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Fuzzy Logic Control of an Electrical Traction Elevator

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Abstract

A novel elevator speed regulation scheme that is based on Fuzzy Logic (FL) technology is presented. The Fuzzy Logic controller has the ability to track a user defined elevator's speed profile without compromising the accuracy in reaching a designated position. The response of the FL controller will be compared with the ubiquitous PID controller by means of computer simulations. Standard cybernetics performance criteria will be used in judging the performance of both controllers. Finally, such a FL based controller maybe easily complimented with additional intelligent features.

Keywords: Feedback Control System, PID controller, Fuzzy Logic, Elevator Control

1. Introduction

Elevators are the primary mean of transportation that is used nowadays in tower buildings. In this century, the trend is higher is better. Dubai has just finished opening its one kilometer tower while Saudi Arabia has announced that they are working on building a one mile tower building! Such high buildings demand high performance elevators, with extra ordinary speed control.

In general, elevators may be classified according to their driving method into three categories; electric, hydraulic and pneumatic elevators. Hydraulic elevators use hydraulic oil driven actuators to raise and lower car and its load, this type of elevators is typically used for low to medium rise buildings. Electric elevators consist of two main types: winding drum and traction elevators.

The applications of winding drum machines are very limited by both code restrictions and practical considerations1.

On the other hand electric traction elevators are elevators in which the energy is applied by means of an electric driven machine. Medium to high speeds and virtually limitless rise allow this elevator type to serve high-rise, medium-rise and low-rise buildings.

Electric traction elevator can be further divided into geared and gearless categories: geared traction elevators are designed to operate within the general range of 100 to 450 ft/min, restricting their use to medium rise buildings, while gearless traction elevators speeds are available in the range of 500 to 1500 ft/min. Such designs offer the advantages of longer life and smoother rides[2].

Many studies were carried out in controlling the elevator systems. For example, Kang, et al.[3] proposed a new strategy to reduce the vertical vibration of the lift car while keeping high speed control and as a result it improved the efficiency of riding elevators. An extended full-order observer is designed to estimate the acceleration feedback of the car and the identification of some mechanical parameters. Both experimental evaluations and computer simulations proved the feasibility of this strategy.

Mannan, et al.[4] proposed an electro-hydraulic system for the control of an elevator with twin cylinders that are located on each side of the elevator car. A PD fuzzy controller is applied to regulate velocity, where as a constrained step PD controller is used to guarantee a minimum non-synchronous error between the motions of the two cylinders.

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Sha, et al.[5] has introduced an approximate linear model for a hydraulic elevator that includes an improved dynamic frictional based model and has investigated a sliding mode control (non-linear) for velocity tracking in the discrete domain. Simulation experiments showed that this approach offers an effective and improved solution for the hydraulic elevator control.

Huayong, et al.[6] studied the computational simulation and experimental research on the variable voltage variable frequency VVVF hydraulic elevator speed control. The research results provided a theoretical basis for the design and application of the VVVF hydraulic elevator. Kim, et al.[7] proposed a two-stage non-linear robust-controller, using Lyapunov method to control the velocity of the hydraulic elevator. On the first stage, a robust controller of the mechanics is synthesized to control the velocity of the car. On the second stage, a robust controller for the hydraulic is designed to track the pressure that is generated by the first controller.

Zhou, et al.[8] introduced a hybrid backup power system, including batteries, ultra capacitors and hydrogen fuel cells in order to get a reliable and effective continuous function elevator in spite of miscellaneous power failures.

In this work Fuzzy Logic (FL) controller is presented to track a reference speed profile for a 2:1 gearless traction elevator and the results will be compared with the standard tuned PID controller performance.

2.1 Elevator model

The long-life, smoothness and high horsepower of gearless traction elevators provide a durable elevator service that can outline the building itself. The first high-rise application of gearless traction elevator was in the Beaver building New York City in 1903, which was followed by such notable installations such as the singer building which was demolished in 1972 and the Woolworth buildings, to name few. Typically elevator machines are either roped with a single or double wrap arrangement. Single wrap arrangement provides traction by the use of grooves that will pinch the ropes with varying degrees of pressure depending on the groove's shape and it's undercutting. The most effective single-wrap arrangement gives 180 degrees of the rope contact with the sheave without deflecting the sheave. On the other hand, double-wrap arrangement is used for high-speed gearless traction machines of 4mps or more to obtain traction and to minimize rope wear.

Conventional elevators are either roped as 1:1 or 2:1 for both car and counter-weight. The savings on using a faster motor that can be built smaller and lighter than lower speed DC motors makes 2:1 roping more attractive for a full range of speed requirements from (0.5-3.5 mps) or more. Also, an advantage in lifting capacity as the 2:1 argument allows the use of higher-speeds and therefore a smaller but faster elevator motor. Finally, the mechanical advantage of 2:1 roping requires that only half the weight to be lifted[9].

