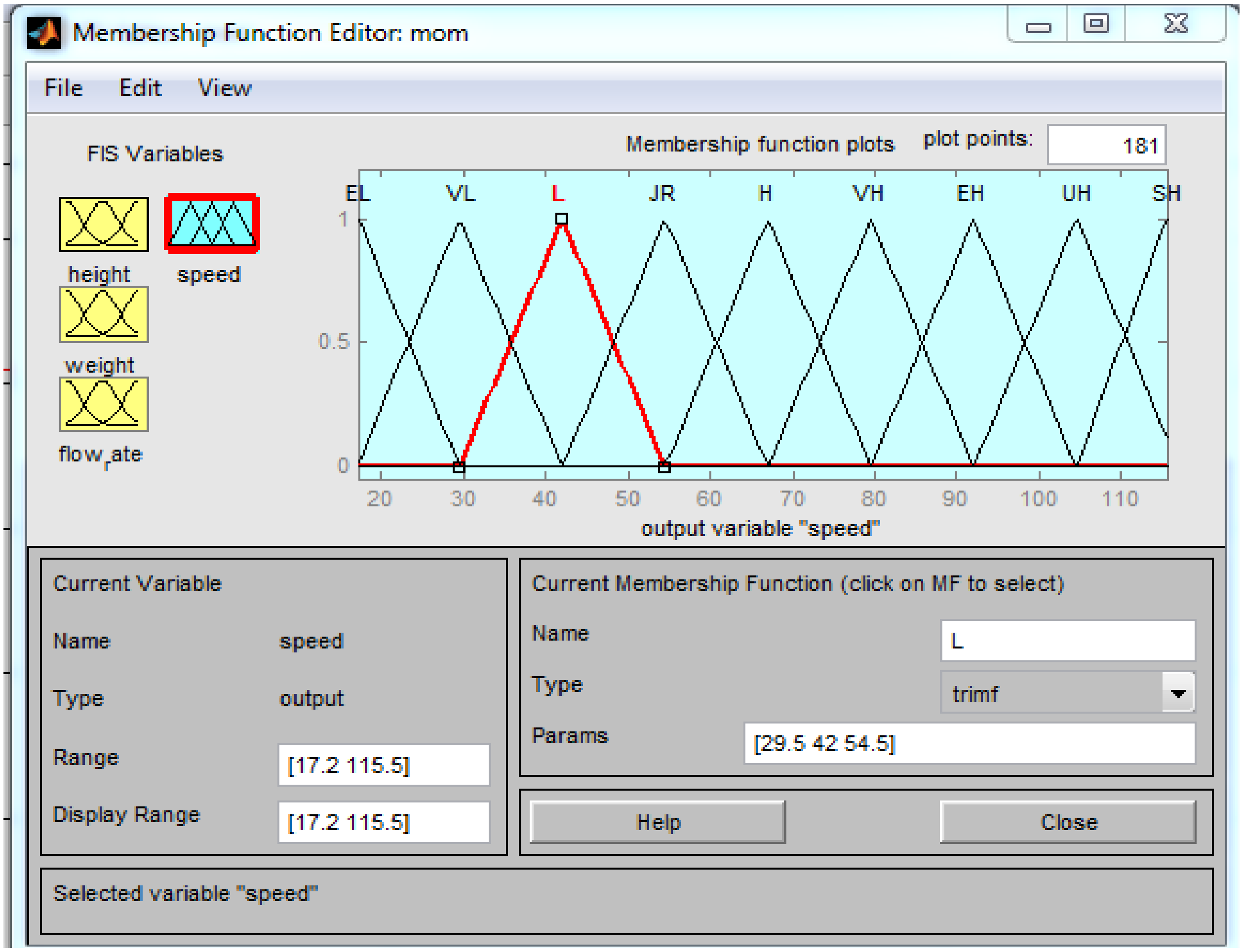


Figure 4.5 FIS representation of output variable speed

The universe of discourse of input parameters flow level parameter is in the range 0L/min to 1250L/min. And it is fuzzified into three triangular linguistic variables as follows

Table 4.5:- the fuzzification of input variable speed in to three linguistic variables

Linguistic variable	Range	Interpretation
FM	[0 312.5 625]	Flow medium
JR	[312.5 625 937.5]	Just right
FF	[625 937.5 1250]	Flow fast

