MULTI-INPUT IFLC FOR MOTION CONTROL OF BLDC MOTORS

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ABSTRACT
Introduction of noise/disturbance causes instability in the control system. Hence, it is very essential to study the effect of noise and to develop immunity in the control system for such noise. For this purpose, a multi-input (two and three input) integrated fuzzy logic controller (IFLC = FLC+PID) for the speed control of BLDC motor is designed and developed. The effects of external white noise of 1, 3 and 5mV on multi-input IFLCs and FLCs for the speed control of BLDC motor were studied experimentally. The experimental result reveals that white noise of 1mV and above cause instability in the system performance. The overall results show that the three-input IFLC is robust and is insensitive to white noise to lesser extent as compared to conventional two-input IFLC and multi-input (two and three) FLC.

Keywords: IFLC, FLC, PID controller, Brushless DC motor.

1. INTRODUCTION
The BLDC motors are gradually replacing DC motors with brushes and AC motors because of their high efficiency and their increasing demand in industrial applications [1]. Many control schemes, such as P, PI, PID, adaptive, and FLCs have been developed for the speed control of BLDC motor [2]. For special applications, these methods fail to control the speed at constant level within short time. Hence, there is a need of IFLC, which is a combination of FLC and PID controller that gives better control of speed.

There have been very few reports on the implementation of FLCs for the speed control of BLDC motor alone or in conjunction with the conventional PID controllers. Bassily et al, designed a fuzzy proportional-integral controller (FPIC) for BLDC motor. A FPIC for the speed control of a BLDC motor was simulated study and not experimental work [3]. Ming-Yuan Shieh and Li T.H.S deigned and implemented IFLC for a DC servomotor system [4]. The IFLC system attempts to control and upgrade existing control systems by using fuzzy decision-making logic. The main advantage of using the IFLC is that one does not have to redesign a standard PID control system. In FLC, the actual values of control signals can be subjected to external disturbances in the form of signals (white noise,). Noise refers to any extraneous random electrical disturbance. When noise is introduced in the control system the instability occurs, such as heavy inrush current, damage to internal circuits of the motor, creating instability in the control system etc [5]. However, this problem has not so far been studied for the speed control applications of BLDC motor. Hence, we have undertaken the study for effect of white noise on BLDC motor speed control system using multi-input IFLC.

First we have designed and implemented three-input IFLC for the real-time speed control of BLDC servomotor (Model-1628T024B) using LabVIEW, signal conditioning extension for instrumentation (SCXI) cards, data acquisition (DAQ) board, Fuzzy logic and PID controller toolkits. This BLDC motor so far has not been subjected to control by the above-mentioned hardware, software and multi-input FLC and IFLC. The performance of multi-input FLC and IFLC is studied for desired speed. Our experimental results have shown remarkable improvement of three-input IFLC over conventional two-input IFLC and FLC (with two and three inputs) for the real-time speed control of BLDC servo motor. Then, we have studied the effect of white noise on the multi-input IFLC for the speed control of BLDC motor.

2. INTEGRATED FUZZY LOGIC CONTROLLER (IFLC)
The basic configuration of IFLC is shown in Figure 1. FLC is used in complementary role to enhance the exiting control system. IFLC is a cascade combination of FLC and PID controller. The PID controller output is final control, but it is initially controlled by FLC. A general FLC consists of four modules; a fuzzification module, a fuzzy rule-base, a fuzzy inference engine and defuzzification module. In the present application seven number fully over-lapped triangular membership functions for fuzzy sets input variables are chosen. The
input variables are error \( (e(k)) \), change in error \( (ce(k)) \), change in change in error \( (cce(k)) \) and change in control action \( (cu(k)) \). The designed Rule base editor has \( 7^2 = 49 \) and \( 7^3 = 343 \) rules for two-input and three-input FLC respectively. The rules are of the form:

For two input FLC,

\[
\text{IF } e(k) \text{ is PL and } ce(k) \text{ is NL THEN } cu(k) \text{ is ZE.}
\]

And for three-input FLC,

\[
\text{IF } e(k) \text{ is PL and } c(k) \text{ is NL and } cce(k) \text{ is ZE THEN } cu(k) \text{ is ZE.}
\]

Figure 1: Three-Input IFLC Block Diagram

Here abbreviations are: Positive Large (PL), Positive Medium (PM), Positive Small (PS), Zero (ZE), Negative Small (NS), Negative Medium (NM), and Negative Large (NL). The other IF-THEN rules are derived accordingly. There are many methods of defuzzification. In this Three-input IFLC. The BLDC motor (1628T 024B) used in the present application is a three-phase precision servomotor with three built in Hall sensors placed electrically 1200 apart. It has a unique patented skew application, we have used Center of Gravity (COG) method for defuzzification. Figure 2 shows the block diagram for studying the effect of noise for three-input IFLC and FLC [6].