The most popular electrical elevator models based on roping techniques are shown in Figure 1. For a complete and thorough discussion of the pros and cons of such schemes the reader is directed to consult some elevator design based handbooks.

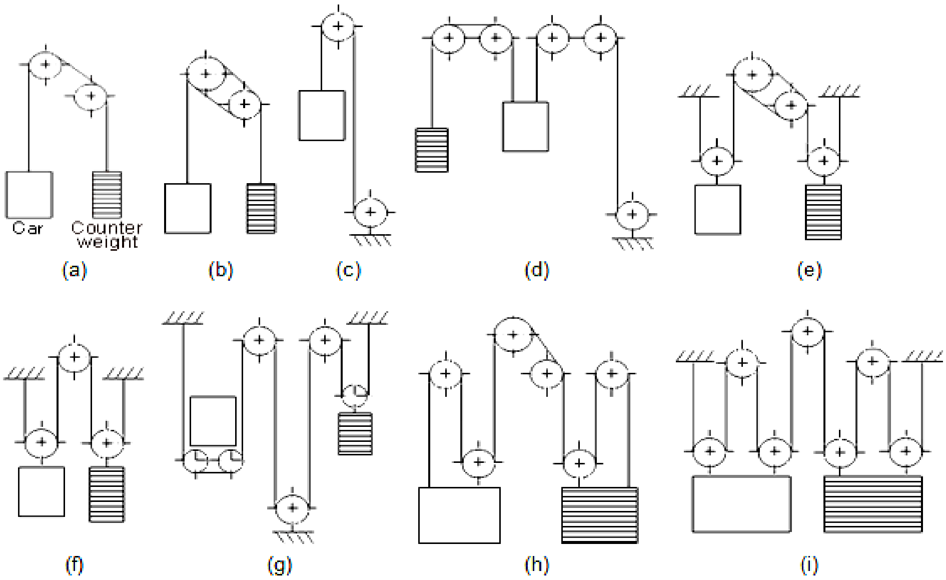

Figure 1. a) 1:1 Half wrap b) 1:1 Full wrap c) 1:1 Drum winding d) 1:1 Drum winding e) 2:1 Full wrap f) 2:1 Half wrap g) 2:1 Half wrap h) 3:1 Half wrap i) 4:1 Half wrap

In this work the controller design will be verified using computer simulations and through a direct comparison with the ubiquitous PID controller. All simulation results in this work are based on a 2:1 gearless electric (DC) traction elevator physical model that is depicted in Figure 2. A summary of the ODE of the elevator mathematical model[10] is provided her as a reference:

$$\dot{i}_a = \frac{V_{in}}{L_a} - \frac{R_a}{L_a} - \frac{K_b}{L_a}\dot{x}_2 \quad \text{...(1)}$$

$$\ddot{x}_2 = \frac{R_2}{J_2}(T_3 - T_2) + K_m i_a \quad \text{...(2)}$$

$$\ddot{x}_1 = \frac{R_1^2 K_{EL}}{2J_1}(x_{EL} - x_1) + \frac{R_1^2 B_{EL}}{2J_1}(\dot{x}_1 - \dot{x}_{EL}) + (X_0 K_0 + T$$

$$\ddot{x}_{EL} = \frac{K_{EL}}{M_{EL}}(x_1 - x_{EL}) + \frac{B_{EL}}{M_{EL}}(\dot{x}_1 - \dot{x}_{EL}) \quad \text{...(4)}$$

$$\ddot{x}_{CW} = \frac{K_{CW}}{M_{CW}}(x_3 - x_{CW}) + \frac{B_{CW}}{M_{CW}}(\dot{x}_3 - \dot{x}_{CW}) \quad \text{...(5)}$$

$$\ddot{x}_3 = \frac{K_{CW} R_3^2}{2J_3}(x_{CW} - x_3) + \frac{B_{CW} R_3^2}{2J_3}(\dot{x}_{CW} - \dot{x}_3) + (T_3 + T_2)\frac{R_3^2}{2J_3}$$

... (6)

Where list of symbols can be found in Table 1.