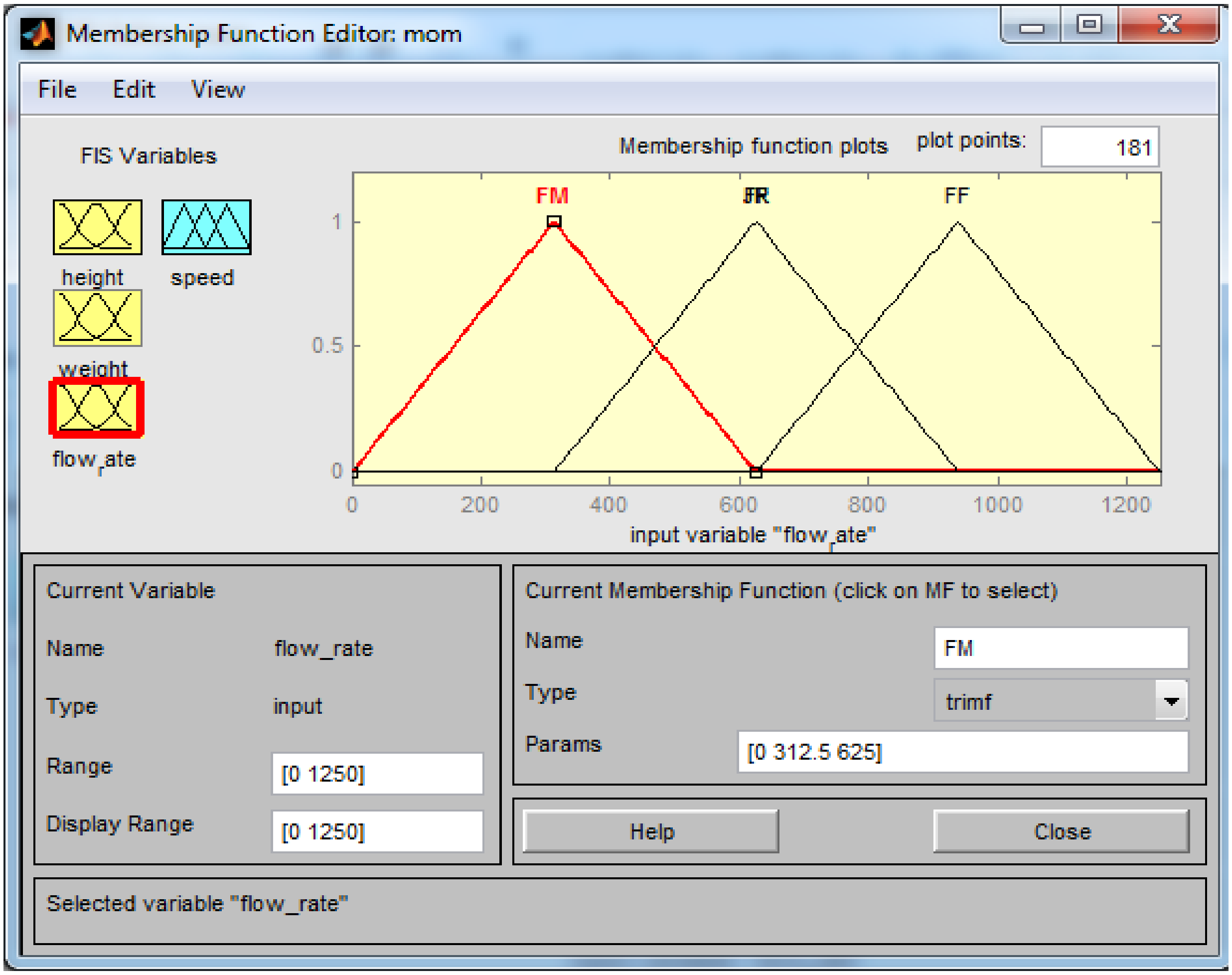


Figure 4.6. FIS representation of input variable flow rate

4.5 Rule of fuzzy logic design for three inputs

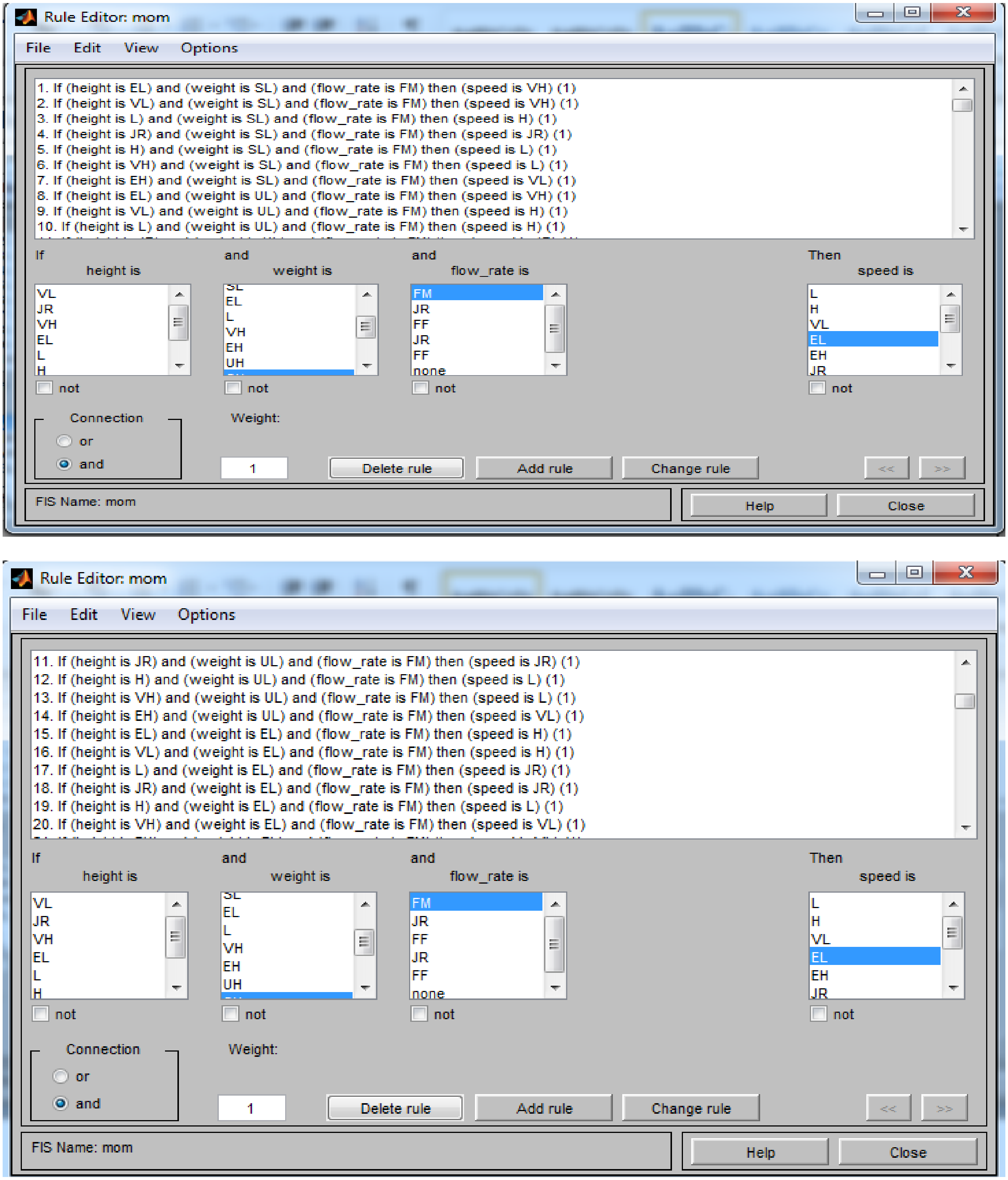
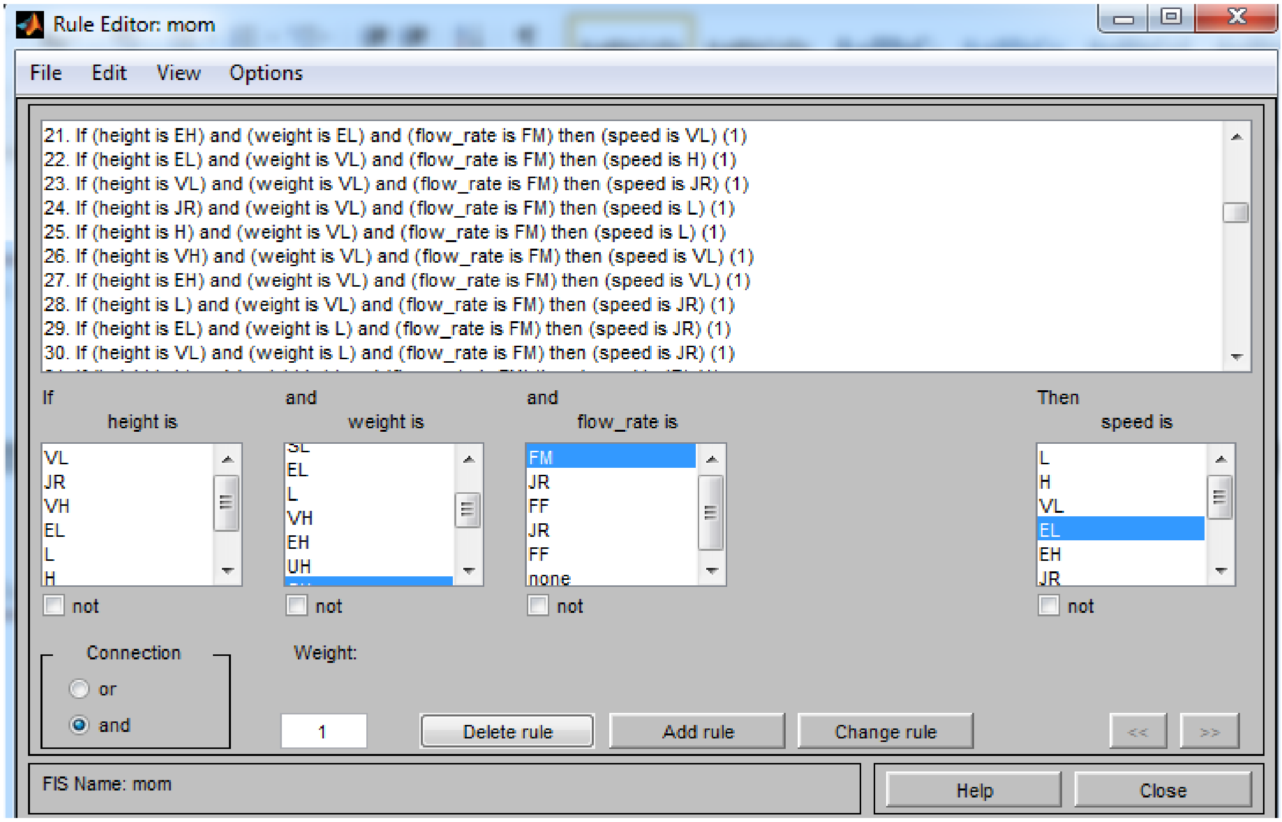


Figure 4.7 generated rule by considering three input and an output



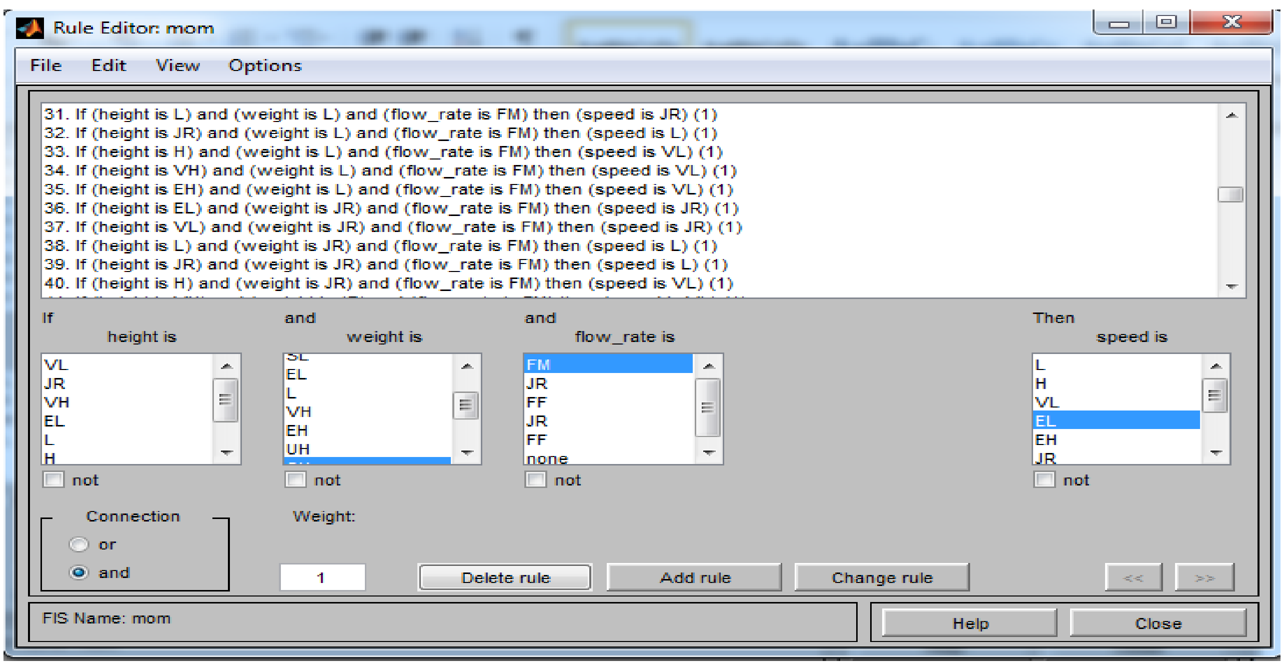
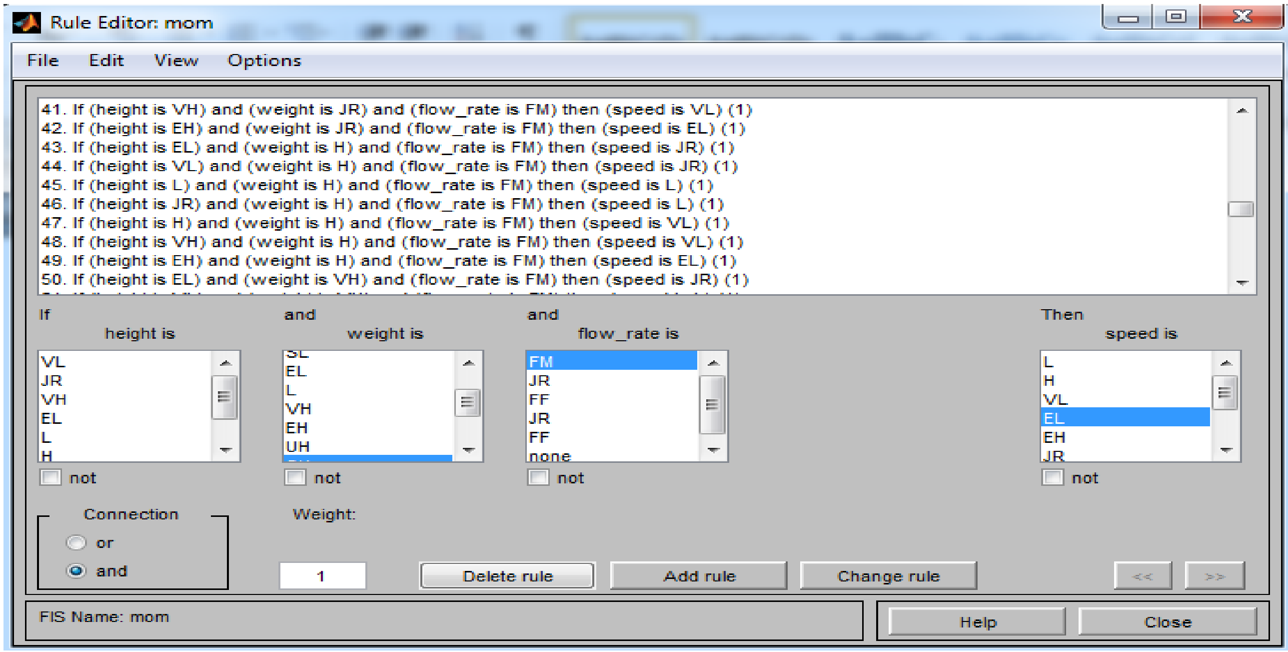


