Vol.67: e24230129, 2024
https://doi.org/10.1590/1678-4324-2024230129
ISSN 1678-4324 Online Edition

BABT
Brazilian Archives of Biology and Technology

Article - Engineering, Technology and Techniques

Investigation of an Intellectual Tracking System Using the Intelligent Controller for Infusion Pump in Medical Applications

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Editor-in-Chief: Alexandre Rasi Aoki
Associate Editor: Alexandre Rasi Aoki

Received: 04-Jul-2023; Accepted: 17-Nov-2023

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HIGHLIGHTS

- Design of infusion pump systems to actuate air control flow control for patients
- A self-adaptive fuzzy controller to operate infusion and deliver better efficiency.
- The hardware and simulation model of infusion pump is developed

Abstract: The paper proposes design and investigates controllers for infusion pump systems to actuate air control flow with improved performance. The actuator is realized with a permanent magnet brushless DC motor controlled by a self-tune PID controller replaced self-tune fuzzy-PID controller. Using the nonlinear model of the infusion pump system includes the motor driver, fuzzy-PID controller, and gear head as the load connected to the analysis of experimental results. The proposed control topology will improve transient responses such as rise time and steady-state error of the infusion pump system. The actuation system needs an efficient actuator with a controller for tracking desired response with self-tuning depending on linear and nonlinear conditions. The complete electromechanical actuator for fin control is modeled in MATLAB/SIMULINK environment. The simulation results show a better transient response and fewer torque ripples in the proposed system and a comparison study is performed for fuzzy-PID and conventional PID controllers.

Keywords: Fuzzy; PID; controller; Infusion Pump; BLDC motor; self-tune.

INTRODUCTION

The use of electromechanical actuation systems is increasing day by day in many tracking applications to improve actuation system performance [1]. The electro-mechanical actuation system is being used in the actuation system of the infusion pumps and infusion pumps [2-4]. The actuator needs to maintain constant torque performance for various dynamic loads. Brushless DC motor is intensively used in many applications like aerospace defense and industrial automation. Electromechanical actuator needs better torque-speed characteristics for which BLDC motor is an ideal choice as an actuator system [5-7]. A drive system for BLDC motor is developed on current control techniques using PWM signals. Among the controller, conventional

PID is the most popular controller in practice and has poor dynamic behavior for nonlinear loads in real-time applications [8-10]. A control algorithm integrating a fuzzy-PID controller and a Brushless DC drive is shown in Figure 1. The control algorithm performs fast operation with a fuzzy-PID controller for nonlinear systems and overcomes its oscillatory response by switching gains of the fuzzy-PID controller [11-14]. The proposed controller has a shorter rising time, and less overshoot and oscillation than PID control, which is an ideal requirement for underwater infusion pumps. To verify the proposed system the complete setup was simulated in a MATLAB-SIMULINK environment.

