KALMAN FILTER FOR SPEED CONTROL OF DC MOTOR FOR ROBOTIC SAFETY CRITICAL APPLICATIONS

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Abstract: ***Estimation of the parameters of the speed control robotic system in wheel chair automation used by physically challenged citizens is very important. Any implementation of this system requires simulation analysis, performance prediction and the control application when fault occurs in wheel chair automation. In this paper a Kalman filter is used for recursively estimating the states and model parameters. The system input and the rotational speed of DC motor, the output are used for the above purposes.***

A model of the feedback system using DC motor consisting of rotational speed and armature current as states is used in the state-space form. Kalman filter algorithm is implemented in mat lab environment to estimate the states in presence of additive white Gaussian noise. The noise is typical of DC motor brush noise. Once, the recursive estimation reaches error Free State condition, the parameters of the system is obtained by regression. Linear regression method is used to obtain the model parameters by know giving the best estimate of the states and model parameters even in the presence of noise. This becomes useful when fault occurs in the feedback system. In such a situation, the motorized wheel chair will be forced to halt instead of uncontrolled movement which may be dangerous to the user.

Key words: Kalman filter, Fault Detection, DC motor, Linear Regression, Parameter Estimation.

I. INTRODUCTION

People with certain disabilities help themselves moving out to places with artificial means, taking advantage of the technological evolution by increasing the quality of their life. Quadriplegics are those who are not able to reach out to any of the extents. The reasons for such decreased motion possibilities can be different: stroke, arthritis, high blood pressure, degenerative diseases of bones and joints and cases of paralysis and birth defects. For Paraplegics to move independently to places there are two medical devices, the exoscelets and the wheelchair. Both of them use electronic systems for the person's movement. Sensors, actuators, communication modules, signal processing units are used for recognizing and monitoring the person's movements, what the person does or wanted to do.

A DC motor is any of a class of electrical machines that converts direct current electrical power into mechanical power and it is used in the wheelchair for speed control system. A DC motor's speed can be controlled over a wide range, using either a variable supply voltage or by changing the strength of current in its field windings. Small DC motors are used in tools, toys and appliances. Larger DC motors are used in propulsion of electric vehicles,elevator and hoists.DC motors are widely used in speed control applications because of its low cost and high reliability.

II. SYSTEM MODELING

Wheelchair operation is based on navigation, which, in this case, is defined as safe transport from the starting point to a given destination. The wheelchair, comparing to the exoscelet, is a more general medical device and a much simpler one[3]. Thus, the wheelchairs are used more often. Nevertheless, only patients with healthy upper extremities (paraplegics) can successfully operate standard electric wheelchairs.

Otto bock B400

Figure 1. Otto bock B400[3]

B400 one of the most compact, versatile and user friendly powered wheelchairs making it great for everyday use. The B400 has a compact width measurement of approx 58cm. This is one of the main reasons this wheelchair has become so popular. It has great maneuverability through narrow areas and is ideal for everyday use. Otto Bock thought long and hard when designing this particular power chair making very user friendly in everyday life situations.

A common actuator used in this wheelchair for speed control systems is the DC motor. It directly provides rotary motion and, coupled with wheels or drums and cables, can provide translational motion. The electric equivalent circuit of the armature and the free-body diagram of the rotor are shown in the figure[4].

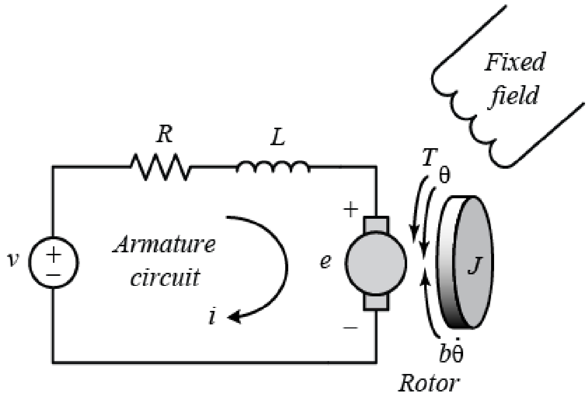

Figure 2.The electric equivalent circuit of the armature and the free-body diagram of the rotor[4]

Where

R=Electric resistance
L=Electric inductance
J=Moment of inertia of the rotor
b=Motor viscous friction constant
θ=Rotational speed of the shaft
T=Motor Torque

In general, the torque generated by a DC motor is proportional to the armature current and the strength of the magnetic field. In SI units, the motor torque and back emf constants are equal, that is $K_t=K_e$,therefore we will use K to represent both the motor torque constant and the back emf constant. From the figure, we can derive the following governing equations based on Newton's 2nd law and Kirchhoff's voltage law.