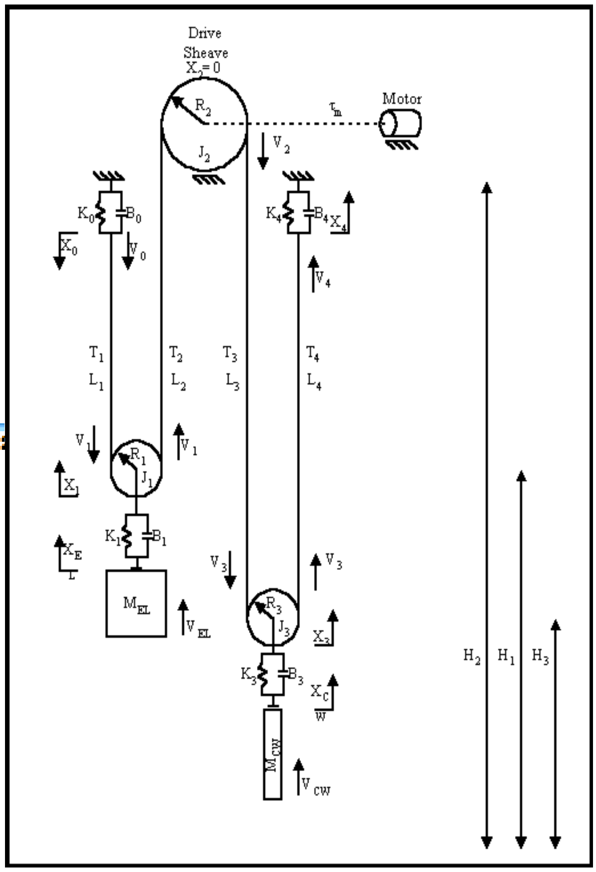

Figure 2. A 2:1 Gearless Elevator Physical Model

Table 1. List of symbols

Symbol	***Description***
i_a	*Armature current*
V_{in}	*Input voltage*
R_a	*Armature resistance*
L_a	*Armature Inductance*
K_m	*Motor armature constant*
K_b	*The emf motor constant*
T_f	*Coulomb friction value (Offset)*
K_f	*Coefficient of viscous friction(Gain)*
R	*Radius*
T	*Tension*
J	*Moment of inertia*
M_{EL}	*Mass of the elevator*
M_{CW}	*Mass of the weight*
K_{EL}	*Stiffness of the elevator*
K_{CW}	*Stiffness of the counter weight*
B_{EL}	*Stiffness of the elevator*
B_{CW}	*Stiffness of the counter weight*
τ_m	*Motor torque*

2.2. Motion Status for the elevator car

A typical speed profile of an elevator car is depicted in Figure 3. The speed profile describes the motion status of the car. When a car starts to move, it enters an acceleration mode until it reaches the constant speed. This speed is maintained until the car has to come to a stop. Before the car commences the stop position, it has to slow down for a safe stop at the destination floor. Besides the motion status of the car, other useful information is given by the speed profile, which include: the time the car takes to reach the contract speed, the time the car spends to travel one floor at constant speed, the time taken to decelerate before the car reaches a complete stop, the distance traveled to reach the constant speed and the distance traveled to slow down from the constant speed before the car stops[11].

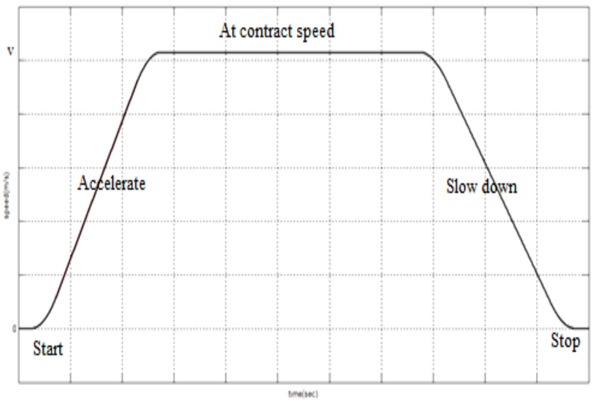

Figure 3. The speed profile for an elevator system

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2.3 Discrete system model

The previous elevator system's model is simulated using Simulink / Matlab for testing the designed controllers. A switching technology through Pulse Width Modulation (PWM) and a universal bridge is used for enabling speed regulation of the PMDC motor system. Figure 4 depicts the closed loop system (feedback) of the major blocks, while Figures 5 and 6 illustrate the details of the subsystems.The speed profile is given as an input for the controller in addition to the desired height (floor level).

