SENSORLESS POSITION CONTROL OF DC MOTOR USING MODEL PREDICTIVE CONTROLLER

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Graphical abstract

Abstract

Sensors like rotary encoders are widely used in measuring the speed and position of DC motor in applications. Due to expensiveness, calibration complexities of these type of encoders, sensorless methods for measurements were used alternatively. This paper presents sensorless position control of a wheeled DC motor using system identified model. This approach overcome some conventional sensorless techniques that uses some approximations. The model is developed using black box identification scheme, based on the identified model, a model predictive controller was designed to track a desired horizontal position of the wheel. Practical experiment shows the concept gives a very good estimation of the position and speed and can be used in control application.

Keywords: Model predictive controller, system identification, sensorless

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1.0 INTRODUCTION

Direct current (DC) motors are widely used in almost every machine industries and vehicles [1], this leads to a numerous work done by researchers to model the DC motors [1-8], and also control of position and speed of the motor [3, 5, 6]. To mention a few, in [1], the DC motor is modelled using electromagnetic interferences signals of contact mechanisms between the brushes and the collector blades. Electro mechanic effects, like cogging and friction, and electromagnetic properties generated by eddy current and magnetic hysteresis where used in the modelling of the DC motor, as shown in [7]. Artificial Neural Network in modelling DC motor is presented in [2, 3]. In [4], Repulsive Particle Swarm Optimization (RPSO) is used in the modelling of the DC motor using Non-linear Auto-Regressive with exogenous input (NARMAX) approach.

In position control of DC motors, many approaches has been exploited by researchers, some use position sensor for the feedback control [3, 5, 9-15]. But these sensors have some disadvantages, they are expensive, very difficult to calibrate, they are prone to measurement noise and so on. To overcome these problems, some researcher use sensorless method of measuring and therefore control of DC motors [16-25]. Rotor position is estimated for feedback control using extended Kalman filter in [16, 22]. Back-EMF sensing methods, like Third Harmonic Voltage Integration (THVI), Terminal Current Sensing (TCS), Back-EMF Integration and PWM strategies, Terminal Voltage Sensing (TVS), sliding-mode observer, model reference adaptive System, adaptive observers, are fully explained in [19, 20, 23-25]. These sensorless techniques have the problems of zero crossings, failure of estimation at particular speeds due nonlinearity of current and speed of motors [19].
Different controllers have been designed in the past, to control position of DC motors. Model predictive controllers (MPCs) are one of the controllers used for controlling all class of motors [26-29]. Due to recent advances that increased the computational power of micro-controllers and DSP chips made MPC applicable in many advance systems [30].

In this work, sensorless control of wheeled DC motor will be presented. The main contribution is in using the identified model of the wheeled DC motor to estimate the horizontal position in meters and speed of the wheel in meters per second directly. This solves the problem of other sensorless that uses the measurements of flux or currents in the motor. It also remedies calibration issues. Black box system identification approach of modelling will be used to develop the wheeled DC motor model to directly estimate the position and velocity in desired unit. Also, using the identified model, MPC will be design to track a specified position. The rest of the paper is organized as follows, in section II, the model of the wheel driven DC motor is derived using system identification, the MPC design is explained in section III, the results of the experimental implementation and validation of the controllers are given in section IV, finally section V gives the conclusion of the work.

2.0 IDENTIFICATION OF DC MOTOR

Experimental setup and identification of the motor is given in this section.

2.1 Experimental Setup

The wheeled DC motor used in this experiment is shown in Figure 1. The DC motor used is MY1016Z2-250W, 24v operating voltage. It has no load speed of 434rpm and no load current of 1.8A. Its output is connected to a pneumatic wheel of radius 130mm via a gear as shown in the diagram. B106 rotary encoder [31] is used in the experiment, it has operating voltage 5v to 24v, pulse of 500P/R and maximum shaft speed of 6000rpm. It is designed to provide pulse feedback when the shaft is rotated. The shaft of the rotary encoder is connected to the DC motor and the pulses are recorded using STM32F4 discovery board which sends the pulses to MATLAB Simulink via computer where the horizontal position and speed of the wheel are computed and recorded.

2.2 Identification of the DC motor

There are three different modelling approaches namely, white-box model which is based on mathematical modelling, black-box model, and grey-box model which are based on system identification [32].

a) White-box model: This type of model is based on first principles, for instance, a model for a physical process derived from the Newton equations or Euler Lagrange methods. All equations and parameters are obtained by theoretical modelling. Their parameters have direct interpretation in first principles.

b) Black box model: This is based on measurement of input and output data. The model structure and parameters are obtained from experimental modelling. To develop black box models, no or very little prior knowledge of plant is needed. The model parameters have no direct relationship to first principles.

c) Grey-box model: This model is based on both insight into the system and experimental data obtained. It is a compromise or combination between white and black box models. The model and structure of this type of model are known, only the values of the parameters are estimated [33, 34].