Figure 4.8 generated rule by considering three input and an output



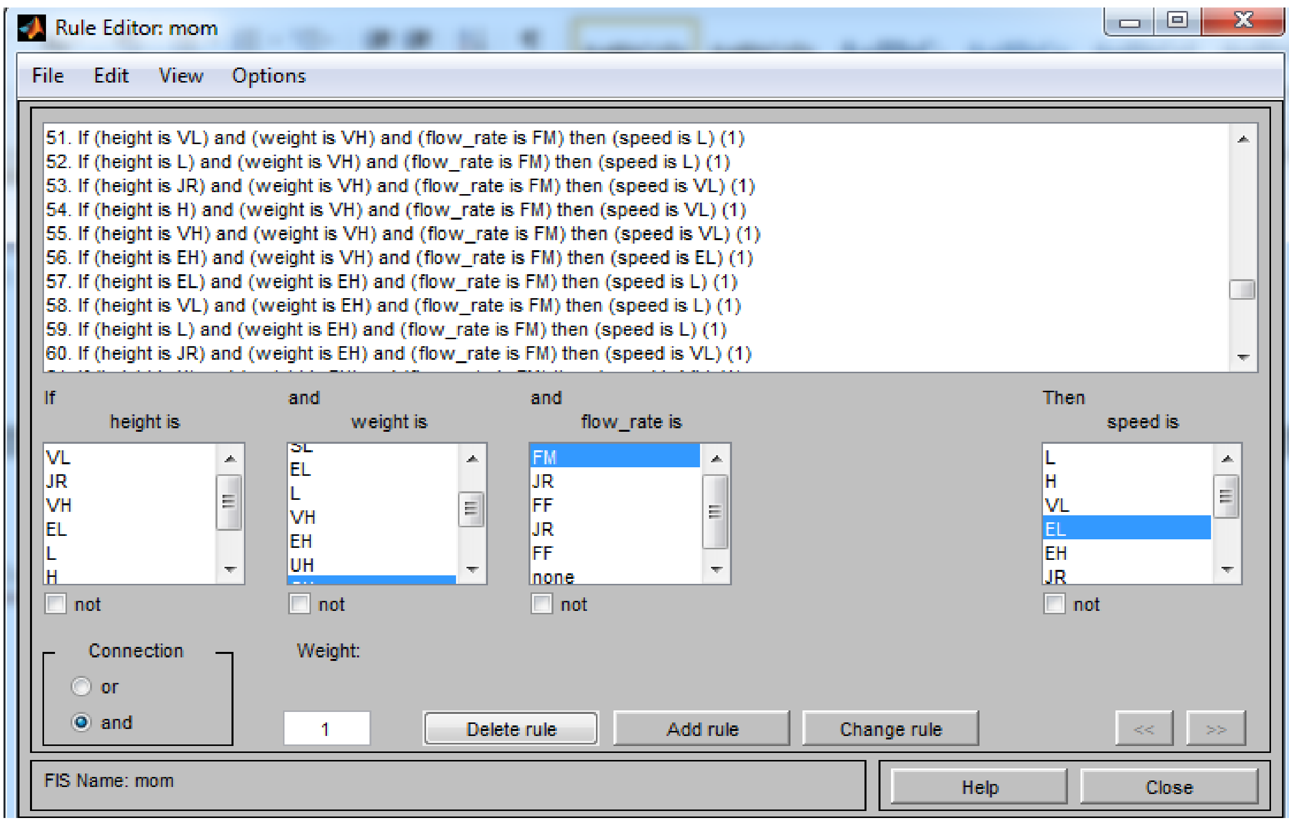
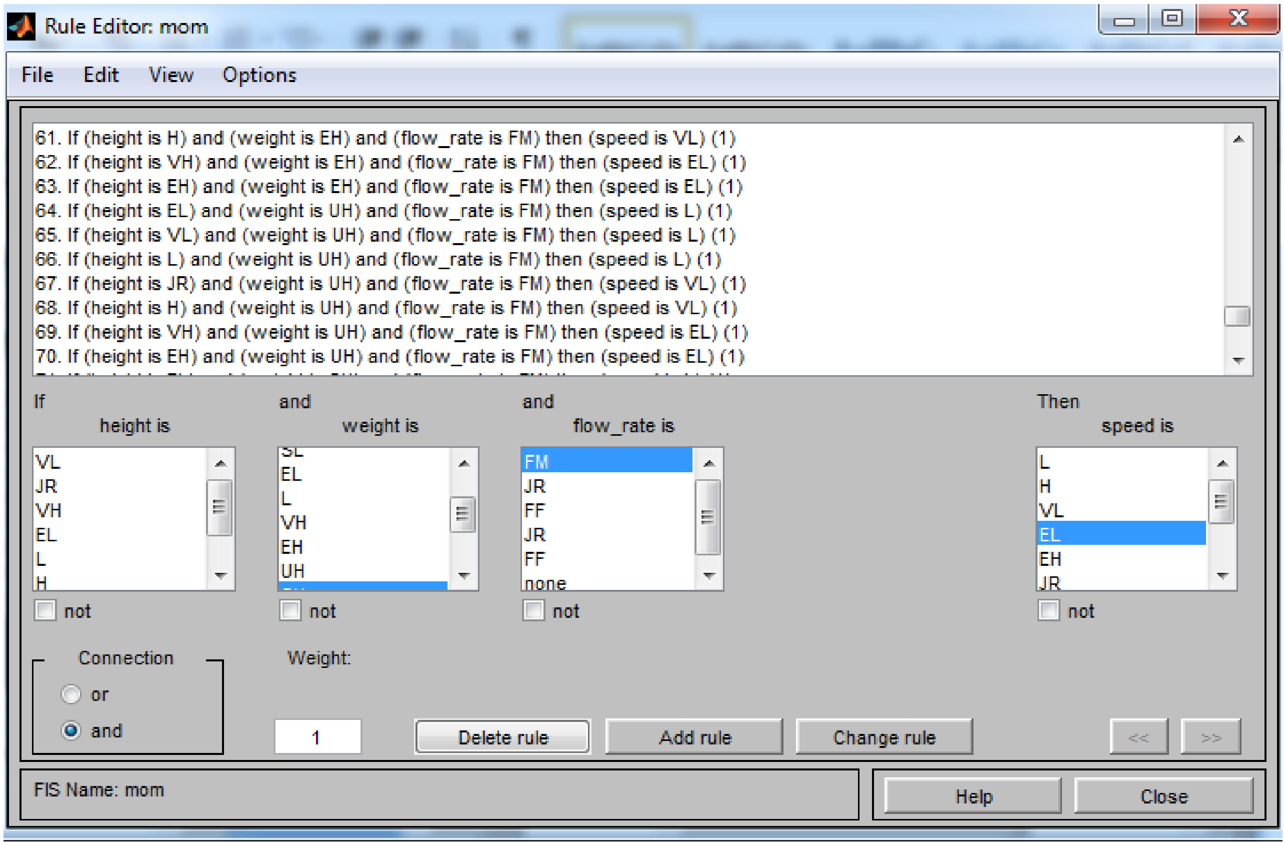


