1988

NEAR EAST UNIVERSTY
DEPARTMENT OF COMPUTER ENGINNERING
COM 400
GRADUATION PROJECT
ROBOTIC SYSTEM

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PREFACE

In this project, the robotic system is studied with intesive care and the application of this unique system is shown.

I would like to thank Prof.Dr. Fahrettin Sadigoglu because of his cotinous help and encourragement.

TIMUR BUKCEZ

TABLE OF CONTENT:

Page
5 - Chapter one - Hıstory of robots - Introductıon
6 - 1)A hıstorıcal representatıon of robots
10 - 1.1 - Robotıc-lıke devıces
1.1.1 - Prostheses
1.1.2 - Exoskelethes
1.1.3 - Telecherıcs
12 - 1.1.4 - Locomotıve mechanısm
1.2 - Classıfacatıon by coordınate system
13 - 1.2.1 - Cylındrıcal coordınate system
1.2.2 - Spherıcal coordınate robots
14 - 12.3 - Joınted arm robots
1.2.2.1 -Pure spherıcal
1.2.2.2 -Paralelagram joınted
15 - 1.2.3.3 -Joınted cylınderıcal
1.2.3.4 -Cartezıan coordınate robots
a)-Cantılevered cartezıen
16 - b) Gantry-style cartesıan
1.3 - Classıficatıon by control method
1.3.1 - Non-servo controlled robots
18 - 1.3.2 - Servo-controlled robots
21 - 1.3.3 - Poınt-to-poınt servo-controlled robots
22 - 1.3.4 - Contınuous-path-servo controlled robots
23 - 3 - Major components of a robot
1 - The manıpulator
24 - 2 - Sensory devıces
3 - The controller
25 - 4 - The power conversıon unıt
5 - Fıxed versus flexıable automatıon
26 - 1 - Reactıon tıme
27 - 2 - Debuggıng
28 - 3 - Resıstance to obselence

29 - 4 - Economic consideration
5 - Socialogical cosequence of robot
30 - 6 - Robotic applications
32 - Chapter two - Robotic sensory devices
- 2.0 Objects
33 - 2.1 - Motivation
34 - 2.2 - Nonoptical-position sensors
35 - 2.3 - Optical position sensors
36 - 2.4 - Robot calibration using an optical incremental encoder
38 - 2.5 - Instability resulting
39 - 2.6 - Velocity sensor
41 - 2.7 - Accelerometers
- 2.8 - Proximity sensor
46 - CAHPTER THREE Computer vision for robotic system : a functional approach
47 - 3.1 - Motivation
48 - 3.2 - Imaging components
49 - 3.2.1 - Point sensors
50 - 3.2.2 - Line sensor
51 - 3.2.3 - Planner sensor
54 - 3.2.3.2 - Rater scan
- 3.2.3.3 - Image capture time
55 - 3.2.4 - Valume sensor
- 3.3 - Image representation
56 - 3.3 - Picture coding
- 3.5.1 Gray-scale imagging
57 - 3.4 - Hardware consideration
58 - 3.5.2 - Binary images
59 - 3.5.3 - Run length coding
60 - 3.5.4 - Differantal delta coding
- 3.6 - Object recognation&categorization
- 3.6.1-Diemensionality reductio
61 - 3.6.2 - Sementation of iomage

62 - 3.6.2.1- Color or gray level
-3.6.2.2 Edge detectıon
63 - 3.6.3 - Object descıptıon or categorısatıon
64 - 3.6.3.1 - Image comparıson
65 - 3.6.3.2 - Template matchıng
66 - 3.6.3.3 - Correlatıon of gra levels
- 3.6.3.4 - Merphologıcal ımage process
67 - 3.7 - Software consıderatıon
- 3.8 - Need for vısıon traınıg
68 - 3.9 - Revıew of exıstıng system
- 3.9.1 - Bınary vısıon system
69 - 3.9.3 - Structered-lıght system
- 3.9.4 - Character recognatıon
- 3.9.5 - The GM-consight I system

CHAPTER ONE

HISTOY OF ROBOTS

INTRODUCTION

As the reader will begin to appreciate, the study of robotics involves understanding a number of diverse subjects. For example, several engineering disciplines as well as those relating to physics, economics, and sociology must be mastered before one can truly acquire more than a nodding acquaintance with the field. This book is intented to be primarily an engineering text.However , before beginning a discussion of the technical aspects of robotics, it is necessary for the reader to become conversant with the language of the subject. Thus the overall objective of this chapter is to provide an overview of robotics, presenting the material in a descriptipe, fairly nontecnical manner.

Specially ,the tobics that are covered are as follows:

1. Historical perspective of robots
2. Clasisification of robots

3. Description of the major robot components

4. Discussion of fixed versus flexible automation

5. Economic considerations used for the selection and justification of robots

6. Sociological consequences of automation / robots

7. Robot state -of-the-art survey

8. Current and future applications of industrial robots

1. A HISTORICAL PERSPECTIVE OF ROBOTS

The word *robot* was first used in 1921 by the Czech playright , novelist, and essayist Karel Capek in his satirical drama entitled R.U.R. *(Rossum's Universal Robots)*

It is derived from the Czech word *robota* , which literally means "forced laborer." or "slave laborer." In his play , Capek pictured robots as machines that resembled people worked twice as hard. These devices had arms and legs and no doubt were similar in many ways to C3-P0 in the 1977 film *Star Wars.* The industriyal robot of today does not look the least bit human and therefore has little in common with Capek's robots.

Although Capek introduced the word "robot" to the world ,the term "robotics" was coined by Isaac Asimow in his shorty story "Runaround,"first published in 1942. This work is also notable because the so-called "Three Rules (or Laws) of Robotics"are presented for the first time:

1.A robot may not injure a human being, or, through inaction, allow one to come to harm.

