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COMPARISON ANALYSIS BETWEEN FUZZY AND FUZZIFIED-PID METHODS ON GUN-BARREL MOTION CONTROL

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ABSTRACT

Cannon guns of 57mm-caliber are some of the main weapons owned by the air defense artillery divisions of Indonesian army. However, some of them still have to be operated manually to provide the direction course of the projectile following the target to be fired. This article presents the comparison of two possible control methods being implementable on the anti-aircraft cannonry system. The first one is the use of fuzzy-logic control method, whereas the second one is the integration of the fuzzy-logic algorithm into the commonly known proportional-integral-derivative control method. The control is aimed to direct the gun barrel toward the desired direction, in terms of both the azimuth and elevation angles based on the target position. The results show fuzzified-PID control method excels the fuzzy-logic control method in terms of steady-state error performance and settling-time performance in general.

Keywords: fuzzy logic control, fuzzified-pid control, gun barrel, steady-state error, settling-time.

INTRODUCTION

Self-reliance is of paramount importance in a state's defense system. It is essential to guard and protect a state's sovereignty with respect to any possible threats coming both from outside or from within the country. Depending on the geographical situation, in general military equipments can be classified into land, air, and sea defense equipments.

A cannon is one type of weapons which can be used to fend off land, air, or sea attacks. The gun-barrel is an important part of the cannonry system. It provides the direction course of the projectile following the target to be fired. As seen in Figure-1, the S-60 57mm cannon is one of the main weapons owned by the air defense artillery division of Indonesian army (*Arhanud*). However, some of them still have to be operated manually. The gun shooters still have to rotate the crankshaft attached to the barrel in order to move the cannon towards the elevation and azimuth angles of the target position. The heavy weight of the cannon also becomes another problem, as it requires many people to maneuver. So far, if the systems are equipped with automatic controls, they are mostly still imported from abroad, then lowering the independence in terms of defense systems (Indrawanto, 2007).

Figure-1. The S-60 57mm single-barrel anti-aircraft gun.

This paper presents the performance comparison of some methods to facilitate the cannoneer to maneuver the gun barrel in the direction of target. The two proposed methods are the use of fuzzy-logic control method and the use of widely known proportional-integral-derivative (PID) control method but being embedded with the used of fuzzy-logic algorithm to determine the gain constants of PID controller. The latter is furthermore to be called as the fuzzified-PID control method.

Fuzzy logic has been proven useful in computation involving perception and cognition, which is, uncertain, imprecise, vague, partially true, or without sharp boundaries. It enables the inclusion of vague human assessments in computing problems and becomes effective to deal with conflict resolution of multiple criteria and better assessment of options. It is also known as being independent of the process control variables (Yan, J. *et al.* 1994; Singh, H., *et al*. 2013; Sivanandam, S.N., *et al.* 2007; Banks, W. and Hayward, G., 2002; Cirstea, M.N. *et al.* 2002; Babuska, R., 1998).

On the other hand, the PID control method has been historically considered to as the most useful controller. This controller combines the benefits obtained from each of the proportional, integral, and derivative control methods. It gives control output with high risetime and small error, as it is widely known that proportional controller has an advantage owing to its high risetime, integral controller is advantageous to reduce error, whereas derivative controller possesses benefits in reducing error and in damping overshoot/undershoot (Ogata, K., 2009; Coughanowr, D. R. and Koppel, L. B., 1965).

In industries requiring a control system with high speed and accuracy, the use of only PID controller may still be considered unsatisfactory. If the controller is set to be very sensitive, the generated over-/undershoots will also be more sensitive resulting in higher oscillation. However, if it is set to be less sensitive, the under-

/overshoots can be reduced, but consequently the required time will be longer, which could cause a problem in industry as well as military weapons. In this case, the second alternative method to consider is the integration of fuzzy-logic algorithm into the common PID controller to obtain its proportional, integral, and derivative gain constants.

The two control methods are to be implemented in a gun-barrel motion control system model. The performances of the two methods to control and adjust the motor rotation to actuate the barrel towards the target direction are compared.

