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

<table>
<thead>
<tr>
<th>Limitations</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>The vehicle must be in a specific place or a certain time to do his duty.</td>
</tr>
<tr>
<td>Dynamic</td>
<td>Vehicle dynamics will affect the planning and production path.</td>
</tr>
<tr>
<td>Fuel</td>
<td>Fuel consumption affect the continuation movement.</td>
</tr>
<tr>
<td>Atmosphere</td>
<td>Wind, rain, atmospheric and other factors that are considered.</td>
</tr>
<tr>
<td>Sensor</td>
<td>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.</td>
</tr>
<tr>
<td>Threat</td>
<td>Moving can be very dangerous in some areas that should be avoided.</td>
</tr>
<tr>
<td>Safety</td>
<td>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.</td>
</tr>
</tbody>
</table>

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](image_url)

PID controller can be defined mathematical following relation.
\[ u(t) = k_p e(t) + \frac{1}{T_i} \int_0^t e(t) dt + T_d \frac{de(t)}{dt} \]  

(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 \( k_d = k_p T_d \).

**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 is 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.

**Defuzzification methods**

Defuzzification methods are generally the most 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:

\[ U_0 = \sum_{i=1}^{M} \sum_{k=1}^{N} w_{ik} \]  

(4)

where, \( w_{ik} \) weight control output (center of \( k \)th output membership function), \( M \) number of fuzzy sets output and \( mf(w_{ik}) \) fuzzy output function that is calculated as follows:

\[ mf(w) = \sum_{i,j} mf_{ij}(w) \]  

(5)

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

\[ mf_{ij}(w) = \delta_{ij} \mu_{ij} \]  

(6)

where, \( \delta_{ij} \) 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 \( \mu_{ij} \) is the height of the consequent fuzzy function obtained from the input class \( i \) and \( j \).
Output of $U_e$ 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:

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

where, $y$ and $y_r$ 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 $a_i, b_i, b_i^+$ 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:

$$W = \begin{bmatrix}
  w_{11} & w_{12} & w_{13} \\
  w_{21} & w_{22} & w_{23} \\
  w_{31} & w_{32} & w_{33} \\
  \vdots & \vdots & \vdots \\
  w_{m1} & w_{m2} & w_{m3}
\end{bmatrix} \hspace{1cm} (9)$$

In the above equation, $w_{11}, w_{12}, w_{13}$ 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.

$$e_H = H_w - H_u$$ \hspace{1cm} (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](image1)

![Figure 4. Fuzzy height control output membership functions](image2)

![Figure 5. Level of decision-making in exchange for changing the ratio to each other](image3)
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.
\[ e_v = V_w - V_u \]  
(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 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.

Finally, the ultimate speed controller is to be calculated as follows.
\[ V_{BS} = V_w + f_v \left( e_v \right) \]  
(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.

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.

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.
\[ e_x = X_w - X_u \]  
(13)

\[ e_y = Y_w - Y_u \]  
(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 \( \chi \) 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.
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>
<thead>
<tr>
<th>Linguistic variable</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>ZE</td>
<td>Zero</td>
</tr>
<tr>
<td>NS</td>
<td>Negative Small</td>
</tr>
<tr>
<td>NM</td>
<td>Negative Moderate</td>
</tr>
<tr>
<td>NL</td>
<td>Negative Large</td>
</tr>
<tr>
<td>NLL</td>
<td>Negative Large Large</td>
</tr>
<tr>
<td>NLLL</td>
<td>Negative Large Large Large</td>
</tr>
<tr>
<td>PS</td>
<td>Positive Small</td>
</tr>
<tr>
<td>PM</td>
<td>Positive Moderate</td>
</tr>
<tr>
<td>PL</td>
<td>Positive Large</td>
</tr>
<tr>
<td>PLL</td>
<td>Positive Large Large</td>
</tr>
<tr>
<td>PLLL</td>
<td>Positive Large Large Large</td>
</tr>
</tbody>
</table>

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

\[ \chi_{BS} = \chi_w + \theta_f (\epsilon_x) \]  

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

![Figure 13. Schematic of angles between route points](image)

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.

\[ \chi_w = \cos^{-1} \left( \frac{V_1 \cdot V_2}{|V_1||V_2|} \right) \]  

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

**IV. SIMULATION RESULTS**

\[
\begin{align*}
    x &= u_1 \cos(\theta) \\
    y &= u_1 \sin(\theta) \\
    \dot{\theta} &= u_2
\end{align*}
\]  

(17)

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

\[
u_1 = 1
\]

\[
u_2 = k_p e(t) + k_i \int e(t) \, dt + k_d \frac{de(t)}{dt}
\]

(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.

\[
y_{\text{out}} = \theta
\]

(19)

\[
y_{\text{ref}} = \text{atan2}(y_r - y, x_r - x)
\]

(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.

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.

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.
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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