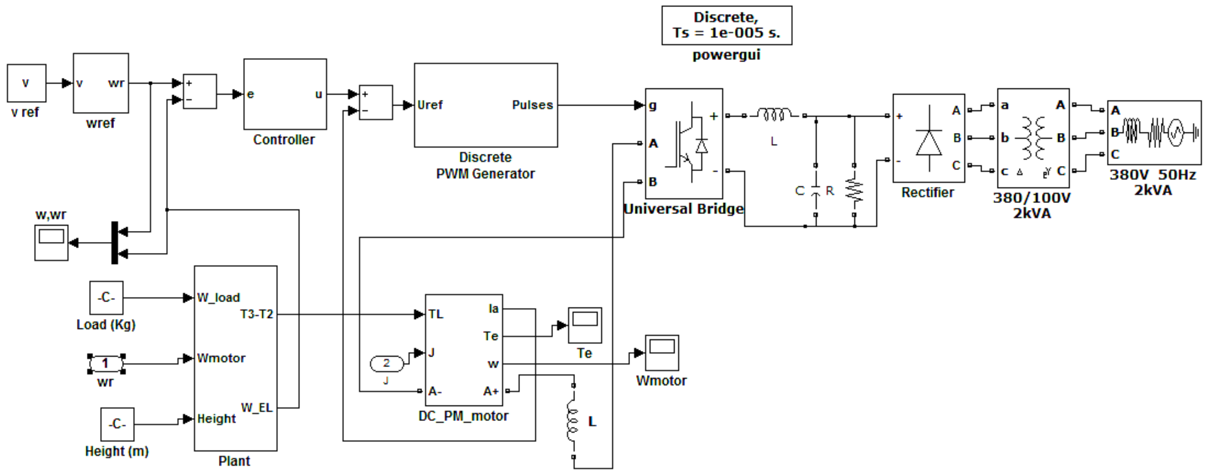

Figure 4. Elevator speed control closed loop system

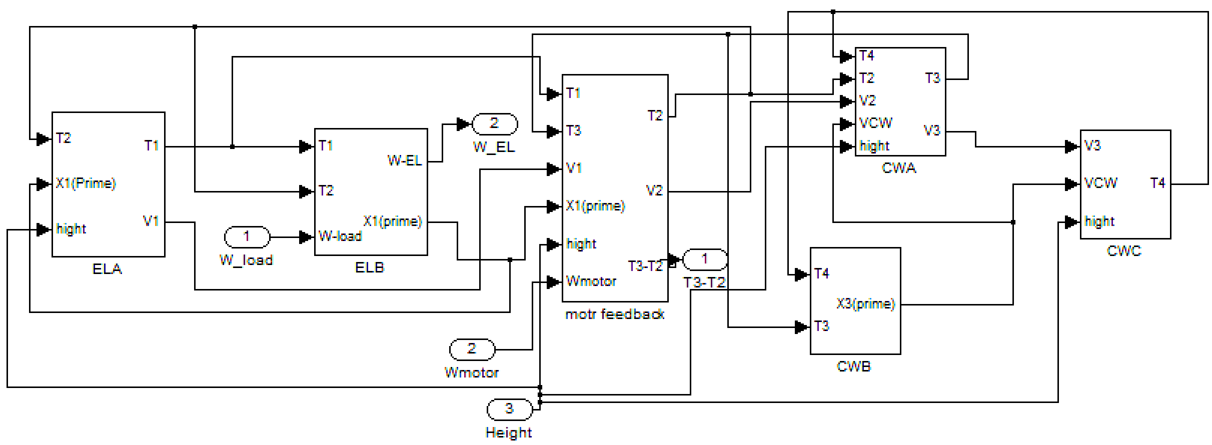

Figure 5. Elevator internal subsystems

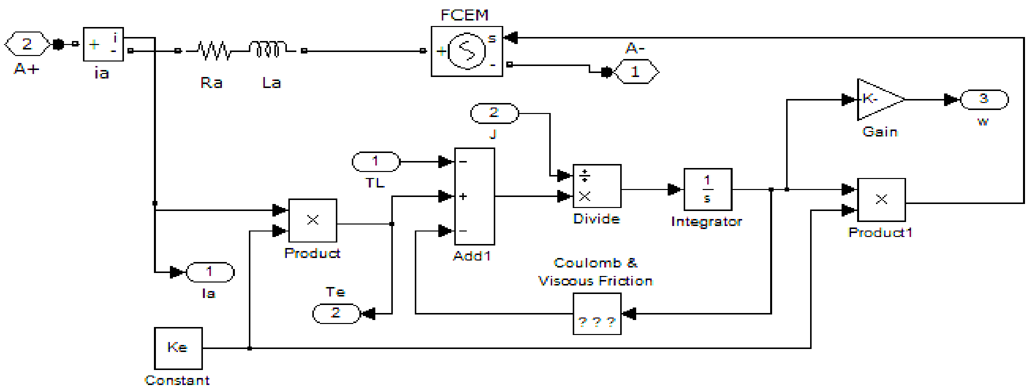

Figure 6. PMDC motor subsystem

3. Fuzzy Logic Controller (FLC) design

A typical Fuzzy Logic Controller (FLC) structure is depicted in Figure 7 The major steps in the FLC design constitutes creating a knowledge base of the rules, establishing membership functions for the inputs (fuzzification) and implementing member functions for the outputs (defuzzification). In this work the sensed input signals that are fed to the FLC are the error and the error rate of change (e , e').

$$e(t) = V_d(t) - V(t) \qquad ...(7)$$

Where $V_d(t)$ is the reference speed (speed profile), and $V(t)$ is the elevator actual speed.

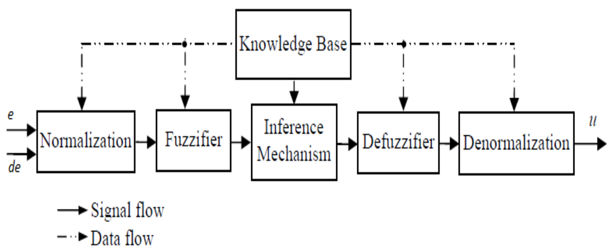

Figure 7. Fuzzy Logic Controller internal structure

Fuzzy Logic Matlab Toolbox is used to simulate the FLC, which can be further integrated into the previous simulations with Simulink.