$$J\ddot{\theta} + b\dot{\theta} = Ki \quad (1)$$

$$L\frac{di}{dt} + Ri = V - K\dot{\theta} \quad (2)$$

Applying the Laplace transform, the above modeling equations can be expressed in terms of the Laplace variable s.

$$s(Js + b)\theta(s) = K\,I(s) \quad (3)$$

$$(Ls + R)\,I(s) = V(s) - K\,s\,\theta(s) \quad (4)$$

We arrive at the following open-loop transfer function by eliminating I(s) from the above two equations.

$$P(s) = \frac{\dot{\theta}(s)}{V(s)} = \frac{K}{(Js+b)+(Ls+R)+K^2} \quad (5)$$

The structure of the control system has the form shown in the Fig. 3 given below.

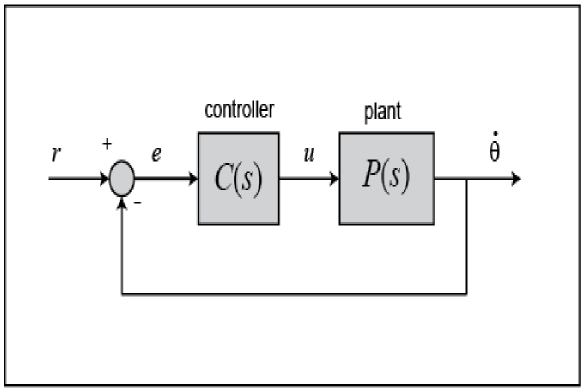

Fig.3 Structure of the control system

The dynamic equations in state-space form are given below.

$$\frac{d}{dt}\begin{bmatrix}\dot{\theta}\\ i\end{bmatrix} = \begin{bmatrix}-\frac{b}{J} & -\frac{K}{J}\\ -\frac{K}{L} & -\frac{R}{L}\end{bmatrix}\begin{bmatrix}\dot{\theta}\\ i\end{bmatrix} + \begin{bmatrix}0\\ \frac{1}{L}\end{bmatrix} V \quad (6)$$

$$y = \begin{bmatrix}1 & 0\end{bmatrix}\begin{bmatrix}\dot{\theta}\\ i\end{bmatrix} \quad (7)$$

These state-space equations have the standard form shown below where the state vector x= $\begin{bmatrix}\dot{\theta}\\ i\end{bmatrix}$ and the input u = V.

$$\dot{x} = Ax + Bu \quad (8)$$

$$y = Cx \quad (9)$$

In order to utilize the discrete Kalman filter,it is necessary to convert the continuous state-space model of equation(6) to discrete state-space model.

III. KALMAN FILTER

System Model

The discrete Kalman filter is applied to the discrete state space model of the speed control system using DC motor. .Because the number of the parameters to be identified is two, a second order system is defined as

$$x_k = Ax_{k-1} + Bu_k + w_{k-1} \qquad (10)$$

Where, x_k is the state vector at k=1,2,3,…n. w_k is the system noise and u_k is the input signal.The output equation can be defined as

$$y_k = Cx_k + v_k \qquad (11)$$

The highest eigen value of A matrix Ω = 2.0025 rad/sec.

Hence, for conversion of continuous to discrete state space form , a sampling interval of $2\pi/(5\Omega)$ = 0.6275 sec is used. The discrete s-s- form is as follows:

$$\dot{x} = Ax + Bu + w_k \qquad (12)$$

$$y = Cx + v_k \qquad (13)$$

where $A = \begin{bmatrix} 0.0018 & 0.0354 \\ -0.0007 & 0.2847 \end{bmatrix}$ and $B = \begin{bmatrix} 0.0644 \\ 0.7146 \end{bmatrix}$

Where the measurement noise v_k is a zero mean white Gausian noise.

Filtering Algorithm

The principle of the Kalman filter is as follows: At time stage k, the predictions of the state vector and the parameter matrices are calculated from the input u=V. We have two distinct set of equations : Time Update *(prediction)* and Measurement Update *(correction)*. Both the equation sets are applied at each k^{th} state. The Kalman filter algorithm is summarized as follows[5].

Time update:

1.$\hat{x}_k^{-} = A\hat{x}_{k-1} + Bu_k$

2.$\overline{P}_k = AP_{k-1}A^T + Q$

Measurement update:

1.$K_k = \overline{P}_k C^T (C\overline{P}_k C^T + R)^{-1}$

2.$\hat{x}_k = \hat{x}_k^{-} + K_k(z_k - C\hat{x}_k^{-})$

3.$P_k = (I - K_k C)\overline{P}_k$

$\hat{x}$:Estimation of the state vector

$\hat{x}^{-}$:Prediction of the state vector

z :Measurement values vector

K :Kalman gain

$\overline{P}$:Prediction of the error covariance

P :Error covariance update

I :Unit matrix

Q :Covariance matrix of system noise

R : Covariance matrix of measurement noise

IV. RESULTS

Conditions for the Experiment

In the experiment,a DC motor with a moment of inertia of the rotor is 0.01 kg.m^2, motor viscous friction constant is 0.1 N.m.s, electromotive force constant is 0.01 V/rad/sec, motor torque constant is 0.01 N.m/Amp,electric resistance is 1 Ohm, electric inductance is 0.5 H was used in simulation.The sampling period was 0.6275 sec. Then this data is applied to Kalman filter algorithm.

