CASE STUDY: FEASIBILITY STUDY OF A MOBILE ROBOT DESIGN

(Case study is from Palm Palm, W. J., Modeling, Analysis, and Control of Dynamic Systems)

Handout 1

Because an engineer's time is valuable, engineering projects usually start with a design feasibility study in which the engineer makes some preliminary calculations based on the proposed design to see if it can meet the given performance specifications. If the design does not appear to be feasible, it is modified and the procedure repeated. If the design does appear feasible, then more detailed calculations are made. The preliminary calculations are based on a simple model of the proposed design; if the design appears feasible, then the engineer can afford to spend more time developing a more detailed model, which is then used to make the refined calculations.

This step-by-step procedure is fundamental to engineering design and decision making. Rarely does an engineer devote much time in developing a very detailed model at the start of a project. By using simple models initially, the engineer avoids wasting time developing and analyzing complex models of a design that might not prove to be feasible. Another advantage of starting with simple models is that they help the engineer to understand the fundamental behavior of the system. The simpler models also provide a means of checking the predictions based on the complex models. This is especially important if computer software is used to make the calculations; the simple models can be solved by hand and used to check the computer output.

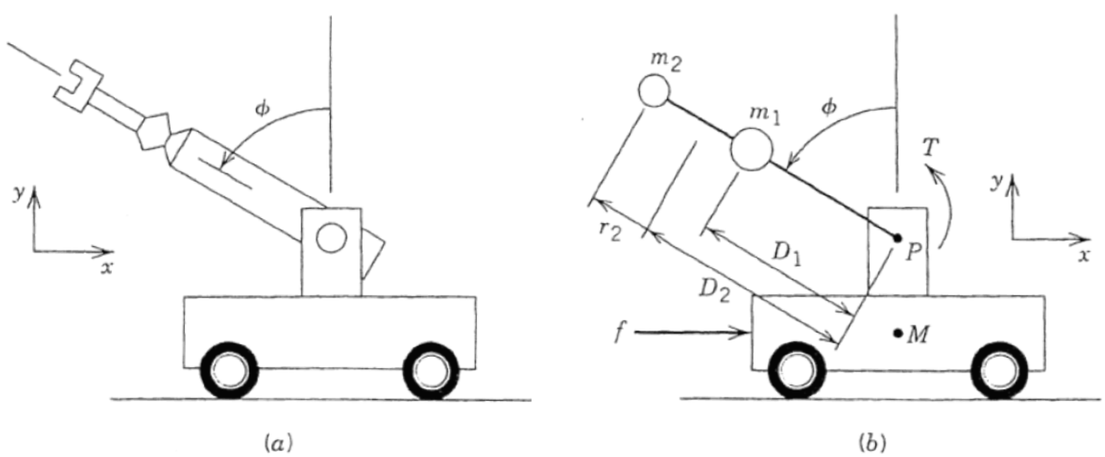

Figure 2.6-1 (*a*) A mobile robot with a translating base and a rotating arm. (*b*) Representation of the robot as a lumped mass system.

We will demonstrate this process by determining whether the motors proposed for driving a mobile robot are powerful enough to meet the desired motion specifications. Figure 2.6-1*a* illustrates a mobile robot consisting of a movable base with an arm mounted on top. Figure 2.6-1*b* is a representation of the robot. The base translates left and right powered by a traction motor producing the force f. The arm rotation in the vertical plane is powered by another motor that produces the torque T. The hand extends and retracts in a translational motion, and can be driven by an electric motor or a pneumatic or hydraulic cylinder. The movable base and wheels have an equivalent mass M, with a mass center located under the arm pivot. The arm mass m_1 and the hand mass m_2 have their mass centers located at distances D_1 and $D_2 + r_2$ from the pivot. D_1 and D_2 are fixed; r_2 is the variable extension of the hand; when the hand is fully retracted, $r_2 = 0$.

The proposed design has the following values. The base mass M is 100 kg. The arm mass m_1 is 30 kg; the hand mass m_2 is 10 kg. The fixed distances are given as: $D_1 = 0.5$ m and $D_2 = 2$ m. The base motor can supply a maximum force of $\pm$ 300 N; the arm motor can supply a maximum torque of $\pm$ 400 N-m. The control system can vary the force f and the torque T, as functions of time, to produce the desired motions. In a later chapter, we will see how this is done.

Suppose that the performance specifications are given as follows. The base must translate a distance of 5 m in 4 s. In that time, the arm must move from horizontal (at $\phi = 90°$) to vertical (at $\phi = 0$). Both the base and the arm start and finish at rest. The hand remains retracted at $r_2 = 0$ during this motion.

- Develop a simplified model of the base and the arm by neglecting the reaction forces that occur at the pivot
- When do the reaction forces become significant?

