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ROBUST EXTENDED KALMAN FILTER IN ONLINE TUNING FUZZY PID CONTROLLER FOR NONLINEAR PATH FOLLOWING ONE UNMANNED GROUND VEHICLES

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Abstract- To move an unmanned vehicle from one location to another location, it must be controlled in motion path. The task of the control system is stabilization device and execution commands generated by the navigation system. The most important issue in unmanned vehicle is route planning and tracking the route. One of the most effective in this regard, is traceability route by vehicle. Here traditional PID control and fuzzy control algorithms to combine and offer a response. To identify the control of the Kalman Filter is used to estimate model parameters. The purpose of this article online setting PID fuzzy controller based on Extended Kalman Filter to achieve the best performance control with high stability. Kalman Filter is a powerful mathematical tool for estimating the random noise measurement is used and it will estimate the steady state system. In this article, online setting PID fuzzy controller based on Extended Kalman Filter to achieve better performance and high stability control is used. The purpose of this paper is to design a controller for unmanned aerial vehicles are to be specified path his way through that with the lowest error, variance and time to close and again without any errors and with the least diversion and time to return to its original location.

Keywords: PID Controller, Fuzzy Controller, Extended Kalman Filter.

I. INTRODUCTION

Today, robots are used in many industrial environments. According to the development of robotic devices and activities of their installations, the robot control in a collaborative environment, many researchers around the world has attracted. Development of robots and expanding their use in various applications, creates a new era in human life. With the tools of soft computing, artificial intelligence and robotics into a new phase of his life. For decades, the vehicle for reconnaissance and military operations in areas that are dangerous to humans, are used. But the role of these cars is gradually changing and have the ability to do more missions.

The cars also used in civilian applications such as extinguishing the fire or Identify some natural disaster and Etc. With the introduction of unmanned vehicles in various applications have been done extensive research in the field of design and control them to achieve specific operational objectives. The main part of the movement of these devices is route planning and tracking [2]. For example, when the vehicle identification, runs its operations, generally a reference to a path that conforms to commands identify predetermined, follows.

During reconnaissance, in order to achieve the objective information, the vehicle must be close to the target is a moving target that often, in the field of vehicle detection equipment used. Generally, the process of planning managing and route planning, arises as an optimization problem. Many of the adverbs and limitations in the optimization problem is described in Table 1. Obviously, the optimization problem becomes more complicated if other restrictions be raised.

Table 1. Planning limitations in the optimization problem

Limitations	Description
Time	The vehicle must be in a specific place or a certain time to do his duty.
Dynamic	Vehicle dynamics will affect the planning and production path.
Fuel	Fuel consumption affect the continuation movement.
Atmosphere	Wind, rain, atmospheric and other factors that are considered.
Sensor	If the sensor requires certain conditions for their performance may impose restrictions on the route. For example, it is necessary for effective imaging cars have a certain distance from Earth.
Threat	Moving can be very dangerous in some areas that should be avoided.
Safety	Avoid collisions with other objects, obstacles and complications land should be considered in the planning process. This is part of the safety equipment systems limitations.

Considering the variety of mission vehicles, increased levels of for their autonomy is increasing. One of the most effective in this regard, traceability route is by car.

For this purpose, increase the autopilot system capable of tracking routes are complex or moving targets, is of great importance. Various methods of tracking control path have been investigated [4-7].

Now, the conventional proportional-integral-derivative (PID) control is known in the industry due to their simplicity, understanding of performance and ease of implementation. Meanwhile, fuzzy control, intelligent control of a duplication of reflection on human logic and mathematical absolute right to control the design, can leak some of the common PID control. However, non-linear fuzzy control and fault control output is fixed [1]. Since the input value stability in the region marked by a membership function, fuzzy control output similar to that in the near or reach to zero. Fuzzy PID control, PID control after the joint compound and fuzzy control algorithm is settled [2-5].

Practical fuzzy PID control method used for a few good end to a multiple of vintage consumer and industrial plant such as control of the slipper bending process. [2], Maintain perfect control of the situation stimulus [3], and speed control for brushless servo drives great efficiency [4], etc. Nevertheless, fuzzy PID controller was introduced in the access control process design experience in different working conditions and their dynamic response based. Therefore, the design of fuzzy rules depends largely on the expertise. No systematic approach to design and a number of rules, inputs and membership functions there. [6, 7]

Accordingly, the public cannot fuzzy PID controller for a huge range of configuration parameters with a lot of noise compliance [13]. Therefore, control methods such as robust control, intelligent ideas, or ways to integrate with PID fuzzy approximation is needed to control this fault [8-13]. With this progressive method, the coefficients of fuzzy PID controller will be about figures and the input and output of the compact MF control error was corrected. And Kalman estimation method dramatic setting for the doctrine of control. Kalman Filter is a powerful mathematical tool for random estimation of noisy sensor measurements [14-16].

The construction, assessment of the state of the system, estimates predict that apply to forestall assessment on the pursuit of name. This estimate retrogressively in all measures of the past, and usually within a few iterations to converge. However, ordinary Kalman Filter for nonlinear problems with small and nearly Gaussian noise statistics are accurate. In addition, many non-linear physical systems are broad and ambiguous. They can then measure the so-called bad because to do wrong. Thus, a competition to find a strong filter that is able to find measurement errors and handle them accordingly [17-29].

Finally, a strong filter targets nonlinear optimization of fuzzy PID controller is used. In order to control problems mentioned decisions, this paper presents a fuzzy PID Tuning online on a Robust Extended Kalman Filter (REKF) to achieve higher control efficiency with better consistency. REKF is a blend of an Extended Kalman Filter (EKF) and results in [23-25] who used strong EKF. Here, a set of fuzzy PID parameters is a vector that indicates the ability to control the situation.

When the vector system is designed to fit completely with working conditions, execution error to zero. In other words, error control system as well as weakness in the ability to control environmental noise effected. If the optimal method of fuzzy PID controller is to act as a filter, then set the vector. Ideally for control as a process model while the selection of the state vector used to control the system as a model size making.

As a result, varying between process and measurement models, measurement error, and error associated with the control system. Therefore, the task of REKF to directly estimate the ideal vector for the next stage based on fuzzy PID controller error now control, the current state vector, and notice. Then the MF and fuzzy rules updated online together to minimize the system error. As a result, fuzzy inference PID has the ability of higher education and quality control significantly impaired even in the case of a complex system environment improved. To evaluate the overall control system offers benefits to the environment Matlab/Simulink, as well as tests in real-time power control system for a specific item, such as electrocardiograms done [30]. Simulation and experimental results demonstrate the effectiveness of the hybrid drive using the proposed control method to achieve the goal of controlling force.

