Fuzzy Logic Control System with Helicopter Takeoff and Landing

Murat HACIMURTAZAOĞLU[*], Novruz ALLAHVERDİ[+]

[*]*Computer Technology Department, Recep Tayyip Erdogan University*
Rize, TURKIYE
murat.hacimurtazaoglu@erdogan.edu.tr

[+]*Computer Engineering Department, KTO Karatay University*
Konya, TURKIYE
novruz.allahverdi@karatay.edu.tr

***Abstract*— In this study, fuzzy expert system is designed for the provision of helicopter takeoffs and landings by fuzzy logic. For this purpose, a model helicopter and the test platform have been created that helicopter movements can be tested. The vertical motion control on the axis defined by the fuzzy logic control system is provided for the helicopter with the generated test platform with four degrees of freedom.**

Fuzzy logic controller was designed with Arduino 2560 control board and Visual Studio 2010 C Sharp program for controlling helicopter model and analysis of motion control was made.

Real-time control of the helicopter created on the test platform was empirically examined through the study.

During the control of the helicopter, helicopter axis values from the imu sensor, and distance values from the ultrasonic distance sensor, which both were placed on the helicopter model, are read with Arduino, and sent to the computer. These values have been made meaningful on the computer. The rendered meaningful data were processed with the designed controller software to form the input values. Net values are obtained with processing the input values in the developed controller algorithms. These Net values were transmitted to the engine on the model with the help of Arduino and control of the helicopter was achieved in the target direction.

Consequently the control of the helicopter movement on the vertical axis was examined as an experiment and simulation.

Keywords*— *Fuzzy control, fuzzy logic control systems, helicopter landing and takeoff, helicopter control, the fuzzy logic control helicopter

I. Introduction

Helicopter air vehicles are widely used in many sectors that benefit from the aviation sector for their ability to do takeoff and landing movements without separating space and type of floor, and for their ability to hover in the air.

Thrust, lift and control forces are provided by rotary flaps of the helicopters. Aircrafts with rotary flaps are quite difficult to control because of the occurrence of movements resulting in adverse effects on other axes other then the force exerted on the axis. In line with this it is necessary to provide the direction towards the indicated position, make the versatile motion control and develop a control system that supports these movements of the aircraft (e.g. [1]).

Helicopters may be in many shapes and sizes. But they all use the same main components. Components of the helicopter can be classified as; cabin that transports the cargo and crew; body in which various components are added as motor; system (transmission) that transmits the power from the engine to the main rotor that enables helicopter's flight aerodynamic; main rotor that provides longitudinal, lateral and vertical thrust; tail rotor system used in some types of helicopters that generates reverse torque to compensate the torque created by the rotation of the rotor; sleigh, wheels, skis, or float landing gear (e.g. [2]).

In the cases where helicopter-specific movements required such as; the suitability of the environment to takeoff, vertical takeoff, condition of hovering in the air, twirling around, lateral flight and low-speed movement, it is an advantage to use unmanned helicopters.

Some issues were investigated from the relevant literature on control of unmanned helicopters such as; helicopter nonlinear fuzzy modelling and performance analysis related studies, as in [3,4,5,6]; control studies on helicopter models and test platforms, as in [7,8,9]; control studies used helicopter flight simulators and controllers, as in [10,11,12,13]; movement analysis on the axis and control applications, as in [14,15,16].

This study was aimed at controlling the movements of the helicopter takeoff and landing with expert system we designed for helicopter model on the test platform we have created.

As a result of the designed system it is expected the device that will allow the motion for helicopter takeoffs and landings in accordance with the specified position, to be made with the help of fuzzy expert system. In this study, sensors placed on model helicopters read the helicopter's position and distance values. The read values are sent to the host computer with the control board (Arduino) and control transactions are performed on the computer. Motor position values produced for motion controls on the specified destination and engines on the helicopter model are controlled via the control board. A real-time test platform has been developed for the design of control systems and tests. The study performed on the test platform and results were analyzed.

II. Materials and Methods

This section includes studies on unmanned helicopters and their control of the takeoff and landing that was provided by fuzzy expert system. A testing platform has been created for testing the control operations of helicopter flight. Control researches were performed on the generated test platform. In this set up helicopter's vertical movements as well as x, y and z-axis position and altitude controls are provided. Control operations have been accomplished via computer.

A. Flight Test Platform for the Helicopter

Helicopter flight test platform we designed, performs the vertical movement control of the helicopter. Designed helicopter flight test platform is shown in Fig. 1.