Figure 4.9 generated rule by considering three input and an output



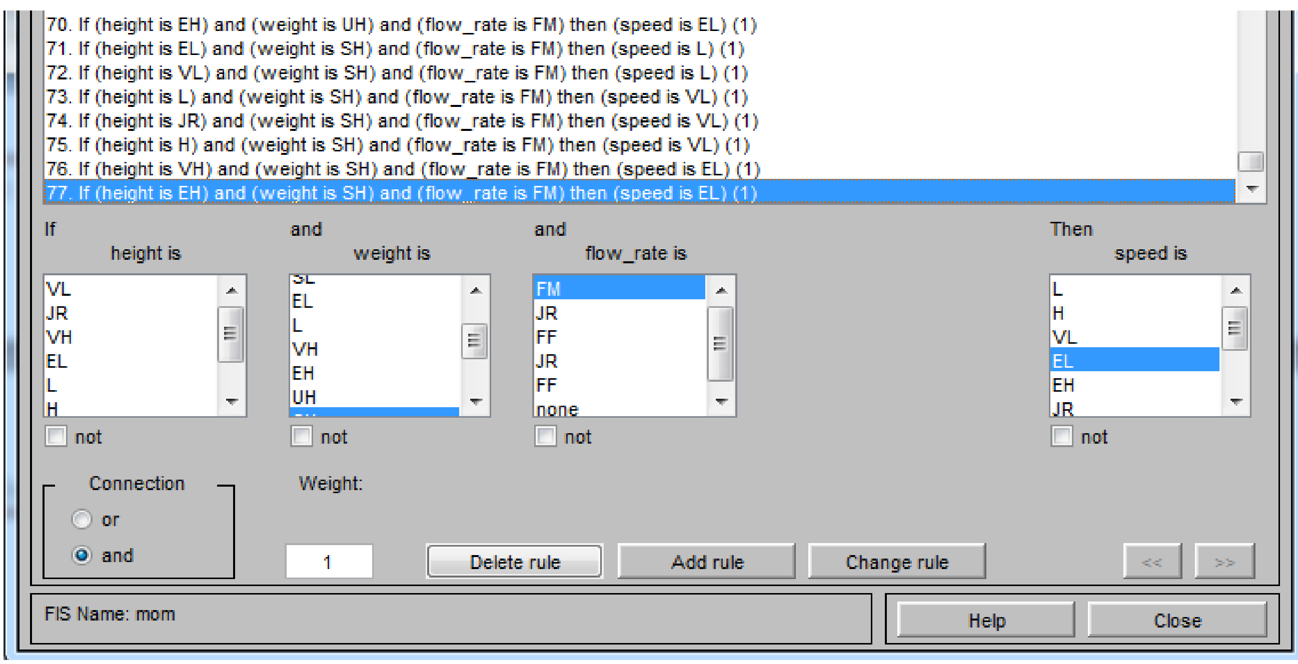


Figure 4.10 generated rule by considering three input and an output

4.6 rule generation

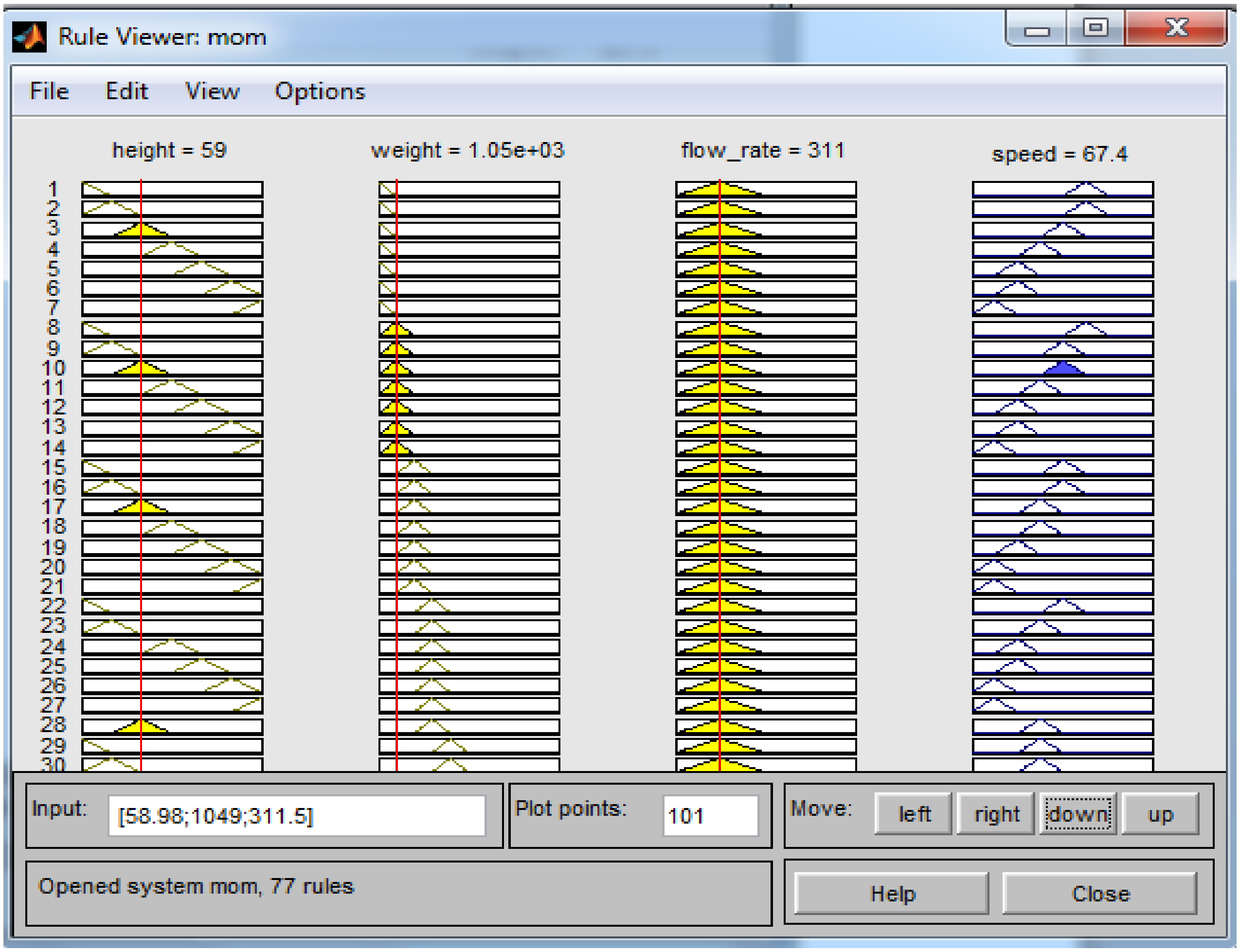


Figure 4.11 generated rule by considering three input and an output

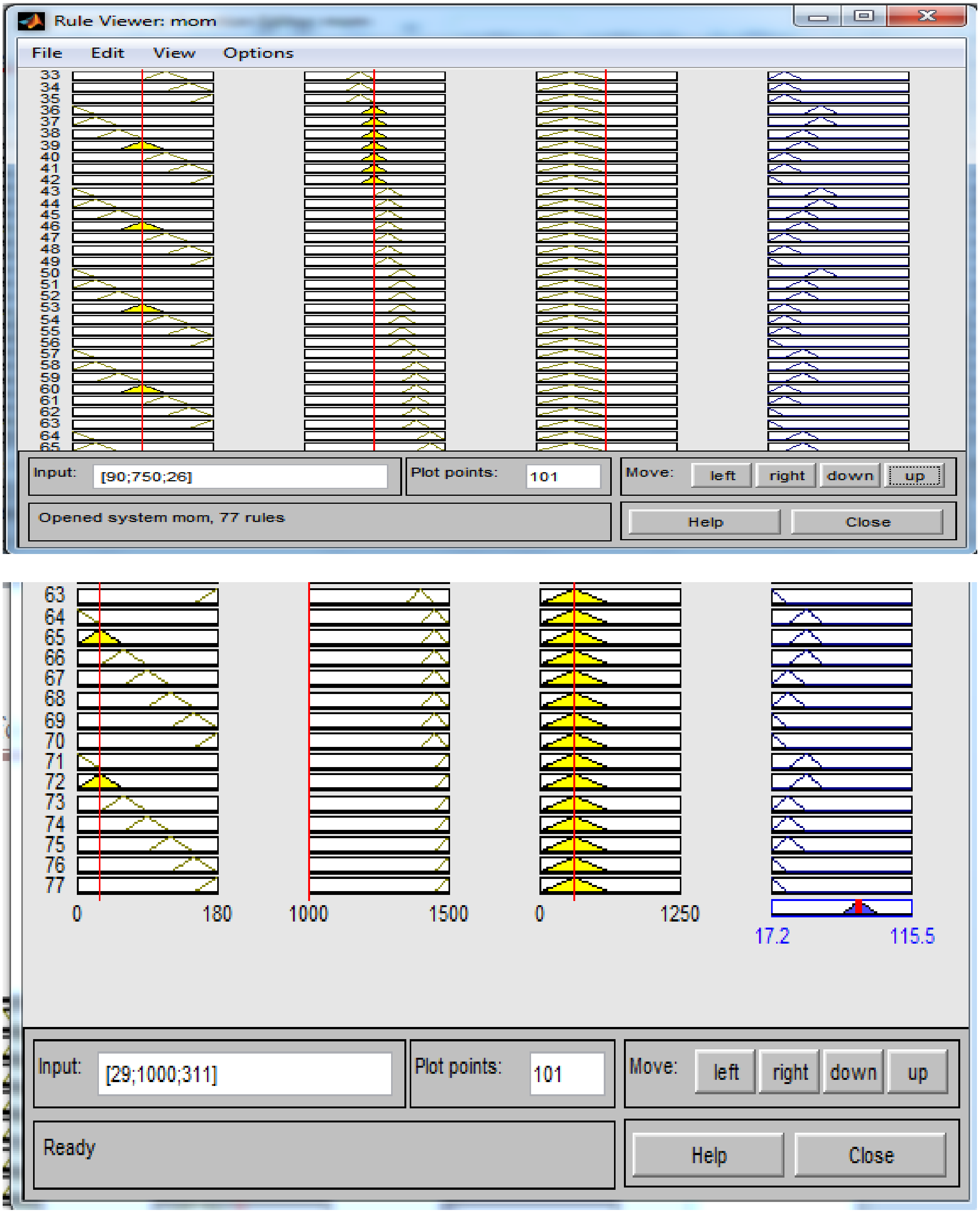


Figure 4.12 overall rule generated system rule

4.7 Surface of three input fuzzy controller design

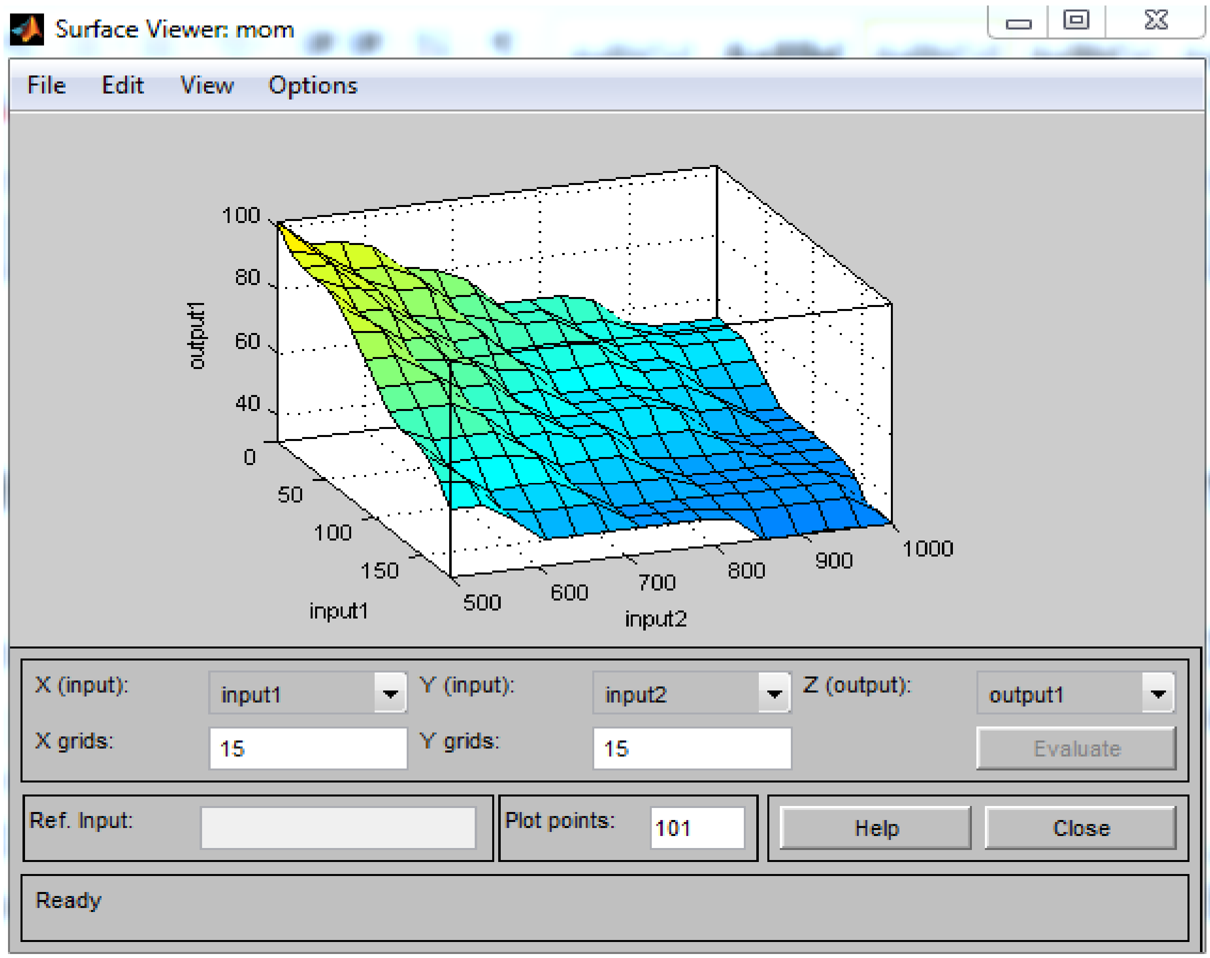


Figure 4.13 controlled Surface of fuzzy controller

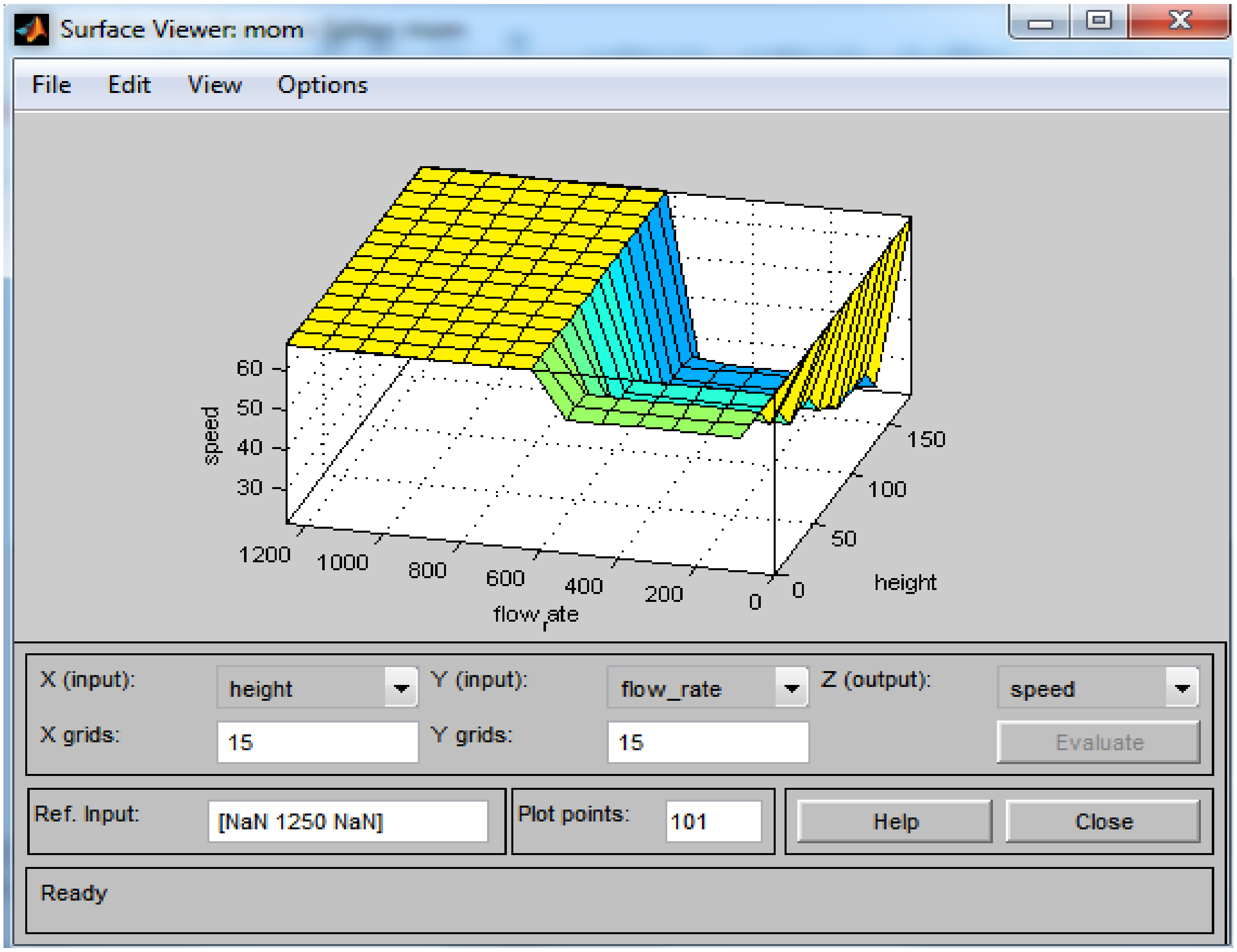


Figure 4.14 controlled Surface of fuzzy controller design

CHAPTER FIVE

5.1 SIMULATION RESULTS AND DISCUSSIONS

The cane flow and level control was modeled, deigned and analyzed in the materials and methods section of this thesis. This chapter deals with the results and discussion of MATLAB simulations. It is concerned with the simulation results of the closed loop control of the system using Fuzzy with MATLAB/SIMULINK. The simulation is analyzed by step response, disturbance rejection and parameter variation (robustness) of the closed loop system. SIMULINK® is a toolbox extension of the MATLAB program. It is a program for simulating dynamic systems. Simulink has the advantages of being capable of complex dynamic system simulations, graphical environment with visual real time programming and broad selection of tool boxes. Its graphical interface allows selection of functional blocks, their placement on a worksheet, selection of their functional parameters interactively, and description of signal flow by connecting their data lines. The Simulink model shown below is used to carry out simulation studies and analyze the performance of the controllers under different operating conditions and controlling techniques.

5.1.1 Simulink model of fuzzy logic based controller