The remainder of this paper is organized as follows: Sections II and III are the procedure of designing a robust controller and Section IV presents the simulation and experimental results. Concluding remarks are presented in Section V.

II. DESIGN OF ROBUST CONTROLLER

A. Analysis of PID Controller

PID controller is the most commonly used control algorithms in the industry. The popularity of PID controllers can be partly strong performance in a wide range of operating conditions and partly simply attributed its performance as to engineers allow the it to operate simple and straightforward manner. As its name implies, the PID algorithm consists of three fundamental parameters of proportional, integral, and derivative is shown in Figure 1. This means that this type of controller operates with an error, integral error, and its derivatives. Acting in accordance with the error, create a rapid response to control output and act in proportion to the error integrator eliminates the steady-state error and finally reduce the volatility will act in accordance with the derived error [45].

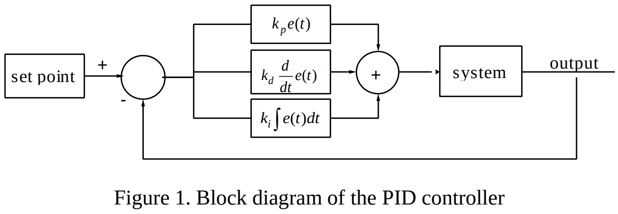

Figure 1. Block diagram of the PID controller

PID controller can be defined mathematical following relation.

$$u(t)=k_p[e(t)+\frac{1}{T_i}\int_0^t e(t)dt+T_d\frac{de(t)}{dt}] \quad (1)$$

where, k_p, k_i and k_d are the proportional gain, integral gain, and the derivative gain, respectively. So that $k_i=\frac{k_p}{T_i}$ and $k_d=k_pT_d$.

B. Analysis of PID Controller by Fuzzy

in this study, the problem of the control system and a control input single output is considered. As is known, due to the simple structure and easy control PID controller is used widely in modern industry. Using a control signal for a conventional PID controller in time domain can be expressed as Equation (1). But conventional PID controller's reasonable performance over a wide range of operating conditions due to performance gains are not fixed. That's why other control techniques such as fuzzy logic controller as an effective solution to adjust the parameters used. From (1), three coefficients k_P, k_i and k_d need to be adjusted using fuzzy tuner. Therefore, the detailed fuzzy PID scheme is clearly shown as in Figure 2.

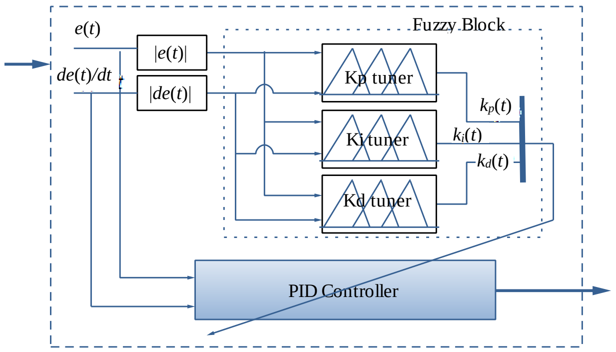

Figure 2. Fuzzy PID control block configuration

Through knowledge of fuzzy logic, fuzzy PID tuners that PID tuning parameters (k_p, k_i, k_d) can be established using the following equation:

$$k_a=k_{a0}+U_a\Delta k_a \;,\; U_a\in[0,1] \;,\; a=p,i,d \quad (2)$$

where U_a is the parameter obtained from the output of the tuning fuzzy controllers, and $\Delta k_a=k_{a1}-k_{a0}$ is the allowable deviation of k_a.

The k_{a0} and k_{a1} set minimum and maximum values of the test in Equation (2) and Figure 1 for three coefficient k_P, k_i and k_d using three independent fuzzy set tuners. As a result, three separate phase P, I and D control combined fuzzy PID controller in general. There are two entrances to the fuzzy controller: Absolute $e(t)$ and the absolute value of the derivative error $de(t)$. The input range is between zero and one, as the absolute measure of system error and its derivative by selective factors of non-linear systems is achieved.

For each input variable is needed is a triangular membership function (MFs). Because there are all triangular membership functions, so we can explain the membership functions as follows:

$$f_{ji}(x)=\begin{cases}1+\frac{(x-a_{ji})}{b_{ji}^-} & \text{if } (-b_{ji}^-)\le(x-a_{ji})\le 0\\ 1-\frac{(x-a_{ji})}{b_{ji}^+} & \text{if } 0\le(x-a_{ji})\le(b_{ji}^+)\\ 0 & \text{otherwise}\end{cases} \quad (3)$$

where, x is the input, $b_{ji}^+, b_{ji}^-, a_{ji}$ are the centroid, left half width, and right half-width of the jth triangle membership function of the ith input, respectively, and N is the numbers of triangles.

The fuzzy PID controller has an output that which is U_p, U_i and U_d. In practice, fuzzy controller with local inference used. This means that every law is derived and the results of this deduction has been collected from individual rules. The most common methods of inference, max-min method, method of max- product and total production method maximum position is where the consensus by a maximum operator or operator's position is clear and fuzzy concept by minimizing or the product is determined.

Minimum-maximum fuzzy relations calculations suggest a good computing environment and setting clear limits to publish it. Finally, a non-fuzzy method for obtaining a clear output of fuzzy results collected is required. Defuzzification methods are generally the most consistent and defuzzification Center. Defuzzification of fuzzy control is widely used for issues that needed a clear output is used, and maximum pattern matching is often a problem where we need to know the class output is used.