MODEL OF THE GUN-BARREL MOTION CONTROL SYSTEM

Working principle of the gun-barrel motion control

The design of the gun-barrel system includes the keypad or joystick as a peripheral to input the reference command, motors being equipped with their respective drivers to actuate the barrel, and elevation- and azimuth-angle sensors. The motor drivers are used to supply motors with certain voltage to rotate the motors, which furthermore will actuate the barrel along certain angles of azimuth and elevation directions. The commands to supply the motors are determined by the fuzzy-logic (FL) controller or by the fuzzified-PID controller. The prototype of the gun-barrel motion-control system is shown in Figure-2.

Figure-2. Prototype of the gun-barrel motion control system.

The use of elevation and azimuth angle sensors

To measure the elevation angle, a potentiometer as shown in Figure-3 is used to adjust the voltage to be inputted to the analog-to-digital converter (ADC) of the microcontroller. The resulted output of the ADC after conversion process is in the form of degree values ranging from 0° up to 90 °. When the potentiometer is adjusted at its minimum position, it represents the angle of 0^0, in the middle position representing 45^0, and at maximum position representing 90^0 of elevation angle.

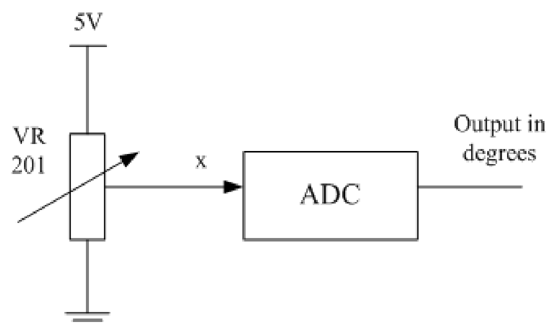

Figure-3. Elevation angle sensor.

An optocoupler as seen in Figure-4 is used to measure the azimuth angle. It results a voltage in the form of ON/OFF clock pulses which will be used by the microcontroller and be interpreted as position angles ranging from 0° to 360°.

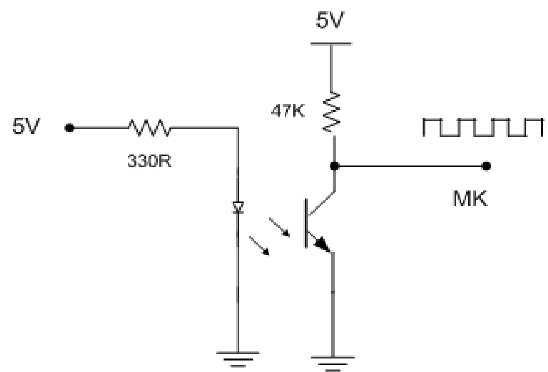

Figure-4. Azimuth angle sensor.

$$A(q)y(k) = B(q)u(k-nk) + y(k) \quad (1)$$

$$A(q) = 1 + a_1q^{-1} + a_2q^{-2} + \cdots + a_{na}q^{-na} \quad (2)$$

$$B(q) = 1 + ba_1q^{-1} + b_2q^{-2} + \cdots + b_{nb}q^{-nb} \quad (3)$$

as shown in Figure-5.

The ARX model contains 2 parameters to be estimated, i.e. *A* and *B*, where each can possess the order from 1 up to *n*. To determine the most suitable order for the plant, comparison of some orders (1 to 4) is done to obtain the order with smallest lost function (Landau, I. D., 2006).

The recursive method is used to find the parameters of the mathematical model of the plant recursively until the least square error is obtained. The measurement results of the motor are used to get the plant parameters a_1, a_2, b_1, and b_2 by using the RLS method (Krneta, R. *et al.* 2005).

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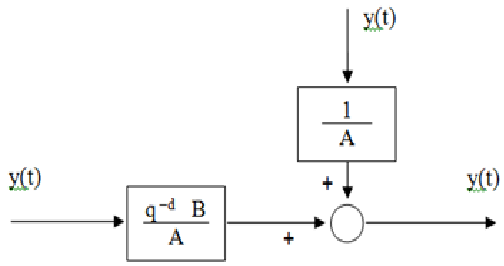

Figure-5. Structure of an ARX model.