In this thesis there are three different sensors used for different purposes, like level sensor used to sense the level of cane fiber in chute, load cells used to sense the weight or amount of cane on the rake carrier and flow sensors used to sense the flow of cane fiber in the process of sugar production. Each sensor is giving the signal depending on the information it gain. The information should have to be controlled or converted using signal conditioning and feed to the analog to digital convertor which is 8 bits (804 part number) and this information is feed to fuzzy logic controller then fuzzy logic controller send signal to the rake carrier motor depending on this information. The proposed fuzzy logic controller has better transient performance than PID controller.

The complete Simulink response of fuzzy logic controller of level and flow controller is shown below.

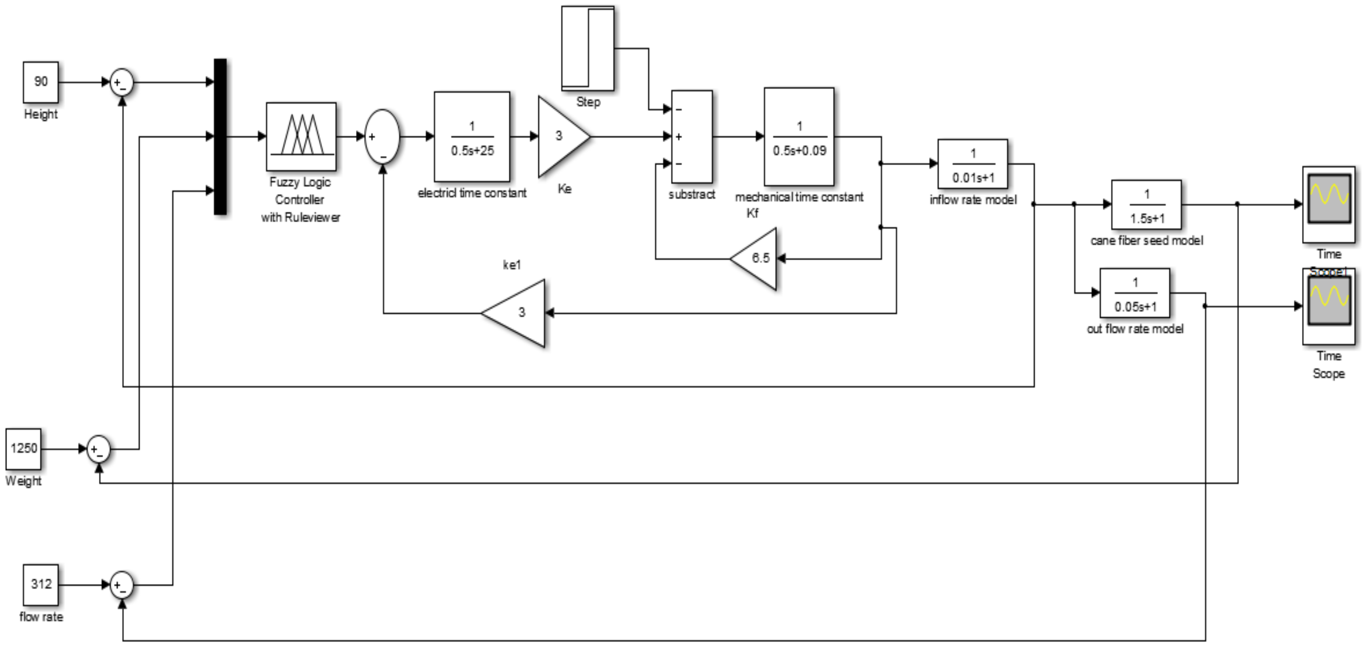


Figure 5.1 the Simulink model of fuzzy logic controller to control the level and flow of cane fibers

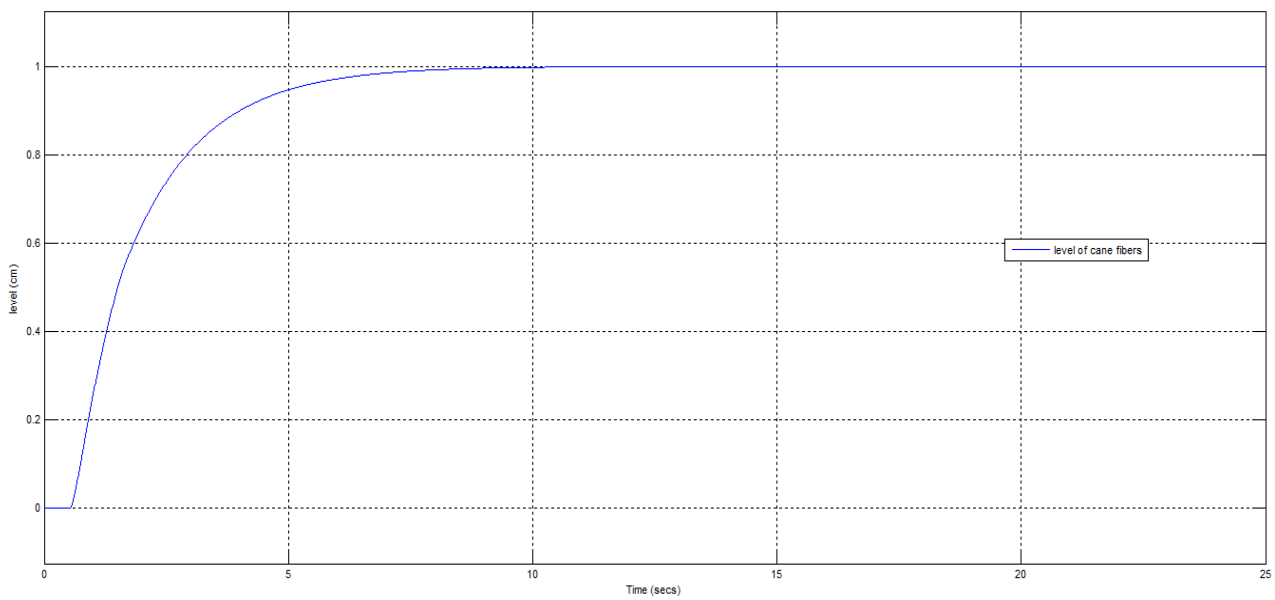


Figure 5.2 simulation result of fuzzy logic based controller for level control of cane fibers

The response of our Simulink model of level controller using fuzzy logic controller show that an increase of weight of cane on the rake carrier leads to an increase in the level of cane fiber or juice in chute and the controller that have been designed is just sending signal depending on the input information it get from sensors. i.e. When our system is operating at just right or normal operation, the level of cane fiber in chute is 90cm and the weight of cane fibers is 750kg and flow rate is 625L/min, at these operations the fuzzy logic controller send signal for rake carrier motor. Similarly if the level of cane fiber and weight of cane fiber is at minimum rate the fuzzy logic controller sends signal to rake carrier motor so that speed of motor increase and the level of cane fiber also increase in chute. If the system is at steady state the system remain constant and the level of cane in chute is fully controlled.

