Modeling Motion Control System for Motorized Robot Arm using MATLAB

Chun Htoo Aung, Khin Thandar Lwin, and Yin Mon Myint

***Abstract*—**In this paper a motion control system of a robot arm is described. Robots arms are built their motion machine, Motors. DC motor is chosen for the robot arm and the author also presents how to choose this motor. The robot arm is with single degree of freedom and motion control system for it is selected using MATLAB Simulink software. This paper is mainly focus to apply MATLAB software to Control system design. The system is simple but it is deigned the motor to move the robot arm to proper angular position according to the input.

***Keywords*—**Control system, DC motor, MATLAB Simulink software, robot arm.

I. Introduction

MOTION control is one of the technological foundations of industrial automation. Whether the motion of a product, the path of a cutting tool, the motion of an industrial robot arm conducting seam welding, the motion of a parcel being moved from a storage bin to a loading dock by a shipping cart, or another application, the control of motion is a fundamental concern. Putting an object in the correct place with the right amount of force and torque at the right time is essential for efficient manufacturing operation.

To be able to control a motion process, the precise position of objects needs to be measurable. Feedback comparison of the target and actual positions is then a natural step in implementing a motion control system. This comparison generates an error signal that may be used to correct the system, thus yielding repeatable and accurate results.

However, the use of feedback can lead to an unstable system whose output may oscillate or even go to infinity with a small input signal. Stability determination is therefore an important design consideration. One specification for absolute stability requires that the poles of the transfer function must be in the left half of the s-plane. Absolute stability, often specified in the frequency domain, is essential and necessary but not sufficient. Frequency domain specifications relating to relative system stability may also be given. For relative stability, a certain phase margin and gain margin may be specified to ensure that the system will remain stable although some parameters change due to temperature changes, aging or other environmental changes. If a system is stable, then other performance criteria, specified in either the time or frequency domain, may be considered to meet the performance requirements. Short-term, or transient, response specifications such as rise-time or percent overshoot to a unit step function input may be given. Fortunately, the advance control calculation can be solved with the help of using Matlab software.

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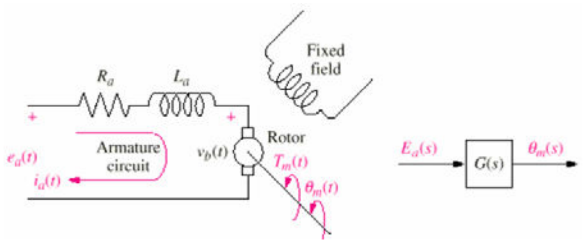
II. Choosing a DC Motor

A DC motor with armature control and a fixed field is assumed. The electrical model of such a DC motor is shown in Fig. 1. The armature voltage, ea(t) is the voltage supplied by an amplifier to control the motor. The motor has a resistance Ra , inductance La and back electromotive force constant, Kb. The back emf voltage, vb(t) is induced by the rotation of the armature windings in the fixed magnetic field. The counter emf is proportional to the speed of the motor with the field strength fixed. That is,

$$v_b(t)=K_b\frac{d\theta}{dt} \quad (1)$$



(a) (b)

Fig. 1 Fixed field DC motor (a) circuit diagram (b) block diagram

Taking the Laplace transform gives:

$$V_b(s)=sK_b\theta(s) \quad (2)$$

The circuit equation for the electrical portion of the motor is:

$$E_a(s)=R_a\, I_a(s)+ L_a s\, I_a(s)+V_b(s) \quad (3)$$

This may also be written as:

$$I_a(s) = \frac{E_a(s) - K_b s\,\theta(s)}{L_a s + R_a} \quad (4)$$

The torque developed by the motor is proportional to the armature current.

$$T_m(s) = K_t I_a(s) \quad (5)$$

This torque moves the armature and load. Balancing the torques at the motor shaft gives the torque relation to the angle that may be expressed as follows:

$$T(t) = J\frac{d^2\theta_m}{dt^2} + D\frac{d\theta_m}{dt} \quad (6)$$

where;

θ_m = the motor shaft angle position,
J = all inertia connected to the motor shaft,
D = all friction (air friction, bearing friction, etc.) connected to the motor shaft