The membership functions for the two inputs and the output are shown in Figure 8. Seven linguistic variables were selected to span the whole input/output range, which are defined as:

Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (ZE), Positive Small (PS), Positive Medium (PM), and Positive Big (PB).

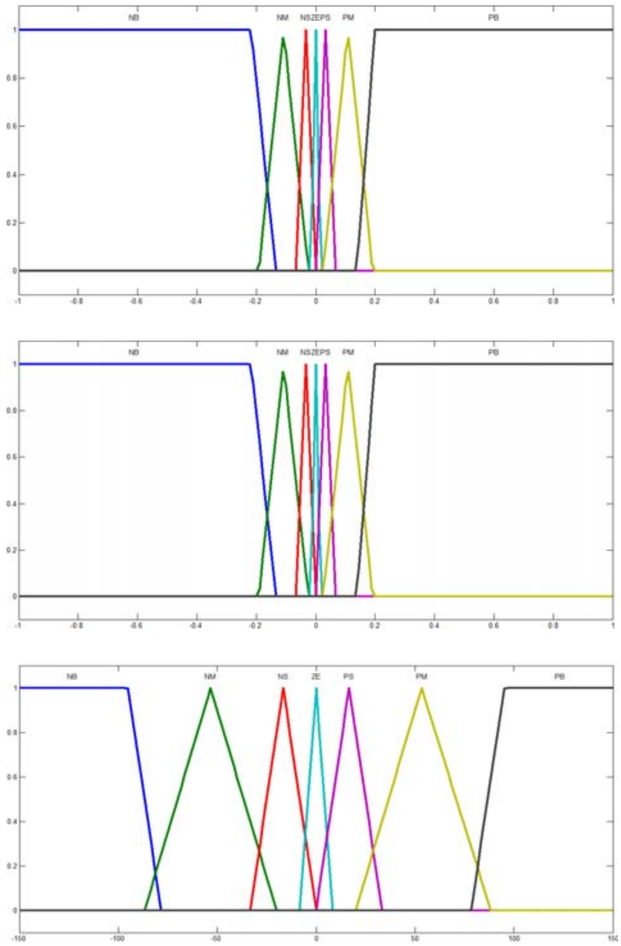

Figure 8. Membership functions, (a) Membership function of error, (b) Membership function of rate of change of error, (c) Membership function of the reference voltage

The proposed rules for the Fuzzy logic controller are summarized in Table 2. The fuzzy inference operation is implemented by using all the 49 rules. The min-max compositional rule of inference and the center-of-gravity method have been used in the defuzzifier process.

Table 2. Fuzzy logic controller rules

$\dot{e}$ \ e	*NB*	*NM*	*NS*	*ZE*	*PS*	*PM*	*PB*
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	PS	PS	PM	PB	PB	PB	PB

Table 3. Elevator system physical parameters

Armature resistance R_a	*0.49* Ω
Armature inductance (L_a)	*4.3 mH*
motorarmature constant (K_m)	*0.49*
Coulomb friction value (Offset)(t_f)	*0.18*
Coefficient of viscous friction(Gain(K_f)	*4.6e-4*
Radius 1 (R1)	*0.2 m*
Radius2 (R2)	*0.3 m*
Radius3 (R3)	*0.2 m*
Moment of inertia (J1)	*0.08 $Kg.m^2$*
Moment of inertia (J2)	*0.15 $Kg.m^2$*
Moment of inertia (J3)	*0.08 $Kg.m^2$*
Mass of the elevator (M_{EL})	*$100<M_{EL}<500$ Kg*
Mass of the weight (M_{CW})	*100 Kg*

5. Numerical example

To test the effectiveness of the Fuzzy Logic Controller (FLC) in contrast to the traditional Proportional, Integral, and Derivative (PID) controller, we have used Matlab computer simulations. The parameters that were used for the 2:1 gearless elevator are fully depicted in Table 3.

The results for both controllers are obtained for the first floor test (Four meter height) and for the 10^{th} floor test (Forty meters height) in order to demonstrate the controller's effectiveness.

Figure 9 and 10 depicts the results for the PID controller. Each figure illustrates position, car velocity profile, car acceleration and jerk. Typically the acceleration range[9] should be between (-1.5 - 1.5) mps^2, which is obviously met by the tuned PID controller. Also, the controller tracking of the speed profile is done nicely with minimal amount of jerk.

On the other hand, Figures 11 and 12 demonstrate the response of the Fuzzy Logic Controller even without membership functions tuning. In addition the FLC may be embedded with some form of an artificial intelligence making it superior over the PID controller.

Further analysis was done using standard performance measures and the results are summarized in Tables 3 and 4, respectively. FLC results demonstrated a superior performance.

