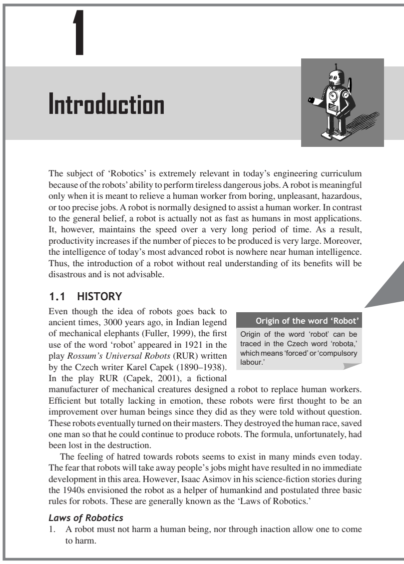
Walk Through



1

Introduction

The subject of 'Robotics' is extremely relevant in today's engineering curriculum because of the robots' ability to perform tireless dangerous jobs. A robot is meaningful only when it is meant to relieve a human worker from boring, unpleasant, hazardous, or too precise jobs. A robot is normally designed to assist a human worker. In contrast to the general belief, a robot is actually not as fast as humans in most applications. It, however, maintains the speed over a very long period of time. As a result, productivity increases if the number of pieces to be produced is very large. Moreover, the intelligence of today's most advanced robot is nowhere near human intelligence. Thus, the introduction of a robot without real understanding of its benefits will be disastrous and is not advisable.

1.1 HISTORY

Even though the idea of robots goes back to ancient times, 3000 years ago, in Indian legend of mechanical elephants (Fuller, 1999), the first use of the word 'robot' appeared in 1921 in the play *Rossum's Universal Robots* (RUR) written by the Czech writer Karel Capek (1890–1938). In the play RUR (Capek, 2001), a fictional manufacturer of mechanical creatures designed a robot to replace human workers. Efficient but totally lacking in emotion, these robots were first thought to be an improvement over human beings since they did as they were told without question. These robots eventually turned on their masters. They destroyed the human race, saved one man so that he could continue to produce robots. The formula, unfortunately, had been lost in the destruction.

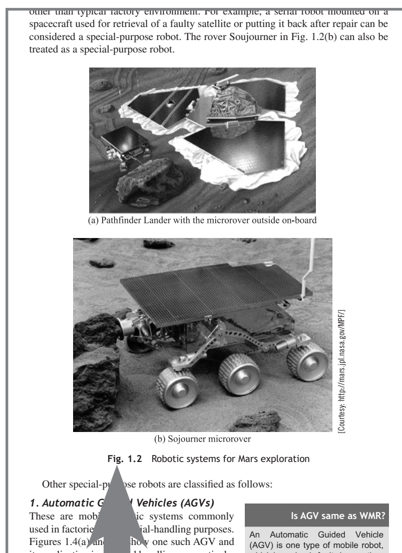
Origin of the word 'Robot'
Origin of the word 'robot' can be traced in the Czech word 'robota,' which means 'forced' or 'compulsory labour.'

The feeling of hatred towards robots seems to exist in many minds even today. The fear that robots will take away people's jobs might have resulted in no immediate development in this area. However, Isaac Asimov in his science-fiction stories during the 1940s envisioned the robot as a helper of humankind and postulated three basic rules for robots. These are generally known as the 'Laws of Robotics.'

Laws of Robotics

1. A robot must not harm a human being, nor through inaction allow one to come to harm.

Textboxes in each chapter provide historical facts and topic-related information to complement the knowledge gained through the text of the book.



other than typical factory environment. For example, a serial robot mounted on a spacecraft used for retrieval of a faulty satellite or putting it back after repair can be considered a special-purpose robot. The rover Soujourner in Fig. 1.2(b) can also be treated as a special-purpose robot.

(a) Pathfinder Lander with the microrover outside on-board

[Courtesy: http://mars.jpl.nasa.gov/MPF/]

(b) Sojourner microrover

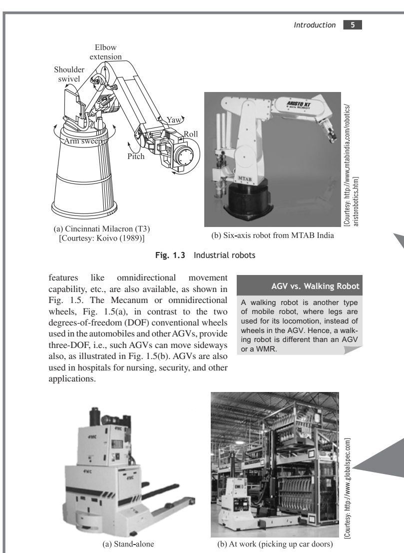
Fig. 1.2 Robotic systems for Mars exploration

Other special-pu se robots are classified as follows:

1. Automatic G d Vehicles (AGVs)

These are mobi ic systems commonly used in factorie ial-handling purposes. Figures 1.4(a) and ho one such AGV and its application in al handling, respectively.