For the case under consideration in this article, the chosen model is of order 2, so that there are 4 system parameters: a_1, a_2, b_1, and b_2, with a_1= -0.5493 , a_2= -0.4507, b_1=0.0031, and b_2=-0.0023. Finally the plant model can be expressed as in Figure 6. *U* represents the voltage input data to the plant, whereas *Y* is the ouput data.

Simulation of the fuzzy-logic control method

Simulation of the fuzzy-logic control method is done for controlling the angles both in azimuth and elevation directions. As can be seen in Figure-7 and Figure-8. As shown, the plant is represented using a discrete transfer function obtained from the previous identification step.

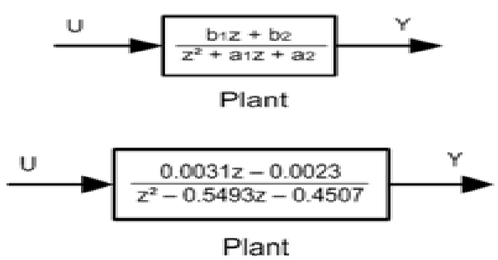

Figure-6. Mathematical model of the plant.

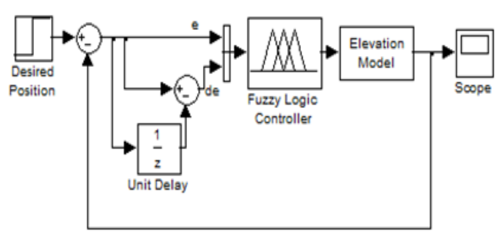

Figure-7. Simulation block of elevation angle direction.

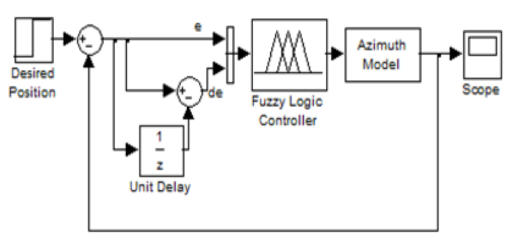

Figure-8. Simulation block of azimuth angle direction.

Fuzzy-logic method implementation

The block diagram to implement the fuzzy-logic control method is shown in Figure-9. The desired position is given through the keypad, whereas the output is the angle value in the desired direction.

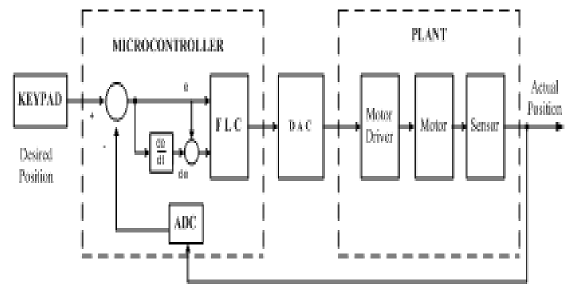

Figure-9. Block diagram of fuzzy-logic control method implementation.

The input data to keypad becomes the voltage reference to be compared with the output voltage of the sensor reading. The obtained voltage error values, in terms of error and delta error, become the input of the fuzzy-logic controller. The output of the controller becomes the input of the motor drivers, which are furthermore used to rotate the motors with certain number of rotations.

The motor rotation is related to the gun-barrel movement as far as certain angles in the direction of azimuth and elevation, referring to the target position as determined based on the command given through the keypad. Both the movement controls along the azimuth and elevation angle directions are in Figure-10 and Figure-11 respectively.

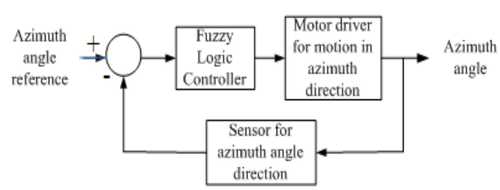

Figure-10. Block diagram for azimuth angle computation using fuzzy logic method.

