New Approach to a Hybrid Fuzzy-Sliding Mode Control to a Brushless AC Motor Scheme

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Abstract - This paper deals with fuzzy-sliding mode control strategies of a Brushless AC Motor. The system combines the performance of fuzzy logic control and sliding mode control. Sliding mode control scheme, fuzzy logic controller strategies and the hybrid fuzzy-sliding mode controller were simulated with Mat lab/ Simulink for comparison. Behind this strategy, the main objective is to improve the performance of the fuzzy sliding mode control scheme. An experimentation, where all the command were implemented to an MSK Board with a PM50 module and a 90W BLAC Motor is used to validate all the result. the BLDC motor frameworks have questionable and nonlinear attributes which corrupt execution of controllers. Sliding mode controllers (SMC) are very useful in controlling the non-linearities in the system. But due to the effect of chattering in SMC based drives, the use of controller is limited. Henceforth a novel hybrid fuzzy sliding mode controller is exhibited in this paper for effectively reducing the chattering effect.

Key Words: *Brushless Motor, Sliding Mode, Fuzzy Logic, Hybrid controller.*

1. INTRODUCTION:

Nowadays, with regard to improvement in use of space capabilities, the process to design spatial robots regarding removal of human parameter keeps expanding, under which is expected that robotic systems play a major role in the future of space applications .

Therefore, the design of dynamic models from space robots has been increasingly drawn into attention .Long time has passed from lifetime of fixed-wing vehicles that such vehicles due to optimization of energy consumption have been widely drawn into attention, yet they have constantly suffered from the lack of power of ability, at the affairs pertaining to unmanned vehicles.

For instance, small air flasks can easily be controlled so far as there do not exist wind and turbulence. Under this state, natural lifting force causes moving aerial vehicle, yet causes decreasing its power of maneuverability. Helicopters have numerous advantages than fixed-wing vehicles and balloons especially at control and the reason for this can be known in their ability in take off and land at small area of space as well as high power of maneuverability. In addition, static flight (hover) has been regarded as one of the capabilities of aerial vehicles, mentioned top of aims.

On the other hand, these advantages lead to difficulty in control of helicopters for which different sensors as well as rapid processing boards are required. Unmanned aerial robots have been regarded as efficient and practical solutions to cope with this challenge in helicopters. Building unmanned aerial robots include synergic combination at different stages including design, selection of sensors and development of controllers.

All the stages are fulfilled in an integrative and parallel way, so that, each one affects another one. To build autonomous unmanned aerial robots, high information on position and direction is required.

Such information is provided through self-stabilizing sensors such as inertial navigation system (INS). Global positioning system (GPS) and/or sensors such as sound navigation and ranging (SONAR) . With regard to increasing trend of research at the area of unmanned vehicles especially quad rotors, the present research will intend to examine, simulate and control aerial robots.

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In recent years, aerial robots or unmanned aerial vehicles (UAVs) regarding removal of human operator have been drawn into attention as the aerial instruments with wide applications and capabilities. With regard to high potential of aerial instruments for flying at points that the manned aerial vehicles fail to access them, investigation, analysis and control of such system have been transformed to an important issue.

Nowadays, UAVs develop an important part of scientific studies pertaining to military industries. Unmanned aerial vehicles compared to the systems that are conducted by man's intervention can have a high protective role in human's life at hazardous environments.

Autonomous aerial vehicles have been witnessed with numerous commercial applications. Recent advancements at areas of energy storage with high density, integrated miniature operators. Micro-electromechanical systems (MEMS), construction of miniature unmanned aerial robots have come to realize.

This has opened the way towards complicated applications at military and non-military markets. Currently, military applications propose the leading part of UAVs with huge increasing in industrial sector. With regard to growing increase of research at the area of UAVs especially quad rotor, the present research seeks to examine, simulate and control these UAVs.