Taking the Laplace transform gives:

$$T_m(s) = Js^2\,\theta_m(s) + Ds\,\theta_m(s) \quad (7)$$

Then the shaft angle is:

$$\theta_m(s) = \frac{T_m(s)}{Js^2 + Ds} \quad (8)$$

If there is a gear train between the motor and load, then the angle moved by the load is different from the angle moved by the motor. The angles are related by the gear ratio relationship, which may be derived by noting that an equal arc length, S, is travelled by two meshing gears. This can also be described by the following equation:

$$S = R_m\theta_m = R_L\theta_L \quad (9)$$

The gear circumference of the motor's gear is 2%Rm that has Nm teeth and the gear circumference of the load's gear is 2%R L that has NL teeth so the ratio of circumferences is equal to the ratio of radii and the ratio of number of teeth so that

$$N_L\,\theta_L = N_m\,\theta_m \quad (10)$$

Or

$$\frac{\theta_L}{\theta_m} = \frac{N_m}{N_L} = n \quad (11)$$

The gear ratio may also be used to reflect quantities on the load side of a gear train back to the motor side so that a torque balance can be done at the motor side. Assuming a lossless gear train, it can be shown by equating mechanical, T_1, and electrical, EI,power that the quantities such as inertia, J, viscous damping D, and torsional springs with constants K may be reflected back to the motor side of a gear by dividing by the gear ratio squared. This can also be described with the equations:

$$J_{mL} = \frac{J_L}{n^2} \quad (12)$$

$$D_{mL} = \frac{D_L}{n^2} \quad (13)$$

$$K_{mL} = \frac{K_L}{n^2} \quad (14)$$

From above equations the block diagram of the armature controlled DC motor can be shown as follow:

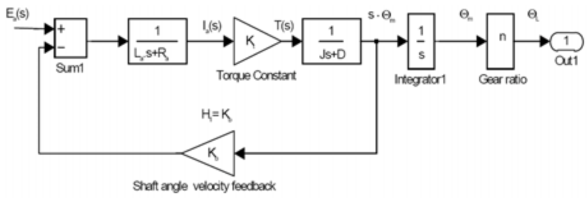


Fig. 2 Armature-Controlled DC Motor Block Diagram

By simplifying the block diagram in Fig. 2, the Armature-Controlled motor transfer function is:

$$G(s) = \frac{\theta_L(s)}{E(s)} = \frac{K_t n}{s[(Js+D)(L_a s+R_a)+K_b K_t]} \quad (15)$$

III. Modeling a Robot Arm

DC motor is used to drive a robot arm horizontally as shown in Fig. 3. The link has a mass, M=5Kg, length L=1 m, and viscous damping factor D = 0.1. Assume the system input is a voltage signal with a range of 0-10 volts. This signal is used to provide the control voltage and current to the motor. The motor parameters are given below. The goal is to design a compensation strategy so that a voltage of 0 to 10 volts corresponds linearly of an angle of 0° to an angle of 90°. The required response should have an overshoot below 10%, a settling time below 0.2 second and a steady state error of zero. The motor parameters are given below.

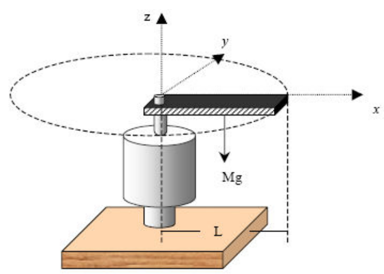


Fig. 3 A single joint robot arm driven by an armature-controlled DC motor

Ja = 0.001 kg-m2/ s2
Da = 0.01 N-m s/rad
Ra = 1 Ohm
La = 0 H
Kb = 1 V-s/rad
Kt = 1 N-m/A

Firstly, consider a system without gears or a gear ratio of 1. The inertia of the rigid link as defined before is:

$$J_L = \frac{ML^2}{12} = \frac{5\times1^2}{12} = 0.4167\ kg.m^2$$

According to the impedance reflection model established before, the total inertia J and total damping factor D are:

$J = Ja + JL = 0.001+0.4167 = 0.4177\ kg.m^2$
$D= Da + DL= 0.01+0.1=0.11$

Substituting the known values into equation (15):

$$G(s) = \frac{\theta_L(s)}{E(s)} = \frac{1}{s[(0.4177s+0.11)(1+0\times s)+1\times1]}$$

$$G(s) = \frac{1}{s(0.4177s+1.11)}$$

The above process could be calculated with MATLAB scripts as follows:

```
J=0.001+0.4167;
D=0.1+0.01;
La=0;
Ra=1;
Kt=1;
Kb=1;
n=1;
Num=Kt*n;
Den=[J*La J*Ra+La*D D*Ra+Kt*Kb 0];
step(Num, Den);
title('Step Response of the Motorized
Robot Arm');
```

The step response of this system is shown in Fig. 4 As we can see the system does not go to a steady state value, but to an increasing angle at constant value. This means the armature rotates at a constant speed, which is achieved by its built-in velocity feedback factor Kb.

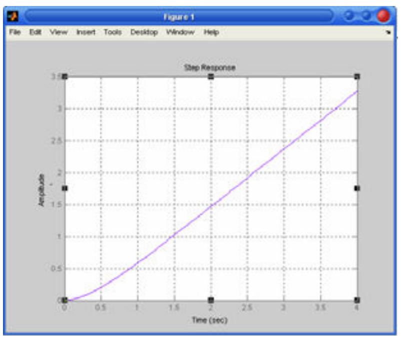


Fig. 4 The motorized robot arm with velocity feedback step response

However, we want the motor to move the robot arm to a proper angular position corresponding to the input. This can be achieved by a positional servomechanism, i.e. feedback the actual robot arm position, θ_L, convert the position information into voltage via a constant Kp and then negatively feed back this signal back into the system. Accordingly, the feedback signal in voltage is $E_f = \theta_L * Kp$ where Kp (V/degree) is the proportional constant depending on the input and desired position output. A simple position sensor is a potentiometer, a variable resistor. The resistor can measure rotational position.

The revised system block diagram is shown in Fig. 5 Suppose the voltage between both ends of the potentiometer is 10V, and that Kp is the ratio of the voltage change to the corresponding angle change. In this case, Kp=(10-0)/(90-0)=0.1111 V/degree; The gear ratio is 1.

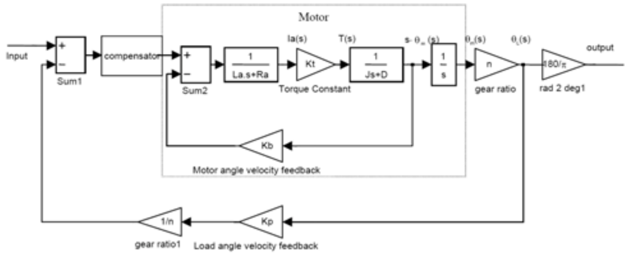


Fig. 5 Position and velocity feedback model of the motorized robot arm

The new transfer function is:

$$G'(s) = \frac{G(s)}{1+G(s).K_p} \tag{16}$$

$$G'(s) = \frac{1}{(0.4177s^2+1.11s+0.0011)}$$

The step response can be determined with the following program:

V=10;
Angle=90;

```
Kp=V/Angle;
G=tf([1],[0.4177 1.11 0]);
sysclose=feedback(G,Kp);
step(sysclose);
```

After position feedback, the steady response tends to be stable as shown in Fig. 6.

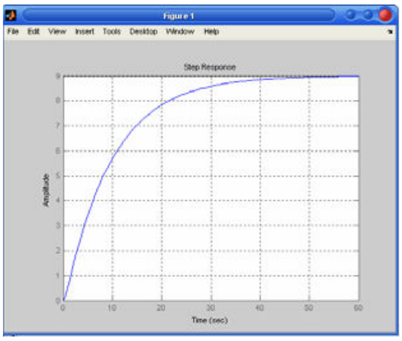


Fig. 6 Step response of the position feedback system

IV. Conclusion

This paper presents modeling the control system for motorized robot arm with a single degree of freedom. The results for the control system are also described. The control algorithm was developed in MATLAB software which is widely used in control application. The system is simple and it is only the part of the author’s studies in MATLAB software but in this system the DC motor moves the robot arm to proper angular position according to the input.

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Mr. Chun Htoo Aung made his first publication of International Paper at this paper “Modeling Motion Control System for Motorized Robot Arm using MATLAB”.