2. A robot must obey the orders given it by human beings except where such orders would conflict with the First Law.

3. A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.

Asimow has stated that workers in the field of artifical intelligence indicated to him that these three laws should serve as a good guide as the field progresses.

Before proceeding with the history of robots themselves, it is interesting to trace briefly the antecedents, of these devices. Surprisingly (perhaps), the concept of a programming machine dates back to eighteenth-century France and includes invertors such as Bouchon ,Vacaunsan , Basile, and Falcon. Possibly the best known of the group is Joseph Jacquard who developed and mechanical loom controlled by punched cards. Its mass production occurred around 1801. In the third decade of the nineteenth century, an American Spender, produced a programmable lathe called the *automat* that was capable of turning out screws, nuts, and gears. Its "programming,"and hence the pattern that was to be cut, was modified through the use of a set of interchangeable cam guides that were fitted on the end of a rotating drum.

The problem of removing hot ingots from a furnace was solved by Seward Babbit in 1892.

He developed and patented a rotary crane equipped with a motorized gripper. In 1938-1939 , Willard Pollard invented a *jointed* mechanical arm that was utilized primarily in paint spraying. A similar device was developed by an employee of the DeVilbiss Co.(a current manufacturer of robots), Harold Roselund.

A "relative" of the robotic manipulator, the *teleoperator* or *teleheric*, was developed during World War 2 to permit an operator to handle radioactive materials at a safe distance. Just after the conclusion of this war , George Devol , the acknowledged "father of the robot," developed a magnetic process controller that could be used a general-purpose playback device for controlling machines . In the same year (1946) , Eckert and Mauchly built the ENIAC , the first large- scale electronic computer, and at the Massachusetts Institute of Technology (MIT) a general-purpose digital computer (*Whirlwind*) solved its first problem. One year later in 1947 , a servoed electric-powered teleoperator was introduced by Raymond Goertz. It permitted the servo-controlled slave to follow the position command of the master (i.e.,the operator). However , no force control was incorporated into the design until the following year. By permitting the load to back- drive the mechanical interface to the master, the sense of touch was restored to the operator. In 1952 the first numerically controlled machine tool was developed at the MIT Servomechanism Laoratory.

It is generally acknowledged that the "robot age" began in 1954 when Devol patented the first manipulator with a playback memory. This device was capable of performing a controlled motion from one point to another (i.e.,point-to-point motion) . In addition , Devol also coined the phrase *universal automation*. (This was to be shortened later to *unimation*.) Five years after this , the first commercial robot was sold by the Planet Corporation. However , in 1960 Devol chose to sell his original robot patents (approximately 40 in all) to Consolidated Diesel Corporation (Condec),which actually developed the Unimate robot at its newly formed subsidiary, Unimation , Inc. The design of the Unimate combined the playback features of numerically controlled capabilites of the telecheris developed by Goertz . Two years later , in 1962, General Motors installed the first Unimate on one of its assembly lines in a die-casting application.

By the mid 1960s , the new field of robotics sparked the formation of several centers of research into this area and the related topic of artifical intelligence (AI) at such institutions as MIT, Stanford University, Stanford Research Institute (SRI) International, and the University of Edinburg in Scotland. In 1967, General Electric Corparation produced a four-legged vehicle (under a Department of Defense contract) that required simultaneous control of the appendages by a human operator. This proved to be extremly difficult to achieve and the project was scrapped. A year , SRI demostrated an "intelligent" mobile robot tjhat had some vision capability (using a TV camera) , an optical range finder , and react sensors.

The device also had the ability to a highly irregular and jerky manner , it was given the name "Shakey."

One of the early innovators in the field of robotics , Victor Scheinman, while working at Stanford University in 1970 demonstrated a computer-controlled manipulator that was powered by servomotors rather than by hydraulics. Three years later, in 1973 , Richard Hohn of the Cincinnati Milacron Corporation produced the first minicomputer-controlled commercial robot. In 1974 Vicarm Inc. introduced the first servomotor- actuated , minicomputer-controlled manipulator. In the same year (1976) as the NASA *Viking 1*and *2* landers used their manipulators to collect samples from the surface of Mars, Vicarm developed the first microprocessor-controlled robot under Navy contract.

A workable robotic vision system was developed by SRI in 1976 and resulted in a system commercialized by Machine Intelligence Corporation. In 1978, Unimation, working with a set of specifications provided by General Motors, developed the programmable universal machune for assembly (PUMA).

1980 saw the establishment of the largest universty-related robotics laboratory , at Carnegie-Mellon University. This year also saw the University of Rhode Island demonstrate a prototype robotic vision system that could handle the "bin picking"problem. A modification of the system was marketed by Object

Recognition Systems, Inc. and demonstrated in 1982.

In 1983 a company called Odetics, Inc. introduced a unique experimental six-legged device that was designed by studying the gait of both human beings and certain insects. Originally called a *functional*, it demonstrated the ability to walk over obstacles and to lift loads up to 5.6 times its own weight while stationary , and 2.3 times its weight moving.

In fact, as early as 1968 , Kawasaki Heavy Industries was granted a licence from Unimation to manufactire their robots. The robot industry grew so rapidly that in 1971 , the Japan Industrial Robot Association (JIRA) was founded . It is interestung to note that despite all of the research activity in U.S. , the Robotic Institute of America (RIA), now called the Robotic Industries Association, an organization primarily for manufacturers and users of robots, was begun only in 1975. Significant industrial effort in the U.S. has occured since then, with the RIA (in its 1982 World Robotics Survey and Directory) listing approximately 28 American firms now involved in the manufacture of robots. Nevertheless, this does demonstrate that the Japanese have been exceedingly active in the industrial application of robots for quite a long time.