Is AGV same as WMR?
An Automatic Guided Vehicle (AGV) is one type of mobile robot, which has wheels for its locomotion.



(a) Cincinnati Milacron (T3) [Courtesy: Koivo (1989)]

[Courtesy: http://www.mtabindia.com/robotics/aristorobotics.html]

(b) Six-axis robot from MTAB India

Fig. 1.3 Industrial robots

features like omnidirectional movement capability, etc., are also available, as shown in Fig. 1.5. The Mecanum or omnidirectional wheels, Fig. 1.5(a), in contrast to the two degrees-of-freedom (DOF) conventional wheels used in the automobiles and other AGVs, provide three-DOF, i.e., such AGVs can move sideways also, as illustrated in Fig. 1.5(b). AGVs are also used in hospitals for nursing, security, and other applications.

AGV vs. Walking Robot
A walking robot is another type of mobile robot, where legs are used for its locomotion, instead of wheels in the AGV. Hence, a walking robot is different than an AGV or a WMR.

[Courtesy: http://www.globalspec.com]

(a) Stand-alone

(b) At work (picking up car doors)

Fig. 1.4 An AGV

Photos of practical robots and their real applications give true understanding and utility of the subject covered in this book.

Control Hardware and Robot Programming **455**

model can be moved around to generate a sequence of robot movements that can be calibrated and programmed for an actual peg in a hole-insertion task.

SUMMARY

In this chapter, the software and hardware requirements for robot control are explained. Different robot-programming languages are explained, along with online and offline robot-programming methodologies. Advantages and disadvantages of both programming are mentioned. Examples with a KUKA robot are also provided.

EXERCISES

13.1 What are the hardware and software requirements for a robot controller?
13.2 How can computing speed associated with trigonometric function be enhanced?
13.3 Explain controller hardware structure of PUMA robot.
13.4 Describe online programming.
13.5 What are the advantages and disadvantages of online programming?
13.6 What are the types of online programming?
13.7 What is the difference between lead-through and walk-through programming?
13.8 What are the typical features of a teach pendant?
13.9 What are the types of offline programming?
13.10 What are the features offline programming environments should have?
13.11 When one should prefer online over offline programming?
13.12 Name a few robot languages and mention their features.
13.13 What are the generations of robot languages?
13.14 Mention the feature of generation of robot languages.
13.15 Why is task-level programming difficult?

WEB-BASED EXERCISES

13.16 What are the types of robot-programming languages used by commercial robot manufacturers?
13.17 Name some robot simulation software for offline programming (other than mentioned in the chapter).
13.18 Find control architecture of KUKA KR C2 controller.
13.19 Which research facilities attempted programming using augmented reality?
13.20 Explain at least two assistive devices for walk-through programming.

Summary at the end of each chapter gives a glimpse of what has been explained in that chapter.

Web-based exercises will keep the readers up-to-date with the latest developments in this area.

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$$p = \frac{110187.12}{2 \times \pi \times (0.1)^2} = 175.35 \text{ N/m}^2 \quad (3.7)$$

3.5.4 Adhesive Grippers

An adhesive substance used for a grasping action can be used to handle fabrics and other lightweight materials. One of the limitations is that the adhesive substance loses its effectiveness with repeated use. Hence, it has to be continuously fed like a mechanical typewriter's ribbon which needs to be attached to the robot's wrist.

3.5.5 Hooks, Scoops, and Others

There exist other types of gripping devices, e.g., hooks, scoops or ladles, inflatable devices, etc., based on the need of item to be handled. For example, Fig. 3.32 shows one of these devices.