Quad rotor has been mentioned as a useful tool for researchers at universities to engage in examining new ideas at different areas including flight control theory, guidance and navigation, real-time and robotic systems. In recent years, most of universities have conducted research on complex aerial manoeuvres through quad rotors for which different controllers have been designed. Since quad rotors are so manoeuvrable, they can be beneficial under any environmental conditions quad rotors with the flight ability in an independent way can assist for removal of required manpower at hazardous situations, whereby this ability represents the main reason for increasing research on these systems in recent years.

With regard to significance of topic of this research, to date numerous activities have been conducted at the area of optimization of UAVs via nonlinear controllers, so that there are numerous ways to control an UAVs . Use of fuzzy logic regarding capabilities of this method in controlling nonlinear systems is one way to control UAVs. For instance, in long lost past, a variety of research to improve membership functions in fuzzy controllers which had been used in UAVs have been conducted via genetic algorithm, that also this theory has been used to detect status of system, indicating such a theory as a suitable method to detect status of aerial robot. An adaptive neuro-fuzzy inference system to control position of an aerial robot at three-dimensional space has been designed in reference, and a new idea which has integrated advantages of neural network method with advantages of fuzzy logic to control an aerial robot has been proposed in.

To date, numerous studies have been conducted at the area of control of quadrotor unmanned aerial robots. According to reference, sliding-mode control approach has been used to regulate the force at quadrotor engines. This is in a way that a sliding surface entitled as the suitable return for force at four engines has been defined, aiming at sliding force to this sliding surface so far as the force at each of these engines removes from this return.

These controllers due to sustainability of system at nonlinear models have been mentioned as a suitable item for control. Yet, the phenomenon of chattering has been found as a defect in these controllers for which no solution has been represented to cope with it.

In an output feedback adaptive fuzzy model following controller is proposed for a nonlinear and uncertain airplane model. The unknown nonlinear functions are approximated by fuzzy systems based on universal approximation theorem, where both the premise and the consequent parts of the fuzzy rules are tuned with adaptive schemes. Thus, prior knowledge and the number of fuzzy rules for designing fuzzy systems are decreased effectively. Also, to cope with fuzzy approximation error and external disturbances an adaptive discontinuous structure is used to make the controller more robust, as long as due to adaptive mechanism attenuates chattering effectively. All the adaptive gains are derived via Lyapunov approach thus asymptotic stability of the closed-loop system is guaranteed.

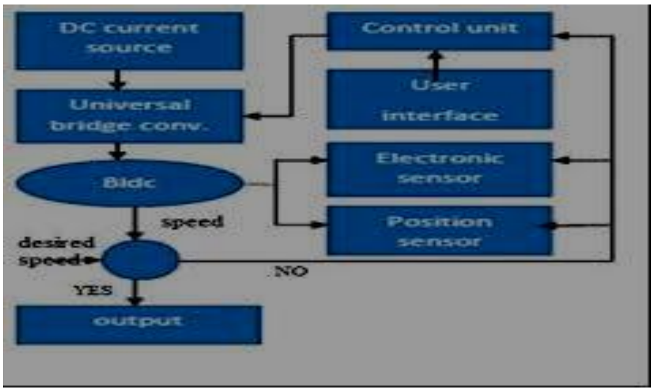
Type-2 fuzzy neural networks have a high ability to detect and control nonlinear systems and change systems over time as well as systems with uncertainties. In the method of designing type-2 fuzzy neural adaptive (inverse) controller has been studied in order to control on-line an example of a nonlinear dynamical system of flying robot. In this reference, the class structure of interval type-2 fuzzy neural networks of T-S model has been displayed first.

It has seven layers that fuzzy operation is carried out by the first two layers, which contains type-2 fuzzy nerves with uncertainty in the center of the Gaussian member functions. The third layer is the layer of rules and in the fourth layer, the operation of reducing degree is performed by matching nodes. Layers of fifth, sixth and seventh include the resulting layer, layers of calculating the center of gravity and layers of output, respectively. To teach network, decreasing gradient algorithm was used with adaptive training rate.