In this work, black box identification approach will be used in the modelling of the wheeled DC motor so that the output of the model will be the desired position in meters, and velocity in meters per second. The advantage of this approach is all the unmodelled uncertainties like gear ratios, gear frictions, and approximations of parameters, like motor inductance, that will be encountered when using white box approach, are overcome in this approach. The following steps are carried out in the identification.

a) Selection model inputs and outputs: The input is the applied voltage to the DC motors using PWM signal. The outputs are the wheel horizontal position and speed in meters and meters per second respectively.

b) Selection of excitation signals: Random PWM signal shown in Figure 2 is used.
c) Model estimation algorithm: Weighted least square method is employ using MATLAB sest command for the estimation. Before the estimation, a filter is used to smoothing the noisy speed measurement from the encoder.

d) Model validation: After identification, the model is validated as shown in Figure 3 and 4 for the position and speed respectively. The effect of the filter incorporated in the identification is seen clearly in Figure 4. The identified model in state space is given in Eq. 1.

\[
\begin{bmatrix}
\dot{z}(t) \\
y(t)
\end{bmatrix} =
\begin{bmatrix}
A_m & 0^T_m \\
C_m & I_{q_xq}
\end{bmatrix}
\begin{bmatrix}
z(t) \\
y(t)
\end{bmatrix} +
\begin{bmatrix}
B_m \\
0_{q_xm}
\end{bmatrix}
\dot{u}(t)
\]

\[
y(t) = [0_m \quad I_{q_xq}]
\begin{bmatrix}
z(t) \\
y(t)
\end{bmatrix}
\]

(3)

The identified model is validated as shown in Fig. 3 and 4. The identified model in state space is given in Eq. 1.

\[
\begin{bmatrix}
\dot{z}(t) \\
y(t)
\end{bmatrix} =
\begin{bmatrix}
A_m & 0^T_m \\
C_m & I_{q_xq}
\end{bmatrix}
\begin{bmatrix}
z(t) \\
y(t)
\end{bmatrix} +
\begin{bmatrix}
B_m \\
0_{q_xm}
\end{bmatrix}
\dot{u}(t)
\]

\[
y(t) = [0_m \quad I_{q_xq}]
\begin{bmatrix}
z(t) \\
y(t)
\end{bmatrix}
\]

(3)

\[
J = \sum_{m=1}^{N_p} x(k_i + m|k_i|^T Q x(k_i + m|k_i|^T + \Delta U^T R \Delta U
\]

Where Q and R are positive definite weighing matrices, and ΔU is future control trajectory with length Nc. Np is the prediction horizon. Figure 5 shows the control block diagram. An embedded integrator is added to the design as shown in Eq. 3. The design parameters are given in Table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>symbol</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prediction horizon</td>
<td>Np</td>
<td>30</td>
</tr>
<tr>
<td>Control horizon</td>
<td>Nc</td>
<td>4</td>
</tr>
<tr>
<td>Sampling time</td>
<td>t</td>
<td>0.02</td>
</tr>
<tr>
<td>State weighting matrix</td>
<td>Q</td>
<td>1/\omega_e</td>
</tr>
<tr>
<td>Output weighting matrix</td>
<td>R</td>
<td>0.1</td>
</tr>
</tbody>
</table>

\[
A =
\begin{bmatrix}
-1.333 & 7.031 & -0.42 & -3.491 \\
-2.939 & -1.179 & 14.85 & 0.9376 \\
-3.443 & -20.04 & -28.43 & 0.1822 \\
-2.551 & -5.397 & -70.18 & -11.46
\end{bmatrix}
\]

\[
B =
\begin{bmatrix}
-0.3208 \\
0.3304 \\
-0.2069 \\
-1.852
\end{bmatrix}
\]

\[
C =
\begin{bmatrix}
104 & -74.58 & 50.87 & -36.96 \\
0.3189 & 1.599 & -0.8143 & 0.5318
\end{bmatrix}
\]

(1)
4.0 RESULTS AND DISCUSSION

The experimental result of the position tracking controller is shown in this section. Figure 6 and 7 shows the position tracking of 2m step signal and 2m sine wave signal respectively, while Figure 8 shows the speed during the sine wave signal position tracking.

The black box identified model gives acceptable estimation of the position and speed of the wheeled DC motor.

5.0 CONCLUSION

Black box identification of wheeled DC motor for sensorless measurements and MPC position controller design using the model is presented in this paper. The controller was designed based on the identified model, and the model was used as an estimator of the wheel position for tracking purpose. The model accurately gives an acceptable estimation of both the position and speed. This sensor-less concept can be used in many applications and replace expensive sensors.

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