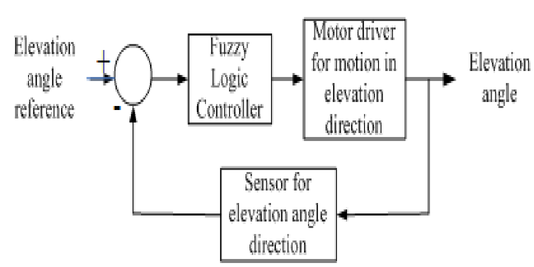

Figure-11. Block diagram for elevation angle computation using fuzzy logic method.

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DESIGN OF THE FUZZIFIED-PID CONTROL

The block diagram of the fuzzified-PID control method is shown in Figure-12. In this method the fuzzy-logic algorithm is embedded into the PID control method to determine the controller gains.

The input variables of the PID controllers include the *error* ($e(t)$), the *delta error* ($\frac{d}{dt}e(t)$), and the *summing error* ($\int e(t)dt$). The controller output variable is in the form of PWM duty-cycle to adjust the supply of motors actuating the gun-barrel.

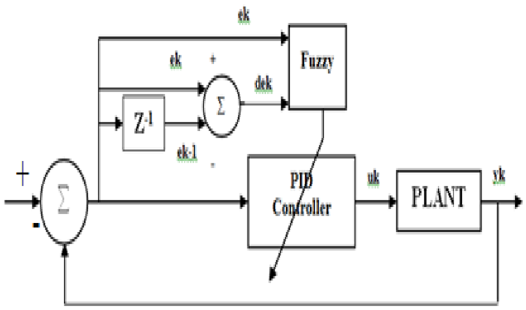

Figure-12. Block diagram of the fuzzified-PID control method implementation.

Fuzzified-PID method implementation

The implementation of fuzzified-PID control method is shown in Figure-13 and Figure-14. The fuzzy-logic method is used to determine the parameters of the PID controller, to compute the azimuth angle in Figure-13, and elevation angle in Figure-14.

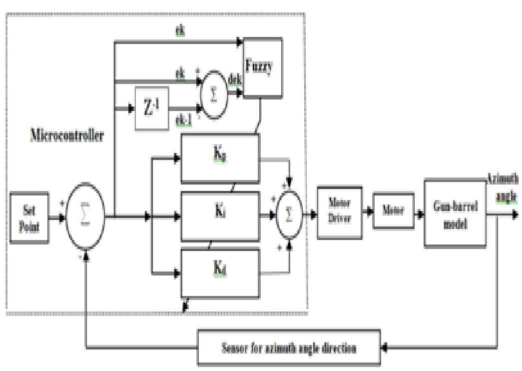

Figure-13. Block diagram for azimuth angle computation using fuzzified-PID method.

As seen, angle sensors, both for the azimuth and elevation directions, are used to get the actual position angles to be compared to the reference values.

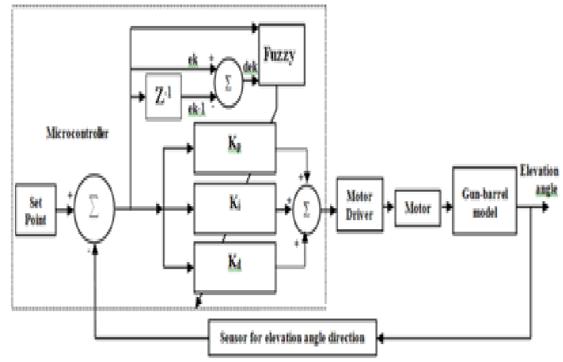

Figure-14. Block diagram for elevation angle computation using fuzzified-PID method.

RESULTS AND DISCUSSIONS

The desired azimuth and elevation angle values are inputted through a keypad or a joystick. These represent the firing target position. The output is in the form of gun-barrel motion along the azimut or elevation directions. The verification has been done both on each part composing the whole system as well as on the whole system integrally.

Fuzzy-logic control method testing results

Verification of the control method has been done by implementing the method to control the barrel movement both in azimuth and elevation directions. Figure-15-17 show the testing results for azimuth angle control.

Figure-15 shows the results of azimuth angle measurement when the given input value is 90^0. The graphic represents the barrel movement towards the position angle of 90^0. The movement takes 21 ms to reach its final position. After standing for 14 ms, the barrel returns back to its initial position of 0^0 in 11 ms.