Finally, in the section of the simulation of adaptive inverse on-line control with interval type-2 fuzzy neural network of model T-S and adaptive neuro-fuzzy inference system (ANFIS) for nonlinear dynamic system, a robot sample drone with certain parameters and with uncertain parameters were compared. The results of simulation show the effectiveness of the proposed method in this reference.

In type-2 fuzzy neural network with fuzzy clustering method is used to identify structures and update the parameters of the condition and the gradient algorithm is used to update the parameters of the result. Also in this reference, it has been indicated that the method of fuzzy clustering is not appropriate for identifying and on-line controlling. In recent years, various methods for training type-2 fuzzy neural networks have been suggested, such as genetic algorithm and PSO.

With the expansion of research in the field of type-2 fuzzy systems, these systems have found wide applications, including the prediction of time series, linear motor control , sliding-mode control and control of robots .



2. LITERATURE SURVEY

The design of the speed controller greatly affects the performance of an electric drive. A common strategy to control an induction machine is to use direct torque control combined with a PI speed controller. These schemes require proper and continuous tuning and therefore adaptive controllers are proposed to replace conventional PI controllers to improve the drive's performance.

This paper presents a comparison between four different speed controller design strategies based on artificial intelligence techniques; two are based on tuning of conventional PI controllers, the third makes use of a fuzzy logic controller and the last is based on hybrid fuzzy sliding mode control theory. To provide a numerical comparison between different controllers, a performance index based on speed error is assigned.

All methods are applied to the direct torque control scheme and each control strategy has been tested for its robustness and disturbance rejection ability.

3. CONTROLLER DESIGN

Controller design for coupled multi-input/multi-output (MIMO) systems can be carried out easily for linear plants with well-known linear design techniques, e.g., pole placement. The resulting large matrices can be handled by modern high-end CPUs. However, from a practical point of view there are some severe drawbacks. A correspondence between system behavior and specific matrix elements often does not exist. Putting the plant into operation is a very difficult task. A change of system structure, caused for instance by a web tear, can result in completely unpredictable and indefinable system reactions.

4. Fuzzy Logic Controller Synthesis

Fuzzy logic controllers consider neither the parameters of the switching power converter or their fluctuations nor the operating conditions, but only the experimental knowledge of the switching power converter dynamics. In this way, such a controller can be used with a wide diversity of switching power converters implying only small modifications. The necessary fuzzy rules are simply obtained considering roughly the knowledge of the switching power converter dynamic behavior.

4.1 Fuzzification

Assume, as fuzzy controller input variables, an output voltage (or current) error and the variation of this error. For the output, assume a signal $u(k)$, the control input of the converter.

A. Quantization Levels

Consider the reference $r(k)$ of the converter output kth sample, $y(k)$. The tracking error $e(k)$ is $e(k) = r(k) - y(k)$, and the output error change $\Delta_e(k)$, between the samples k and $k - 1$, is determined by $\Delta_e(k) = e(k) - e(k - 1)$.

These variables and the fuzzy controller output $u(k)$, usually ranging from − 10 to 10 V, can be quantified in m levels $\{-\ (m - 1)/2,\ +(m - 1)/2\}$. For offline implementation, m sets a compromise between the finite length of a lookup table and the required precision.