Therefore, in this study, the results of fuzzy reasoning output of the fuzzy sets of input gathering operations acquired and developed fuzzy rules, where method max-min aggregation and the phase of the center is used. The fuzzy control, we can compute the controller output U_p, U_i or U_d with a pair of inputs:

$$U_0=\frac{\sum_{k=1}^{M} mf(w_k).w_k}{\sum_{k=1}^{M} mf(w_k)} \;,\; a=p,i,d \quad (4)$$

where, w_k weight control output (center of kth output membership function), M number of fuzzy sets output and $mf(w_k)$ fuzzy output function that is calculated as follows:

$$mf(w)=\sum_{i,j} mf_{ij}(w) \quad (5)$$

where, $mf_{ij}(w)$ as a result of fuzzy function when the first and second inputs, respectively, i and j are in class.

$$mf_{ij}(w)=\delta_{ij}\mu_{ij} \quad (6)$$

where, δ_{ij} is a activated factor, which is active when the input $|e(t)|$ is in class i, and the input $|de(t)|$ is in class j and μ_{ij} is the height of the consequent fuzzy function obtained from the input class i and j.

$$\mu_{ij}=\min[f_{i1}(|e(t)|), f_{i2}(|de(t)|)] \quad (7)$$

Output of U_a settings fuzzy controller and output values can only be included in the same are generally set, fuzzy rules depends on the type of program that control and monitoring of these rules can be witnesses or scientific experience obtained.

However, no systematic method for the design and testing of rules and membership functions of the input system so fuzzy it lacks the ability to learn and adapt, especially about the object nonlinear control there, the uncertainty is high and ambient noise.

Therefore, a comparative approach to combining the fuzzy controller traditional PID controller to implement a new strong as a result is required, fuzzy PID controller configurable online on Extended Kalman Filter on one of the solutions to achieve the best control. The error function obtained as follows:

$$E = \frac{1}{2}(y - y_r)^2 \tag{8}$$

where, y_r and y respectively reference input to control the system (or target amount) and the output of the system. The purpose is to control how the error function to be minimized by taking the parameters of fuzzy membership functions.

The goal is to control how the error function to be minimized by taking the parameters of fuzzy membership functions. As mentioned above, the fuzzy PID controller is optimized by Kalman estimation techniques. So it can be input using a Kalman Filter shape and weight of the controller output membership functions during operation of the system is developed.

The following factors determine the fuzzy input membership functions a_j, b_j^-, b_j^+ and output weights w_j automatically by a strong set of extended Kalman Filter. This new method is fully described and detailed in reference [1].

III. FUZZY DESIGN NAVIGATION SYSTEM

Route points, points of reference are defined in a coordinate system. After you select and defining the route, is required to design an equipped to adequately algorithm to be able to generate appropriate commands.

Route points are defined in a matrix as follows:

$$W = \begin{bmatrix} w_{11} & w_{12} & w_{13} \\ w_{21} & w_{22} & w_{23} \\ w_{31} & w_{32} & w_{33} \\ \vdots & \vdots & \vdots \\ w_{n1} & w_{n2} & w_{n3} \end{bmatrix} \tag{9}$$

In the above equation, w_{i1}, w_{i2}, w_{i3} shows a three-dimensional coordinate Route points in space relative to an inertial reference frame. Since it is assumed that the navigation system is completely separate from the internal autopilot, so three separate controllers for the navigation system is designed fuzzy. Accordingly, are used in all controllers for fuzzy inference of max-min composition Mamdani and average centers defuzzification.

A. Height Fuzzy Control System

Duty to deliver and maintain the desired height of the vehicle at the height of the fuzzy controller. The fuzzy controller input height error is defined as.

$$e_H = H_w - H_u \tag{10}$$

where, H_w is the desired height or altitude of the route and H_u is the height of the vehicle.

Height fuzzy controller input is the height error and output is angle screwed. In order to increase the speed setting and increase continuity in response, has been used of triangular membership functions to appropriately as a function with fuzzy membership.

The selected membership functions for the error function of the height and angle of the screw are shown in Figures 3, 4 and 5, respectively and the level of decision-making in exchange for changing the ratio to each other is shown.

Linguistic variables used in Figures 5 and 6 are defined in Table 2. In order to use fuzzy logic controller is needed to establish a base rules. In this issue of the use of five law presented in Table 3.

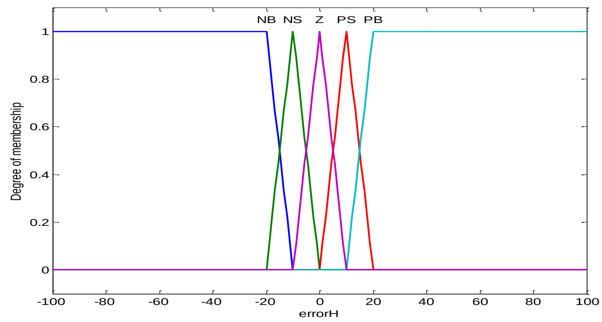

Figure 3. Input membership functions fuzzy control height

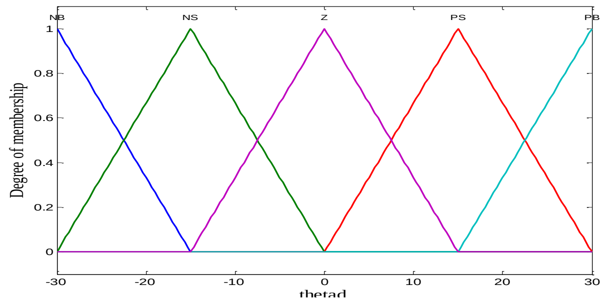

Figure 4. Fuzzy height control output membership functions

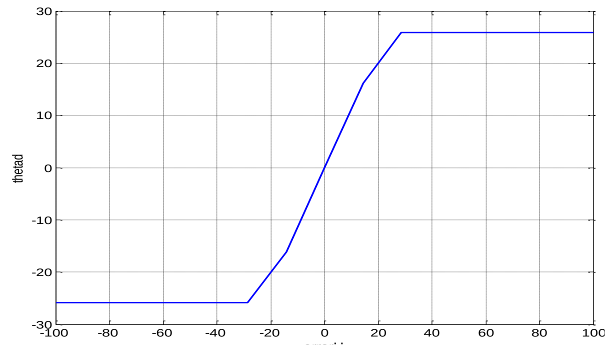

Figure 5. Level of decision-making in exchange for changing the ratio to each other

Table 2. Linguistic variables used in height controller

Linguistic variable	Description
Z	zero
NS	Negative Small
NB	Negative Big
PS	Positive Small
PB	Positive Big

Table 3. Fuzzy control laws height

Fuzzy control laws height		Rule 1	Rule 2	Rule 3	Rule 4	Rule 5
if	e_H	NB	NS	Z	PS	PB
then	f_H	NB	NS	Z	PS	PB

B. Speed Fuzzy Control System

Speed fuzzy controller responsible for delivering and maintaining the speed of the vehicle is responsible for at optimum speed. The fuzzy controller input speed error is defined as follows.

$$e_V = V_w - V_u \tag{11}$$

where, V_w is optimum speed passage and V_u is speed vehicle the rest of the way.