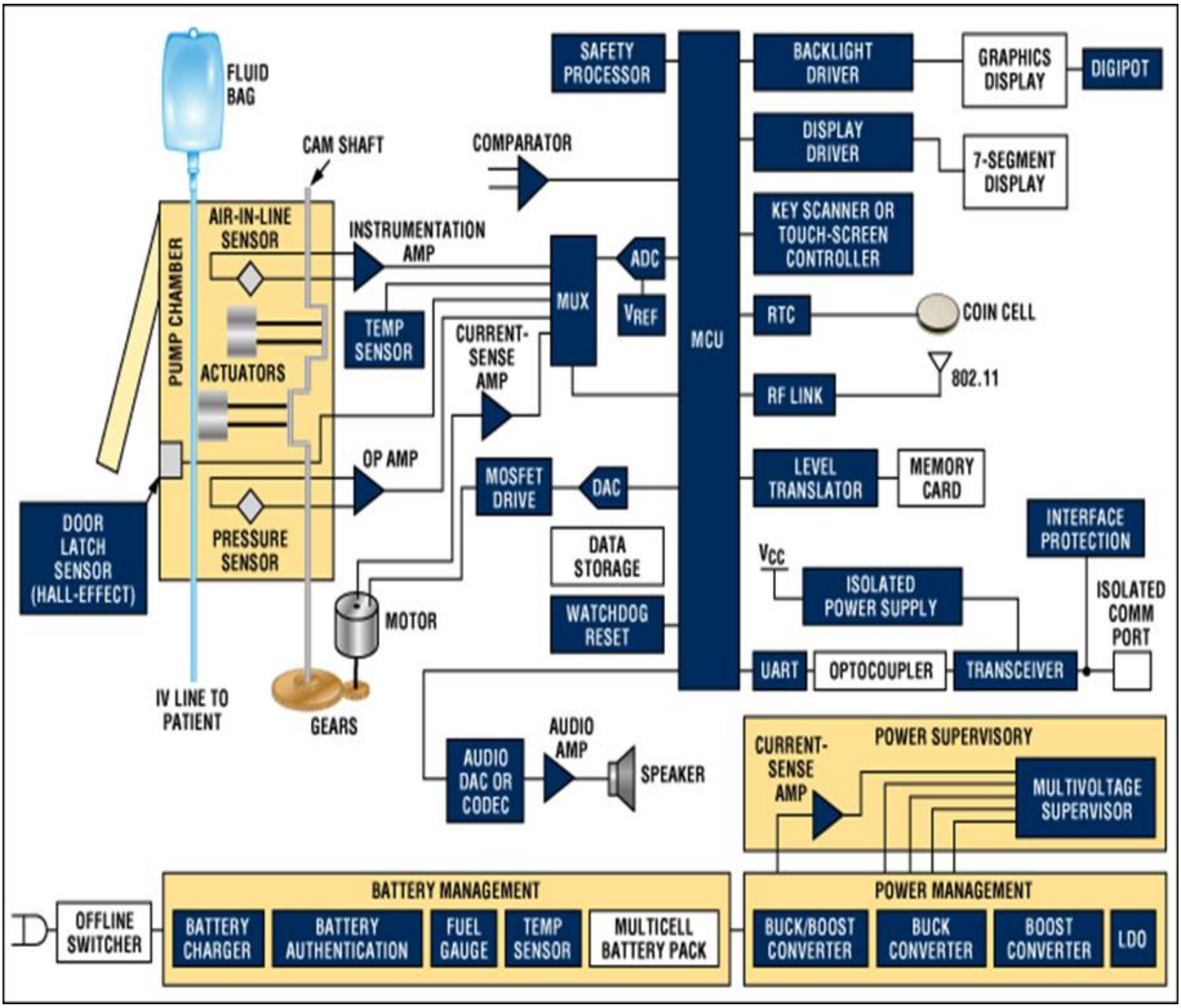

Figure 1. Overview of Infusion Pump

MATERIAL AND METHODS

Modeling and tuning controllers is a difficult task in the BLDC motor drive system. The design of the BLDC motor drive controller requires three feedback closed loops in considering current speed and position. The first closed loop is a current controller that performs by limiting the maximum current to protect the motor and the second closed loop is a speed controller to maintain the fin at the desired speed limit. The outer (third) closed loop is a position controller to maintain the fin at a set desired position in infusion pumps. The PID controllers are used for feedback systems due to their simplicity and ease of operation conventionally, showing poor performance during the change in load and change of commands. Tuning the control gain is tedious and time-consuming. To overcome the limitations fuzzy-based PID controllers are proposed. Fuzzy PID does not require complex mathematical modeling and they are more suitable in a nonlinear environment. It extends its advantage with minimized error and faster response compared to conventional one.

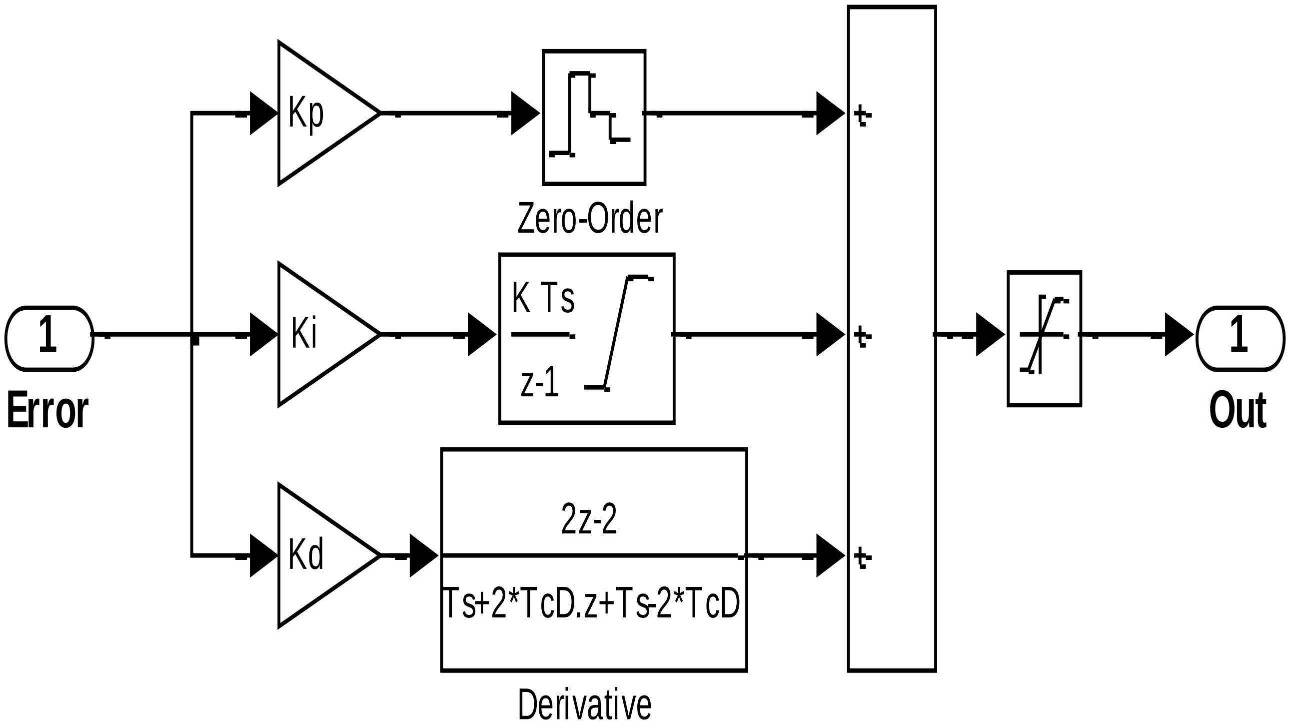

Figure 2. Conventional PID controller

$$C(z) = K_p + K_i T \frac{z}{z-1} + \frac{K_d}{T} \frac{z-1}{z} \tag{1}$$

K_p - Proportional gain
K_i - Integral gain
K_d - Derivative gain
T - Sampling time in sec