Fig. 1 Helicopter flight test platform

Test platform composed of nested pipes comprising plastic and aluminum that allows vertical movement of the helicopter. Model helicopter is connected on the platform by a wooden connection apparatus that allows the movement on the axes. Helicopter connection apparatus is formed with ball system and designed to be able to perform the helicopter movements on the x and y-axis. Helicopter movement on the z-axis is performed in it is connected apparatus.

Some weights are placed into the box that is connected to the platform to prevent the uncontrolled movement of the helicopter.

B. Model Helicopter Control System

Align brand T-Rex 500 RC model helicopter was used on the test platform to test the control studies performed. The model helicopter's remote control system was disabled. The helicopter control was performed with the control computer. Computer's communication with helicopter is provided by a control board (Arduino Mega 2560), which is placed on the helicopter.

Technical characteristics of the materials used to form the model helicopter are as shown in Table 1 and the technical figure representation is as shown in Fig. 2.

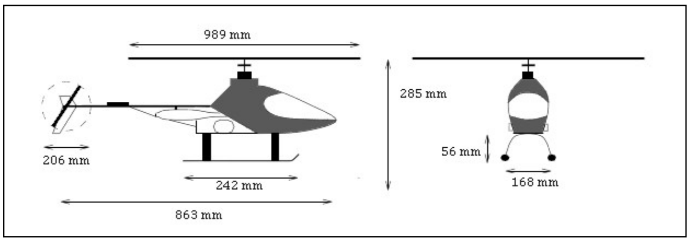

Fig. 2 Technical figure for model helicopter

TABLE I

TECHNICAL CHARACTERISTICS FOR THE MODEL HELICOPTER

Product	Feature
Length	863 mm
Height	285 mm
Main blade length	425 mm
Main rotor diameter	989 mm
Tail rotor diameter	206 mm
Weight (With Motor)	1210 g
Main motor	500 MX Brushless Dc Motor (1600 KV)
Servomotor	DS515M Digital Servo
Servomotor	DS525M Digital Servo
Esc	RCE – BL70G Brushless ESC
Model	T – REX 500 Dominator Set
Flybar	Microbeast PLUS Flybarless System
Blade	425 Carbon fiber wing

MaxSonar (e.g.[17]) distance measuring sensors are used to control the helicopter's altitude and Pololu brand imu (e.g.[18]) sensor unit is used to control helicopter's coordinate on the axis.

Align 500 MX brushless motor is used for the main rotor and tail rotor control and 70 Amp electronic speed controller (esc) is used for the motor speed control. To perform the rotor controls 4 pieces servomotors are used. 3 of the servomotors placed on the front part of the helicopters to control the main rotor and one of the servomotors placed on rear part of the helicopter to control the tail rotor. The settlements on the helicopter servomotors are shown in Fig. 3.

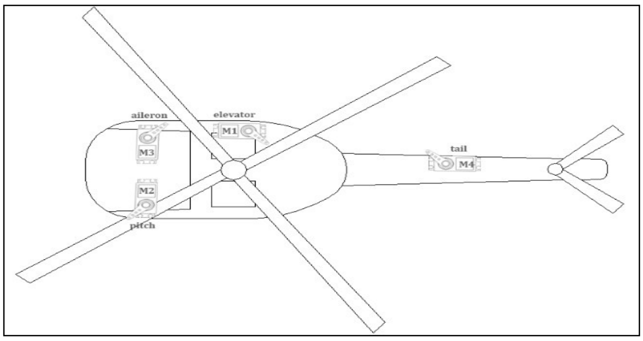

Fig. 3 Settlements on the helicopter servomotors

Servomotor definitions and motion controls for the servomotors that are shown on the helicopter settlement in Fig. 3 are as shown in Table 2.

TABLE II

MOTOR DEFINITIONS AND MOTION CONTROL

Motor	Definition	Motion Control
Elevator	M1	Cyclic back and forward movement of helicopter
Pitch	M2	Determination of pal angle and Determination of buoyancy force ratio
Aileron	M3	Determination of the helicopter to the right and to the left tilting movements
Tail	M4	Tail servo, rotation control

The main rotor control motor movement that provides helicopter to move in the target direction utilizing the input values for coordinate and altitude read from sensors are as shown in Table 3.