The input speed fuzzy controller is speed error and its output added speed to vehicle speed to reach the desired speed. For increase the speed setting and increase continuity in the system response, the triangular membership functions as fuzzy membership function is used with the appropriate overlap.

Figures 6 and 7 show membership functions selected for the speed error and the output of the fuzzy system. Figure 8 indicates the level of decision making for changes in the ratio to each other.

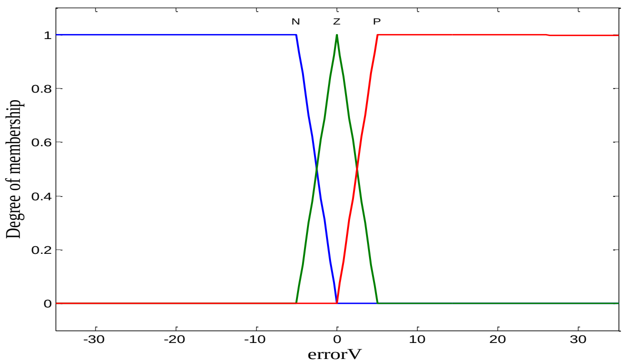

Figure 6. Input membership functions fuzzy control speed

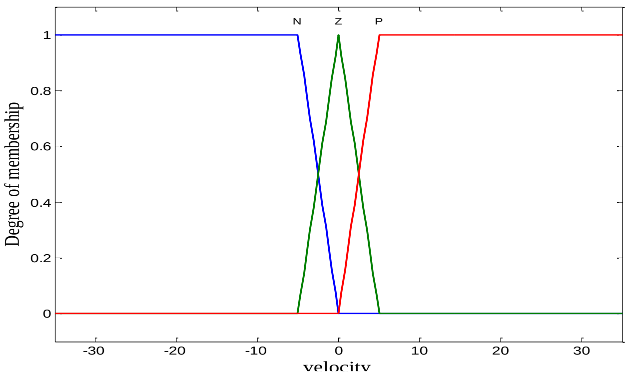

Figure 7. Output membership functions fuzzy speed control

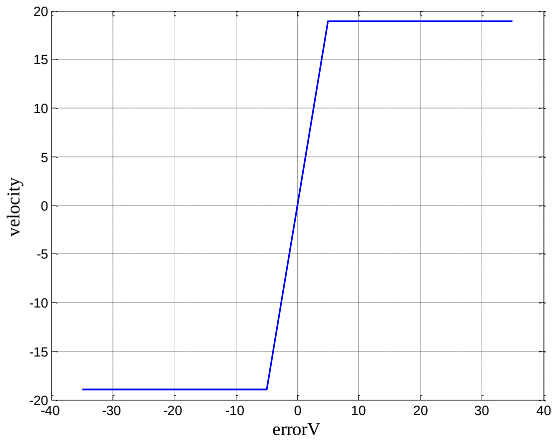

Figure 8. Level of decision making for changes in the ratio to each other

Finally, the ultimate speed controller is to be calculated as follows.

$$V_{BS} = V_w + f_V\left(e_V\right) \tag{12}$$

In the above equation, V_{BS} a speed sent to internal autopilot and f_V fuzzy controller is used. Linguistic variables used in Figure 8 and Figure 9 are as Table 4.

Table 4. Linguistic variables used for a speed control

Linguistic variable	Description
Z	Zero
N	Negative
P	Positive

In order to use fuzzy logic controller is needed to establish a base rules. In this issue of the use of three law presented in Table 5.

Table 5. Fuzzy speed controller laws

Fuzzy control laws height		Rule 1	Rule 2	Rule 3
if	E_V	N	Z	P
then	F_V	N	Z	P

C. Direction Fuzzy Controller System

The direction fuzzy controller duty on the optimal delivery of direction vehicle is responsible. The fuzzy controller input error page location is defined as follows.

$$e_x = X_w - X_u \tag{13}$$

$$e_y = Y_w - Y_u \tag{14}$$

where, X_w is the optimal location or position path of the x-axis and X_u the position of the vehicle in the x-axis and Y_w is the optimal location or position path of the y-axis and Y_u the position of the vehicle in the y-axis.

Direction fuzzy controller input is error location and output its χ angle of the path. For increase the speed setting and increase continuity in the system response, the triangular membership functions as fuzzy membership function is used with the appropriate overlap.

Figures 9 and 10 membership functions selected for the location error in x-axis and y-axis and output of the fuzzy direction system is shown in Figures 11 and 12 which indicate the level of decision making for changes in the ratio to each other.