However, the FLC rule base and the membership functions were not optimized yet they still provided a very competitive speed tracking and regulation.

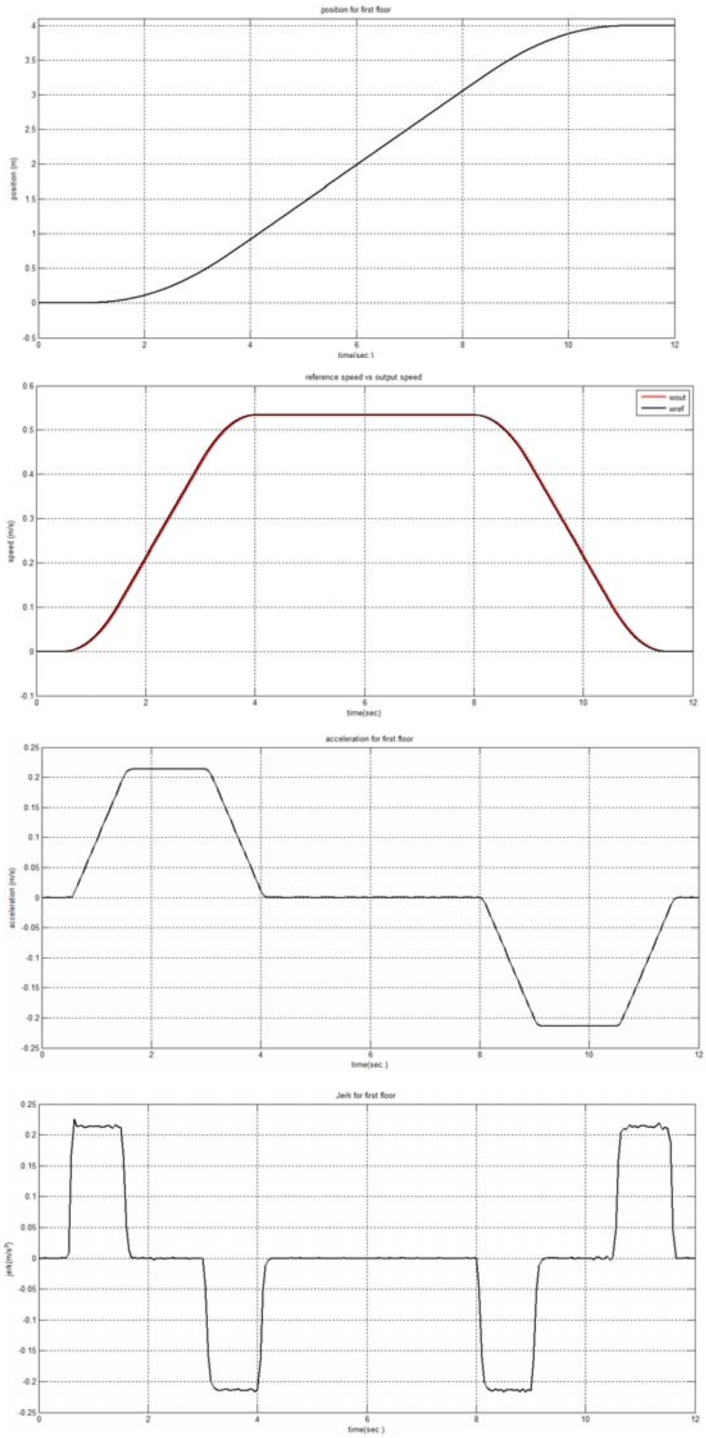

Figure 9. PID controller responses a) Position at 4m height b) Reference speed vs. actual speed for 4m height c) Acceleration for 4m height d) Jerk at 4m height