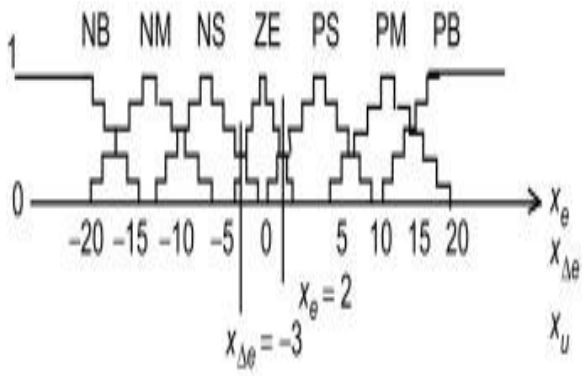
B. Linguistic Variables and Fuzzy Sets

The fuzzy sets for x_e, the linguistic variable corresponding to the error $e(k)$; for $x_{\Delta e}$, the linguistic variable corresponding to the error variation $\Delta_e(k)$; and for x_u, the linguistic variable of the fuzzy controller output $u(k)$ are usually defined as positive big (*PB*), positive medium (*PM*), positive small (*PS*), zero (*ZE*), negative small (*NS*), negative medium (*NM*), and negative big (*NB*), instead of having numerical values.

In most cases, the use of these seven fuzzy sets is the best compromise between accuracy and computational task.

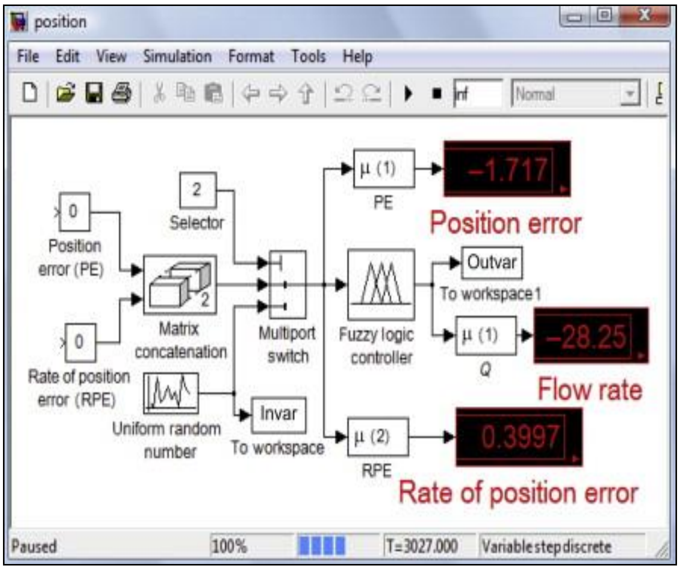
C. Membership Functions

A fuzzy subset, for example, $\mathbf{S}_i$ ($\mathbf{S}_i$ = (NB, NM, NS, ZE, PS, PM, or PB)) of a universe E, collection of $e(k)$ values denoted generically by $\{e\}$, is characterized by a membership function μ_{Si}: $E \rightarrow [0,1]$, associating with each element e of universe E, a number $\mu_{Si}(e)$ in the interval [0,1], which represents the grade of membership of e to E. Therefore, each variable is assigned a membership grade to each fuzzy set, based on a corresponding membership function (Fig. 35.75). Considering the m quantization levels, the membership function $\mu_{Si}(e)$ of the element e in the universe of discourse E, may take one of the discrete values included in $\mu_{Si}(e) \in \{0; 0.2; 0.4; 0.6; 0.8; 1; 0.8; 0.6; 0.4; 0.2; 0\}$. Membership functions are stored in the database.



A basic plant uncertainty representation is $G_p(s) = G_{po}(s) + \Delta_a(s)$, where $G_{po}(s)$ is the nominal plant model and where $\Delta_a(s)$ is the additive uncertainty. Other uncertainty representations include the output multiplicative uncertainty, $G_p(s) = (I + \Delta_o(s))G_{po}(s)$, and the input multiplicative one, $G_p(s) = G_{po}(s)(I + \Delta_i(s))$. For design purposes, it helps to normalize the uncertainty representations. For example, consider that the real plant is represented with an output multiplicative uncertainty, and let $\Delta o(s)=Wo(s)\tilde{\Delta}o(s)$, where $\tilde{\Delta}o(s)$ and $W_o(s)$ are proper and stable with $||\tilde{\Delta}o(s)||\infty\leq 1$ and where $W_o(s)$ is a frequency-dependent scaling matrix. In this case, the unity feedback system in Figure 3.1 will be robustly stable if and only if $||T_o\ W_o||_\infty \leq 1$. Fuzzy Logic Expert System Simulation

