Improved PID Controller for DC Motor Control

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Abstract. Presented is an improved version of the PID controller (PIDC) for DC motor control. The PIDC is a very cheap and easy controller to implement and is currently in use in many systems. There are instances whereby higher precision is required and an improved version of the PID can serve. The systems might not be necessary limited to marine systems. Hence, saving the need for more costly redesign. The PIDC proposed was compared with the PID. Results show that the PIDC has superior performance compared to the PID. Hence, it is an indication that the PID could still withstand future developments; that is maintaining its characteristics of simplicity and cheapness.

1. Introduction

Electric motors have a wide range of applications as results of remarkable improvements in technology. Some the areas include positioning in large telescopic antennas, tracking of radar systems, aircraft systems actuators, marine systems actuators and robotic systems [1-3]. Achieving desired objectives sometimes only require simple and cheap designs.

Rubaai and Kotaru [4] and Benard [5] explored the artificial neural networks for direct current (DC) motor control. In the works of Hameed and Mohamed [6], the fuzzy logic control technique was combined with the artificial neural network counterpart was applied. The fuzzy logic technique was investigated by Sadiq et al in their studies [7-9]. Rajesekhar et al. [10, 11], utilised the fractional-order proportional integral derivative (PID) along with the artificial bee colony algorithm in their works. In the studies conducted by Mishra et al., the proportional-integral (PI) control method was harnessed for motor control. The PID control methods have the advantage of simplicity, easy implantation and also a lot was known about it. Despite all these, some systems require better performance which cannot be attained with the ordinary PID control scheme. Hence, the need enhanced version of the PID [12]. The study was on exploring the reaching law for enhancing the PID controller performance which is referred to as the PIDC for the armature controlled direct current (DC) motors.
2. Methodology

2.1. Plant modelling

The system plant is an armature controlled DC motor. Equations (1) – (4) give the motor transfer function. The parameters: $K_T$, $J$, $L_a$, $R_a$, $B$ and $K_b$. The values of the aforementioned parameters are: 0.085 Nm, $5.0 \times 10^{-4}$ kgm$^2$/s$^2$, negligible, 5 ohms, $6.0 \times 10^{-3}$ Nm/sec and 0.1 V/rad/sec respectively.

\[
G(s) = \frac{\theta(s)}{E_a(s)} = \frac{K_T}{(As^3 + Bs^2 + Cs)}
\]

\[
A = JL_a; B = JR_a + BL_a
\]

\[
C = BR_a + K_bK_T
\]

2.2. The Improved PID Control (PIDC) System

Equation (8) is the reaching law and equation (9) is the sliding mode function. Replacing left-hand side of (8) with the control signal and $f$ with $s$ in the $sgn$ function and negating the right-hand side, and inserting (9) after the operation resulted in (10). Equation (10) now has the property of the proportional and derivative of the PID controller. Equation (11) resulted after adding the integral component in equation (10). The improved PID control law was as given by (11).

\[
s = -D * sgn(s) - Ks
\]

\[
s(t) = ce(t) + \dot{e}(t)
\]

\[
u = D * sgn(f) + Ke + \dot{e}
\]

\[
u = D * sgn(f) + Ge + H\dot{e} + MS\text{ed}t
\]
Table 1. Unit step response without disturbance.

| Parameters               | Controllers |
|-------------------------|-------------|
|                         | PID         | PIDC        |
| Overshoot (%)           | 8.0000      | 0.0000      |
| Rise time (s)           | 0.0700      | 0.1000      |
| Settling time (s)       | 0.2000      | 0.2000      |

Figure 1. Unit step response and error graphs without disturbance.

The results from the Table 1 and Figure 1a show that the system response with the PIDC was the best. It has no overshoot, with a rise time of 0.1s and 0.2s settling time. The system having the PID was characterized with an overshoot of 8% overshoot, a rise time of 0.07s, settling time of 0.2 and also a steady-state error of about 1.5% lapsing up to 2.5s response duration. It can be seen from Figure 1b the system with the PIDC has less error accumulation than with PID. The error is the difference between the reference and the response obtained. All the errors of the system with both control scheme diminish with time which implied high stability tendency of the system [13-15].