2. *CLASSIFICATION OF ROBOTS*

What exactly is a robot? Webster defines a robot as: An automatic apparatus or device that performs functions ordinarily ascribed to humans or operates with what appears to be almost human intelligence. The RIA developed the following , more complete definition: A robot is a reprogrammable , multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks.

2.1.Robotic-Like Devices

There are a number of devices that utilize facets of robot technology and are therefore often mistakenly called robots. In fact, Engelberger has referred to them as "near relations." There are at least four such classes of mechanisms, two of which we have already briefly encountered in the preceding section. These are:

2.1.1. Prostheses. These are often referred to as "robot arms" or "robot legs." Even though they can make use of either hydraulic or servomotor actuators, utilize servo control, and have mechanical linkages, they do not have their own "brains" and are truly programmable.The impetus to produce an action (called the "command signal") in such a device originates in the brain of the human being. It is then transmitted via nerves to the appropiate appendage, where electrodes sense the nerve impulses. These are processed electronically by a special-purpose computer (on hand).

2.1.2. ***Exoskeletons.*** As shown in figure 2.1.2, these are a collection of mechanical linkages that are made to surround either human limbs or the entire human frame.They have the ability to amplify a human's power. However, it is clear that they cannot act independently and, are not robots. In fact, when an exoskeletal device is used, the operator must exercise extreme caution, due to the increased forces and/or speeds that are possible.

2.1.3. ***Telecherics.*** As mentioned previously, these devices permit manipulation or movement of materials and/or tools that are located many feet away from an operator. Even though telecheric mechanisms use either hydraulic or servomotor actuators, which are usually controlled in a closed-loop manner, they are not robots because they require a human being to close the entire loop and to make the appropriate decisions about position and speed. Such devices are especially useful in dealing with hazardous substances such as radioactive waste. It has also been proposed that they be used in undersea exploration.

2.1.4. ***Locomotive Mechanism.*** These are devices that imitate human beings or animals by having the ability to walk on two or four legs. Although the multiple appendages can be highly sophisticated collections of linkages that are hydraulically or electrically actuated under closed-loop control, a human operator is still required to execute the locomotive process(i.e., make decisions concerning the desired direction of the device and to coordinate limb motion to achieve this goal.)

Having described what is not a robot , we now devote the remainder of this section to classifying the various types of robotic devices. Classification will be performed in two different ways, based on:

. The particular coordinate system utilized in designing the mechanical structure

. The method of controlling the various robotic axes

2.2.Classification by Coordinate System

Although the mechanics of a robotic manipulator can vary considerably, all robots must be able to move a part (or another type of "load") to some point in space. The major axes of the device, normally consisting of the two or three joints or degrees of freedom that are the most mechanically robots (and often located closest to the base), are used for this purpose. The majority of robots, therefore, fall into one of four categories with respect to the coordinate system employed in the design of these axes. That is, they can be described as being either cylindrical, spherical, jointed, or Cartesian devices. Each of this categories is now discussed briefly.

2.2.1. Cylindrical Coordinate Robots

When a horizontal arm (or "boom") is mounted on a vertical column and this column is then mounted on a rotating base, the configuration is referred to as a cylindrical coordinate robot. This is shown in figure 2.2.1. As can be seen the arm the ability to move in and out (in *r* direction), the carriage can move up and down on the column (in the *o* direction). Usually, a full 360 degrees rotation in *o* is not permitted, due to restrictions imposed by hydraulic, electrical, or pneumatic connections or lines. Also there is a minimum, as well as a maximum extension , due to mechanical requirements.Consequently, the overall volume or *work envelope* is a portion of a cylinder.

2.2.2. Spherical Coordinate Robots

When a robotic manipulator bears a resemblance to a tank turret , it is classified as a spherical coordinate device (see figure 2.2.2.). The reader should observe that the arm can move in and out (in the *r* direction) and is characterized as being a *telescoping boom* , can pivot in a vertical plane (in the *o* direction) , and can rotate
in a horizontal plane about the base (in the *o* direction) . because of mechanical and/or actuator connection limitations, the work envelope of such a robot is a portion of a sphere. Commercially available sphrical coordinate robots are being built by Prap, Unimation, and United States Robots.

2.2.3. Jointed Arm Robots

There are actually three different types of jointed arm robots:

2.2.3.1. Pure Spherical : In this, the most common of the jointed configurations, all of the links of the robot are pivoted and hence can move in a rotary or "revolute" manner . The major advantage of this design is that it is possible to reach close to the base of the robot and over any obstacles that are within its workspace. As shown in figure 2.2.2.1., the upper portion of the arm is connected to the lower portion (or forearm). The pivot point is often referred to as an "elbow" joint and permits rotation of the forearm (in the alpha direction). The upper arm is connected to a base (or sometimes a *trunk*) . Motion in a plane perpendicular to the base is possible at this *shoulder* joint (in the beta direction). The base or trunk is also free to rotate , thereby permitting the entire assembly to move in a plane parallel to the base (in the *y* direction). The work envelope of a robot having this arrangment is approximately spherical

2.2.3.2. Parallelogram Jointed: Here the single rigit-number upper arm is replaced by a multible closed-linkage arrangement in the form of a parallelogram (see figure 2.2.2.2.) The major advantage of this configuration is that it permits the joint actuatirs to be placed close to, or on the base of, the robot itself. This means that they are not carried *in* or *on* the forearm or upper arm itself, so that the arm inertia and weight are considerably reduced. The result is a larger load capacity than is possible in a jointed spherical device for the same-size actuators. Another advantage of the configuration is that it produces a manipulator that is mechanicallt stiffer than most others. The major disadvantage of it arrangement is that the robot has a limited workspace compared to a comparable jointed spherical robot .

