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FUZZY PID BASED INTELLIGENT HEART RATE CONTROLLER FOR PACEMAER

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Abstract—The combination of medical science and engineering has developed many electro-medical devices such as artificial organs, surgical robots, advance prosthetics, new pharmaceutical drugs and kidney dialysis. Electro-medical devices proved that it has boon for human being. It has not only diagnosed the diseases of patient but also has improved the quality of life of the patients. In last few decades many electro-medical device are introduced one them is pacemaker. A pacemaker is a small artificial electro-medical device that is placed in the chest or abdomen to stimulate the heart muscles to regulate the rhythm of heart in case of any problem in natural heart electric system such as arrhythmias, cardiac arrest etc. Performance of pacemaker depends not only on pacemaker controller circuitry and sensors but also depend on controller which used and its performance.
In this work, we used Fuzzy PID controller with pacemaker and heart to improve the performance of pacemaker in term of minimizing overshoot, rise time and settling time. Fuzzy PID controller is a combination of PID controller and Fuzzy logic controller. That's way it has characteristics of both controllers. The main advantage of Fuzzy PID controller is that it is used in both linear and nonlinear system. In this work removed overall overshoot and minimized rise time and settling time as compare to previous controllers by using Fuzzy PID controller.

Keywords: Fuzzy PID, fuzzy logic controller, PID controller, heart electric system, pacemaker

I. INTRODUCTION

According to world health organization (W.H.O) 2018 cardiovascular disease is the largest cause of death in the world as well as in India, around 17.3 million peoples are died in a year. Cardiovascular disease is included arrhythmias, heart attack, heart failure, peripheral arterial disease, peripheral vascular disease, rheumatic heart disease, congenital heart disease, stroke, deep vein thrombosis and pulmonary embolism. Cardiovascular disease is related to the abnormality function of heart like irregular pattern heart beat. In an irregular heart rhythm, the heart is to slow or to fast that means heart is contract in irregular pattern. The irregularity of heart is major cause of death at times. We can prevent the sudden death of patient by early treatment and proper diagnosis of heart disease. Pacemaker is a medical device used for treatment of cardiovascular surgery. Pacemaker stimulates the heart muscles to regulate the rhythm of heart [10], when any problem occurs in natural heart electric system of heart. Pacemaker is provide regular heart rhythm and saved life.
We control the pacemaker by different controller like PID controller, fuzzy logic controller, fractional order PID controller and etc. Nowadays everyone have a different lifestyle, and this lifestyle affect the heart rate, some people are more active in physical activities whose heart rate is higher as compare to normal heart rate, and some people are lazy whose heart rate is slow compare to normal heart rate, emotional changes of body is also affected the heart rate. So to overcome these situations the pacemaker is embed with different type of sensor example metabolic sensor and dual sensor. Sensor detects the abnormalities of heart and conveys to main processing unit, controller adjusts them and output unit gives regular heart rate.
This optimized the cardiac rate output through adjusting the pacing rate. This work discusses about the FUZZY PID controller used to control the pacemaker and optimize the better result as compare to PID controller, FUZZY logic controller, and FOPID controller.

A. Heart Rate Controller

Cardiovascular system is a closed loop system with controllers and filter with unity negative unity feedback [12] that is used for control the abnormal heart rhythm of patient. Fig.1. shows block arrangement of heart rate regulating system which contains a pacemaker, controller and heart transfer function with negative feedback.

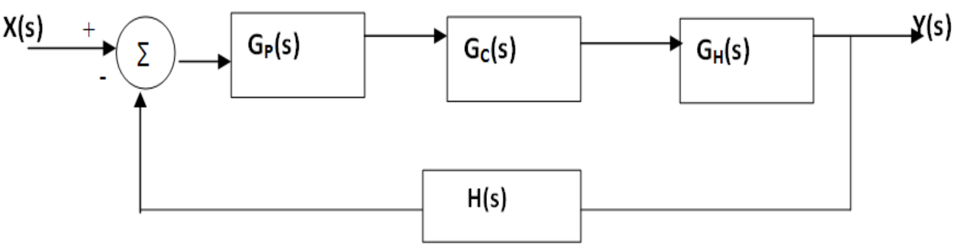

Fig.1: Block diagram of heart rate controller

Here,

X(s) = Actual heart rate

Y(s) = Desired heart rate

$G_P(S)$ = Transfer function of pacemaker

$G_C(s)$ = Transfer function of controller

$G_H(s)$ = Transfer function of Heart

H(s) = unity feedback

Transfer function of heart and transfer function of pacemaker fixed as described in [11], only the transfer function of controller is varying which depend on the controller types. Different controller is used to control the pacemaker like PID controller, FUZZY logic controller, FOPID controller.