TABLE III

MOTOR MOTION FOR MAIN MOTOR CONTROL

Motion	Aileron	Elevator	Pitch
Right tilting	+ (↓)	(↔)	+ (↑)
Left tilting	- (↑)	(↔)	- (↓)
Forward movement	+ (↓)	- (↑)	- (↓)
Back movement	- (↑)	+ (↓)	+ (↑)
Takeoff	- (↑)	- (↑)	+ (↑)
Landing	+ (↓)	+ (↓)	- (↓)

C. Helicopter Control and Communication

The helicopter is controlled by the computer control program that was written in Microsoft Visual Studio 2010 C#. Helicopter's communication with the computer is performed by the Arduino Mega 2560 control board. Control board's communication with computer takes place via the USB 3.0 port.

Read values over the helicopter are sent to the control computer by the control board. With the values of interpreted on computer, the motor speed and motor angle are calculated. With the calculated values that sent to the control board, the engine speed and the angle values are changed.

D. Fuzzy Expert System Design

The fuzzy expert system that is used for the control of takeoff and landing in the direction of the desired position of the helicopter; includes sections of real input and output values and identification of the possible value range of these values, fuzzy membership functions for scaling the input and output values as well as for the fuzzification of each input and output values, fuzzy control rule-base, fuzzy inference, defuzzification.

The fuzzy expert system is designed as to realize the desired height of the takeoff and landing movements in line with the specific position of the helicopter. Coordinates and elevation position values of the helicopter are read as input values from sensors that are placed on the helicopter and transferred to the computer via the Arduino control board. Control computer processes the data received as input values at the fuzzy control unit, and achieves servo and esc net values. The resulting output value is transferred to the control board, and position values of the servos and ESC placed on the helicopter is renewed. Fig. 4 shows the structure of the control block.

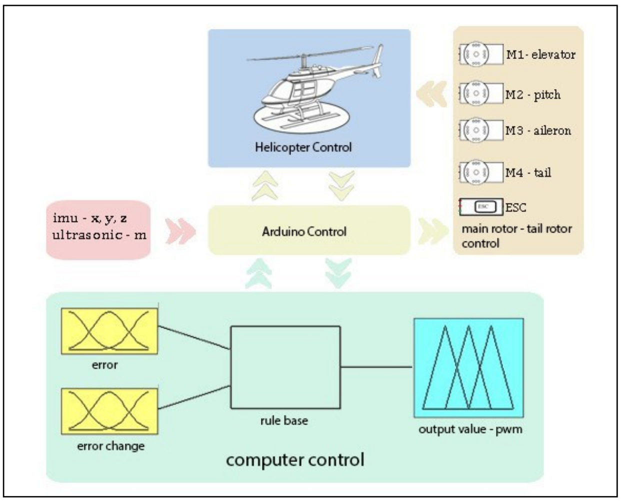

Fig. 4 Structure of the control block

1) Definition of Input and Output Value

The input values consist of the error values that gives instantaneous changes occurring on altitude values (Rm), error change values that instantaneous changes occurring on error values, and the coordinate values on x, y, z axes (Rx, Ry and Rz) that specifies the position of the helicopter.

Rxe, Rye, Rze and Rme input values represent the instantaneous changes between the reference position values and obtained position values.

Sample calculation for the Rxe input value:

Rxe = reference x coordinate value – instant x coordinate value

Rxce, Ryce, Rzce and Rmce input values represent the difference between the instantaneous error value and a previous error value.

Sample calculation for the Rxce input value:

Rxce = Rxe – previous Rxe

The output values comprised of pwm signal control information that controls the rotor speed and servo position in order to control the movement of the helicopter in the specified position. The main rotor and tail rotor are controlled according to the coordinate values and distance information. The output values consist of the control values 'esc' in order to control the rotational speed of the main rotor, 'ts' in order to control tail rotor servo, 'as' in order to control aileron servo, 'es' in order to control elevator servo, and 'ps' in order to control pitch angels.

2) *Fuzzification of the Input and Output Values*

The input and output values are read as numeric values that are converted to values expressed symbolically during the fuzzification process.