Table 5.1 Response of fuzzy controller for controlling level of cane fiber in chute

No	**Parameters**	**Value**
1	Rise time	0.0817 second
2	Settle time	0.274 second
3	Overshoot	0 %

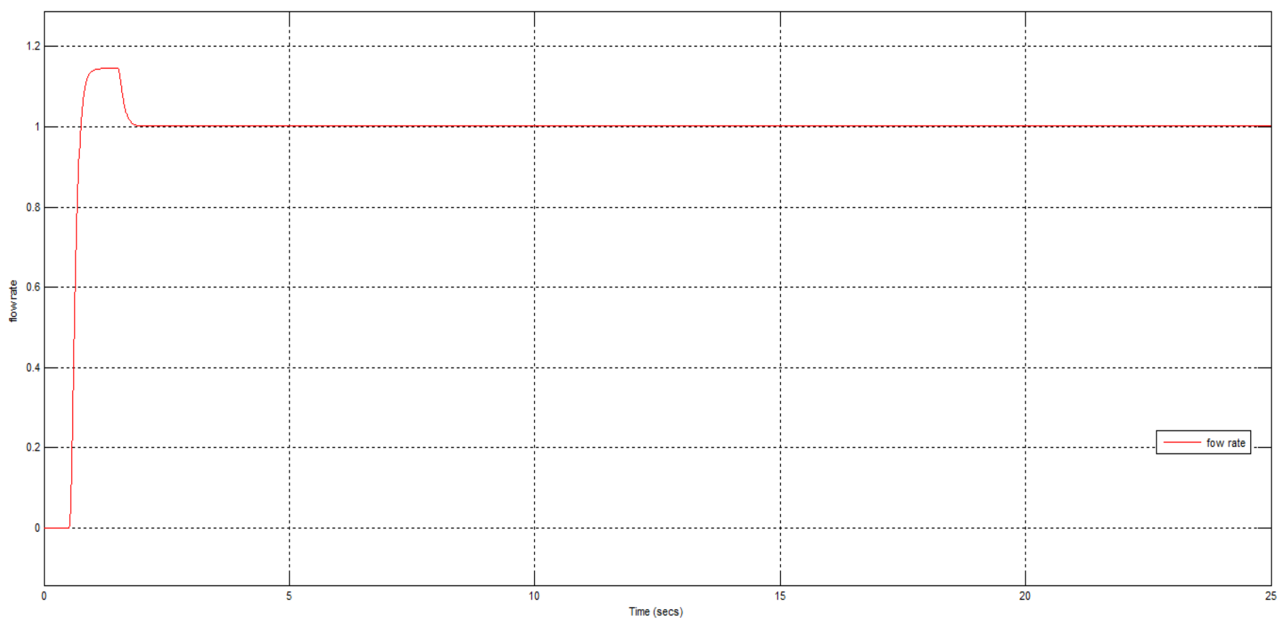


Figure 5.3 Simulation result of fuzzy logic controller to control the flow of cane fiber

Fuzzy logic based cane fiber flow control have better stability, small overshoot, and fast response with no complexity, Hence, fuzzy logic controller is having better performance for controlling cane fiber flows.

Table 5.2 Response of fuzzy controller for controlling flow of cane fiber

No	Parameters	Value
1	Rise time	0.154 second
2	Settle time	0.349 second
3	Overshoot	14.245%

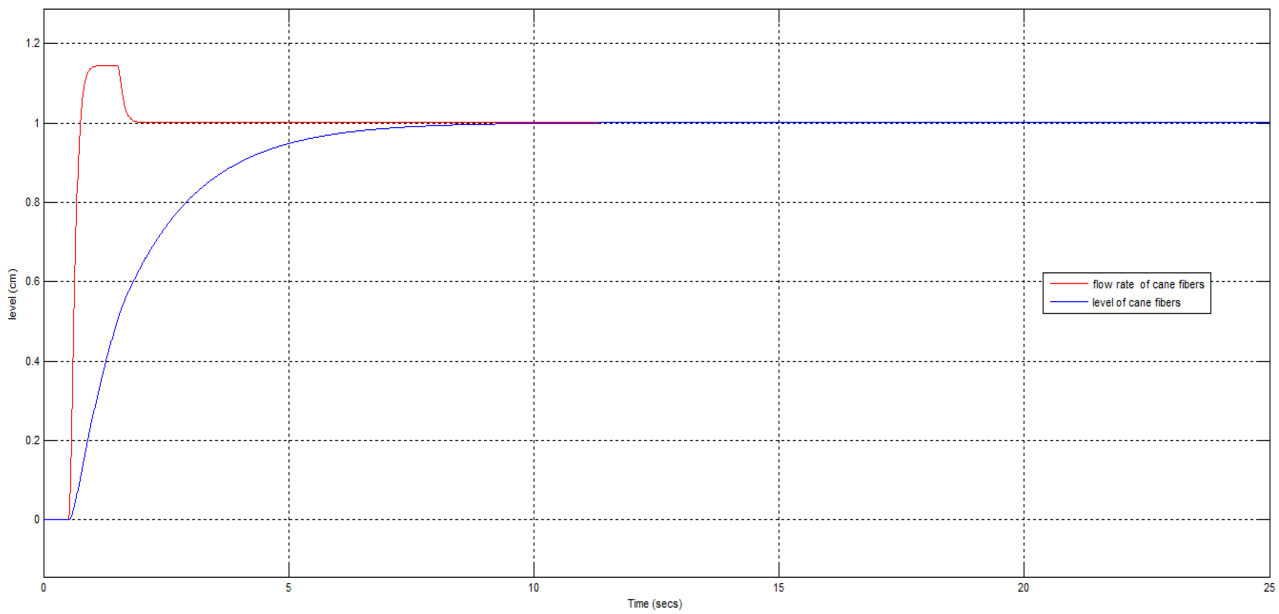


Figure 5.4 the simulation result of fuzzy logic based flow and level control of cane

As the weight of cane on the rake carrier is increasing the amount of cane fiber feed to chute is increasing and the level of cane fiber in the chute is increasing highly. Then the fuzzy logic controller send command to rake carrier motor so that the speed of rake carrier is slow and the level of cane fiber is constant and out flow rate due to compaction of cane fiber by the roller is decreasing and constant after the exposing of air from the juice.

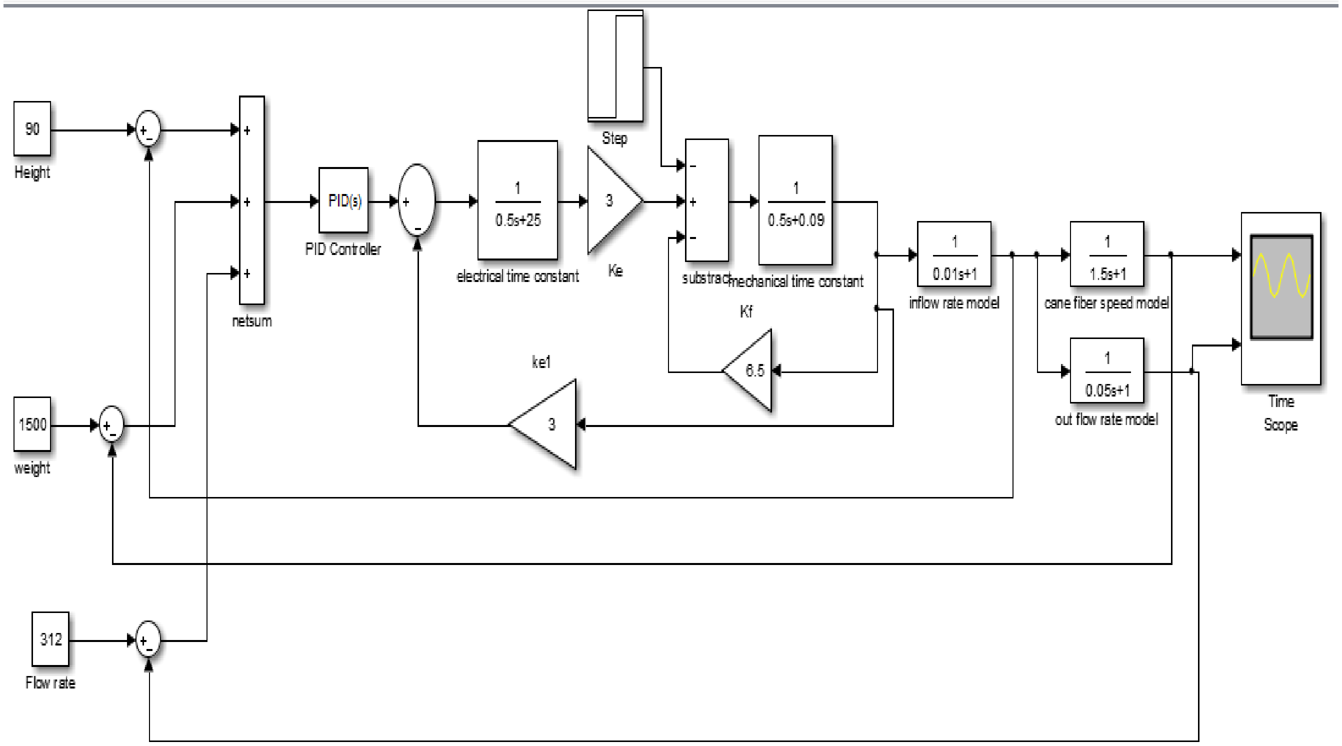


Figure 5.5 Simulink model of PID controller for flow and level control of cane

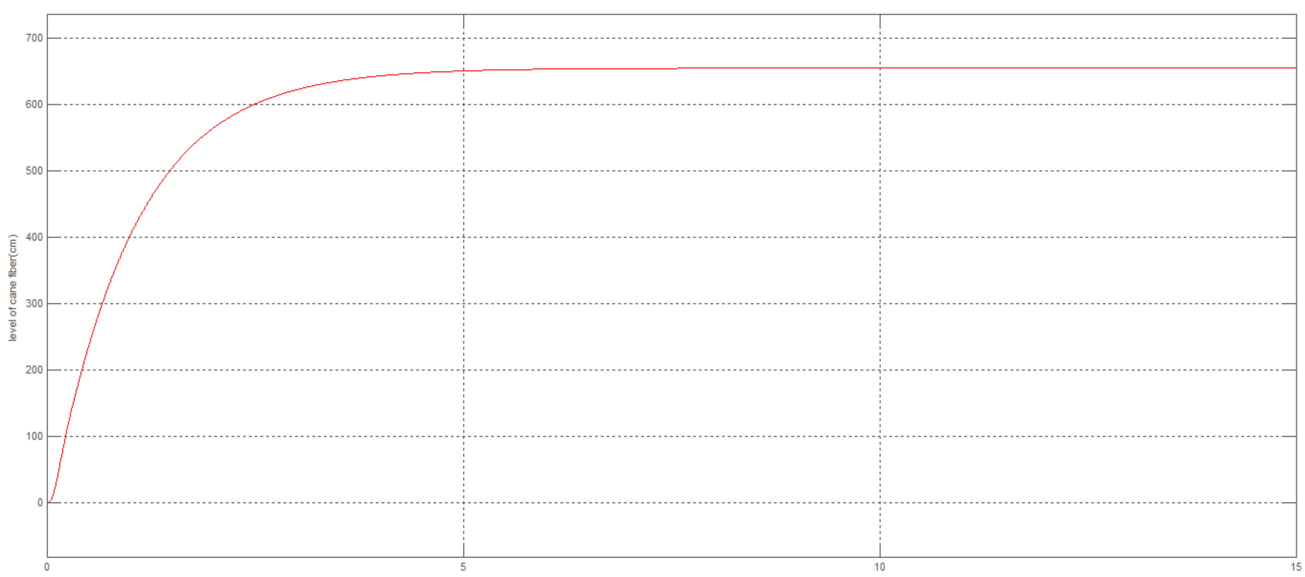


Figure 5.6 Simulation result of PID controller for level control of cane

Table 5.4 Response of PID controller for controlling level of cane fiber in chute

No	**Parameters**	**Value**
1	Rise time	0.109 second
2	Settle time	0.303 second
3	Overshoot	4.75%

PID controller can be understood as a controller that takes the present, the past, and the future of the error into consideration. Tuning a control loop is the adjustment of its control parameters (proportional band/gain, integral gain/reset, derivative gain/rate) to the optimum values for the desired control response. Stability (bounded oscillation) is a basic requirement, but beyond that, different systems have different behavior, different applications have different requirements, and requirements may conflict one with another.