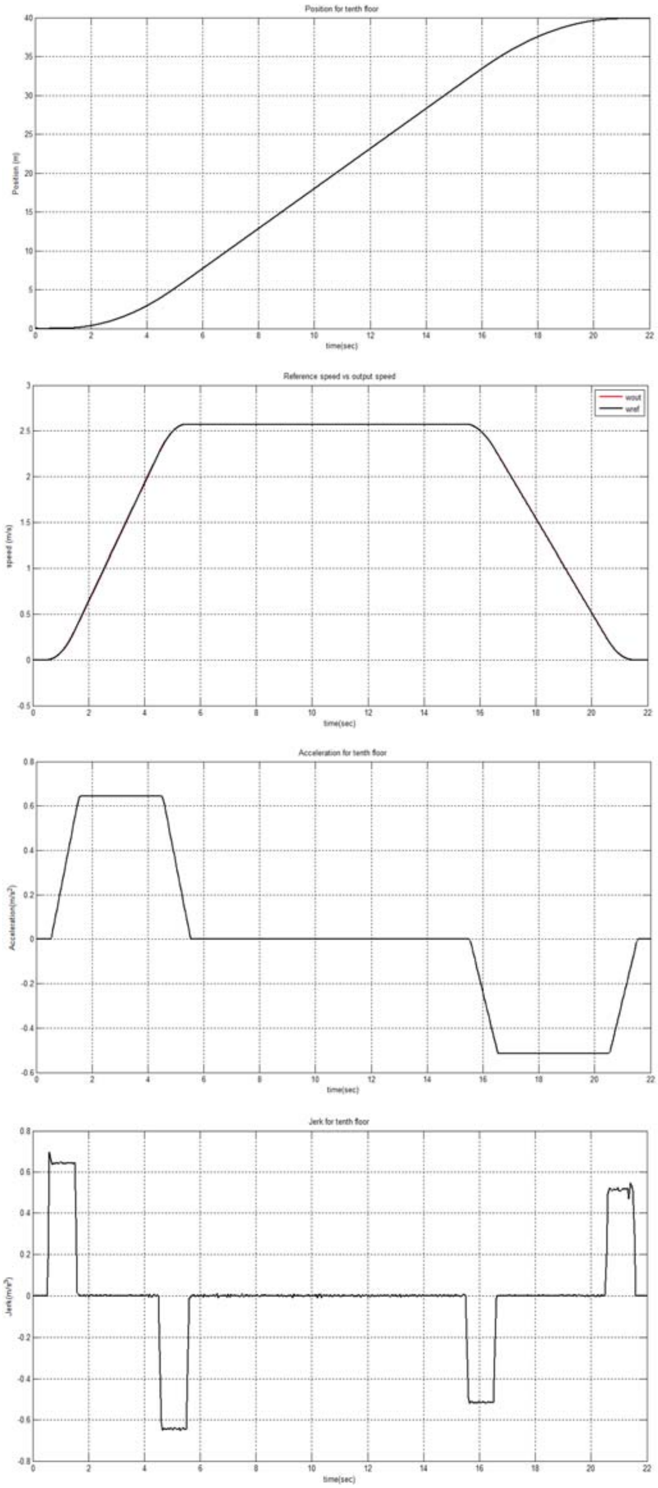

Figure 10. PID controller responses a) Position at 40m height b) Reference speed vs. actual speed for 40 m height c) Acceleration for 40 m height d) Jerk at 40 m height

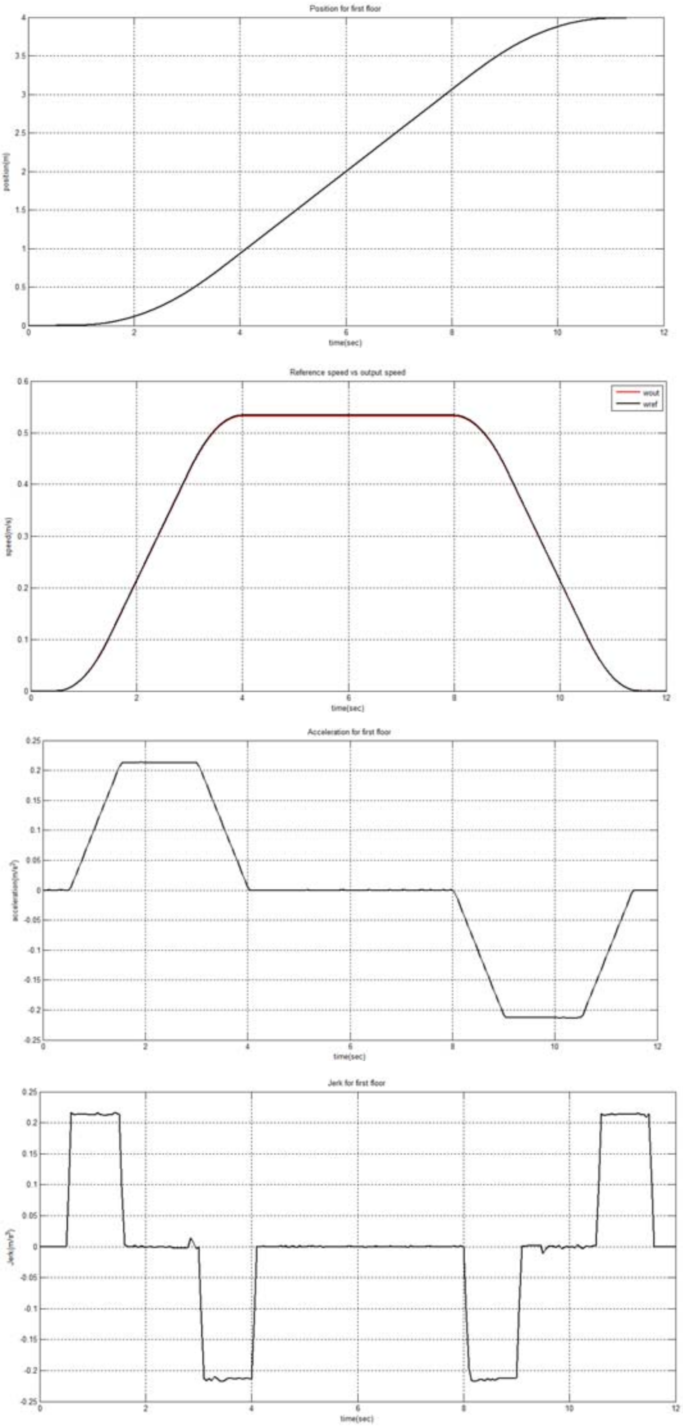

Figure11. FLC responses a) Position at 4m height b) Reference speed vs. actual speed for 4m height c) Acceleration for 4m height d) Jerk at 4m height