In this work, we used Fuzzy PID controller along with pacemaker and heart transfer function. Taken the case of an old age patient whose average heart beat is 65bpm, we have tried to optimize the results obtained in [11] by using Fuzzy PID controller.

B. Pacemakers

A pacemaker is a small artificial medical device that is placed in the chest or abdomen to stimulate the heart muscles to regulate the rhythm of heart in case of any problem in natural heart electric system[10] such as arrhythmias. In arrhythmias the heart can beat too slow (bradycardia), to fast (tachycardia) or a blockage in the hearts electric system that cause the heart does not pump enough blood to the body, and then patient of arrhythmias fell tiredness, fainting and shortness of breath. Pacemaker can help to regulate abnormal heart rhythms. Pacemaker is containing a pulse generator with electronic circuits and battery and one or more electronic leads.

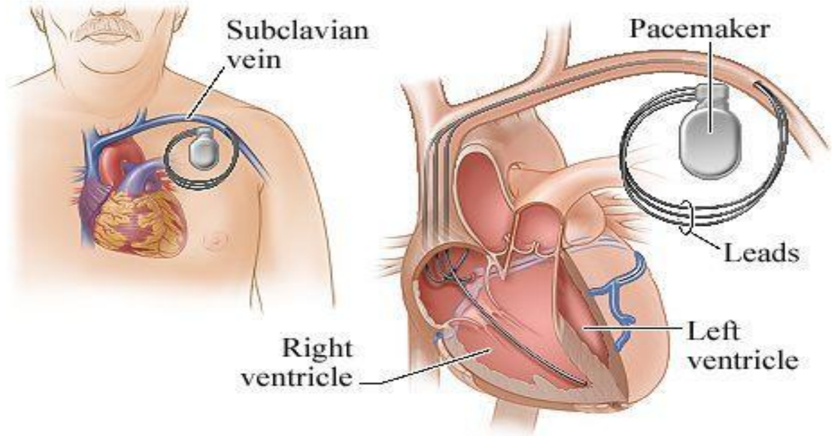

Fig.2: Pacemaker placed in body

C. FUZZY PID CONTROLLER:-

As I discussed previously a Fuzzy PID controller is a combination of the classical PID controller and the Fuzzy logic controller in an healthy way and thus a new intelligent controller has been accomplished. Fuzzy logic controller section tune the parameter of PID controller i,e Fuzzy logic controller has supervisory role to readjust the gain of the PID controller during the system operation and also a fuzzy switching method gives smooth control during switching between Fuzzy logic controller and conventional PID controller.[3] Fig.3 shows block diagram of fuzzy PID controller used with feedback system. The generalized equation of the transfer function of fuzzy PID controller is given by

$$G(S) = \frac{Y(S)}{X(S)} = K_P(\text{readjusted}) + K_I(\text{readjusted})/S + K_D(\text{readjusted})*S$$

Where,

G(S)=controller output

Y(S) =control signal

X(S)=Output signal of fuzzy logic controller

K_P(readjusted) =Readjusted proportional gain by fuzzy logic controller

K_I(readjusted) = Readjusted integral gain by fuzzy logic controller

K_D(readjusted)= Readjusted derivative gain by fuzzy logic controller

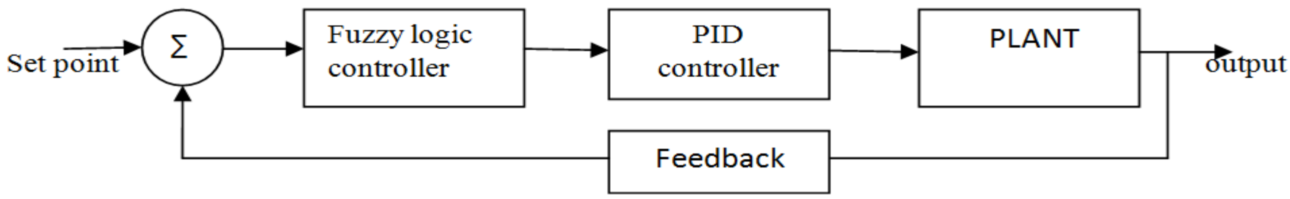

Fig-3 block diagram of fuzzy PID controller

II. DESIGN METHODOLOGY

Block diagrams shown below has cascaded blocks of heart, pacemaker and Fuzzy PID controller connected with unity negative feedback. We have related heart and pacemaker with transfer function [10]