*2.2.3.3. **Jointed Cylindrical***: In this cofiguration , the single *r-axis* member in a pure cylindrical device is replaced by a multible-linked open kinematic chain, as shown in figure 2.2.2.3. Such robots tend to be precise and fast but will generally have a limited vertical (z direction) reach. Often the z-axis motion is controlled using simple (open-loop) air cylinders or stepper motors, whereas the other axes make use of more elaborate electrical actuation (e.g., servomotors and feedback).

A subclass of the jointed cylindrical manipulator is the *selective compliance assembly robot* (or SCARA) type of robot. Typically, these devices are relativly inexpensive and are used in applications that require rapid and smooth motions.

2.2.3.4. Cartesian Coordinate Robots: In this, the simplest of configurations, the links of the manipulator are constrained to move in a linear manner. Axes of a robotic device that behave in this way are referred to as "prismatic." Let us now consider the two types of Cartesian devices.

a. Cantilevered Cartesian: As shown in figure 2.2.2.4.(a),the arm is connected to a trunk , which in turn is attached to a base. It is seen that the members of the robot manipulator are constrained to move in directions parallel to the

Cartesian x,y,and z axes. Devices like these tend to have a limited extention from the support frame, are less rigid, but have a less restricted workspace than other robots. In addition, they have good repeatability and accuracy and are easier to program because of the "more natural" coordinate system.Certain types of motions may be more difficult to achieve with this configuration, due to the significant amount of computation required. Control Automation did manufacture a robot that was capable of unrestricted straight-line paths.

b. Gantry-Style Cartesian: Normally used when extremly heavy loads must be precisely moved, such robots are often mounted on the ceiling. They are generally more rigid but may provide less access to the workspace. In the last few years, a # of smaller devices in this class have emerged. In this instance, a framed structure is used to support the robot, thereby making it unnecessary to mount the device on the ceiling. The geometry of a gantryCartesian device is shown in figure 2.2.2.4.(b-1). A robot is not limited to only three degrees of freedom. Normally, a wrist is affixed to the end of the forearm. For example, as shown in figure 2.2.2.4.(b-2), axes that permit *roll,pitch*, and *yaw* are possible. Moreover , the entire base of the robot can be mounted on a device that permits motion in a plane.From this discussion it should be clear to the reader that robots with as many as eight axes can be constructed.

2.3. Classification by Control Method

As mentioned above, the second method of classification looks at the technique used to control the various axes of the robot. The four general classes are

2.3.1. Non- servo-controlled Robots: From a control standpoint, the non-servo-controlled or *limited-sequence robot*is the simplest type. Other names often used to described such a manipulator are *end point robot* , *pick-and-place robot,or bang-bang robot.* Regardlessof mechanical configuration or use, the major characteristic of such devices is that their axes remain in motion until the limits of travel (or " end stops") for each are reached. Thus only two positions for the individual axes are assumed. The non-servo nature of the control implies that once the manipulator has begun to move, it will continue to do so until the appropriate end stop is reached. There will be no monitoring of the motion at any intermediate points. As such, one refers to this class of robot as being controlled in an *open-loop* manner.

"Programming" a lilimited -sequence robot is accomplished by setting a desired *sequence* of moves and adjusting the end stops for each axis accordingly. The manipulator "brain" consists of a controller/sequencer. The "sequencer" portion is generally a motor-driven rotary device with a number of electrical contacts. The energized axis will continue to move untel the "programmed" end stop is reached. This information is then used to cause the sequencer to index to the next step in its "program." It is important for the reader to understand that this is the only time that information is "feedback"to the sequencer.

A typical operating sequence for a hydraulic or pneumatic non-servo-controlled robot is also follows:

1. A program "start" causes the conroller/sequencer to signal control valves on the manipulator's actuators.

2. This causes the appropriate valves to open , thereby permitting air or oil to flow into the corresponding pistons and the member(s) of the manipulator begin to move.

*3.*These valves *remain open* and the members continue to move until they are physically restrained from doing so by coming into contact with appropriatelly placed end stops.

4. Limit switches , generally located on the end stop assemblies , signal the end of travel to the controller/sequencer , which commands the open valves to close.

5. The sequencer now indexes to the next step and the controller again outputs signals to actuator valves, thereby causing other members of the manipulator to move. Alternatively, signals can be sent to an external device such as a "gripper," causing it to open or close as desired.

6. The process is repeated until all steps in the sequence are executed. Other attributes and/or capabilities worthy of mention for this class of robot are as follows:

. Conditional modification of the programmed sequence is possible if some type of external sensor is employed. Robots having this ability normally can perform one program.

. Open-loop or non-servo control is often used in smaller robots because of its low cost and simplicity.

. It is possible to have a number of "intermediate" stops for each of the axes. This allows the manipulator to be programmed for more complex paths and permits a limited degree of *path control.*

. Although the controller normally applies full power to an axis that is selected by the sequencer and turns this power off only when the limit stop is reached, it is possible to achieve a degree of decleration into the stop by using shock absorbes or appropriate valving at the end stops. This result is less stress on the components of the manipulator and on the part being moved.

2.3.2. Servo-controlled Robots: Servo-controlled robots are normally into either *continuous-path* or *point-to-point* devices. In either case, however, information about the position and velocity is continuously monitored and feedback to the control system associated with each of the joints of the robot. Consequently, each axis loop is "closed." Use of closed-loop control permits the manipulator's members to be commanded to move and stop *anywhere* within the limits of travel for the individual axes.

In addition, it is possible to control the velocity, acceleration, deceleration, and jerk for the various axes between the endpoints. Manipulator vibration can, as a consequence, be reduced significantly. Besides the above, servo-controlled robots also have the following additional features and/or attributes.

. A larger memory capaciyt than in non-controlled devices. This implies that they are able to store more positions (or points in space) and hence that the motions can be significantly more complex and smoother.