Figure 2: Block Diagram for Effect of Noise on Multi-input IFLC

3. EXPERIMENTAL SET UP

Figure 3 shows the system configuration block diagram for the speed control of a BLDC motor drive. Figure 4 shows the VI block diagram for the effect white noise on Three-input IFLC. The BLDC motor (1628T 024B) used in the present application is a three-phase precision servomotor with three built in Hall sensors placed electrically 120° apart. It has a unique patented skew-wound technology. The signals from the three Hall sensors are combined together using X-OR gates to obtain a train of TTL compatible pulses. These TTL pulses are converted into analog voltage using F/V converter (IC LM 2907). The voltage from F/V converter is fed to personal computer using LabVIEW (6i), SCXI 1122 analog input card and the DAQ (PCI MIO 6024E) board. The process variable (speed of the motor) is measured and compared with the set point to obtain \( e(k) \). The variables \( e(k), ce(k) \) and \( cce(k) \) are fed to the controller \( \text{FLC/IFLC} \). Depending on the input, the controller gives out control signal. This control voltage is added with white noise and is fed to PWM controller IC (UC 3625) through DAQ board and SCXI 1124 analog output card. The PWM controller (UC 3625) generates the three-phase PWM signals. These signals are amplified using transistorized driver circuit; this in turn drives the BLDC motor. The whole cycle is repeated till the set point is achieved. This configuration forms the closed loop feedback control system for controlling speed of BLDC motor using IFLC and FLC.

Figure 3: Experimental Setup for Speed Control of BLDC motor

Figure 4: VI Block Diagram for Effect of White Noise on Three-Input IFLC

4. EXPERIMENTAL RESULTS

The experimental results for the speed control of BLDC motor are discussed here for desired speed and effects of noise (random/white). Figure 5 shows the experimental transient response for the speed control of BLDC motor using multi input IFLC for the desired speed of 2500rpm. The IFLC with three-inputs gives the settling time of 1.6 seconds as compared to 1.75 seconds in the case of two-input IFLC. Figure 6 shows the experimental transient response for effect of white noise
on multi-input IFLC for the speed control of BLDC motor at the desired speed of 2500rpm. The detailed experimental results for multi-input FLC, IFLC and their effects on white noise are presented in the Table 1.

<table>
<thead>
<tr>
<th>Transient response for *st, os/us, osl, sse</th>
<th>FLC 2input</th>
<th>FLC 3input</th>
<th>IFLC 2input</th>
<th>IFLC 3input</th>
</tr>
</thead>
<tbody>
<tr>
<td>For desired speed of 2500 rpm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>st=2sec, os/us=0, osl=0, sse=0</td>
<td>st=1.8sec, os/us=0, osl=0, sse=0</td>
<td>st=1.75sec, os/us=0, osl=0, sse=0</td>
<td>st=1.6sec, os/us=0, osl=0, sse=0</td>
<td></td>
</tr>
<tr>
<td>White noise 1mV</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>osl=-10 rpm, sse=-15 rpm</td>
<td>osl=-5 rpm, sse=-5 rpm</td>
<td>osl=-10 rpm, sse=-10 rpm</td>
<td>osl=-5 rpm, sse=-5 rpm</td>
<td></td>
</tr>
<tr>
<td>20rpm, 15rpm, rpm</td>
<td>20rpm, rpm, rpm</td>
<td>20rpm, rpm, rpm</td>
<td>20rpm, rpm, rpm</td>
<td></td>
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<tr>
<td>5mV</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>osl=-40 rpm, sse=-25 rpm</td>
<td>osl=-20 rpm, rpm, rpm</td>
<td>osl=-30 rpm, rpm, rpm</td>
<td>osl=-20 rpm, rpm, rpm</td>
<td></td>
</tr>
<tr>
<td>75rpm, 50rpm, rpm, rpm</td>
<td>75rpm, rpm, rpm, rpm</td>
<td>75rpm, rpm, rpm, rpm</td>
<td>75rpm, rpm, rpm, rpm</td>
<td></td>
</tr>
</tbody>
</table>

In the fuzzy systems, more than one rule may be fired at the same time, but with varying strengths leads to a crisp control action through the process of defuzzification. This provides faster settling time, quicker rise time with no overshoots/undershoots and zero steady state error as compared to auto-tuned PID[7-10].

The power spectral density of white noise is independent of the operating frequency. It is well known that, the bandwidth of white noise is infinite. The filter with infinite bandwidth is required to suppress the white noise. The signal conditioning circuit used in the present application is a band-limited low pass filter. Therefore the some frequencies of the white noise are not filtered completely. Hence, to suppress the white noise, the control system with infinite bandwidth filter is required.

5. CONCLUSIONS

The IFLC is designed and developed for the speed control of BLDC motor using virtual instrumentation technique (LabVIEW). The FLC is designed for two- inputs \( e(k) \) and \( ce(k) \) with single output \( cu(k) \). This controller where further combined with PID controller to form IFLC. The designed controllers were compared with each other. It is noteworthy that FLC and IFLC give lesser settling time than PID controller. The response of the system can be further improved by varying the values of \( e(k) \), \( ce(k) \) and \( cu(k) \). Thus the IFLC is observed to be superior, more robust, faster, flexible, insensitive to the parameter variations, easy to configure and implement as compared FLC and auto-tuned PID controllers. The present can be used for position control applications for antenna positioning in radar systems.

REFERENCES


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