The basic model of conventional PID controller as shown in Figure 2 is used in position, speed, and current controllers but their gain values Kp, Ki, and Kd are differed as per the position and current magnitude working ranges. From the PID control law, the mathematical formulation of the discrete controller is formed as per equation 1. Fuzzy PID controller is impended based P,I and D values with the range of membership is the function used as unity +1, and hence it is required to scale the control signals before and after fuzzy inference as shown in Figure 3.

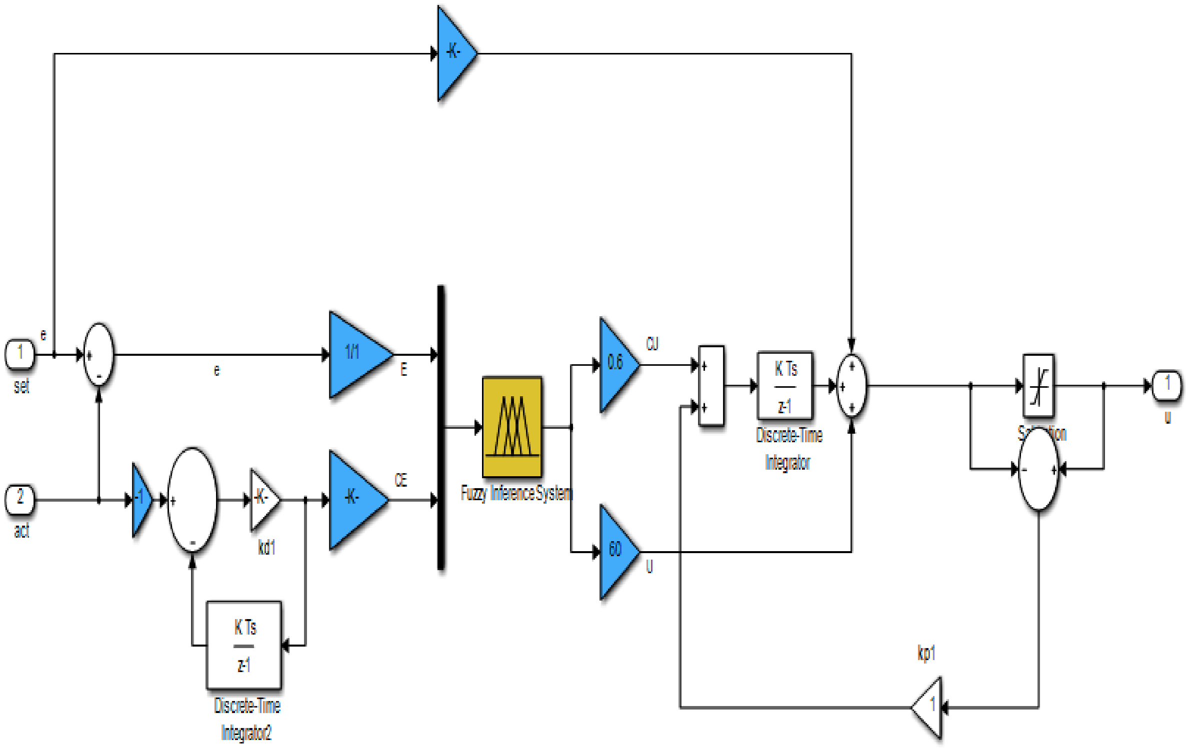

Figure 3. Combination of Fuzzy PID controller

Reference current magnitude Idc* is the output of the outer loop position controller and gate pulse duty cycle is the output of the inner loop current controller and compared with the actual measured and feed current controller. The scaling factors are derived from conventional PID controller gains as per equation (2)-(5). One feed-forward path is provided to ensure the working of proportional action when the fuzzy PID controller is linear. Anti-windup feature is included to control the saturation level of the output response signal, so as to improve the quick response of the fuzzy PID controller.

$$GE = \frac{1}{\max .error} \tag{2}$$

$$GCE = GE * \left(K_p - \sqrt{K_p^2 - 4K_i K_d}\right)\frac{K_i}{2} \tag{3}$$

$$GU = \frac{K_d}{GCE} \tag{4}$$

$$GCU = \frac{K_i}{GE} \tag{5}$$

GE - Error normalization factor

GCE - Change in measurement normalization factor

GU - Response de-normalization factor

GCU - Change in response de-normalization factor

Input and output variables are mapped via membership functions to work with a fuzzy inference system as shown in Figure 4. They are triangular and cross neighbor sets at a membership value of 1. Mamdani type inference is used for the inference engine and the center of gravity method is used for defuzzification. The linguistic variables are divided into seven groups and they are all - negative large, nm - negative medium, ns - negative small, NZ-negative zero, z- zero, Pz- positive zero ps- positive small, pm - positive medium, and pl - positive large.