7 pcs fuzzy subsets are defined in the fuzzy expert system, for the input values belonging to each position value and for the output variables that obtained with processing of the input values. The fuzzy subsets of the input value are calculated like as it is shown in Formula 1 and the fuzzy subsets of the output value is calculated like as it is shown in Formula 2.

$$\sum_{n=0}^{t}\left(\left(m \pm \left|\frac{m}{t} * \frac{n}{s}\right|\right)\right) - m \quad (1)$$

$$\sum_{n=0}^{t}\left(\left(m \pm \left|\frac{t*n}{s}\right|\right)\right) - m \quad (2)$$

In Formula 1 and Formula 2, 't' control value expresses number of subsets desired for identification as range of values of fuzzy subsets (Since 0 is a value for the fuzzy subset calculation, if the number of subset is equal to 7, t becomes 6), 's' control value expresses changes on the density range parameters, 'm' control value expresses the targeted normal value of control variable (target value).

The input values, the fuzzy subsets and the change interval of fuzzy sets defined for the input parameters are as shown in Table 4. The output signal values, the fuzzy subsets and the change interval of fuzzy sets defined for the output parameters are as shown in Table 5. Since verbal expressions of fuzzy subsets are same and defined change intervals for each input value is calculated by the same formula, input variables presented in a single row

TABLE IV

FUZZY SETS FOR INPUT VALUES

Input Value	Fuzzy Sets	Change Intervals
∀(RXe, RYe, RZe, RXce, RYce, RZce, RMe, RMce) for input parameter	Position Negative Error Big (NHB) – Position Negative Error Med. (NHO) – Position Negative Error Small (NHK) – Position Error Zero (HS) – Position Positive Error Small (PHK) – Position Positive Error Med. (PHO) – Position Positive Error Big (PHB)	$\sum_{n=0}^{6}\left(\left(m - \left|\frac{m}{5} * \frac{n}{5}\right|\right)\right) - m$ – $\sum_{n=0}^{6}\left(\left(m + \left|\frac{m}{5} * \frac{n}{5}\right|\right)\right) - m$

TABLE V

FUZZY SETS FOR OUTPUT VALUES

Output Value	Fuzzy Sets	Change Interval
∀(esc, ts, as, es, ps) for output parameter	Position Negative Big (NB) - Position Negative Medium (NO) – Position Negative Small (NK) - Position Zero (S) - Position Positive Small (PK) - Position Positive Medium (PO) – Position Positive Big (PB)	$\sum_{n=0}^{6}\left(\left(m - \left|\frac{t*n}{5}\right|\right)\right) - m$ – $\sum_{n=0}^{6}\left(\left(m + \left|\frac{t*n}{5}\right|\right)\right) - m$

Graphical view of the fuzzy sets for the error value of the input values and intensity parameters for the error value changes are as shown in Fig. 5, and graphical view of the fuzzy sets for the output value intensity parameters are as shown in Fig. 6.

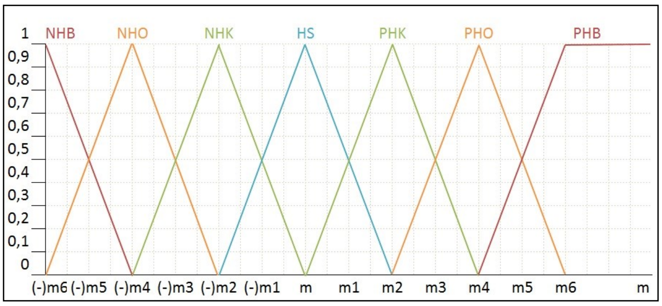

Fig. 5 Fuzzy sets for input value

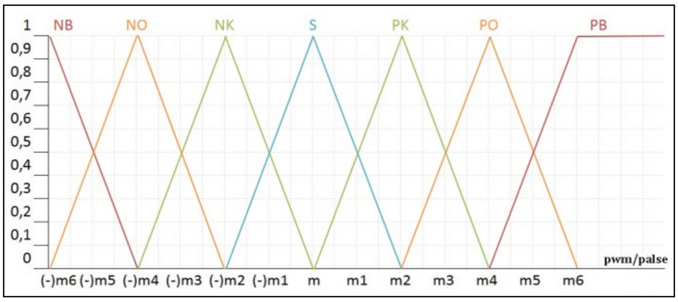

Fig. 6 Fuzzy sets for output value

3) *The Creation of Fuzzy Rules and Fuzzy Inference*

The designated rules are edited to include all different possibilities. The system is formed in result of selecting best rules characterized the system of in terms of calculation and performance. System was designed to provide the best performance results to be obtained with evaluating all possibilities.

With the creation of fuzzy rules control board has been provided to be stimulated sensitively as soon as possible.

In the fuzzy expert system that design and control units are performed, 49 pcs fuzzy control rules are used for angular control units, esc value and servo motor position.