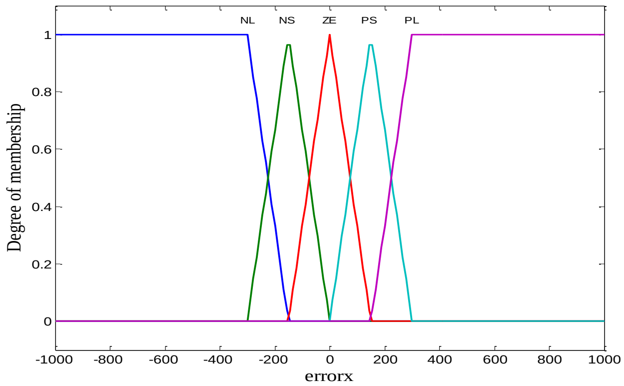

Figure 9. Input membership functions fuzzy direction controller in *x*-axis

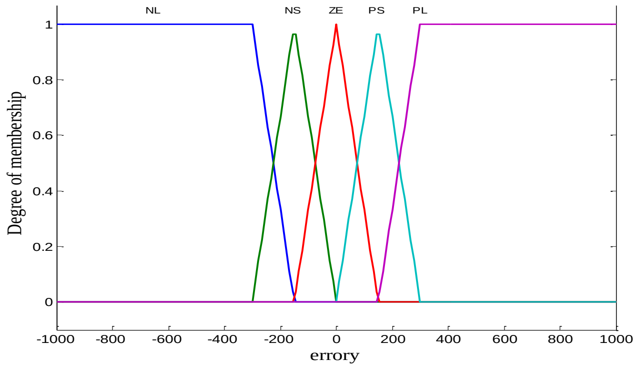

Figure 10. Input membership functions fuzzy direction controller in *y*-axis

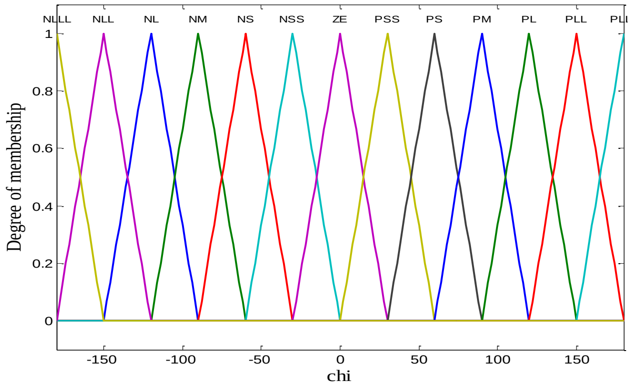

Figure 11. Output membership functions fuzzy direction controller

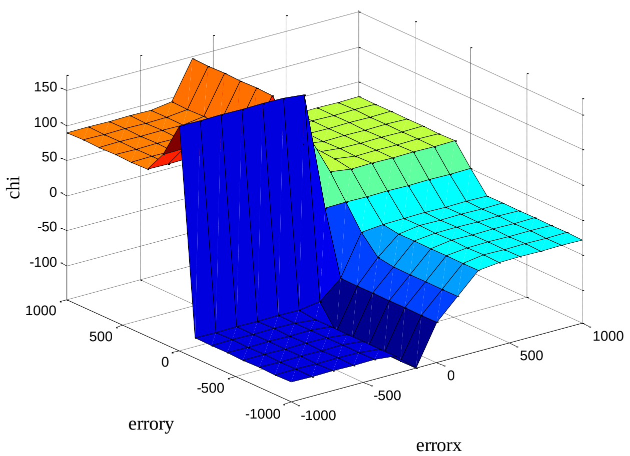

Figure 12. Level of decision making for changes in the ratio to each other

Linguistic variables used in Figures 9-11 and are as Table 6. In order to use fuzzy logic controller is needed to establish a base rules. In this issue of the use of 25 law presented in Table 7.

Table 6. Linguistic variables used for a direction controller

Linguistic variable	Description
ZE	Zero
NS	Negative Small
NM	Negative Moderate
NL	Negative Large
NLL	Negative Large Large
NLLL	Negative Large Large Large
PS	Positive Small
PM	Positive Moderate
PL	Positive Large
PLL	Positive Large Large
PLLL	Positive Large Large Large

Table 7. Fuzzy direction controller laws

fuzzy direction controller laws		Rule 1	Rule 2	Rule 3	Rule 4	Rule 5
		NL	NS	ZE	PS	PL
Rule 1	NL	NL	NLL	NM	NS	NSS
Rule 2	NS	NL	NL	NM	NSS	NSS
Rule 3	ZE	PLLL	PLLL	ZE	ZE	ZE
Rule 4	PS	PL	PL	PM	PSS	PSS
Rule 5	PL	PM	PLL	PM	PS	PSS

Finally, the ultimate direction controller is to be calculated as follows.

$$\chi_{BS} = \chi_w + f_\chi\left(e_\chi\right) \tag{15}$$

where, f_χ is fuzzy direction controller such that from difference between the vehicle location and place route points in *x-y* page calculating an angle χ also Angle passes through a point-to-point path of the next track that is shown Figure 13.

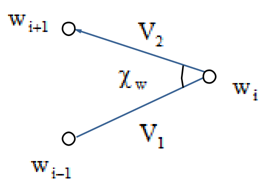

Figure 13. Schematic of angles between route points

In the two-dimensional vector space consisting of a waypoint and previous waypoint and the waypoint to waypoint after it was formed. The angle between the two vectors have the same angle and direction the vehicle is calculated as follows.

$$\chi_w = \cos^{-1}\left(\frac{V_1.V_2}{|V_1||V_2|}\right) \tag{16}$$

This angle is calculated for each waypoint is added to the output of fuzzy control.

IV. SIMULATION RESULTS

Simulation is done in MATLAB 2014a. According to [1] UGV system of equations of motion in the follow equations.

$$\begin{cases} \dot{x} = u_1 \cos(\theta) \\ \dot{y} = u_1 \sin(\theta) \\ \dot{\theta} = u_2 \end{cases} \quad (17)$$

Fuzzy self-tuning PID controller design by Extended Kalman Filter robust to these signals u_1 and u_2 are defined as follows.

$$u_1 = 1$$
$$u_2 = k_P e(t) + k_i \int e(t)\,dt + k_d \frac{de(t)}{dt} \quad (18)$$

In other words, it is assumed UGV moves at a constant speed using a control signal and set the pan UGV will be tracking the desired trajectory.

$$y_{out} = \theta \quad (19)$$
$$y_{ref} = \text{atan2}(y_r - y, x_r - x) \quad (20)$$

If the output of the system is considered to be 19 and the output reference 20 also considered where x and y of UGV position in two-dimensional and two-dimensional plane are in the reference path, with the desire to be tracking the desired trajectory. The path of the reference is shown in Figure 14.

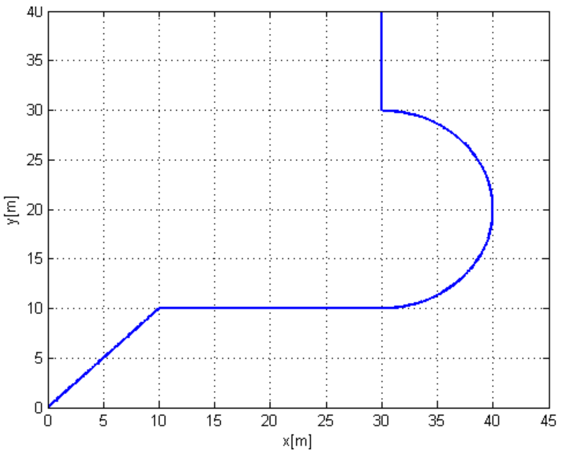

Figure 14. The reference trajectory for UGV

The direction of the tilt path of, horizontal, vertical and circular and to assess the ability of the control system is appropriate. In this project a fuzzy PID controller using a Kalman Filter to track the path of a strong developed unmanned ground vehicle used. The aim of this project is to design a controller for a vehicle unmanned ground that specified path of his to be run with minimal error and quickly to close and again without any error to location our initial return. After doing the calculations in the project programs required to achieve the following results have goals.