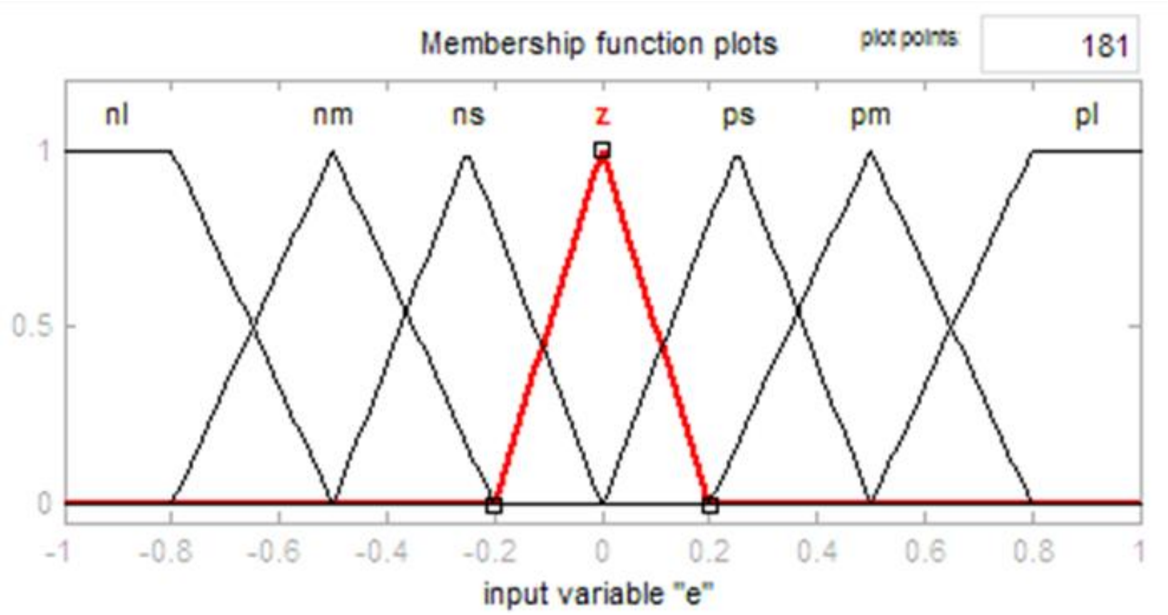

Figure 4. Membership Functions of ‘e’ ‘ce’ ‘u’

Table 1. Fuzzy rule-based matrix

e	**nl**	**nm**	**ns**	**nz**	**z**	**pz**	**ps**	**pm**	**pl**
nl	nl	nl	nl	nl	nl	nl	nm	ns	z
nm	nl	nl	nl	nl	nm	nm	ns	z	ps
ns	nl	nl	nm	nm	ns	ns	z	ps	pm
nz	nl	nl	nm	ns	z	ps	pm	ps	pm
z	nl	nm	ns	ns	z	ps	ps	pm	pm
pz	nm	ns	ns	ps	z	pm	pz	ps	pl
ps	nm	ns	z	ps	ps	pm	pm	pl	pl
pm	ns	z	ps	ps	pm	pl	pl	pl	pl
pl	z	ps	pm	pm	pl	pl	pl	pl	pl

Inference engine work is based on rules as per Table 1, there are 9×9=81 rules are possible in the matrix. The top row and left column of the matrix indicate the fuzzy set of the variables ‘e’ and ‘ce’ respectively and the variable ‘u’ is shown in the body of the matrix. The surface view of the fuzzy PID controller is shown in Figure 5, whereas the x-axis is error ‘e’, y-axis is changing in measurement ‘ce’ and z-axis is output response ‘u’ results in plot shows a smooth surface.