Handout 2

In order to move a positive distance, starting from rest and then stopping, the base must have a positive acceleration followed by a negative acceleration. Two acceleration versus time functions that will accomplish this are shown in Figure 2.6-3*a*. These are called *acceleration profiles*. Both profiles will accomplish the task. The linear profile requires a larger acceleration but the switched profile can cause jerky motion and is hard on the equipment. Thus we choose the linear profile. The equation of this profile is

$$\ddot{x}(t) = A\left(1 - \frac{1}{2}t\right) \tag{2.6-4}$$

where A is the maximum acceleration required. The expressions for $\dot{x}(t)$ and $x(t)$ are found by integrating twice and using the fact that $x(0) = \dot{x}(0) = \dot{x}(4) = 0$.

$$\dot{x}(t) = A\left(1 - \frac{1}{4}t\right)t \tag{2.6-5}$$

$$x(t) = \frac{1}{2}A\left(1 - \frac{1}{6}t\right)t^2 \tag{2.6-6}$$

Because $x(4) = 5$ m, the previous equation shows that A must have the value $A = 1.875$ m/s^2. The speed and position profiles are shown in Figure 2.6-3*b*, *c*.

Using the same approach for the arm motion, we specify a linear acceleration profile

$$\ddot{\phi} = B\left(1 - \frac{1}{2}t\right) \tag{2.6-7}$$

Integrating twice and using the fact that $\phi(0) = \pi/2$, $\dot{\phi}(0) = \dot{\phi}(4) = \phi(0) = 0$, we obtain

$$\phi(t) = -0.295\left(1 - \frac{1}{6}t\right)t^2 + \frac{\pi}{2} \tag{2.6-8}$$

- Plot the motor force versus time, and motor torque versus time, and determine whether the motor is powerful enough

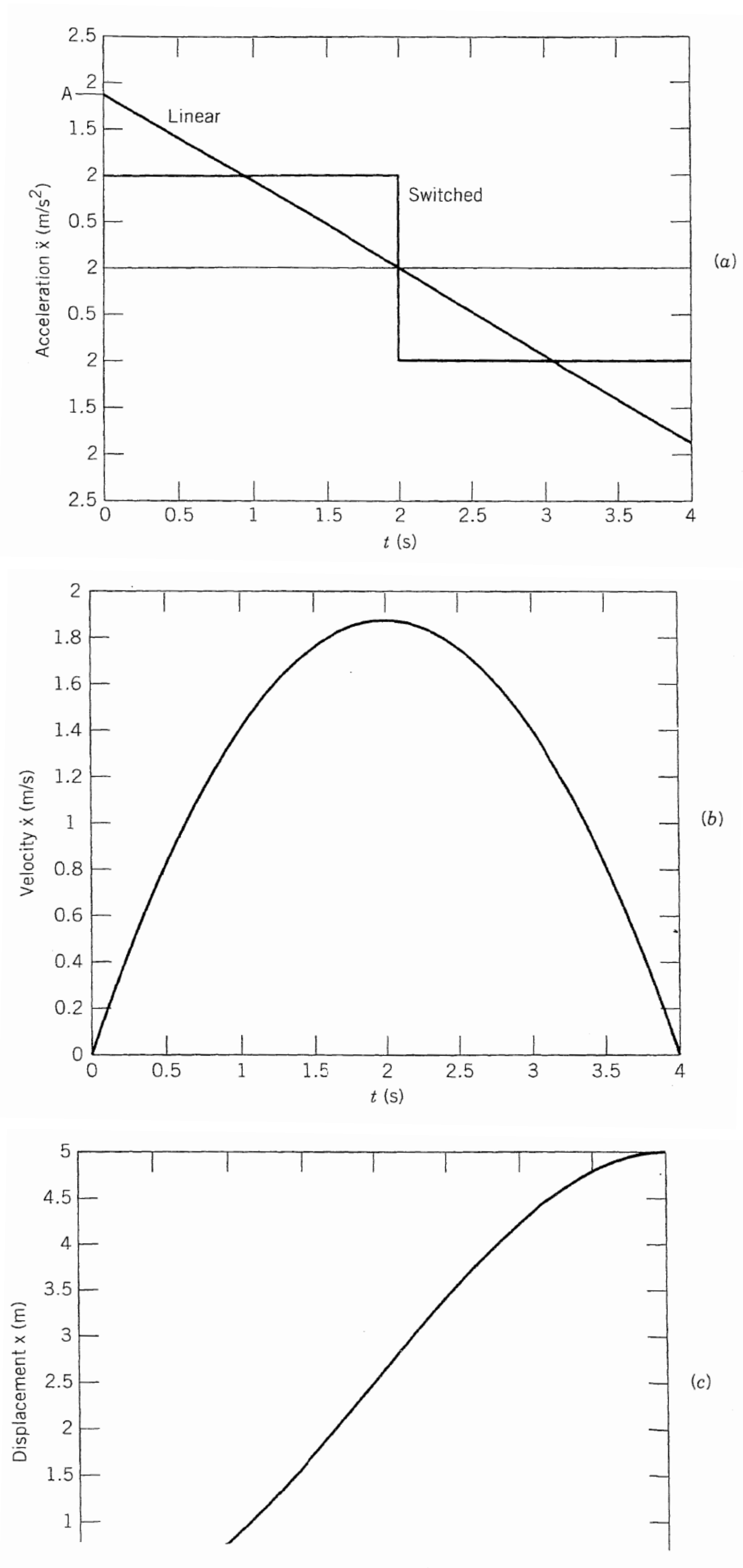

Figure 2.6-3 Motion profiles. (*a*) Two possible acceleration profiles. (*b*) Velocity profile based on the linear acceleration