Transfer function of heart = $\frac{8}{s+8}$

Transfer function of pacemaker = $\frac{169}{s^2+20.8s}$

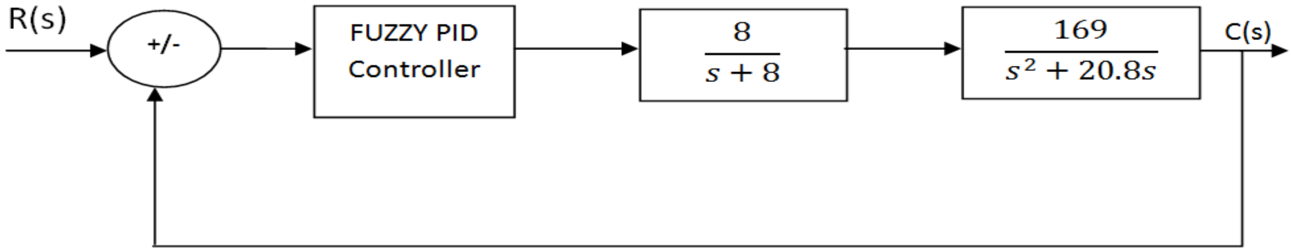

Fig.4. Block diagram FUZZY PID based heart rate controller

A. Design of FUZZY PID controller:

As we discus above FUZZY PID controller is a combination of FUZZY logic controller and PID controller.

B. Compensator formula of PID controller of FUZZY PID controller:

$$P + I\frac{1}{s} + D\frac{N}{1+N\frac{1}{s}}$$

Where,

P = Proportional

I= Integral

D = Derivative

N = Filter coefficient

C. Fuzzy membership functions and rule bases of Fuzzy logic controller of Fuzzy PID controller:

In Fuzzy PID controller's fuzzy logic controller taken two input variable one is heart rate error 'e' and second is the change of heart rate error 'dele' and one output variable control loop 'ctrlop'. Fuzzy inference block of fuzzy logic controller is given below

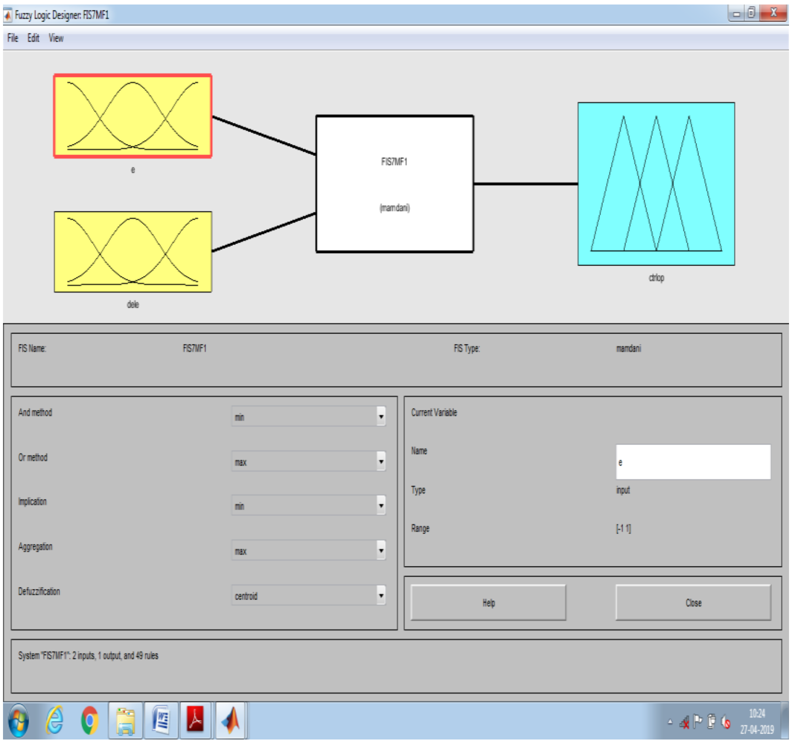

Fig.4: structure of the fuzzy inference block

The fuzzy rule bases of fuzzy logic proportional integral derivative controller are illustrated in table 4.1 and the meaning of the linguistic variables is describe in table 4.2

Table 1: Fuzzy rule bases of the Fuzzy PID controller

e\dele	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	PS	PS
NS	NB	NB	NM	NS	NS	PS	PS
Z	NB	NS	NS	Z	Z	PM	PM
PS	NM	NS	Z	PS	PS	PB	PB
PM	NS	Z	PS	PM	PM	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