The rule base for the controlling of distance value, position error value and position error changes value are as shown in Table 6. Obtained the error value is shown with 'e' and the error change value is shown with 'ce'. We do not want to describe all of the net values; hence some are not included in the Table 6.

TABLE VI

RULE BASE

ce \ e	NHB	NHO	NHK	HS	PHK	PHO	PHB
NHB	PB	PB					
NHO							
NHK				PK			
HS				S			
PHK							
PHO							
PHB						NB	NB

4) Defuzzification

This area refers to the transformation process for scaling actual numerical value of the fuzzy output value obtained from the fuzzy inference unit before being sent to the control system.

In the defuzzification process, in order to determine the output values of the fuzzy logic controller to be applied in the control system; membership severity degrees of the error and the error changes are calculated for each rule, and calculated values are netted on the logical combination set.

The center of gravity method is used for the defuzzification process.

The rules are expressed as shown in Formula 3 with taking the rules shown in Table 6 into consideration.

$$\mu T(p)=\{\min[\mu NHB(x),\mu NHB(z)], \ldots \min[\mu PHB(x),\mu PHB(z)]\} \quad (3)$$

When the expression that obtained from Formula 3 is abbreviated, the formula is obtained as shown in Formula 4.

$$\mu T(p) = \frac{\sum_{i=1}^{n} u_i * \mu(u_i)}{\sum_{i=1}^{n} \mu(u_i)} \quad (4)$$

III. REAL – TIME EXPERIMENTAL RESULTS

In this section, the results obtained from real-time control process with the application of fuzzification and defuzzification using a helicopter flight test platform, are examined

The altitude value that is desired for helicopter to reach and the position values that is requested for helicopter to move over, are determined as a reference value.

Input variable values are obtained by calculating to the specified reference values with instantaneous coordinate and position data that read from the sensors placed on the helicopter.

The pwm signal change values, which will impact on the engines as a result of processing the input parameters, are calculated as the net output value for each motor.

The motor control is carried out by updating the motor position values with the calculated values.

Fuzzification of the input values that shows the calculation realized with the fuzzy expert system and obtaining net values are as shown in Fig. 7.

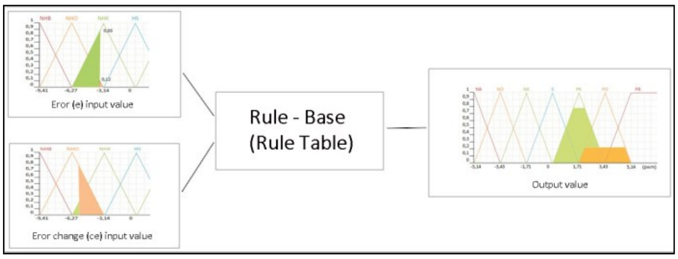

Fig. 7 Fuzzification of input values and defuzzification

In order to realize the control process; the reference values used in calculation have been determined as 94,09 degrees for x-axis, 94,77 degrees for y-axis, 122,31 degrees for z-axis and 150 cm for the target altitude. In order to calculate the fuzzy subsets, sensitivity value (s) determined as 10 and subsets value (t) as 6 (0 - 6, a total of 7 subsets).

TABLE VII

FUZZY SETS AND CHANGE INTERVALS

Label	Explanation	X-axis (x)	Y-axis (y)	Z-axis (z)	Distance (m)
NHB	Negative Error Big	[< -9,41 v -6,27]	[< -9,48 v -6,32]	[< - 12,23 v - 8,15]	[< -15,00 v -10,00]
NHO	Negative Error Medium	[-9,41 v -3,14]	[-9,48 v -3,16]	[-12,23 v -4,08]	[-15,00 v - 5,00]
NHK	Negative Error Small	[-6,27 v 0,00]	[-6,32 v 0,00]	[-8,15 v 0,00]	[-10,00 v 0,00]
HS	Error Zero	[-3,14 v 3,14]	[-3,16 v 3,16]	[-4,08 v 4,08]	[-5,00 v 5,00]
PHK	Positive Error Small	[0,00 v 6,27]	[0,00 v 6,32]	[0,00 v 8,15]	[0,00 v 10,00]
PHO	Positive Error Medium	[3,14 v 9,41]	[3,16 v 9,48]	[4,08 v 12,23]	[5,00 v 15,00]
PHB	Positive Error Big	[6,27 v 9,41 >]	[6,32 v 9,48 >]	[8,15 v 12,23 >]	[10,00 v 15,00 >]

When fuzzy subsets were calculated with the help of Formula 1, fuzzy sets obtained for input values and change intervals are as shown in Table 7.