3.2. Unit step response with pulse disturbance (positive)
The response with positive pulse disturbance was as given by Figure 2a and Table 2. The disturbance (DIS) appeared between 2.5 to 3.5s of the system response. Figure 2b is the graphical presentation of the errors that occurred.

Table 2. Unit step response with pulse disturbance (positive).

| Parameters               | Controllers |
|-------------------------|-------------|
|                         | PID         | PIDC        |
| Overshoot (%)           | 8.0000      | 0.0000      |
| Rise time (s)           | 0.0700      | 0.1000      |
| Settling time (s)       | 0.2000      | 0.2000      |
| Compensation ability (%)| 93.0000     | 100.0000    |
Figure 2a give the system response and was tabulated in Table 2. The results are similar to without disturbance except that it can be seen that with the PIDC there was a total compensation of the disturbance whereas with the PID it was annulled up to 93%.

Figure 2b shows the errors of the DC motor system. The system designed with the PIDC has by far lesser amount of error compared to with the PID. The appearance of the pulse disturbance makes the system amount of error higher than without it as presented earlier, while it remains the same with the PIDC. This ability makes the PIDC system response better than with the PID. The errors all diminish with time, hence the chances of the systems being stable are high.

3.3. Unit step response with pulse disturbance (negative)
The system performance response with the negative pulse disturbance was as given by Figure 3a and Table 3. The disturbance (DIS) also lapses between 2.5 to 3.5s and Figure 3b are the errors plots of the system.

| Parameters               | Controllers |
|--------------------------|-------------|
|                          | PID         | PIDC        |
| Overshoot (%)            | 8.0000      | 0.0000      |
| Rise time (s)            | 0.0700      | 0.1000      |
| Settling time (s)        | 0.2000      | 0.2000      |
| Compensation ability (%) | 93.0000     | 100.0000    |
Figure 3. Unit step response and plot of errors with negative pulse disturbance.

Table 3 and Figure 3a showed the tabulated results obtained which are similar to, with the positive pulse disturbance. Except that the pulse direction is opposite. The error plots are as given by Figure 3b. They are also similar to the ones obtained with the positive pulse disturbance.

3.4. Unit step response with B reduced to 30%

The effect of reduction of the system dynamic friction (B) to 30% on the performance were as given by Figure 4a which were then tabulated in Table 4. Figure 4b give the errors aroused in the process.

Table 4. Unit step response with B reduced to 30%.

| Parameters       | Controllers |
|------------------|-------------|
|                  | PID         | PIDC        |
| Overshoot (%)    | 39.0000     | 0.0000      |
| Rise time (s)    | 0.0500      | 0.1000      |
| Settling time (s)| 0.3500      | 0.2000      |

Figure 4. Unit step response and errors portrait with B reduced to 30%.
The results in Table 4 and Figure 4a showed that the system with the PIDC has a better result. It maintained its parameters as the case without disturbance effect. The system implemented with the PID has its performance worsens. It resulted in 39% overshoot, settling time of 0.35s and also has a steady-state error of about 1% throughout.

In terms of the errors resulted, the system with the PIDC has the least which was same as without any disturbance. It worsens for the system with the PID as illustrated by Figure 4b. The dying-out nature of the error graphs indicates the possibility of the systems to be stable.

3.5. Unit step response with $B$ increased by 110%

The results achieved for the system with its dynamic friction ($B$) added by 100% as illustrated by Figure 5a. Table 5 shows the results in tabular form and Figure 5b portrays the resulted errors of the system.

### Table 5. Unit step response with $B$ increased to 110%.

| Parameters        | Controllers |
|-------------------|-------------|
|                  | PID         | PIDC        |
| Overshoot (%)     | 0.0000      | 0.0000      |
| Rise time (s)     | 0.0500      | 0.1000      |
| Settling time (s) | 0.2500      | 0.2000      |

![Figure 5](image_url). Unit step response and errors graph with $B$ increased by 110%.