From Figures 15, 16 and 17 it can be found that trace route was very close to the target, even in the event of their matches the reference direction as well. Function using the PID controller fuzzy a little improvement over the use of the PID controller traditional.

But volatility remains, however, when the controller set online PID Fuzzy based on Extended Kalman Filter used to do, quality control is very desirable so that the steady-state error is very small. The project is a new method of fuzzy PID controller can be adjusted online based on a Kalman Filter developed strong offers.

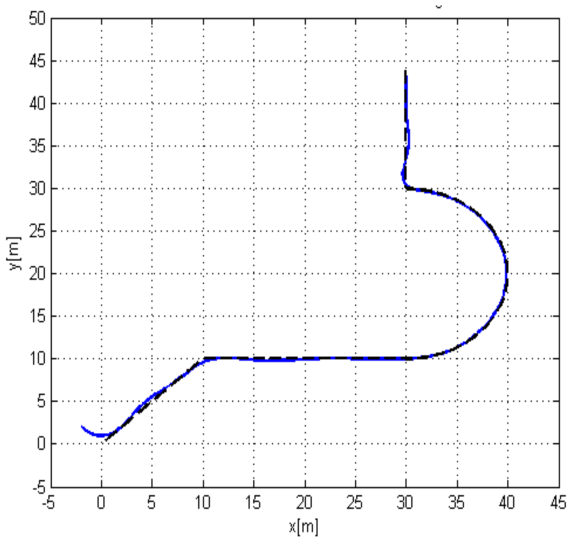

Figure 15. How to trace route reference two-dimensional plane

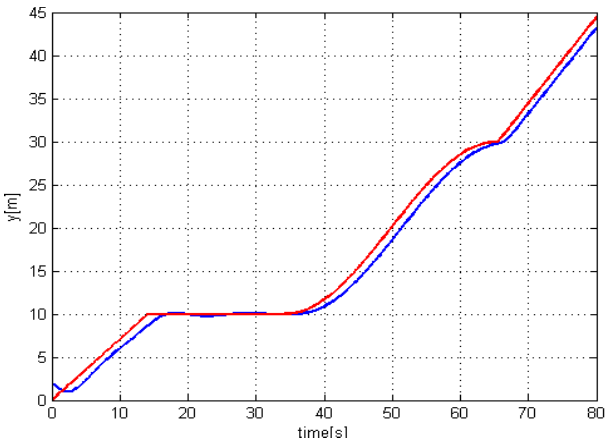

Figure 16. Time drawing for y

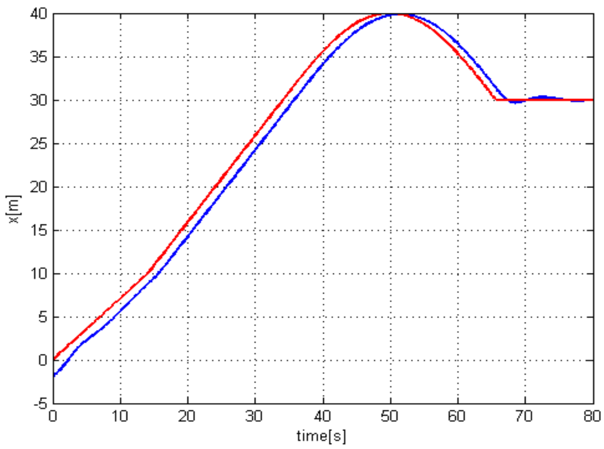

Figure 17. Time drawing for x

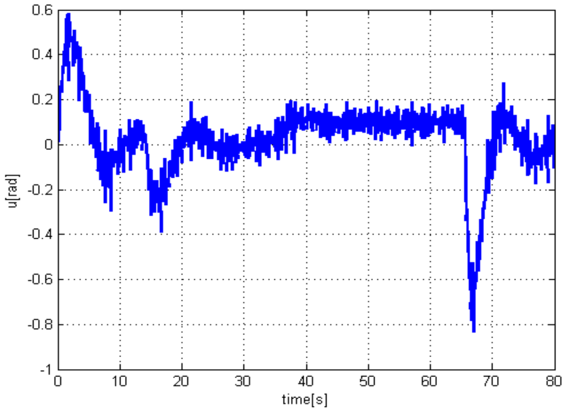

Figure 18. Drawing control signal u_2

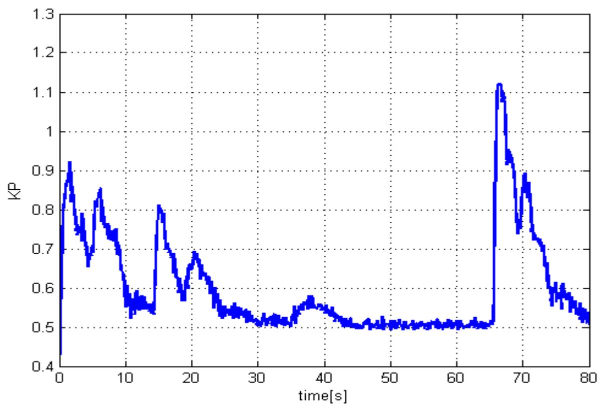

Figure 19. The k_p variable tuned by extended Kalman Filter

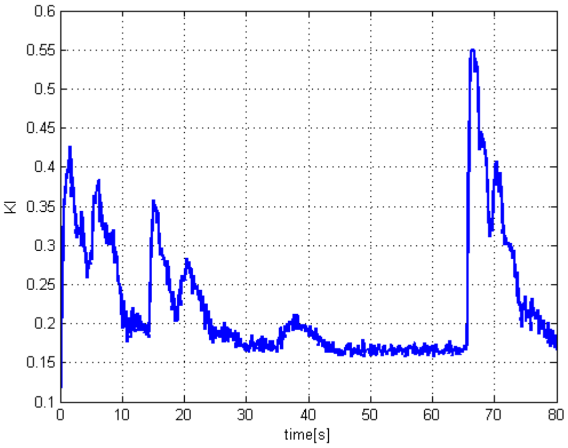

Figure 20. The k_i variable tuned by extended Kalman Filter

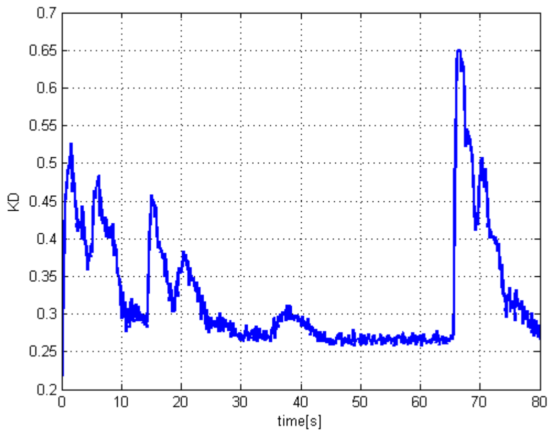

Figure 21. The k_d variable tuned by extended Kalman Filter

V. CONCLUSIONS

The most important thing unmanned vehicles in route planning and route tracking. One of the most effective in this regard, traceability route is by car. Here industrial control and PID control algorithm incorporating fuzzy, and we offer as an answer. The Kalman Filter is used to estimate model parameters. The project aims to set up online fuzzy PID control based on the Kalman Filter is developed to achieve the best performance control with high stability. Online tuning fuzzy PID control in the project based on extended Kalman Filter to achieve better performance and high stability control is used and this is why, often in areas and battlefields and military applications, a robot is difficult, after the robot must do more resistant to other types of robots against disturbances and noises in these areas have. The aim of this project is to design a control system for robots. So that he can set his path in such a way that the least error, variance and time to close and their commander in the region has implemented operations expected and without any errors and with a minimum of time to return to its original location.

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REFERENCES

[1] Ch. Lemire, "Unmanned Aerial Vehicle Trajectory Tracking Using Type-2 Fuzzy Logic", A Thesis for the Degree of Master of Science in Electrical and Electronics Engineering, Submitted to the Division of Graduate Studies of Royal Military College of Canada, April 2008.

[2] M. Hashem Sadraey, "Design of a Nonlinear Robust Controller for a Complete Unmanned Aerial Vehicle Mission", A Thesis for the Degree of Doctor of Philosophy in Aerospace Engineering, Submitted to the Department of Aerospace Engineering and the Faculty of the Graduate School of the University of Kansas, 2005.

[3] R. Beard, et al., "Autonomous Vehicle Technologies for Small Fixed-Wing UAVs", Journal of Aerospace Computing, Information, and Communication, Vol. 2, January 2005.

[4] H. Wang, J. Gao, "Trajectory Tracking Control for Uninhabited Air Vehicles", IEEE International Conference on Computational Intelligence for Modelling Control and Automation, and International Conference on Intelligent Agents, Web Technologies and Internet Commerce (CIMCA-IAWTIC'06), Beijing, China, 2006.

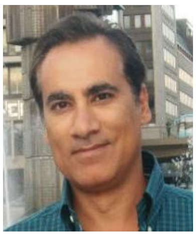
[5] D. Gates, "Nonlinear Path Following Method", Journal of Guidance, Control, and Dynamics Vol. 33, No. 2, 2010.

[6] T. Soleymani, F. Saghafi, "Fuzzy Trajectory Tracking Control of an Autonomous Air Vehicle", 2nd International Conference on Mechanical and Electronics Engineering (ICMEE 2010), Vol. 2, pp. 347-352, 2010.