5.2 Manual tuning technique

For manual tuning in online system, one of the methods is first setting all gains to zero. Increase the value until the constant oscillation of the output is obtained and then should be set to approximately half of that value for a quarter amplitude decay type response. After that increase to minimize the P term offset in a particular time for the process considering that too much can be a cause of instability. Finally, increase, if required, until the system becomes acceptably quick to reach the Set Point and decrease the oscillation. However, too much KD will lead to overshoot in the system. A quick PID controller loop normally has a little overshoots to achieve the desired value very fast; but in some systems cannot receive overshoot. In these systems a KP should be set remarkably less than half of the KP setting which provoked oscillation, to make over-damped in the closed-loop system.

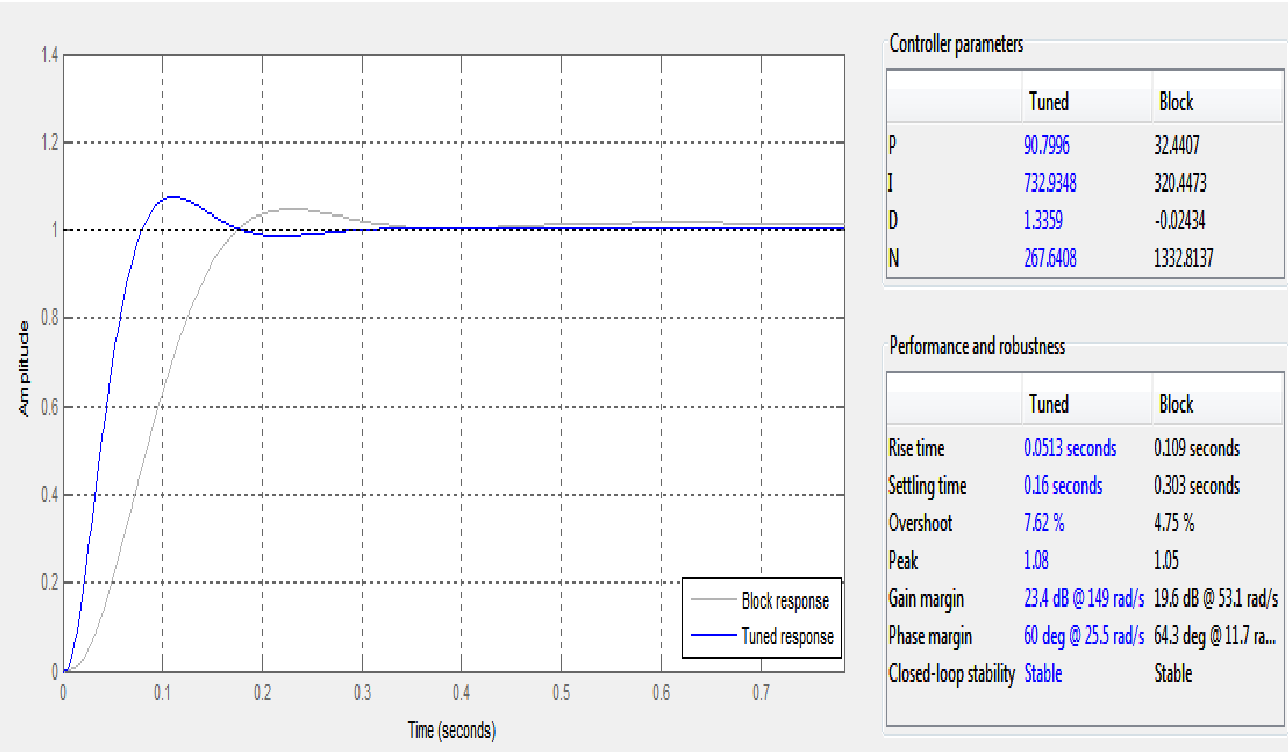


Figure 5.7 tuned response of PID controller for level control of cane

PID tuning is a difficult problem, even though there are only three parameters and in principle is simple to describe, because it must satisfy complex criteria within the limitations of PID control. There are accordingly various methods for loop tuning.

The step response of the closed loop system with PID controller is shown in the Figure 5.7

As it is observed from the figure, with the MATLAB/SIMULINK PID tuning extension tool box the step response of the system gets increased in percent overshoot, but decreased in both settling time and rise time while the steady-state error is zero.

Table 5.5 Response of PID controller for controlling level of cane fiber in chute after applying manual tuning

No	**Parameters**	**Value**
1	Rise time	0.0513 second
2	Settle time	0.16 second
3	Overshoot	7.62%

Table 5.6 Comparison result of fuzzy with that of PID for level control of cane fiber

No	**Parameters**	**PID controller**	**Fuzzy controller**
1	Rise time	0.109 second	0.0817 second
2	Settle time	0.303 second	0,274 second
3	Overshoot	4.75%	0 %

Table 5.7 Effect of independent tuning of P, I, D on the closed response

Parameters	Rise time	overshoot	Settling time	Steady state error	Stability
Increase, Kp	Decrease	increase	Small increase	Decrease	Decrease
Increase, Ki	Small decrease	increase	Increase	Large decrease	Decrease
Increase, Kd	Small decrease	decrease	Decrease	Small change	Improve

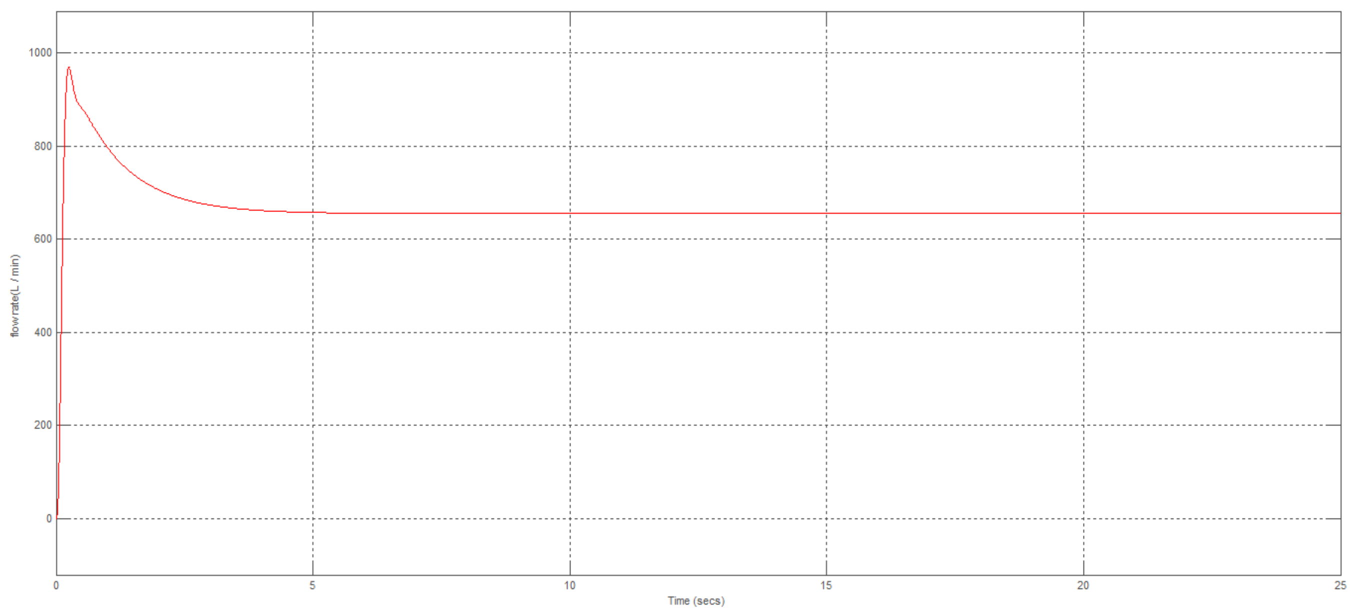


Figure 5.8 Simulation response of flow controller using PID controller

Table 5.8 Response of PID controller for controlling flow of cane fiber

No	Parameters	value
1	Rise time	0.076 second
2	Settle time	4.78 second
3	Overshoot	48.507%

Table 5.9 Comparison result of fuzzy with that of PID for flow control of cane fiber

No	Parameters	PID controller	Fuzzy controller
1	Rise time	0.076 second	0.154 second
2	Settle time	4.78 second	0.349 second
3	Overshoot	48.507%	14.245%

The capability of the controllers in disturbance rejection is checked by adding step disturbance signal from signal builder that has magnitude of two as shown in figure 5.7 and control signal that is input to the plant after settling time. Fuzzy controller has better disturbance rejection than PID controller.