Figure 5a and Table 5 are illustrations of the system performance. The system response, with the PIDC, was the same as without any disturbance effect and with $B$ reduced to 30%. Here as well it was better than with PID. Although there is a bit of improvement with PID compared to when the $B$ was 30% in terms of the other parameters, the 1.5% steady-state error still exist.

The PIDC maintain the lead in terms of the amount of error resulted as shown in Figure 5b. The error of the system with the PID reduced compared to the previous case. The resulted errors also diminished with time. Hence, indicating the likelihood of system stability.

3.6. Unit step response with $J$ reduced to 30%

Presented in Table 6 was the system performance obtained with the combined moment of inertia reduced by 50% which ties to perceive what happens when the loading effect suddenly decreases by close to 50% on the motor system. Figure 6a also shows the response while Figure 6b is the resulting system errors.
Table 6. Unit step response with $J$ Reduced to 30%

| Parameters               | $PID$     | $PIDC$    |
|--------------------------|-----------|-----------|
| Overshoot (%)            | 0.0000    | 0.0000    |
| Rise time (s)            | 0.0500    | 0.1000    |
| Settling time (s)        | 0.2000    | 0.2000    |

Figure 6. Unit step response and plot of errors with $J$ decreased to 30%.

The system performance as given by Figure 6a and Table 6. The overshoot, rise time and settling time for the PIDC remained as 0%, 0.1s and 0.2s respectively, which are 0%, 0.05s and 0.2s with the PID. The system with the PID still has the 1.5% steady-state error which in this case diminishes to about 1% around 2.5s and continues to the end.

Regarding the errors as shown in Figure 6b. It was same for the PIDC and it was lesser with the reduced $J$ and all subsided with time, hence, an indication of stability.

3.7. Unit step response with $J$ increased by 110%

The response with the moment of inertia raised by 110% is as given by Table 7 and Figure 7a. Figure 7b was the graphs of the errors.

Table 7. Unit step response with $J$ Increased by 110%

| Parameters               | $PID$     | $PIDC$    |
|--------------------------|-----------|-----------|
| Overshoot (%)            | 20.0000   | 0.0000    |
| Rise time (s)            | 0.1000    | 0.1000    |
| Settling time (s)        | 0.3000    | 0.2000    |
Figure 7. Unit step response and errors plot with $J$ increased by 110%.

Figure 7a shows the system response and its summary in Table 7. The system with the PIDC was better. Performance of the system with the PID worsened in terms of overshoot and settling time compared with reduced $J$ to 30%.

The error plots were as given in Figure 7b. The PIDC has the least amount of error. The errors here also all die-down with time portraying high probability of the system stability.

3.8. Summary of results
The system was subjected to different test and results revealed the high robustness of the PIDC. Despite the varying conditions the system implemented using the PIDC maintained the same results throughout which was the same as without any changes. Some level of robustness was shown by the system with PID which changes as the level of disturbance changes. An insight into the system stability was the dying-away of the error signals under all conditions. Hence, the proposed control scheme has portrayed the ability to remarkably improve the motor control system.

4. Conclusion
The improved PID controller PIDC was successfully applied for control of an armature controlled DC motor. It was evaluated most likely associated disturbances referred to as the positive pulse effect and the negative pulse effects; these were to simulate what happens when the armature voltage suddenly increases and in the latter case sudden decrease. Others are the dynamic friction reduction to 30% and increase to 110%; to simulate changes in the dynamic friction which is, in reality, is not fixed it changes. Next was the reduced system moment of inertia to 30% and then increased by 110%; which was an effort to simulate what happens to the system due to changes loading. Even though different conditions are imposed on the system, the system implemented with the PIDC maintained the same results throughout which was the same as without any disturbance injected. Thus, a high level of robustness of the PIDC was portrayed. A certain level of robustness was shown by the system with PID which changes depending on the introduced perturbation. Information on the system stability was revealed as the error die away with time under all examined conditions meaning that the system has a high chance of being stable under the conditions. Therefore, the presented control method has indicated the ability to remarkably improve the armature controlled motor control system. It may not be limited to such a system as further works could reveal other possibilities. Hence, it indicated that the PID could still withstand future developments while maintaining its characteristics of being simple and cheap. The work is novel in the sense that to best of the authors there no such proposed.
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