[7] S. Park, J. Deyst, J. How, "A New Nonlinear Guidance Logic for Trajectory Tracking", AIAA Guidance, Navigation, and Control Conference and Exhibition Providence, Rhode Island, 2004.
[8] A. Tsalatsanis, et al., "Multiple Sensor Based UGV Localization Using Fuzzy Extended Kalman Filtering", Mediterranean Conference on Control and Automation, Athens, Greece, July 27-29, 2007.
[9] K.K. Ahn, D.Q. Truong, "Online Tuning Fuzzy PID Controller Using Robust Extended Kalman Filter", Journal of Process Control, Vol. 19, pp. 1011-1023, 2009.
[10] Z. Michalewicz, D. Fogel, "How to Solve It: Modem Heuristics", Springer-Verlag, Berlin, Germany, 2000.
[11] P. Van Laarhoven, E. Aarts, "Simulated Annealing: Theory and Applications", Kluwer Academic Publishers, Boston, Dordrecht, London, 1987.
[12] F. Glover, "Tabu Search - Part I", URSA Journal on Computing, Vol. 1, No. 3, pp. 190-206, 1989.
[13] S. Boettcher, A.G. Percuss, "Effects of Swarm Size on Cooperative Particle Swarm Optimization and Nature's Way of Optimizing", Artificial Intelligence, 2000.
[14] Y.Q. Qin, et al., "Path Planning for Mobile Robot Using the Particle Swarm Optimization with Mutation Operator", IEEE International Conference on Machine Learning and Cybernetics, Vol. 4, 2004.
[15] M. Saska, et al., "Robot Path Planning Using Particle Swarm Optimization of Ferguson Splines", IEEE Conference on Emerging Technologies and Factory Automation (ETFA'06), 2006.
[16] A. Kelly, "A Feedforward Control Approach to the Local Navigation Problem for Autonomous Vehicles", Carnegie Mellon University, Tech. Rep. CMU-RI-TR-94-17, 1994.
[17] S. Park, J. Deys, J.P. How, "Performance and Lyapunov Stability of a Nonlinear Path-Following Guidance Method", Journal of Guidance, Control, and Dynamics, Vol. 30, No. 6, pp. 1718-1729, 2007.
[18] C.B. Low, "A Trajectory Tracking Control Design for Fixed-Wing Unmanned Aerial Vehicles", IEEE International Conference on Control Applications, Yokohama, Japan, pp. 2118-2123, 2010.
[19] Y. Baba, H. Takano, M. Sano, "Desired Trajectory and Guidance Force Generators for an Aircraft", AIAA, Guidance, Navigation and Control Conference, San Diego, CA, July 29-31, 1996.
[20] F. Baralli, L. Pollini, M. Innocenti, "Waypoint-Based Fuzzy Guidance for Unmanned Aircraft: A New Approach", AIAA, Guidance, Navigation and Control Conference, Monterey, California, pp. 1-8, August 5-8, 2002.
[21] Y.Q. Qin, et al., "Path Planning for Mobile Robot Based on Particle Swarm Optimization", Robot 26.3, 2004.
[22] M. Innocenti, L. Pollini, D. Turra, "Guidance of Unmanned Air Vehicles Based on Fuzzy Sets and Fixed Way Points", AIAA Journal of Guidance, Control and Dynamics, Paper 2002-4993, Vol. 27, No. 4, 2002.
[23] K. Sefer, E. Emre, K. Okyay, M. Umit, "A Frugal Fuzzy Logic Based Approach for Autonomous Flight Control of Unmmanned Aerial Vehicles", LNCS, Springer Verlag, Vol. 3789, pp. 1155-1163, 2005.
[24] F.M. Raimondi, M. Melluso, "Stability and Noises Evaluation of Fuzzy/Kalman UAV Navigation System", 48th IEEE Conference on Decision and Control (CDC'2009), Combined with 28th Chinese Control Conf., Shanghai, China, pp. 768-775, Dec. 16-18, 2009.
[25] I. Kaminar, A.M. Pascoal, P.P. Khargonekar, E.E. Coleman, "A Velocity Algorithm for the Implementation of Gain-Scheduled Controllers", Automatica, Vol. 31, No. 8, pp. 1185-1191, 1995.
[26] W. Rugh, J.S. Shamma, "Research on Gain Scheduling", Automatica, Vol. 36, No. 9, pp. 1401-1425, 2000.
[27] J. Magni, S. Bennani, J. Terlouw, "Robust Flight Control: A Design Challenge", Springer-Verlag, Vol. 224, 1997.
[28] G.C. Goodwin, "A Brief Overview of Nonlinear Control", Proceeding of the Centre for Integrated Dynamics and Control, Department of Electrical and Computer Engineering, University of Newcastle, Australia, 2002.
[29] A.E. Bryson, Y.C. Ho, "Applied Optimal Control", MA: Blaisdell Publishing Company, 1969.