According to Table 7, change interval for input value and error change value, for the control process of the x-axis are as shown in Formula 5; and x-axis input value membership function graph are as shown in Fig. 8.

$$-9,41 < \text{error (e)} < 9,41$$
$$-9,41 < \text{error change (ce)} < 9,41 \quad (5)$$

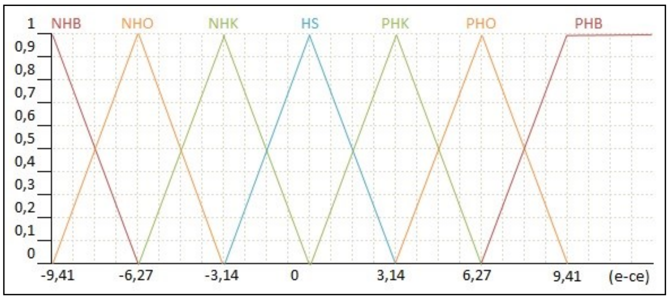

Fig. 8 X-axis input value membership function

In calculation of the output pwm signal value that will affect the engine, target exchange value, sensitivity value and subset value were determined, 0, 7 and 6, respectively.

When fuzzy subsets were calculated with the help of Formula 2, fuzzy sets obtained for the net output values; and change intervals are as shown in Table 8.

TABLE VIII

OUTPUT SETS AND CHANGE INTERVAL

Label	Explanation	Output
NB	Negative Big	[-5,14]
NO	Negative Med.	[-3,43]
NK	Negative Small	[-1,71]
S	Zero	[0]
PK	Positive Small	[1,71]
PO	Positive Med.	[3,43]
PB	Positive Big	[5,14]

According to table 8, change interval of the output variable value that will control the variable values of pwm signal are as shown in Formula 6, and membership function graph of output value are as shown in Fig. 9.

$$-5,14 < pwm < 5,14 \quad (6)$$

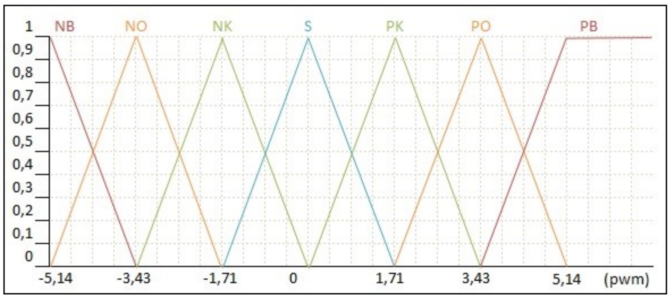

Fig. 9 Membership function graph of output value

For x-axis:

As a result of changes occurred on the x-axis, instant x_1 value was read as 90,73 and x_2 value was read as 92,01. In this situation, error and error change values are calculated as following:

Error (e_1) = 3,36
Error (e_2) =2,08
Change error (ce) = -1,28

The following results are obtained when net values were calculated for error and error change input values.

e = HS for $\mu(e=2,08) = 0,34$
e = PHK for $\mu(e=2,08) = 0,66$
ce = NHK for $\mu(ce=-1,28) = 0,41$
ce = HS for $\mu(ce=-1,28) = 0,59$

As a result of the processing the fuzzy rules obtained from knowledge base and linguistic variables that came from the fuzzification unit, logical inference engine control action was created.

According to created control action, when error and error change process that occurs on the x-axis continue to be conducted, following rules obtained by utilizing inference table for e = 2,08 and ce = -1,28 net values.

Rule 1 : min(($\mu(e=2,08) = 0,34$) , ($\mu(ce=-1,28) = 0,41$)) = 0,34 (pwm=PK)
Rule 2 : min(($\mu(e=2,08) = 0,34$) , ($\mu(ce=-1,28) = 0,59$)) = 0,34 (pwm=S)
Rule 3 : min(($\mu(e=2,08) = 0,66$) , ($\mu(ce=-1,28) = 0,41$)) = 0,41 (pwm=S)
Rule 4: min(($\mu(e=2,08) = 0,66$) , ($\mu(ce=-1,28) = 0,59$)) = 0,59 (pwm=NK)

Net pwm output value that will have an impact on x-axis is calculated as -0,25, when the output value that will be applied to the control system is calculated with the help of Formula 4 in the calculation of the output pwm net value of the fuzzy logic controller.