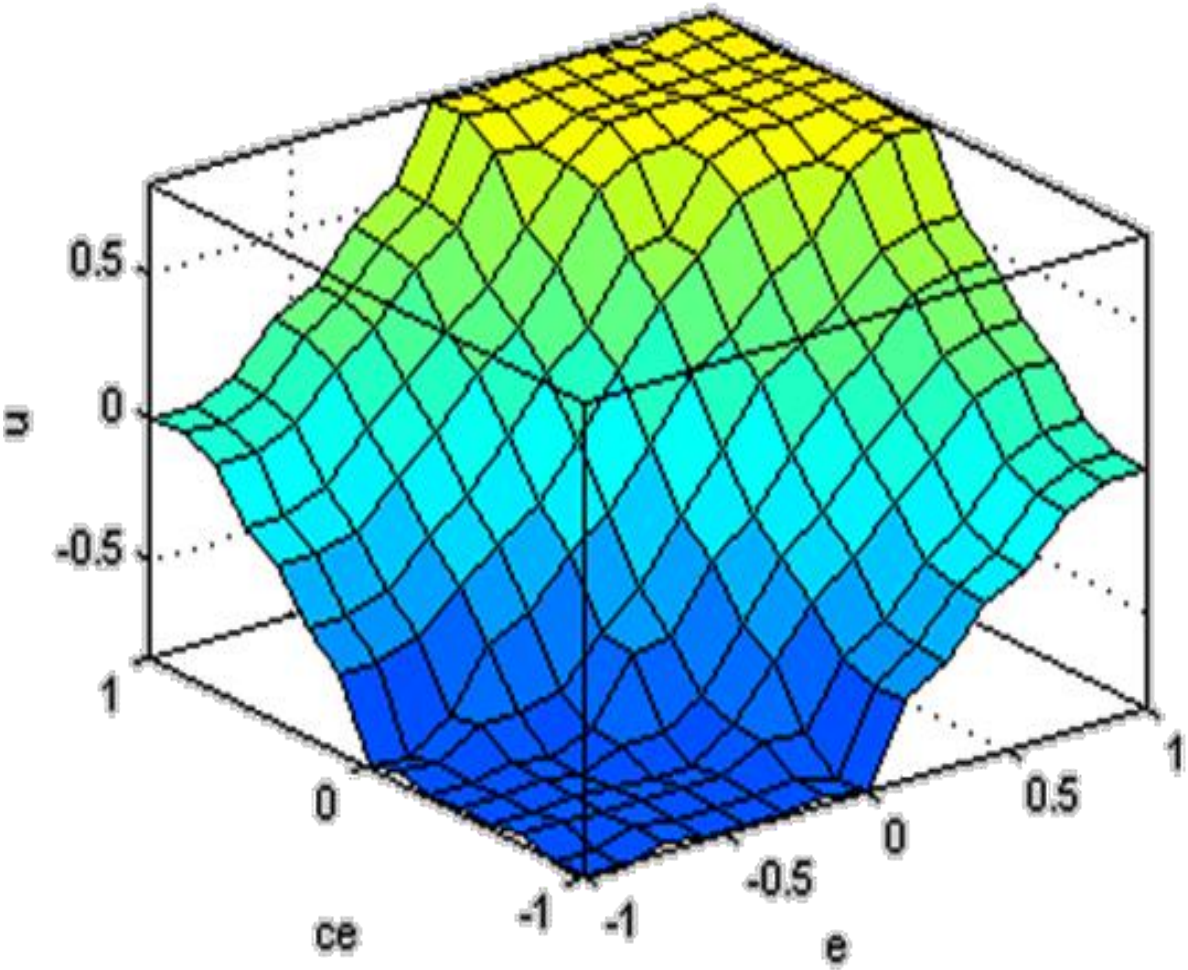

Figure 5. Surface viewer of fuzzy PID controller

RESULTS AND DISCUSSION

The simulation implementation of Infusion pump fin position control drive in MATLAB and simulated in for commanded signal and several tests are performed to validate the controller design as per Figure 6.