[30] K.J. Astrom, B. Wittenmark, "Adaptive Control", Second Edition, Addison-Wesley, 1995.
[31] M. Golden, B. Ydstie, "Bifurcation Analysis of Drift Instabilities in Adaptive Control, 30th IEEE Conference on Decision and Control, Vol. 2, pp. 1108-1109, 1991.
[32] M. Schoenauer, S. Xanthakis, "Constrained GA Optimization", ICGA, 1993.
[33] J. Tu, S.X. Yang, "Genetic Algorithm Based Path Planning for a Mobile Robot", IEEE International Conference on Robotics and Automation (ICRA'03), Vol. 1, 2003.
[34] D. Karaboga, B. Akay, "A Survey: Algorithms Simulating Bee Swarm Intelligence", Artificial Intelligence Review, Vol. 31, No. 1-4, pp. 61-85, 2009.
[35] J. Wang, D. An, C. Lou, "Application of Fuzzy-PID Controller in Heating Ventilating and Air-Conditioning System", IEEE International Conference on Mechatronics and Automation, China, pp. 2217-2222, 2006.
[36] C.D. Lee, C.W. Chuang, C.C. Kao, "Apply Fuzzy PID Rule to PDA Based Control of Position Control of Slider Crank Mechanisms", IEEE International Conference on Cybernetics and Intelligent Systems (CIS) and Robotics, Automation and Mechatronics (RAM), Singapore, p. 508, 2004.
[37] N.B. Kha, K.K. Ahn, "Position Control of Shape Memory Alloy Actuators by Using Self-Tuning Fuzzy PID Controller", IEEE International Conference on Industrial Electronics and Applications, Singapore, 2006.
[38] R. Ahmed, O. Abdul, C. Marcel, "dSPACE DSP-Based Rapid Prototyping of Fuzzy PID Controls for High Performance Brushless Servo Drives", IEEE International Conference, USA, pp. 1360-1364, 2006.
[39] X. Huang, L. Shi, "Simulation on a Fuzzy-PID Position Controller on the CNC Servo System", IEEE Sixth International Conference on Intelligent Systems Design and Applications, China, 2006.
[40] D.Q. Truong, K.K. Ahn, K.J. Soo, J.H. Soo, Application of Fuzzy-PID Controller in Hydraulic Load

Simulator", IEEE International Conference on Mechatronics and Automation, Harbin, China, pp. 3338-3343, 2007.
[41] K.K. Ahn, D.Q. Truong, Y.H. Soo, "Self-Tuning Fuzzy PID Control for Hydraulic Load Simulator", IEEE International Conference on Control, Automation and Systems, Korea, pp. 345-349, 2007.
[42] M. Guzelkaya, I. Eksin, E. Yesil, "Self-Tuning of PID-Type Fuzzy Logic Controller Coefficients via Relative Rate Observer", Engineering Applications of Artificial Intelligence, Vol. 16, pp. 227-236, 2003.
[43] J.J. Simon, K.U. Jeffrey, "A New Extension of the Kalman Filter to Nonlinear Systems", International Symposium Aerospace/Defense Sensing, Simulation and Controls, Orlando, 1997.
[44] D.J. Jwo, S.H. Wang, "Adaptive Fuzzy Strong Tracking Extend Kalman Filter for GPS Navigation", IEEE Journal of Sensors, Vol. 7, No. 5, pp. 778-789, 2007.
[45] K. Kazuyuki, C.C. Ka, W. Kajiro, "Estimation of Absolute Vehicle Speed Using Fuzzy Logic Rule-Based Kalman Filter", American Control Conference, Seattle, Washington, pp. 3086-3090, 1995.
[46] T. Perala, R. Piche, "Robust Extended Kalman Filtering in Hybrid Positioning Applications", 4th Workshop on Positioning, Navigation and Communication, Hannover, Germany, pp. 55-63, 2007.
[47] C.S. Rodrigo, C.Z. Aldo, "Fuzzy Logic Based Nonlinear Kalman Filter Applied to Mobile Robots Modelling", IEEE International Conference on Fuzzy Systems, Budapest, Hungary, pp. 1485-1490, 2004.
[48] G.V. Puskorius, L.A. Feldkamp, "Neurocontrol of Nonlinear Dynamical Systems with Kalman Filter Trained Recurrent Networks", IEEE Transactions on Neural Networks, Vol. 5, No. 2, pp. 279-297, 1994.
[49] D. Simon, "Fuzzy Membership Optimization via the Extended Kalman Filter", 19th International Conference of the North American on Fuzzy Information Processing, Atlanta, GA, USA, pp. 311-315, 2000.
[50] S.D. Mirel, "Preliminary Tests Based on Fuzzy Intelligence on a System of Non-Destructive Examination", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 24, Vol. 7, No. 3, pp. 37-41, September 2015.

BIOGRAPHIES



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