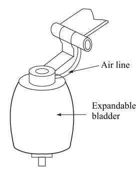

Fig. 3.32 Expandable bladder to grip objects with holes from inside

3.5.6 Selection of Grippers

Some of the criteria to be used in selecting an appropriate gripper are highlighted below:

- One needs to decide the drive system. In fact, in an industrial scenario where electric and pneumatic power sources are easily available, one needs to decide the type. If fast but not so accurate motion is desired then pneumatic should be preferred. Otherwise, one can go for electric. For heavy objects, certainly one must prefer hydraulic, as pointed in Section 3.2.
- Object or the part surface to be gripped must be reachable by a gripper.
- The size variation should be kept in mind. For example, a cast object may be difficult to put in a machine chuck.
- The gripper should tolerate some dimension change. For example, before and after machining a workpiece, their sizes change.
- Quality of surface area must be kept in mind. For example, a mechanical gripper may damage the surface area of an object.
- Force should be sufficient to hold an object and should not fly away while moving with certain accelerations. Accordingly, the materials on the surfaces of the fingers should be chosen.

SUMMARY

A robot is moved by actuators. Different forms of actuators, namely, electric, hydraulic and pneumatic types are explained. For electric motors, their typical specifications and

Selection of components and necessary calculations give a student a practical approach to the subject, and provide a practicing engineer useful information for real product applications.

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WEB-BASED EXERCISES

Based on Web search find the answers to the following questions:

8.11 Find at least three commercial software that are capable of performing dynamics of a robot manipulator.
8.12 What are other possible dynamic formulations (methodologies) for robot dynamics?
8.13 What are the commercial software for a specific architecture of a robot?

MATLAB BASED EXERCISES

8.14 Find the joint torques for the manipulator in Exercise 8.3.
8.15 Find simulation results for the three-link manipulator while no torque is applied but the gravity is acting. The initial conditions for the generalized coordinates are
$\theta_1(0) = \theta_2(0) = \theta_3(0) = 0$ rad; $\dot\theta_1(0) = \dot\theta_2(0) = \dot\theta_3(0) = 0$ rad/sec
Take the geometric and inertial parameters as
$a_1 = a_2 = 1$ m; $a_3 = 0.5$ m; $m_1 = m_2 = 1$ kg; $m_3 = 0.5$ kg
8.16 Write a program to generate the joint torque and force for the RP manipulator based on the equations of motion derived in Exercise 8.4 while the trajectories are defined using Eq. (8.122). Take $\theta(0) = 0$; $\theta(T) = \pi/2$; $b(0) = 0$; $b(T) = 0.1m$—θ and b are respectively the joint variables for the revolute and prismatic joints. Consider $T = 10$ sec.
8.17 Repeat Exercise 8.16 for the PR robot manipulators of Exercise 8.6.

ROBOANALYZER BASED EXERCISES

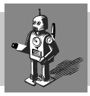
8.18 Validate the results of Exercise 8.14. Visualize the animation.
8.19 Generate inverse and forward dynamics results of two-link RP and PR arms whose dynamic equations were derived in Exercises 8.5 and 8.6, respectively. Take numerical data from Exercises 8.16.
8.20 Perform inverse and forward dynamics of the KUKA KR-5 robot available in RoboAnalyzer environment.

MATLAB-based exercises enhance the problem-solving skill with ease.

In-house developed software usage not only allows the reader to get results for complex problems but also provides the possibility of writing new programs based on the existing ones.

C

Use of RoboAnalyzer[1]



In this appendix, the steps to use the RoboAnalyzer software developed by the author and his students at IIT Delhi are explained. It is an improved version of the RIDIM (Recursive Inverse Dynamics for Industrial Manipulators) programs appeared in the first edition of this book in 2008. RoboAnalyzer (RA) has the visualization feature through 3-dimensional models of robots, including many standard robots like KUKA, ABB, Fanuc, and others. It can be used to learn DH parameters, kinematics, and dynamics of serial robots, and allows 3-dimensional (3D) animation and graph plots as outputs. In essence, learning the physics of robotics with joy is emphasized through RA, rather than only mathematics.

RoboAnalyzer can be installed on a computer with windows operating system by downloading from the website mentioned in the footnote.

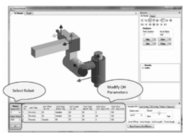


Fig. C.1 Robot-model selection and redefine the DH parameters

The following sections explain the main features of RoboAnalyzer.

C.1 VISUALIZE DENAVIT-HARTENBERG PARAMETERS

After selecting a robot and redefining its Denavit-Hartenberg (DH) parameters, as shown in Fig. C.1, users can visualize each DH parameter by selecting a joint and

1 RoboAnalyzer (RA) software and the users' manual can be downloaded free from http://www.roboanalyzer.com. Also available from http://www.mhhe.?? Several students since 2009 (Mr. C.G.