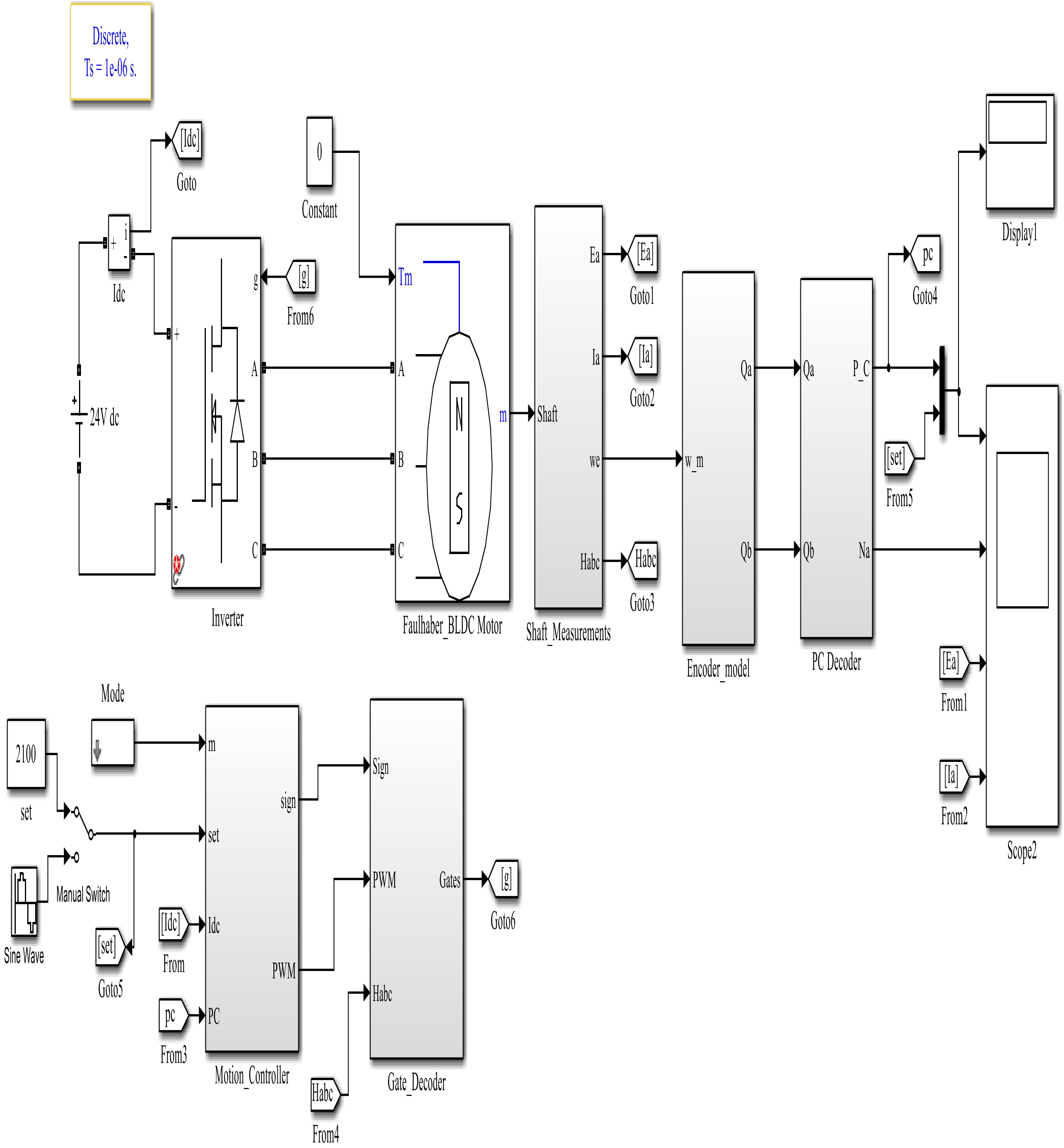

Figure 6. Simulink Block diagram of infusion pump

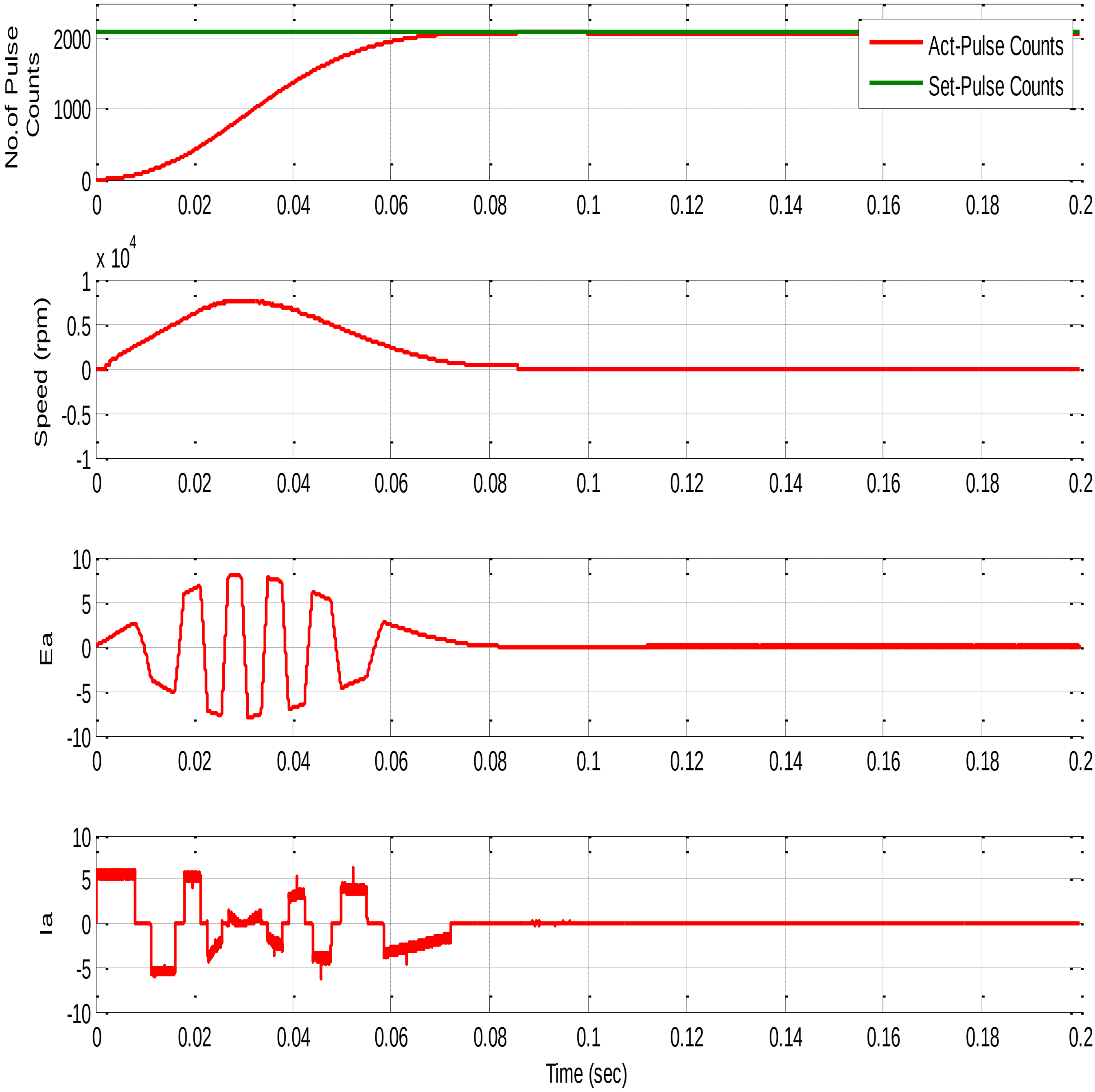

Figure 7. Conventional PID controller for Infusion Pump

The analysis for conventional PID and fuzzy PID controller response are presented in Figures 7 and 8 to verify the dynamic behavior in terms speed, current and back-EMF of proposed controller. Simulation is carried up to 0.2 seconds and the initial position was changed for commanded value of 2100 counts. The results suggest in speed control fuzzy performance is better than conventional one including settling errors. In proposed system two gear heads are designed with gear ratio of 1:14 and 1:135.

The incremental encoder will increment the pulse counts of 0.25 in each edge. So one revolution of motor will give us 100ppr that can be possible in 400 edges then (400*14*135) 100 pulse counts are possible for one revolution. The pulse counts required for 360 is 756000 pulse counts, for one degree fin movements 2100 pulse counts. For step change of speed analysis is carried are as shown in Figure 9 show the speed step up from 2000rpm into 10000rpm at 0.05 sec then step down to 10000rpm into 5000rpm at 0.1 sec. The fin is required to move to 2 degree then in that case position analysis is carried for 4100 counts.