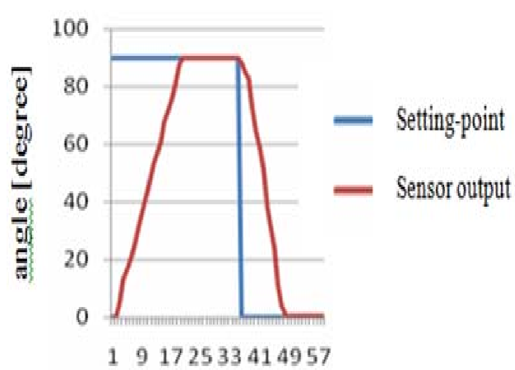

Figure-15: The motion control along the azimuth direction, starting from initial position of 0^0, being moved to setting-point of 90^0, and then back to 0^0.

Figure-16 shows the results of azimuth angle measurement when the given input value is 180^0. The graphic represents the barrel movement towards the

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position angle of 180^0, which takes 37 ms to reach its final position. After standing for 12 ms, the barrel returns back to its initial position of 0^0 in 31 ms.

Figure-17 shows the results of azimuth angle measurement when the given input value is 270^0. The graphic represents the barrel movement towards the position angle of 270^0, which takes 45 ms to reach its final position. After standing for 14 ms, the barrel returns back to its initial position of 0^0 in 40 ms.

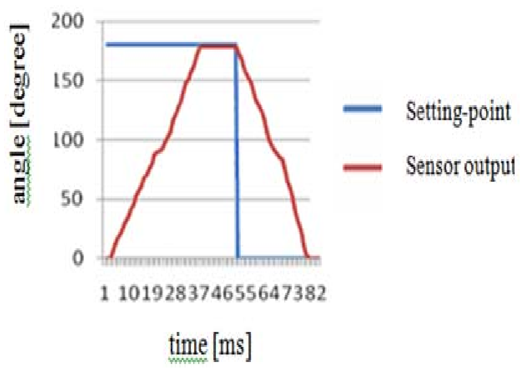

Figure-16. The motion control along the azimuth direction, starting from initial position of 0^0, being moved to setting-point of 180^0, and then back to 0^0.

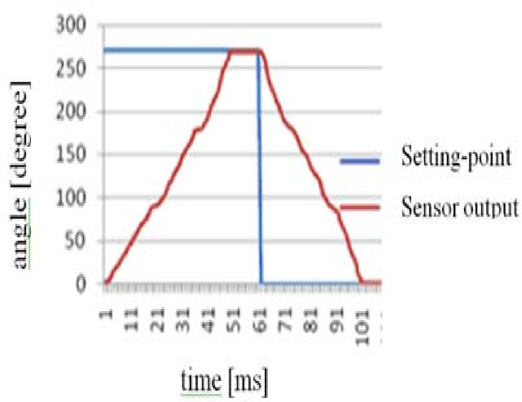

Figure-17. The motion control along the azimuth direction, starting from initial position of 0^0, being moved to setting-point of 270^0, and then back to 0^0.

Those previous three figures indicate that the designed fuzzy-logic motion control performs well to actuate the gun-barrel model. If it is now desired to examine the control method performance when implemented along the azimuth and elevation angle direction, then the results are shown in Figure-18 and Figure-19.

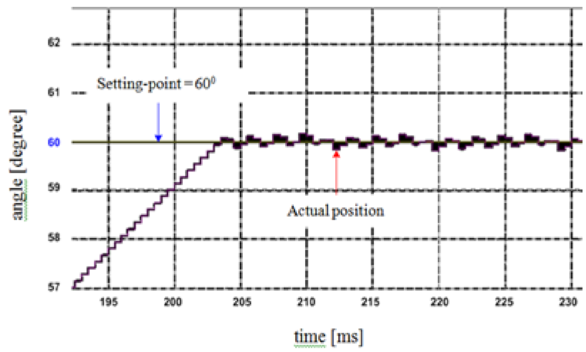

Figure-18. System response during azimuth angle computation using setpoint value of 60^0.