.The end of the manipulator can be moved in any one of three different classes of motion:

point-to-point: where the endpoints of the motion are important but the path connecting them is not.

straight line: where it is important to cause a specified location on the manipulator, often referred to as the *tool point*, to move from the initial point to the final one in a *linear* fashion (in three- dimensional space).

continuous path: where points along the path are connected so that the instantaneous position and either its spatial or time.

. Within the limits imposed by the mechanical components, positional accuracy can be varied by adjusting the gaina of appropriate amplifiers in the servo loops.

. Joint actuators are usually either hydraulic valve/piston arrangements or servomotors.

. Programming is generally done in what is referred to as *teach mode*. The manipulator is manually moved to a sequence of desırd poınts. The coordınates of each of these are stored ın the robot's (semıconductor) memory.

. It ıs possıble to program each axıs to move to almost any poınt ıts entıre range of travel. Consequently, thıs affords the user wıth a great deal of flexıbılıty ın the type of motıons that are possıble. It ıs ımportant to understant that such coordınatıon among the robot axes ıs normally done "automatıcally" under mını-or mıcro-computer control.

. It ıs possıble to permıt branchıng operatıons whereby alternatıve actıons are taken by the manıpulator based on data obtaıned from external sensors. Thıs capabılıty arıses from the extensıve use of mıcroprocessors ın the robot controller.

. Because servo-controlled robots generally have consıderably more complex control, computer, and mechanıcal structures than non-servo-controolled devıces, they may be more expensıve and somewhat less relıable. Neverthless, theır great flexıbılıty makes them extremly attractıve and cost-effectıve ın a large number of applıcatıons.

With these featıres ın mınd, the following represents a typıcal aperatıng sequence for a general servo-controlled robot:

1. At the begınnıng of the program, the actual posıtıon of the manıpulator joınts ıs obtaıned from approprıately mounted sensors. The desıred posıtıon ınformatıon ıs sent out to the ındıvıdual axes from a master computer.

2. For each joint, the actual and desired positions are compared and an "error" signal is formed. This is used to drive the individual joint actuators.

3. As a result, the members of the robotic manipulator move. Position, velocity, and any other physical parameter of the motion are monitored or estimated, and this is used to automatically modify the error signals accordingly.

4. When the error signals for all the individual axes are zero, the members stop moving and the manipulator is "home".

5. The master computer then sends out the next taught point, and steps 1 through 4 are repeated. This process continues until all of the desired points have been reached.

2.3.3. Point-to-point Servo-controlled Robots: are widely used for moving parts from one location to another and also for handling various types of tools. Although they can perform all of the tasks of the pick-and-place robot, they are far more versatile because of their ability to be multiply programmed and also because of their program storage capability. A typical point-to-point application might be the unloading or loading of a pallet of parts. In the former case, the robot would be taught each of the *n* locations on the pallet. It would then move to the first of these taught points, pick up the part, move to a position above the conveyor, and place the part onto the conveyor. The manipulator would repeat the action for each of the remaining (n-1) locations on the pallet. Such an application, while possible with a simple, nonservo pick-and-place device, would probably require a servo-driven x-y table that would actually move the pallet reletive to the fixed pickup point. An ex. of the loading a pallet is shown in the figure 2.3.3.

For the class of closed-loop control robot being considered here, only the initial and final points are taught. The path used to connect the two points is unimportant and is, therefore, not progrmmed by the user. More sophisticated point-to-point robots permit straight-line or piecewise-linear motions.

2.3.4. Continuous-path Servo-controlled Robots: Many applications do not require that the manipulator have a long reach or be able to carry a large load. In particular, there is an entire class of applications where it is most important to folllow a complex path through space and possibly to have the end of the arm move at high speeds. Ex. of these applications include spray painting, polishing, grinding, and are welding. In allinstances, the tool carried by the manipulator is fairly light but the required motion to perform the task may be quite complex. A continuous-path (CP) robot is usually called for in these cases.

Although points must still be taught prior to executing a program, the method of teaching is usually quite different from that used for the point-to-point servo-controlled robot. Unlike the procedure described above, points are not *recorded* manually in the CP robot. What happens is that in the teach mode, an automatic sampling routine is activated which can record points at a rate of 60 to 80 times a second for approximately 2 minutes. An operator simply moves the tool over the desired path with the sampler running. The sampling rate is usually high enough so that when the recorded points are "played back", extremly smooth motion results. It is clear that a large memory is required since as many as 9600 points may be recorded in the 2-minute period. To facilitate the accurate recording of complex paths, the tool can be moved over the desired path during the teaching phase at a slow speed. Platback, however, will be independent of the recorded speed, so rapid and accurate curve tracing is possible.

3.MAJOR COMPONENTS OF A ROBOT

Although the mechanical, electrical, and computational structure of robots can vary considerably, most have the following four major components in common: **(1).** a manipulator or arm (the "mechanical unit"), **(2).**one or more sensors, **(3).** a controller (the "brain") , and **(4).** a power supply.

1. ***The Manipulator:*** This is a collection of mechanical linkages connected by joints to form an *open-loop kinematic chain.* Also included are gears, coupling devices, and so on. The manipulator is capable of movement in various directions and is said to do "the work"and "manipulator" are often used interchangeably , although, strictly speaking, this is not correct.

Generally, joints of a manipulator fall into one of two classes. The first, *revolute,* produces pure rotary motion. Consequently, the term *rotary joint* is often used to describe it. The second, *prismatic*, produces pure linear or translational moyion and as a result, is often referred to as a linear joint. Each of the joints of a robot defines a *joint axis* about or along which the particular link either rotates or slides (translates). Every joint axis defines a *degree of freedom (DOF),* so that the total number of DOFs ie equal to the number of joints. Many robots have six DOFs, three for *positioning* (in space) and three for *orientation,* it is possible to have as few as two and as many as eight degrees of freedom.