MATLAB programming examples help a student to master solving complex problems with ease.

Example 6.19 **Inverse Kinematics of the Articulated Arm Using MATLAB**

In order to solve Example 6.18, a MATLAB program can be written, as shown in Fig. 6.16, which can be stored in a file, say, 'ch6ikin3aa.m' that can be run to yield the above results. Moreover, by changing the values of "a2" "a3," and "px," "py," "pz" that correspond to the robot's DH parameters and the end-effector position, respectively, many other solutions can be generated.

```
%Non-zero constant DH parameters
a2=1; a3=1;

%Input
px=1; py=0; pz=0;

%Intermediate calculation
delxy = px*px+py*py; del=delxy+pz*pz;

%Calculations for theta_1
th11=atan2(py,px);
th12=pi+atan2(py,px);

%Calculations for theta_3
c3=(del-a2*a2-a3*a3)/(2*a2*a3); s3=sqrt(1-c3*c3);
th31=atan2(s3,c3); th32=atan2(-s3,c3);

%Calculation for finding theta_2
s21=(-(a2+a3*cos(th31))*pz-a3*s3*delxy)/del; c21=((a2+a3*cos(th31))
*delxy+a3*s3*pz)/del;
s22=(-(a2+a3*cos(th31))*pz+a3*s3*delxy)/del;
c22=((a2+a3*cos(th31))*delxy-a3*s3*pz)/del;
th21=atan2(s21,c21); th22=atan2(s22,c22);
th23=pi-th21; th24=pi-th22;

%Angles in degree
r2d=180/pi;
th11d=th11*r2d,  th12d=th12*r2d,  th21d=th21*r2d,  th22d=th22*r2d,
th23d = th23*r2d, th24d = th24*r2d, th31d=th31*r2d, th32d=th32*r2d
```

Fig. 6.16 Texts of file 'ch6ikin3aa.m' for inverse kinematics of articulated arm

6.2.4 A Wrist

Consider the wrist architecture shown in Figs. 5.38 and 6.16, whose kinematic relations are given in Eq. (6.12b). It is desired to find the joint variable, θ_1, θ_2 and θ_3, corresponding to a given end-effector orientation, **Q**, with the following form:

$$\mathbf{Q} \equiv \begin{bmatrix} q_{11} & q_{12} & q_{13} \\ q_{21} & q_{22} & q_{23} \end{bmatrix} \quad (6.41)$$

can be interpreted as the projection of **a** onto the vector **b** whose result is multiplied by the magnitude of the latter. Now, if these two vectors are orthogonal to each other, i.e., if $\theta = 90^o$, the dot product vanishes, namely, $\mathbf{a}^T\mathbf{b} = 0$.

A.2.3 Vector or Cross Product

A vector or cross product between two Cartesian vectors, say, **a** and **b**, denoted by **c**, is defined as

$$\mathbf{c} = \mathbf{a}\times\mathbf{b} = \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \end{vmatrix} = (a_2b_3 - a_3b_2)\mathbf{i} + (a_3b_1 - a_1b_3)\mathbf{j} + (a_1b_2 - a_2b_1)\mathbf{k} \quad (A.11a)$$

where $\times$ denotes the symbol for the cross product, whereas $|\bullet|$ represents the *determinant* of the arguments •. The result of Eq. (A.11a) can also be expressed as

$$\mathbf{c} \equiv \begin{bmatrix} a_2b_3 - a_3b_2 \\ a_3b_1 - a_1b_3 \\ a_1b_2 - a_2b_1 \end{bmatrix} \quad (A.11b)$$

In Eq. (A.11a), the result of the cross product is also a vector **c**, as indicated in Eq. (A.11b), which is orthogonal to the two vectors **a** and **b**. The magnitude of vector **c** is denoted as c that can be given by

$$c = ab\sin\theta \quad (A.12)$$

where θ is the angle between the vectors **a** and **b**, as shown in Fig. A.3. In order to obtain the direction of the resultant vector **c**, the right-hand rule is applied, i.e., if the palm of a right hand is placed along the vector **a**, and then turned towards the vector **b**, the thumb points out in the direction of the vector **c**. It is also shown in Fig. 13.13.