The Covariance Matrices of Noise

The main source of motor noise is the commutator/rotor brushes, which can bounce as the motor shaft rotates[6]. This bouncing, when coupled with the inductance of the motor coils and motor leads, leads to electrical noise on the power line and can even induce noise in nearby electronic circuits. By varying the voltage the speed of the motor can be controlled.The covariance matrices of system noise Q and measurement noise R are set from the noises produced in the DC motor. It is assumed that the system noise and the measurement noise are white Gaussian. The variances of these noises are calculated. Then assuming that there is no correlation, the covariance matrices of the system noise Q and of the measurement noise R are set to

$$Q = \begin{bmatrix} 0.009 & 0 \\ 0 & 0.08 \end{bmatrix} \qquad (14)$$

$$R = [0.1] \qquad (15)$$

Starting values

The starting values of the estimation of the state vector and parameters are set to some desired values. For the covariance matrix of the estimation error,

$$P_0 = \begin{bmatrix} 0.1389 & 0 \\ 0 & 0.0389 \end{bmatrix} \qquad (16)$$

can be used.

Discussion of Results

Figure 4 shows the behavior of estimated values of $\hat{x}$ ($\begin{bmatrix}\dot{\theta}\\ i\end{bmatrix}$), calculated with the Kalman filter algorithm in presence of additive white gausian noise. The error between the state and the final values is very small (0.005). The Linear regression method is used to obtain the model parameters by knowing the input and output values[7].

For a step input (u_k=1), equation (10) is written as

$$x_k = Ax_{k-1} + Bu_k + w_{k-1} \qquad (17)$$

$$x_{k+1} = Ax_k + Bu_{k+1} + w_k \qquad (18)$$

By taking the difference between the above equations (17) and (18),and noting that u_k=u_{k+1},

$$x_{k+1} - x_k = A(x_k - x_{k-1}) + (w_k - w_{k-1}) \qquad (19)$$

It is seen from Figure.4(a) that after t>6.275 sec, steady state is reached and the effect of additive noise is minimal. Hence, in equation (19), the matrix elements of A can be estimated by regression.

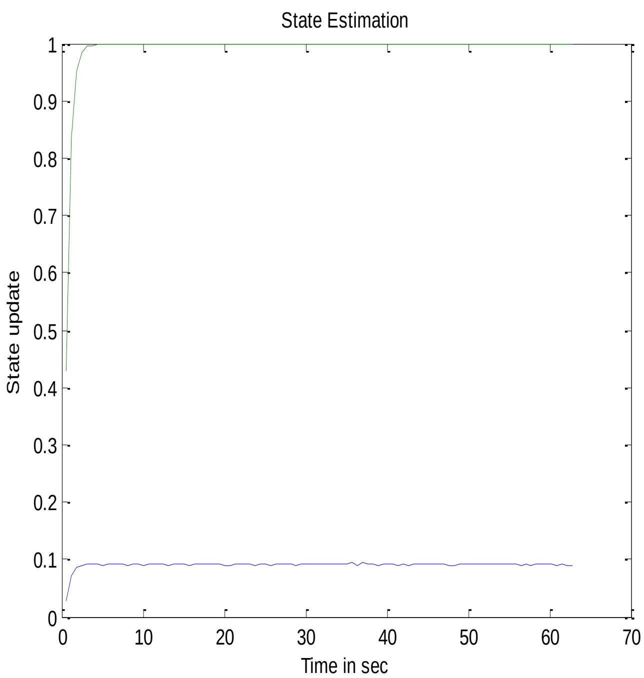

Figure 4.Result of State estimation

V. CONCLUSION

This experiment shows that a Kalman filter can be used to estimate the state vector and the parameters of the speed control robotic system in presence of the covariance matrix in wheel chair automation used by physically challenged citizens.The States and the Parameters are estimated using the measurements of armature current and the rotational speed of the rotor shaft The results show that the Kalman filter is capable of giving the best estimate of the states and model parameters even in the presence of noise. This becomes useful when a fault occurs in the feedback system. In such a situation, the motorized wheel chair will be forced to halt instead of uncontrolled movement which may be dangerous to the user.

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