Figure-18 shows the profile of barrel movement along the azimuth direction when the desired angle is set to be 60^0. It can be seen that the steady-state condition of barrel position at 60^0 of azimuth angle is reached after 204 ms. It is shown also that the deviation from its setting-point value is around 0.15^0, indicating that the sensor output value is 60° - 0.15° = 59.85°.

Referring to the setting-point value of 60^0, the final steady-state accuracy can be obtained as follows:

$$\frac{59.85^0}{60^0} x100\% = 99.75\% \tag{4}$$

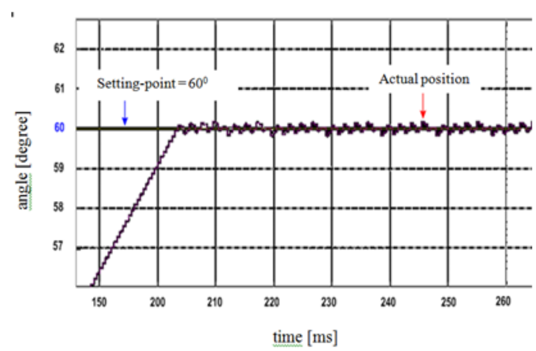

Figure-19. System response during elevation angle computation using setpoint value of 60^0.

Figure-19 shows the profile of barrel movement along the elevation when the desired angle is set to be 60^0. It can be seen that the steady-state condition of barrel position at 60^0 of elevation angle is reached after 203 ms. It is shown also that the deviation from its setting-point value is around 0.2^0, indicating that the sensor output value is 60° - 0.2° = 59.8°.

Referring to the setting-point value of 60^0, the final steady-state accuracy value can be obtained as follows:

$$\frac{59.8^0}{60^0} x100\% = 99.67\% \tag{5}$$

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The resume of some measurement results of barrel angles control both along the elevation and azimuth directions is shown in Table 1. It gives an average position accuracy value of 99.59%, or an average error of 0.40%.

Table-1. Resume of position accuracy and steady-state error measurement results calculation.

Movement direction	Barrel angle	Position accuracy [%]	Error [%]	Settling-time [ms]
Elevation	15^0	98.67	1.33	57
	45^0	99.44	0.55	160
	60^0	99.67	0.33	203
	90^0	99.77	0.23	295
Azimuth	60^0	99.75	0.25	204
	90^0	99.83	0.17	292
	180^0	99.77	0.23	2200
	360^0	99.86	0.14	3500
Average		99.59	0.40	

Fuzzified-PID control method testing results

Verification of the fuzzified-PID control method has also been done by implementing the method to control the barrel movement both in azimuth and elevation directions. Figure-20-21 show the testing results for azimuth and elevation angles control respectively.

When the setpoint value of azimuth angle is determined at 90^0, it is shown in Figure-20 that using sampling time of 20 ms, the rise time of 0.38 second is achieved after 19 samplings, the settling time of 0.74 second is attained at the 37^{th} sampling.

Using a setpoint value of 60^0 for elevation angle, it is shown in Figure-21 that the rise time of 0.68 second is achieved after 34 samplings, the settling time of 0.88 second is attained at the 44^{th} sampling.

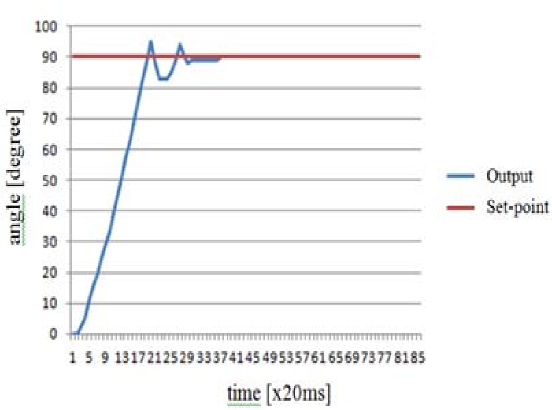

Figure-20. System response during azimuth angle computation using setpoint value of 90^0.