Regardless of its mechanical configuration, the manipulator defined by the joint-link structure generally contains three main structural elements: the *arm,* the *wrist*, and the *hand* (or end effector). besides the mechanical components, most manipulators also contain the devices for producing the movement of the various mechanical members . these devices are referred to as *actuators* and may be pneumatic, hydraulic, or electrical in nature. they are invariably coupled to the various mechanical links or joints (axes) of the arm either directly ir indirectly. In the latter case, gears, belts, chains, harmonic drives , or lead screws can be used.

2. Sensory Devices: These elements inform the robot controller about the status of the manipulator. This can be done continuously or only at the end of a desired motion. Sensors used in modern robots can be divided into two general classes:

. Nonvisual

. visual

The first group includes limit switches (e.g., proximity, photoelectric, or mechanical), position sensors (e.g., optical encoders, potentiometers, or resolvers), velocity sensors (e.g., tachometers), or force and tactile sensors (for overload protection, path following, calibration, part recognition, or assembly work). The second group consists of vidicon, pled to appropriate image-detection hardware. They are used for tracking, object recognition, or object grasping.

3. The Controller: Robots controllers generally perform three functions:

* They initiate and terminate the motion of the individual components of the manipulator in a desired sequence and at specified points.

* They store position and sequence data in their memory.

* They permit the robot to be interfaced to the "outside" world via sensors mounted in the area where work is being performed.

To carry out these tasks, controllers must perform the necessary arithmetic computations for determining the correct manipulator path, speed, and position. They must also send signals to the joint-actuating devices and utilize the information provided by the robot's sensors. Finally, they must permit communication between peripheral devices and the manipulator.

Robot controllers usually fall into one of the following classes:

* Simple step sequencer.
* Pneumatic logic system.
* Microcomputer.
* Minicomputer.

4. The Power Conversion Unit: The purpose of this part of the robot is to provide the necessary energy to the manipulator's actuators. It can take the form of a power amplifier in the case of servomotor-actuated systems, or it can be a remote compressor when pneumatic or hydraulic devices are used.

Up to this point, we have been concerned primarily with the classification of robots according to their geometry or control scheme. In addition, we have briefly described in the current section the major components that one expects to find in any industrial robotic device.

5.FIXED VERSUS FLEXIBLE AUTOMATION The age of automation started in the 18. Century when machiness began to take over jobs that had previously been performedby human beings. Since that time, new machiness have been finding their way into factories as more and more new products have been conceived. Up to time of the first robot, these machines have had major thing in common: They have been designed to perform essantially one task with little capabilitiy for changing. For example, where as the devices that produce bottles can be adjusted to produce bottles of different sizes, they can not produce light bulbs. Generally, machines of this type are referred to as fixed automated devices and the process that incorporates them is called fixed (or hard) automation.

With the advent of the industrial robot, a new method of automating products become possible . Called flexible automation, a single complex machine was now able to perform a multitude of of jobs with relatively minor modification and litlle "down time" needed when changing from one task to another.

1.Reaction time: In general when a fixed automated device is to be used in a process for the first time , it must be designed, built, and tested before it can be used. As an example let us suppose that a plant manager decides to introduce a new product into an existing facility. To do this,an assembly process requiring new machinery is necessary. The traditional approach is to have the plant's manifacturing engineering staff study the problem and than generate a set of specificationsfor the device that will perform the requiring tasks. After evaluating competitive bids, a manufacturer of this special-purposedevice willbe selected. A period of time will then go by while the machine is fabricated. It is not unlikely that during this time , the original specifications will have to be modified, thus, postponingthe actuall delivery date of equipment. Eventually, however, the fixed automateddevice will be installed at the manufacturing facility. At this point, it probably cannot be used to produce anything yet , because it must first be tested and adjusted. Such a process may take months. When it is finally ready to go, many months and even years may have elapsed since the idea to produce the new product was conceived. The long lead time may be accptable in some instances, but it may also mean that in certain highly competitive industries, the edge has been lost.

How could flexiable automation help solve the problem ? First a robot is an off-shelf device. Once the appropriate type of unit is selected, a rather short period will elapse beforethe robot is delivered to the factory. Once it is uncrated it is essentially "ready to go". Inreality, a period of time must be allocated for personal to become acclimatedand for programming. Also techniques and devices that permit the appropriate parts in the particular process to be properly presented to the robot must be developed, although this will often be done during the planning stage and while the robot is built.These devices are referred to as the roboting tooling and might consistand shakers. In point of fact, it is the unique gripper that permits the off-the-shelf robot to the costimized to a particular task. In any case, it is most likely that the robots will be able to do the job after a relatively short period. Moerever, if any variability developes in the process it will usually be quite easy to compensate for this with the robot. For example, if small size changes in metal casting occured with time due to mold wear, it might be possible to handle any misaligment problems by modifying then robots program. Such might not be true with the fixed automated device.

It is clear thatuse of a robot may significantly reduce the lead time required to start producing a new product and will faciliate changes necessiated by proces variability. Thus even though a robot may cost significantly more than the fixed automated equipment initially , the robot will actually be less costly when time is factored in.

2.Debugging: As mentioned above, once a fixed automated device is delivered to the plant, it must be placed into operation. Due to the fact that is a special purpose electromechanical device for which there is little or no past history of operation, this will often require a good deal of "fine tuning". For example, limit switches and perhaps other sensors will have to correctly postione, solenoidsproperly adjusted, and so on. In some instances , it many even be necessary to redesign and rebuilt entire portionesof the machine before satisfactory operation is achieved. All of this will , no doubt , make the debuggingor shakedown part of the procedure a time-consuming affair. On the other hand, If if a robot is to be used the perform the same task, the debugging operation will take a significantly shorter time. Since the robot is an off-the-shelf piece of auromation, power connections, perhaps commpressed air lines, and proper positioning will be required. Also the appropriate gripper will have to be available, although such devices were prooperly ordred at the same time as the robot.