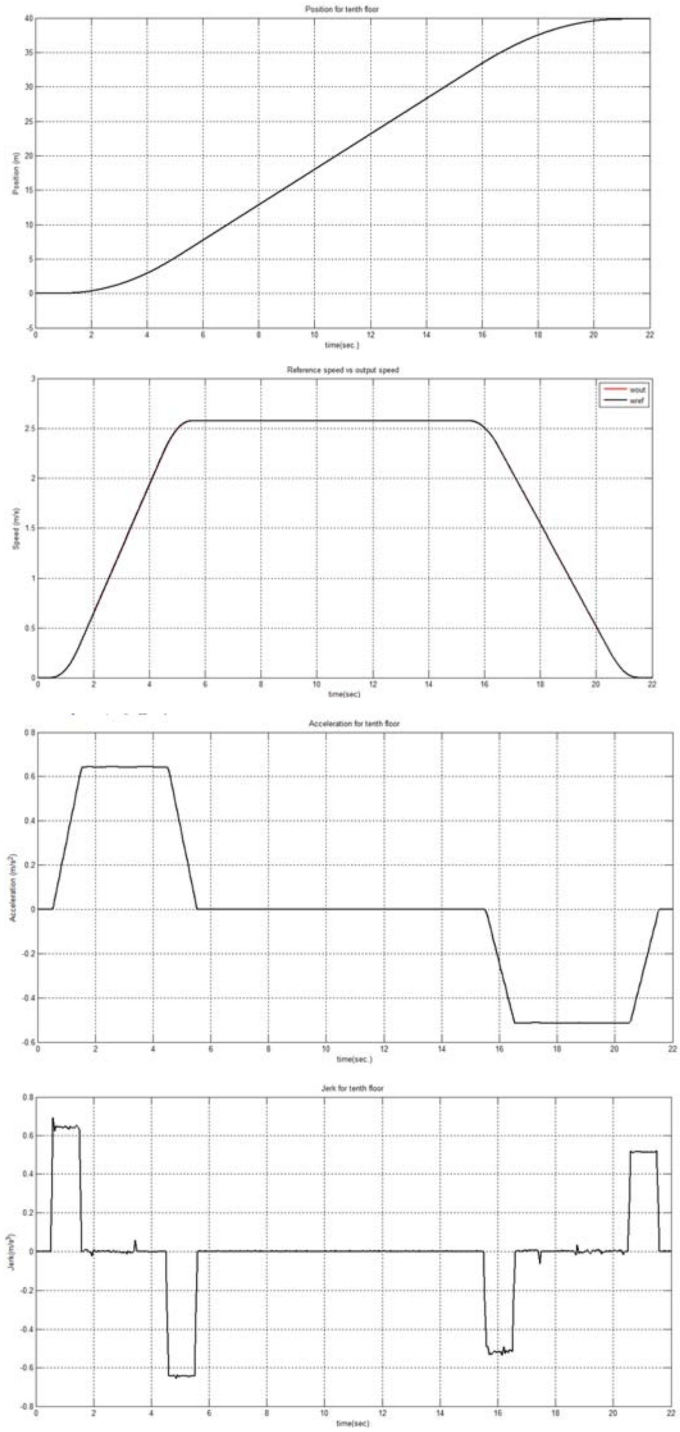

Figure12. FLC responses a) Position at 40 m height b) Reference speed vs. actual speed for 40 m height c) Acceleration for 40 m height d) Jerk at 40 m height

Table 3. Cost function for PID and FLC at 4m height

Controller	*ISE*	*IAE*	*ITAE*
PID	8.012e-005	0.02204	0.1069
FLC	1.701e-005	0.01037	0.05161

Table4. Cost function for PID and FLC at 40m height

Controller	*ISE*	*IAE*	*ITAE*
PID	0.0001099	0.03416	0.3159
FLC	7.282e-005	0.03333	0.3149

6. Conclusions and Future Work

A fuzzy logic based controller was introduced to regulate the speed and position of a 2:1 electric traction elevator system. The FLC successfully tracked a given user speed profile with minimal amount of jerk.

A complete comparison with the standard tuned PID controller was carried out. The standard performance criteria results showed superiority of the FLC over the PID controller speed regulation.

The fuzzy logic performance may be enhanced further by tuning the parameters of the membership functions and compliment it with some form of intelligence.

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