The x-axis control is provided with the net output value obtained from the calculation results by adding value to the pwm signal.

A. Real-Time Simulation Results

At the rolling motion of the helicopter taken at any given time of the application; changes in the value of the pwm signal obtained from the defuzzification process, as a result of the fuzzification of the input values of x-axis position error and x-axis position error change; are as shown in Fig. 10.

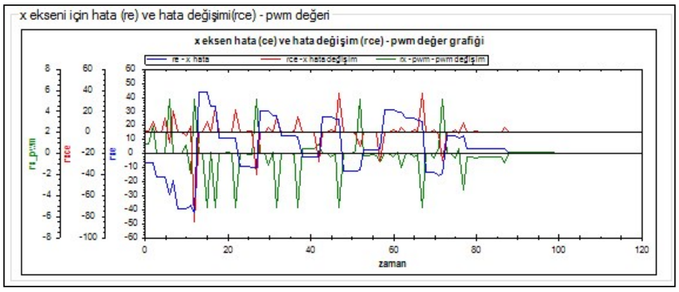

Fig. 10 Pwm signal value graph for as a result of x axis changes

At the pitching motion of the helicopter taken at any given time of the application; changes in the value of the pwm signal obtained by the defuzzification process as a result of the fuzzification of the input values of y-axis position error and y-axis position error change; are as shown in Fig. 11.

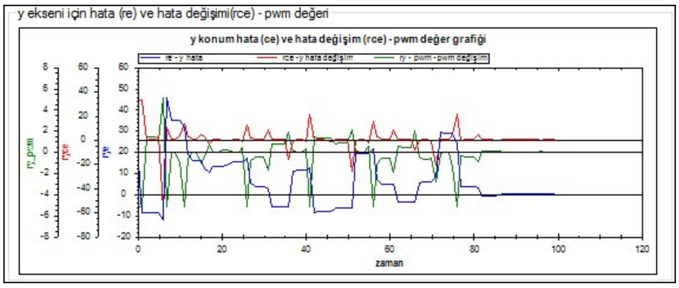

Fig. 11 Pwm signal value graph for as a result of y axis changes

At the yawing motion of the helicopter taken at any given time of the application; changes in the value of the pwm signal obtained by the defuzzification process as a result of the fuzzification of the input values of z-axis position error and z-axis position error change; are as shown in Fig. 12.

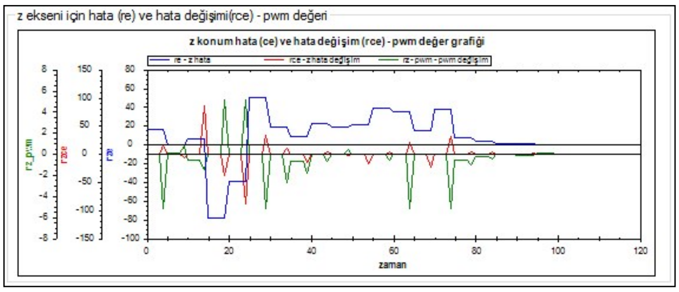

Fig. 12 Pwm signal value graph for as a result of z axis changes

At the vertical motion of the helicopter taken at any given time of the application; changes in the value of the pwm signal obtained by the defuzzification process as a result of the fuzzification of the input values of altitude error and altitude error change; are as shown in Fig. 13.

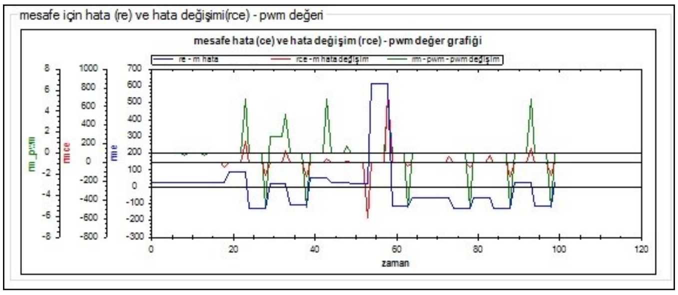

Fig. 13 Pwm signal value graph for as a result of altitude value changes

IV. CONCLUSIONS

In this research, a fuzzy expert system was designed to ensure the takeoffs and landings of the helicopter through fuzzy logic. For this purpose, a model helicopter and test platform that can test helicopter movement was formed. The control of vertical movement on the axis defined by the fuzzy logic control system with four degrees of freedom was provided with the use of created test platform.