3.Resistance to obsolescense: Enbelgerhas said that resistance to obsolesnce is the "very essence of the robot". Unlike a piece of fixed automation which is capable of performing only a single, specific task, the robot is not limited particular industry. In fact, many of the robots that were purchasedin the early 1960s are still operational despite the fact that they are considerably less sophisticated than modern day units. Is it this aspect that makes flexiable automation such an attractive alternative to companies that regularly require model changes that necessiate retooling. Theses industries can now retool, in part, by reprogramming their robots and also by utilizing different types of grippers.

Consequently, downtime and costs can be reduced cosiderably.

Theses manufacturers have discover that because a robot can be placed into operation in a much shoerter time when the design, building, and debuggingof a fixed automated device are taken in tha account, they can probably begin to produce their product much faster. Also even though a robot is a complex device, its capital cost may actually be lower than that a comperable hard automated machine. For although the cost of the developing a robot may be great, it can be amortized over a large number of units and many different custemers, where as all of the development costs for special-purpose devices must usually be borne by a single user. Consequently, on a per units, these cost will be relatively small when alarge number to be purchased.

The final reason for choosing a robot to perform a limited range of tasks is that, besides the time and costs factors discussed above, the device can always handle other manufacturing tasks, if necessary. The manufacturer recognize that even though modification or complete change over of a process cannot be anticipated at the time of purchased, the robot will be able to adapt to new situation if the time ever arises when change is necessary or desirable. Although it does not cost any more to get the ability to change, it is the knowledge that it is, there which is confirming. Of course, this is one of the major advantage of flexiable automation.

4.Economic consideration : The important result of this section has been to demonstrate clearly that from an econamic point of wiev, robots seems to mahe a great meke of sense. However, what about the human element? What will be impact on the workers themselves of introduction these devices into the workplace? We present possible answers to these and other problems.

5.Sociological Cconsequences of Robots : With the introduction of the robot, the 20.centruy worker may well face many of the same problems as those of these of 18.centruy counter part and in addition, a host of others. If, as has been said, the robot will be the catalyst for initiating the second industrial revolution, an important question that must be asked is : What will be the effect on society as a whole and the individul worker in particular? Clearly, there are no path answers to such a question, norare there easy solutions to yhe problems that will inevitably arise, and in certain instances have already arisen, when robots and other high level intelligant automation devices are introduced into the manufacturing environment. In this section we wish to make the reader aware of the difficulties rhat american sociaty will face as this new form of technology becomes a "way of life".

TABLE :U.S AND JAPANESE ROBOT PRODUCTION.

	UNITS /YEAR		***VALUE (MILLIONS)***	
YEAR	**U.S**	**JAPAN**	**U.S**	**JAPAN**
1979	**614**	**2,763**	**$ 62.5**	**$ 81.1**
1980	**1,118**	**4,493**	**$ 101,0**	**$ 205.3**
1981	**1,993**	**8,182**	**155.0**	**310.7**
1982	**2,585**	**14,937**	**190.0**	**471.0**
1983	**3.060**	**18,599**	**240.0**	**612.9**

1984	**5,137**	**23,249**	**332.6**	**766.1**
1985	**6,209**	**31,900**	**442.7**	**2,150**
1990	**21,575**	**57,450**	**1,884**	**4,450**

6.Robotic Aplications : Current and Future

Inthis relative infancy, the state of the art of robotic applications is, in some ways paralelling the development of digitial computers. When they first introduced, compyters were useed for tasks that had previously benn performed for people. This was a natural application, for it was obvious that the new device would be able to perform such jobs much faster and even more reliably than people could perform them. However, as time progressed, it was recognized that tasks that had herefore been rejected as being imposible to undertake because of excessive manower and/or time requirements werer now possible to attempt. Thus problems that were "not practicle"to solve were handled with relative ease. Besides being able to solve such problems, it became apperent that there werer many applications for the computer that had never been thought of before its development. In a sense, what happened was the people took off their "blinders" and allowed their imaginations free reign. The result of this has been that computers are now apllied in many areas other than the more traditional "number crunching" that wsas initially envisioned as the major use. The fields of control learning and teaching devices, handling of large data bases, and artificial intelligence come to mind, to name but a few nontraditional aplications. But where do we stand with robots?

Current Robotic Applications

a)Welding : Welding is one of the major uses for an industrial robot. Actually, two distinct types of welding operations are readily and economacily performed by robots :spot and arc welding. In the former case, the robot is thaught a series of distinct points. Since the metal parts that are to be joined may be quite irregular, a wirst with good dexterity is often required. This permits the welding tool to be aligned properlyat the desired weld point without the gun coming into contact with other portions of the part.

The second ype of welding aplication, is also utilized extensively by the auto industry

b)Spray painting: The spray paintimg operation is one that human beings should not perform both because of the potentional fire hazard and the fact that a fine mist of paint is carciogenic.

Programming a spray painting robot is usually performed by the best human operator. His actions are than mimicked by one or more robots. The spray painting application generally does not require the use of external sensors. However it is necessary that the part to be painted be accurately presnted to the manipulator.

c)Grinding: In this grinding applications, there is always some uncertainty in the diemension of the part being worked on. As a result, sensory information is often needed to permit the robot to more accurately “feel“ the actual contour of the part. This is especially important in the case of smoothinig of the arc weld bead. Relatively simple touch sensors that provide this information are currently available .

--------- CHAPTER TWO--------

ROBOTIC SENSORY DEVICE

2.0 OBJECTIVES :

In general its found that some are inherantly digitial devices where as others are essentially analog in nature.