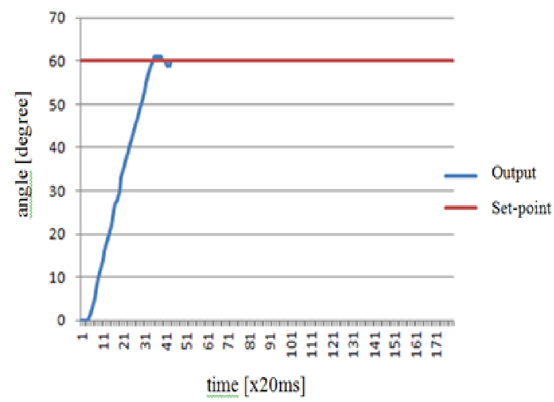

Figure-21. System response during elevation angle computation using setpoint value of 60^0.

Comparison of FL and fuzzified-PID control results

Results comparison of the implementation of both control methods is shown in Table-2 and Table-3. Table-2 shows the comparison of steady-state error and settling-time performances along the azimuth direction of barrel movement, whereas Table-3 along the elevation direction.

Table-2 shows that during the barrel movement control along the azimuth direction, implementation of fuzzified-PID (FL-PID) control method gives better performance than the fuzzy-logic (FL) control method, both in terms of steady-state error as well as settling-time performances.

Table-2. Comparison of steady-state error and settling-time performances along the azimuth direction of movement.

Set-point [deg]	Output [deg]		Error [%]		Settling-time [ms]	
	FL	FL-PID	FL	FL-PID	FL	FL-PID
60	58.85	60	0.25	0.00	204	460
90	89.85	90	0.17	0.00	292	740
180	179.6	180	0.23	0.00	2200	820
360	359.5	360	0.14	0.00	3500	1380
Average			0.19	0.00		

Table-3 shows that during the barrel movement control along the elevation direction, implementation of fuzzified-PID (FL-PID) control method in general gives better performance than the fuzzy-logic (FL) control method, especialy in terms of steady-state error performance. However, in terms of settling-time performance the fuzzy-logic control method seems to give better results. It is due to the angle-range control considered along the elevation direction.

Table-3. Comparison of steady-state error and settling-time performances along the elevation direction of movement.

Set-point [deg]	Output [deg]		Error [%]		Settling-time [ms]	
	FL	FL-PID	FL	FL-PID	FL	FL-PID
15	14.8	15	1.33	0.0	57	620
45	44.75	45	0.55	0.0	160	740
60	59.8	60	0.33	0.0	203	880
90	89.8	-	0.23	0.0	295	-
Average			0.61	0.0		

To obtain the general conclusion, the results of testing along the azimuth and elevation directions are shown in Table-4. It can be seen that in general the fuzzified-PID control method excels the fuzzy-logic control method both in terms of steady-state error as well as settling-time performances.

Table-4. Comparison of steady-state error and settling-time performances during the barrel-movement control.

Move-ment Direc-tion	Set-point [deg]	Output [deg]		Error [%]		Settling-time [ms]	
		FL	FL-PID	FL	FL-PID	FL	FL-PID
Azi-muth	60	58.85	60	0.25	0.00	204	460
	90	89.85	90	0.17	0.00	292	740
	180	179.6	180	0.23	0.00	2200	820
	360	359.5	360	0.14	0.00	3500	1380
Eleva-tion	15	14.8	15	1.33	0.00	57	620
	45	44.75	45	0.55	0.00	160	740
	60	59.8	60	0.33	0.00	203	880
	90	89.8	-	0.23	0.00	295	-
Average				0.40	0.00		

CONCLUSIONS AND FUTURE STUDIES

Based on the results of the two control methods implementation on the gun-barrel model, it has been shown that in general the fuzzified-PID control method excels the fuzzy-logic control method both in terms of steady-state error and settling-time performances. However, during the control of gun-barrel movement along the elevation direction, the fuzzy-logic control performance seems to perform better than the fuzzified-PID control in terms of settling-time. Faster technique in (Yang, G. *et al.* 2014) and implementation of projectile-deviation measuring system (Zaifei, S., and Chunping, W., 2014) are considered for future studies.

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