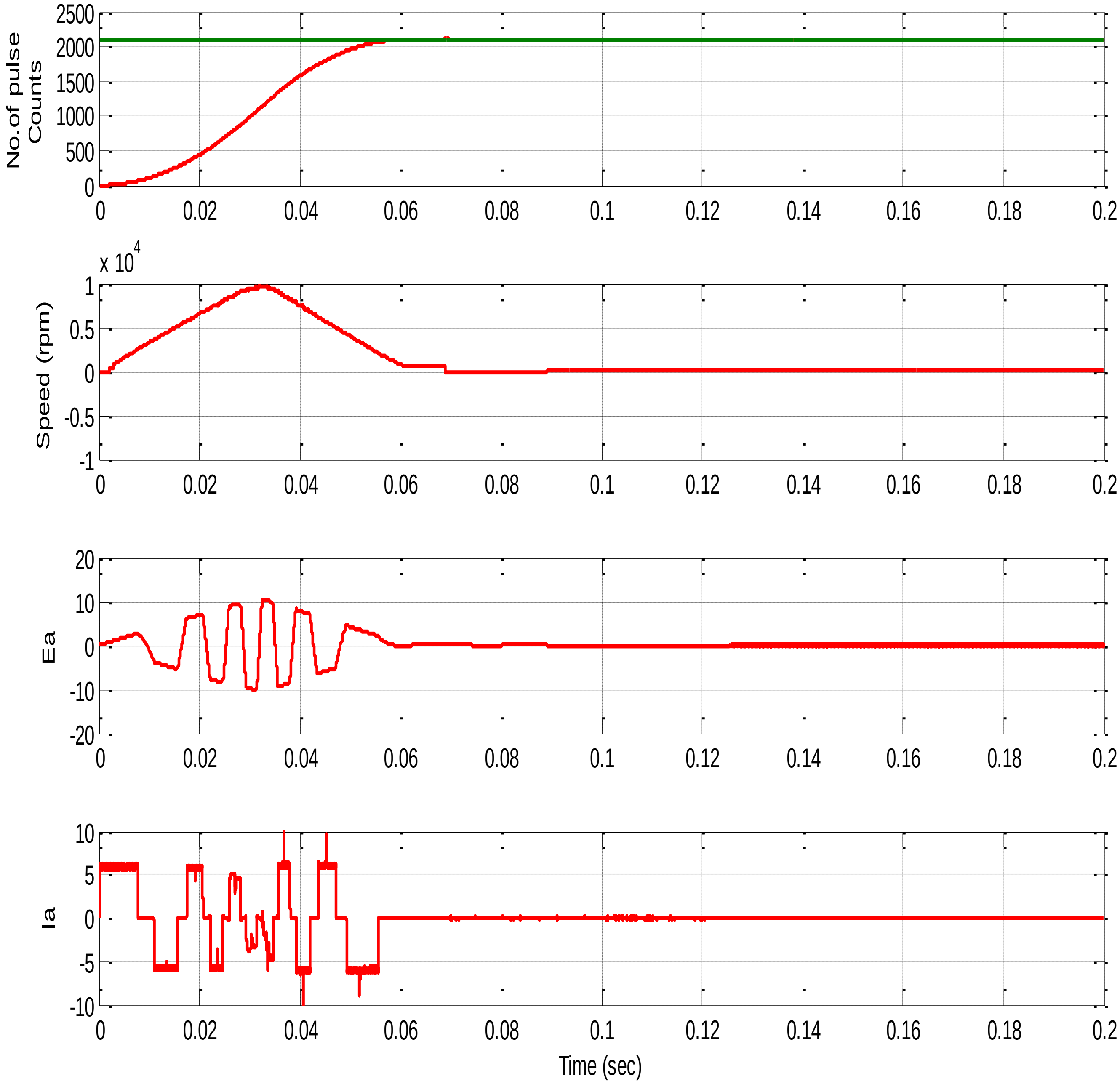

Figure 8. Fuzzy PID controller for Infusion Pump

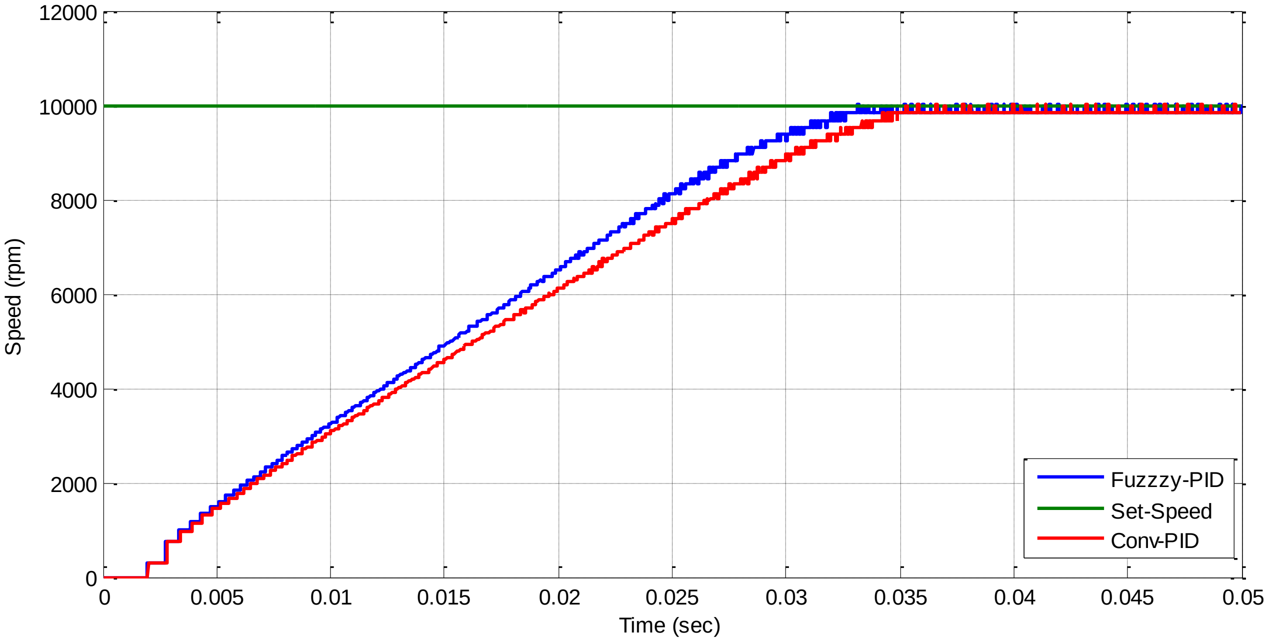

Figure 9. Speed control for Infusion Pump System

A comparison is made with the dynamic behaviors and presented in Table 2. With the rising time (Tr), percentage of maximum overshoot (Mp) and ± percentage of steady-state error, the performance of fuzzy PID is better than the conventional ones in all operating conditions of commanded signals.

Table 2. Result comparison of Conventional PID and Fuzzy PID

Controller Parameter & Set Position	Conventional PID				Fuzzy PID			
	Tr (milli-sec)	Mp (%)	Ts (milli-sec)	± Error (%)	Tr (milli-sec)	Mp (%)	Ts (milli-sec)	± Error (%)
Step change motion 0 to 2100 counts	0.65	0	0.35	-6.66	0.54	1.11	0.19	+1.22
Step change motion 2100 to 4200 counts	0.1	22.22	0.2	+5.55	0.15	5.55	0.25	+1.66
Step change motion 4200 to 2100 counts	0.2	0	0.35	-5.55	0.15	1.11	0.25	-1.33
Step change motion 2100 to 0 counts	0.1	22.22	0.2	-3.33	0.15	5.55	0.25	-1.44

The algorithm achieved with less rise time makes key improvements in the overall tracking system with less rise rime and settling time. The up-to-date investigation and experimental results tabulated are directed to implementing a fuzzy-PID controller for all tracking applications to hold better tracking responses.

CONCLUSION

A fuzzy-PID tracking method is presented and compared conventional self-tune-PID controller. Initially, an experimental test is carried out in MATLAB SIMULINK, and comparison results describe the superior the proposed fuzzy control algorithm. The results of numerical simulations show that, when compared to other controllers, the suggested technique has greater control performance, stronger resilience, better adaptation to diverse roadways, and shorter braking distance. The test results confirm the proposed fuzzy-PID control algorithm stability offers a low-cost, simple-to-implement, and simple-to-interpret alternative and has improved solution count and timing, which is important for assessing flow accuracy and uniformity at low flow rates.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

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