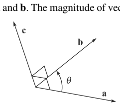


Fig. A.3 Vector (cross)-product of two Cartesian vectors

The cross product has the following properties:

$$\mathbf{a}\times\mathbf{b} = -\mathbf{b}\times\mathbf{a};\ \mathbf{a}\times(\mathbf{b}\times\mathbf{c}) = (\mathbf{a}^T\mathbf{c})\mathbf{b} - (\mathbf{a}^T\mathbf{b})\mathbf{c};\ \text{and}\ \mathbf{a}^T(\mathbf{b}\times\mathbf{c}) = |\mathbf{a}\quad\mathbf{b}\quad\mathbf{c}| \quad (A.13)$$

A.2.4 Cross-Product Matrix

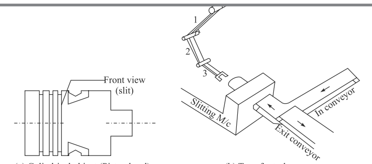
A cross-product matrix is always associated with a three-dimensional Cartesian vector, say, **a.** When the matrix is pre-multiplied with another three-dimensional Cartesian vector, say, **b**, it results in the cross product between the two vectors, as shown in Section A.2.3. If $\mathbf{a}\times\mathbf{1}$ denotes the cross-product matrix associated with the vector **a** then

$$(\mathbf{a}\times\mathbf{1})\mathbf{b} = \mathbf{a}\times\mathbf{b} \quad (A.14a)$$

The 3×3 matrix $(\mathbf{a}\times\mathbf{1})$ is a skew-symmetric matrix and singular. Its representation in terms of the components of the vector $\mathbf{a} \equiv [a_1 \quad a_2 \quad a_3]^T$ is given by

$$\begin{bmatrix} 0 & -a_3 & a_2 \end{bmatrix}$$

Mathematical Fundamentals quickly revise the basics of mathematics required for the topics covered in the book without the need of referring other books immediately.



(a) Cylindrical object (Piston head) (b) Transfer task

Fig. 14.10 An industrial task by a robot arm

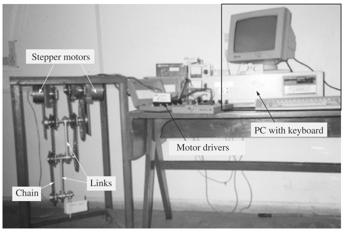


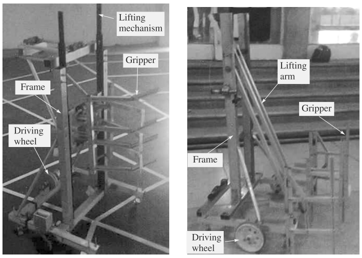
Fig. 14.11 Photograph of the HaPRA with its controller

14.2.4 Gripper for Cylindrical Objects

This gripper was designed in another B.Tech final-year project keeping in mind that the same can be used by HaPRA explained in Section 14.2.3 (Agarwal and Singh, 2004). For a range of cylindrical shapes, the gripper was synthesized as a six-bar linkage, as shown in Fig. 14.12(a). Its complete kinematic analysis was performed using the motion module of Pro-E software. Finally, the gripper was fabricated and interfaced with a stepper motor to demonstrate its motion capabilities, Fig. 14.12(b).

Robots built by the students give readers the confidence to build their own robots that will certainly enhance their knowledge about the subject.

used a pulley arrangement to lift the gripper assembly, while a four-bar parallelogram mechanism was used in the manual robot. The latter could extend almost about half a meter in front of the robot to be able to place the blocks inside the boundary line of the 10-sided polygon. Once the design was done, the next challenge was to fabricate, assemble, program, and make them run successfully. Steps similar to Section 14.1.1 were followed as per the Gantt chart shown in Fig. 14.6.



(a) Automatic robot (b) Manual robot

Fig. 14.5 Robots for ROBOCON 2007

14.2 HARDWARE DEVELOPMENTS

In this section, several other hardware developments of robots are explained.

14.2.1 RoboMuse

RoboMuse, as shown in Fig. 14.7, is a line-following mobile robot capable of handling few kilograms of payload. It was originally manufactured as a part of ROBOCON 2008 by IIT Delhi's robotics team. After participation in the event, a live 24×7 demo of the robot was planned in the Student Activity Centre of the campus. The salient features of the RoboMuse were as follows:

1. It had three Maxon motors: Two were for driving wheels and one to lift the charging rod up and down.
2. Supply voltage was 12 V dc from a lead-acid battery (current capacity: 4.3