A fuzzy logic controller is designed to simulate the FLES once it has been verified with the rule viewer using MATLAB Simulink. The FLC block in Simulink has two inputs (PE and RPE) and one output (flow rate). Figure 18 shows the finalized FLC with all the sources and sinks connected to it. Since the load distribution affects the total PC significantly, position (h) of the vehicle is used as a controlled variable in the control system of an IACTV. Using MATLAB Simulink, the FLC shows the output result of flow rate (Q) as −28.25 based on two inputs of PE and RPE as −1.717 and 0.3997, respectively, which can be observed using three display results of the control systems. It is noticed that the inlet valve needs to be open 28.25% with the outlet valve in the closed position since the vehicle position is 1.717 cm lower than the desired position.



4. BRUSHLESS DC ELECTRIC MOTOR

Brushless DC electric motor (**BLDC motors**, **BL motors**) also known as **electronically commutated motors** (ECMs, EC motors), or **synchronous DC motors**, are synchronous motors powered by DC electricity via an inverter or switching power supply which produces an AC electric current to drive each phase of the motor via a closed loop controller. The controller provides pulses of current to the motor windings that control the speed and torque of the motor.

The construction of a brushless motor system is typically similar to a permanent magnet synchronous motor (PMSM), but can also be a switched reluctance motor, or an induction (asynchronous) motor.

4.1 ADVANTAGES OF THIS MOTORS ARE:

The better speed versus torque characteristics, high dynamic response, high efficiency and reliability, long operating life, noiseless operation, higher speed ranges, and reduction of electromagnetic interference (EMI) . His main characteristics is that it is an electrical motor which does not require an electrical connection between stationary and rotating parts, and is categorized based on PMs mounting and the back-EMF shape. Mathematical modelling gives more comprehension of the system before controlling it. More control strategies are developed but an intelligent controller can provide high accuracy when mathematical model is more complicated.

Here, a vector control is proposed, at the first time, to show the effectiveness of the Brushless AC command and control. This strategy is more popular in industrial applications. One type of such controllers is the Sliding Mode Controller which and gives more details about all the possibilities for all applications. But, here, simple Sliding Mode Controller is adopted. Nowadays, fuzzy logic controller strategy was developed and presents more control performance. In this control strategy, some constant parameters are needed to be defined and determined carefully

4.2 Disadvantages of commutator

- The friction of the brushes sliding along the rotating commutator segments causes power losses that can be significant in a low power motor.
- The soft brush material wears down due to friction, creating dust, and eventually the brushes must be replaced. This makes commutated motors unsuitable for low particulate or sealed applications like hard disk motors.
- The resistance of the sliding brush contact causes a voltage drop in the motor circuit called *brush drop* which consumes energy.
- The repeated abrupt switching of the current through the inductance of the windings causes sparks at the commutator contacts. These are a fire hazard in explosive atmospheres, and create electronic noise, which can cause electromagnetic interference in nearby microelectronic circuits.

During the last hundred years high power DC brushed motors, once the mainstay of industry, were replaced by alternating current (AC) synchronous motors. Today brushed motors are only used in low power applications or where only DC is available, but the above drawbacks limit their use even in these applications. Brushless motors were invented to solve these problems.

5. CONCLUSION

In this paper, an attempt is made to develop a methodology using a Sliding Mode Controller combined with a Fuzzy Logic Controller applied to control a Brushless ACMotor drive.Vector control, Sliding Mode Control, Fuzzy LogicControl and Fuzzy-sliding mode control are used to control a Brushless AC Motor.The method based on the hybrid controller is proposed and applied. The result shows the effectiveness and performance of this method. In this paper, it is highlighted that the SMCFLC is the best controller

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