In order to control the helicopter model, the fuzzy logic controller was designed by using control board Arduino Mega 2560 and Visual Studio 2010 C Sharp programs, and then the movement control was analyzed.

Real-time control of the helicopter on the test platform in accordance with the work done has been investigated experimentally. For the control of the helicopter, with imu placed on the model helicopter, the axis values and with ultrasonic distance sensor, distance values are read and sent to the computer with the help of the control card. In order to make a meaningful data of these values on the computer, specific codes are written in C# program. Processing of the meaningful data with the designed controller program created input values. By processing input values with the developed controller algorithms, net values were obtained. Movement control of the helicopter according to the target direction was achieved by the transmission of the resulting net values to the engines on the model with the help of the Arduino control board.

REFERENCES

[1] M. Hacımurtazaoğlu, "Fuzzy Logic for Automatic Landing and Takeoff of Helicopters to be Provided Through", Elect. and Comp. Syst. Edu. Mas. Thesis, The Graduate School of Natural and Applied Science of Selcuk University, Konya, Turkiye, June 2016.

[2] Anonymous, *Rotorcraft Flying Handbook. Flight Standards Service. 2000*, Federal Aviation Administration: U.S. Department of Transportation.

[3] D. Iakovou, "Fuzzy control for helicopter aviation", *Control Engineering, 2002.*

[4] K. Tanaka, H. Ohtake, and H.O. Wang, "A practical design approach to stabilization of a 3-DOF RC helicopter", *IEEE transactions on control systems technology, 12(2),* p. 315-325, 2004

[5] B. Kadmiry, and D. Driankov, "A fuzzy flight controller combining linguistic and model-based fuzzy control. Fuzzy Sets and Systems", 146(3): p. 313-347, 2004

[6] S. Franko, "İnsansız Helikopterin Model Öngörülü Kontrolü, in Fen Bilimleri Enstitüsü" E. Eng. Mast. Thesis, İstanbul, Turkiye, 2010,

[7] M. Fogh, "Autonomous Helikopter", Aalborg University, 2004

[8] R. Jensen, and A.K.N. Nielsen, "Robuts Control of an Autonomous Helicopter", Aolborg University. p. 89, 2005

[9] G.M. Hoffmann, "Precision flight control for a multi-vehicle quadrotor helicopter testbed. Control engineering practice", 2011

[10] P.Z. Molenaar, "Model Predictive Control to Autonomous Helicopter Flight", Technische Universiteit Eindhoven, Eindhoven, 2007.

[11] I.A. Raptis, "System identification for a miniature helicopter at hover using fuzzy models", *Journal of Intelligent and Robotic Systems*, 2009. 56(3): p. 345-362.

[12] M. Camilleri, K. Scerri, and S. Zammit. "Autonomous flight control for an RC helicopter", *16th IEEE Mediterranean Electrotechnical Conference.* 2012

[13] A.N. Khizer, "Takagi-Sugeno Fuzzy Model Identification for Small Scale Unmanned Helicopter", *Indonesian Journal of Electrical Engineering and Computer Science*, p. 487-495, 2014

[14] B. Kadmiry, and D. Driankov, "Fuzzy control of an autonomous helicopter", *IFSA World Congress and 20th NAFIPS International Conference*, Joint 9th. 2001

[15] V.E. Ömürlü, "İnsansız Dört Rotorlu Hava Araçları İçin Değişken Serbestlik Dereceli Yere Sabit Uçuş Kontrol Sistemi", TOK, 2009

[16] J. Ye, "Fuzzy control of small-scale unmanned helicopter", *25th Chinese Control and Decision Conference (CCDC)*, 2013

[17] Corporation, P. XL-MaxSonar-EZ0 Sonar Maxbotix XL-MaxSonar-EZ0 Sonar Range Finder MB1200 2001-2016 [cited 2013 06,10,2013]; Sonar Range Finders]. Available from: https://www.pololu.com/product/1650.

[18] Corporation, P. MinIMU-9 v3 Gyro, Accelerometer, and Compass MinIMU-9 v3 Gyro, Accelerometer, and Compass (L3GD20H and LSM303D Carrier) 2001-2016 [cited 2013 06,10,2013]; Accelerometers, Gyros, & Compasses]. Available from: https://www.pololu.com/product/2468.