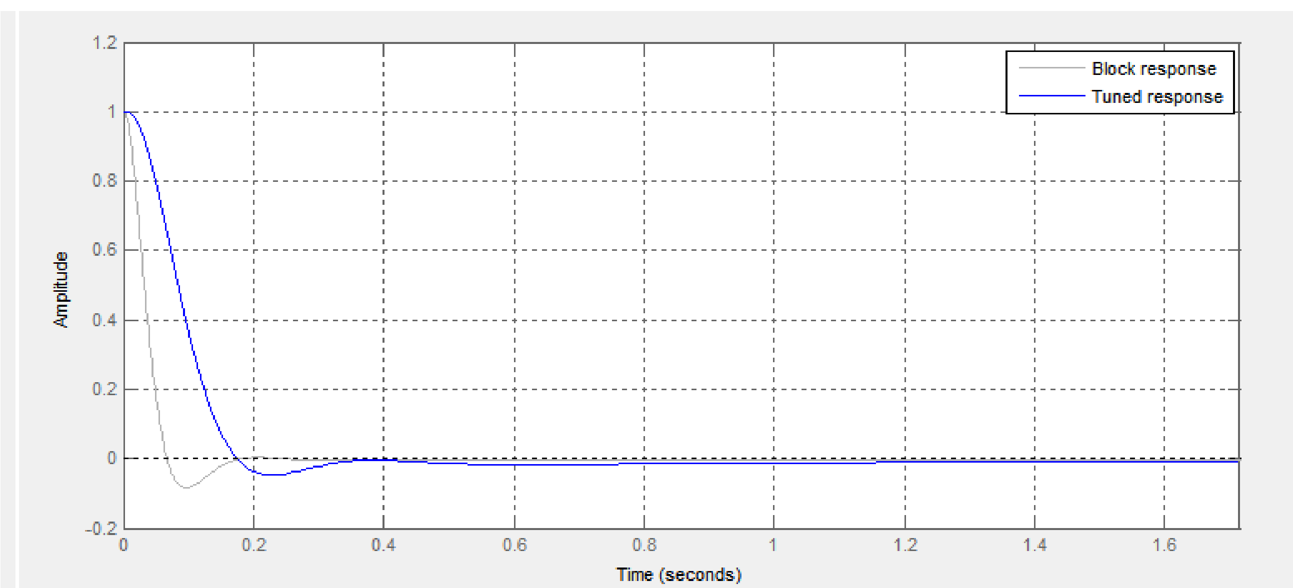


Figure 5. 9 Disturbance signal added to control signal after settling time

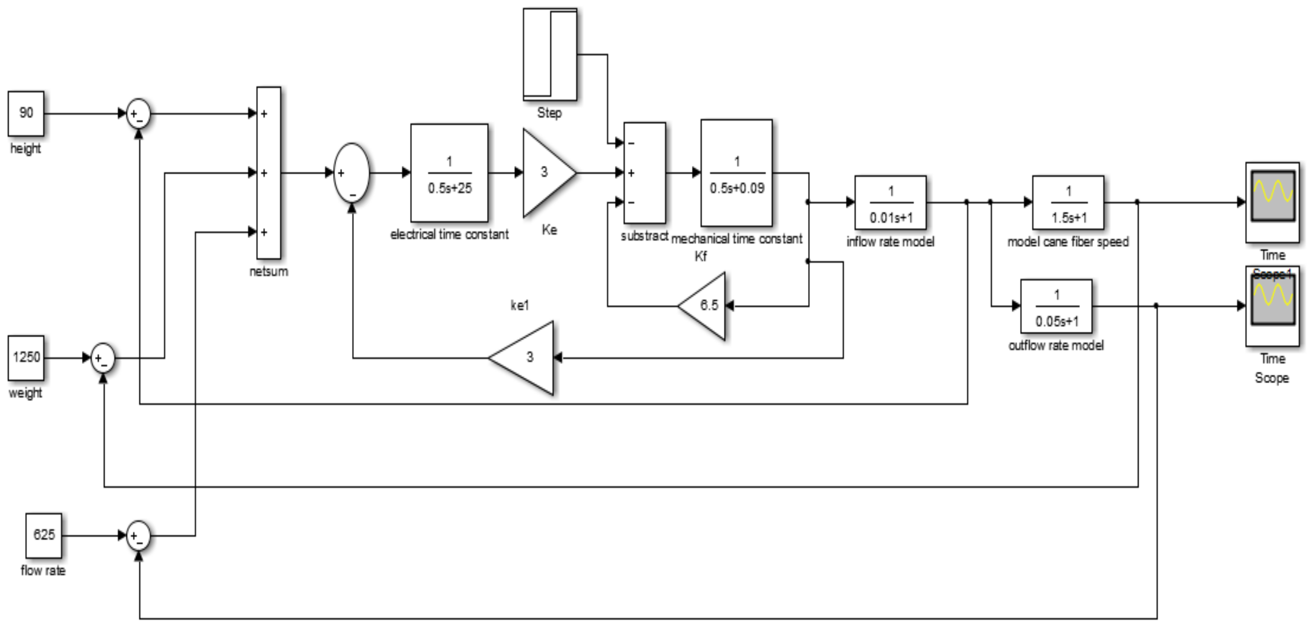


Figure 5.10 Simulink model of cane flow and level controller without any controller

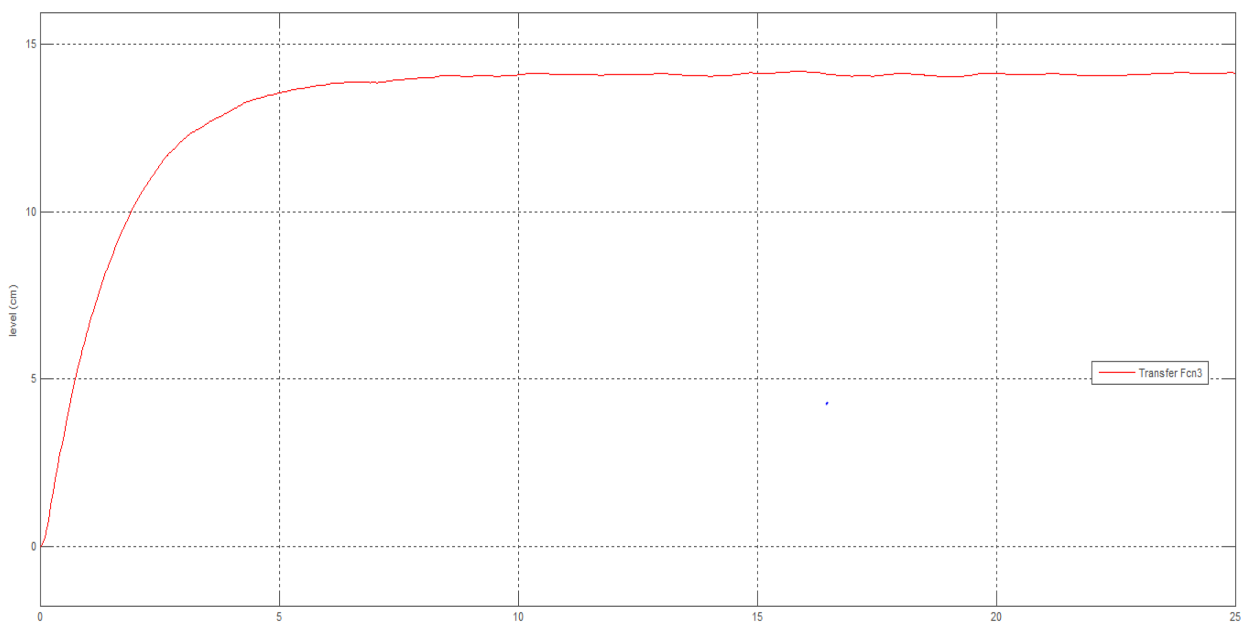


Figure 5. 11 simulation result of cane level without any controller

In order to minimize the overshoot, improve the settling time and the steady state error of the system. Introducing different controller is needed to maintain the desired level of cane fiber in chute and flow of cane fibers.

Table 5.10 Response for controlling level of cane fiber in chute without any controller

no	**Parameters**	**Value**
1	Rise time	13.171 second
2	Settle time	Infinite
3	Overshoot	40.53%

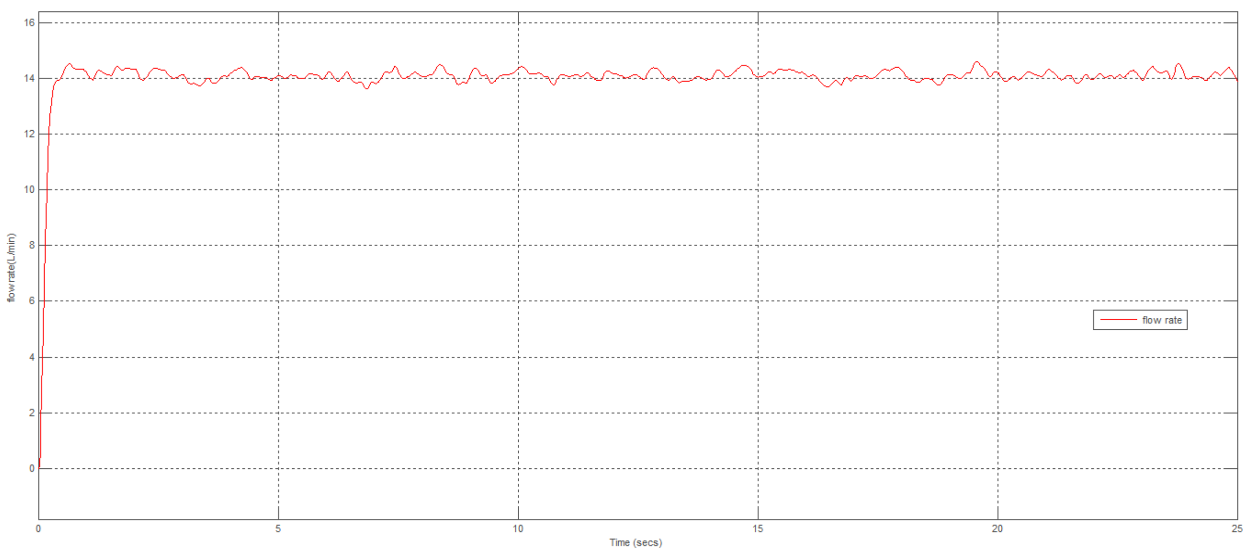


Figure 5.12 simulation result of cane flow controller without any controller

The performance of controlling of flow of cane fiber without controller is very poor in in terms of settling time, with very high steady state error and final value.

Table 5.11 Response of no controller for controlling flow of cane fiber

No	Parameters	Value
1	Rise time	19 second
2	Settle time	Infinite
3	Overshoot	48.53%

As we have seen from the simulation response of flow controller the response of fuzzy logic controller have better performance than that of PID controller and system without controller is having large settling time and it response is with much steady state error.

CHAPTER SIX

6.1 CONCLUSIONS AND RECOMMENDATIONS

In this thesis, flow and level control of cane is presented. After proper assumptions and approximations are made to linearize the mathematical equations describing the chute, transfer function are obtained in frequency domain. The results of traditional PID level and flow controller are not satisfactory to the higher degree of accuracy condition. Fuzzy logic controller is proposed to improve the performance of PID controller for flow and level control. Both the transient and steady state performances of the controller are improved by increasing the number of membership functions. The performance of the proposed fuzzy and PID controller is tested through simulation studies using MATLAB/SIMULINK. It is observed from the simulation results that the average overshoot is 0%, rising time 0.0817 seconds and the settling time is 0.274 seconds with the proposed fuzzy controller while overshoot is 7.62%, rising time is 0.0513 seconds and settling time is 0.16 seconds with traditional PID controller.

The proposed fuzzy controller is able to maintain cane flow and level is maintained within tolerable limits in spite of the parameter variation like delay time, time constant and DC gain. Furthermore, the capability of disturbance rejection is cheeked by giving step signal after settling time and it founded better than traditional PID.

The shape and distribution of the membership functions used in the design of fuzzy controller should be chosen with care to achieve system stability and robustness.

6.2 Recommendation

Even though assumptions and approximations are made to linearize the mathematical equations describing the chute, fuzzy logic based level and flow controller are not satisfactory to the higher degree of accuracy condition. Therefore the rule base and scale factor can be optimized with genetic algorithm for further improvements in the performance of fuzzy logic controller for flow and level control of cane. And hardware of self-tuning fuzzy controller can be developed for flow and level control of cane.

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APPENDICES

1. If (height is EL) and (weight is SL) and (flow rate is FM) then (speed is VH) (1)
2. If (height is VL) and (weight is SL) and (flow rate is FM) then (speed is VH) (1)
3. If (height is L) and (weight is SL) and (flow rate is FM) then (speed is H) (1)
4. If (height is JR) and (weight is SL) and (flow rate is FM) then (speed is JR) (1)
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