Table 2: meaning of the linguistic variable

Error (e)		**Change in error (dele)**		**Output variable (Ctrlop)**	
NM	Negative Middle	NM	Negative Middle	NM	Negative Middle
NS	Negative Small	NS	Negative Small	NS	Negative Small
Z	Zero	Z	Zero	Z	Zero
PS	Positive Small	PS	Positive Small	PS	Positive Small
PM	Positive Middle	PM	Positive Middle	PM	Positive Middle
PB	Positive Big	PB	Positive Big	PB	Positive Big

D. Simulink model

Simulink model is used for FPID controller. As we above study FPID controller is a combination of fuzzy logic controller and PID controller. Only In a MATLAB simulink we connected the fuzzy logic controller with PID controller. Simulink model of heart rate controller with FPID controller is shown in fig 5

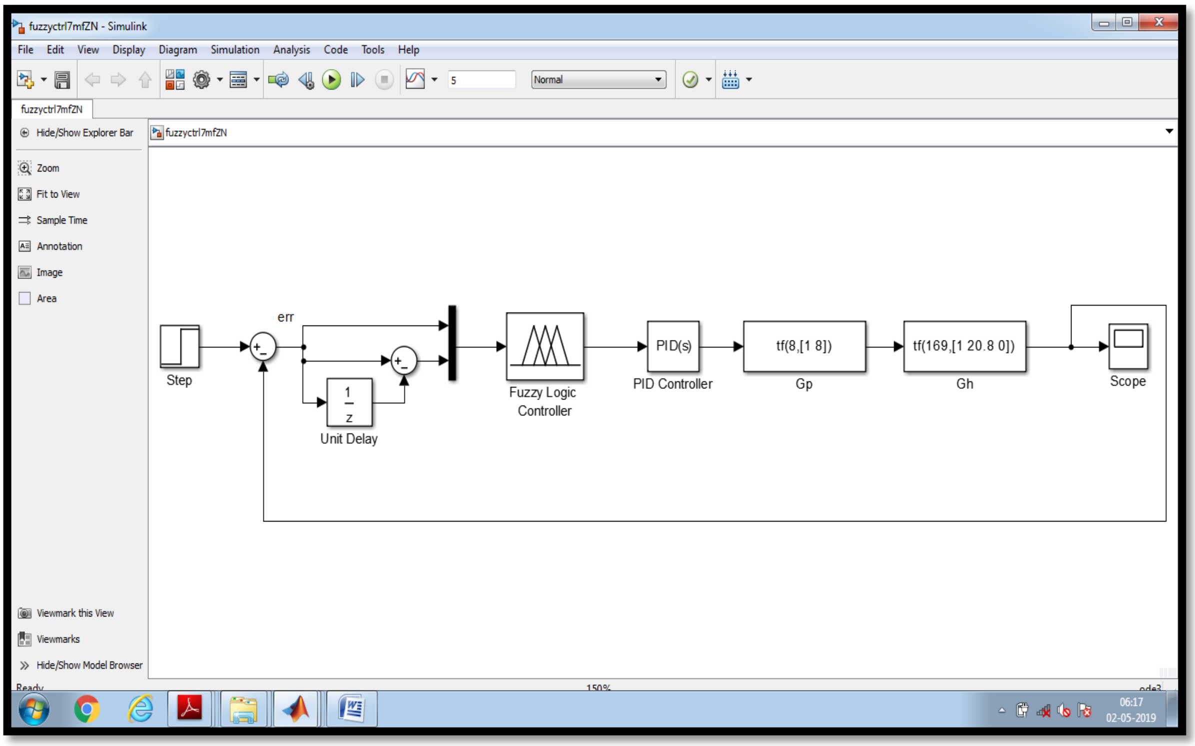

Fig5: simulink model of FPID controller based heart rate controller

III. 3. RESULTS

After connecting the FUZZY PID controller with heart and pacemaker according to the simulink diagram which is given above and applying appropriate values in compensator formula of PID controller of FUZZY PID controller then seen in the step response of simulink model minimized overshoot, rise time and settling time.
Results obtained after applying these below-mentioned values is:
Compensator formula of PID controller of FUZZY PID controller is

$$P + I\frac{1}{s} + D\frac{N}{1+N\frac{1}{s}}$$

Set these values in above formula
P = 2.124/a
I= 2.124/ (0.2437*a)
D = (2.124*0.0609)/a
N = 500

Here all the parameter P, I and D of compensator formula is divided by 'a' for removing the oscillation.
We find that at, a = 0.005 The oscillation of controller is removed.
Use of these values in FPID controller step response was obtained. This response revealed the following results:
Rise Time: 0.1145
Settling Time: 0.1734
Overshoot: 0.0094
We have seen that all the parameter Rise time, settling time and overshoot are reduced as compare to base paper.
Diagram of Step Response of pacemaker with FPID controller is given below in Fig.6

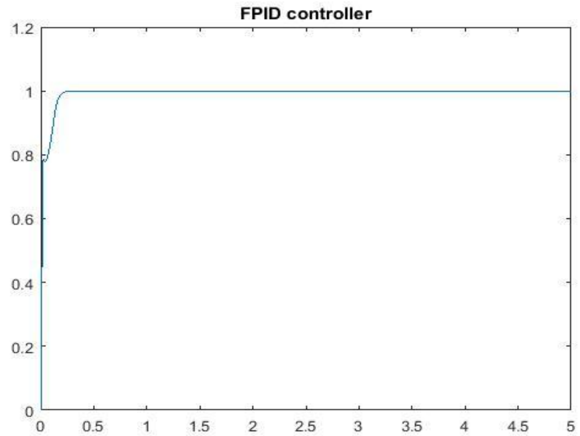

Fig6: step response of pacemaker with FPID controller

We have seen that FPID controller with pacemaker and heart gives more satisfactory values of overshoot, rise time and settling time compare to previous techniques.

Table.3. Comparison between previous technique and proposed techniques

Controller	Rise Time (t_r)	Settling time (t_s)	%Overshoot
ZN tuned FOPID (previous technique)	0.1367	0.2761	2.05
Self tuned FPID (proposed technique)	0.1145	0.1734	0.0094
Inference drawn	Decreased	Decreased	Decreased

This above comparison between my proposed techniques and previous technique shows that is basically my proposed technique reduced overall overshoot and minimized rise time and settling time as compare to previous technique of my base paper. Hence overall performances of Fuzzy PID controller are better as compare to FOPID controller.

A. A brief comparison of total previously work and proposed work:

Table 4: A brief comparison of total previously work and proposed work

Controller	Rise time (t_r)	Settling time(t_s)	% Overshoot
PID controller with ZN tuned	0.0714	1.0204	23.55
PID controller with TL tuned	0.0860	0.4098	11.73
PID controller with Relay tuned	0.3121	1.0617	5.48
Fuzzy controller	0.3442	0.7563	2.09
FOPID controller with ZN tuned	0.1367	0.2761	2.05
FUZZY PID controller (proposed technique)	**0.1145**	**0.1734**	**0.0094**

IV. CONCLUSION

This research is work on heart rate controller using Fuzzy Proportional Integral Derivative controller to improve the performance of pacemakers and help to cardiac patient to spend better quality of life. In this work gives the main focus on old aged people whose heart rate is 65 bpm. Mostly we have seen that the old aged peoples are suffering from arrhythmia problem. The main work of pacemaker to control the heart rate.

Pacemaker is upcoming remedy for cardiac patients, which is attached with heart and continuously monitors the heart activates and respond accordingly. Performance of pacemaker depends not only on pacemaker controller circuitry and sensors but also depend on controller which used and its performance.

different types of controller are used with different tuning techniques method. Firstly used PID controller with Ziegler – Nichols tuning Method, Tyreus - Luyben tuning method and relay tuning method improved the performance of pacemaker respectively but not gives satisfactory result. After that we have seen that used fuzzy logic controller instead of PID controller. Fuzzy logic controller gives better performance as compare to PID controller. Researchers are continuously researched and used FOPID controller with z-n tuning to improve the performance of the pacemaker that technique gives better result of step response compared to previous techniques[11]. Necessary condition for Stable control system is that minimized rise time, settling time and overshoot as possible as. This work is improvement[11] where used Fuzzy PID controller.

Fuzzy PID controller is a combination of Fuzzy logic controller and PID controller. So Fuzzy PID controllers have the characteristic of both Fuzzy logic controller and PID controller that's way FPID controller is superior to the conventional PID controller and fuzzy logic controller. FPID can be tuned by carrying the tuning rules from PID domain to fuzzy domain. FPID controller is a computationally effective and suitable for implementation in a real time closed-loop digital control. FUZZY PID controller has effective control capability for both linear and nonlinear system.

In this work used FUZZY PID controller, pacemaker and heart together in the form of closed loop with negative feedback and observed that response and seen that obtained smooth satisfactory result i.e. minimum rise time, minimum settling time and overshoot overall minimized compared previous used controller. Therefore it's conclude that the overall performance of Fuzzy PID controller is better as compare to PID controller, Fuzzy logic controller and FOPID controller.

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