Sensors can be divided into two basic classes. The first, called internal state sensors consist of devices used to measure position, velocity or accelaration of robot joints and / or and effector. Specify , the following devices that fall into this class will be discussed :

- potentiometers
- synchros
- resolvers
- linear inductive scalers
- differentional tranformers
- optical interrupts
- optical encoders
- tachometers
- acclerometers
-

The second class called external state sensors, is used the monitor the robots geometric and/ or dynamic relation to its task, environment,or the objects that is handling. Such devices can be of either the visiul or nonvisiol varierty. The former group of sensors is treated . We discussed this techniques that permit the monitoring of 1- distance from an object or an obstraction 2- toouch / slip 3- force / torque

- strain gages
- pressure transducers
- ultrasonic sensors
- electromagnetic sensors
- elestromtric materials

2.1 Motivation :

Successive control of mosts robots depends on being able to obtain information about the joint and / or effector. It is therefore necessary to havedevices that provide such information and can be readily utilized in a robot for this purpose. In particular, position, velocity. And / or acceleration must be measured to ensure that the robotic manipulator moves in a desired manner with little or no oscillation at the final position. These so called "internal state sensors" must not only permit the required deggree of accuracy to be achieved, but they must also be cost effective since each of the robot axes will be normaly utilize such devices. As a consequence the sensor selection and the decision to place it either or load side or on the output of the joint actuator itself is influenced by such factors as overal sensors cost, power needs for a particular joint, maximum permissible size of the actuator, sensor resolution, and the need to monitor directly the actions of the joint. These ideas are discussed with workings of the sensors themselves.

Although it is possible to utilize a robot without any external sensing whatsoever, more and varied applications require such devices. Thus, in addition to the control of the robotic manipulatoritself, certain more sophisticatedtasks require variety of quantitiesbe monitoredat the gripper. The data gathered by sensors placed on or near the gripper can then be utilized by the robots controller to modify or adapt to a given situation. For example, if it is necessary to handle several different parts, some of which are rather fragile, it is important to measure thee instanteneous gripping force being applied and adjust it to be sufficiant to pick up an object without crushing it. Of course the particular application will influence the type, costrucion, and cost of such sensors.

2.2 Nonoptical-position Sensors

Here we discuss the operation and aplications of simple internal state sensors that can be monitor joint position. Included are the potentiometer, synhro, resolver, and LVDT. It will be seen that some of this devices are inherently analog and some are digitial in nature.

Potetiometers : The simplest device that can be used to mesure position is the potentiometer or “pot”.Appliedto robots, such devices can be made to monitor can be made to monitor either angular position of a revolute joint or linear position of a prismatic joint. A pot can be constracted by winding a resistive element in a coil configuration. By appliying a dc voltage Vs accros the entire resistance R, the voltage Vout is proportonal to the linear or rotary distance of sliding contact from reference point a.

1) Synchro : As mentioned above, a significant practical problem with the pot is that it requires a pysical contact in oreder to produce an output. There are,however a variety of sensing devices and techniques that avoid this difficulty. The first one that we discuss is the synchro, a rotary transducer that converts angular displacement into an ac voltage or ac voltage into an angular displacement. Historically, this device was used extensively during WORLD WAR II, but technological innovations that produce other postion-sensing elements caused it to fall from favor In recent years , however, advances in solid-state technology have again made the synchro a posible alternative for certain types of systems, among them robots.

2) **Resolvers :**The resolver is actually a form of synchro and for that reason is often called a synhro resolver. One of the major differences between the two devices is that the stator and rotor windings of the resolverare displaced mechanically 90 deggre to each other instead of 120 degree as is case with the synhro.

An alternative form of resolver has two stator and two rotor windings. For example, if the former is used as an input, the unused stator winding is normally shorted.

3) Linear Variable Differential Transformers: Another device that is both extermely rugged and capable of accurate position determination is the linear varieble differential transformer. The electromechanical transducer is capable of producing a voltage output that is proportional to the displacement of the movable member relative to the fixed one.

2.3) Optical Position Sensors: The sensors can theoreticaly be used to determine the position of a robotic joint. However, for one or more pacticle reasons,doing so is either not possibleor often difficult and/or inconvenient. Another class of sensor, utilizing optical hardware and techniques, can quite frequently be used to perform the position determination taSK with relative ease and suprizing accuracy.

points is not important , and hence little or no position information is utilized by the robot's control system except at the trajectory end point. The actuators drive the joints of the robot until the final position is sensed, at which time the actuating signals are removed. In effect, an open loop control scheme is used. "Programming"is accomplished by moving the end point sensors to different locations.

It might appear that a simple mechanical switch is an ideal device for thia application. However,because of the needed to interface to switvch with a microprocessor, the inevitable contact bounce problem and the limited life expectancy make this approach relativelyimpracter for commerical robots.

b)Optical Encoders : one of the most widely position sensors is the optical encoder. Capable of resolutions that are more than adequate for robotic aplications, this noncontact sensory devices come into two distinct classes : 1- absolute and 2- incremental. In the former case, the encoder is able to give the actual or rotational position even if the power has just been applied to the electromechanical system using the sensor. Thus a robot joint equipped with an absolute encoder will not require any calibration cycle since the controller will immediately, upon power-up, know the actual joint position.

One question that may have occured to the reader is how can an *incremental* device be used to obtain to absolute position information required by a robot? Indeed, it apperas on the surface that it can not and that the need for knowledge about where a robot axis actually is within its workspace can be met only by an absolute device. However, this is not tha case and, infact there are at least two distict methods in current use which permit the incremental ancoder to be utilized as an absolute device, with the resultant cost savings.

1. Zero references channel : The diffuculty with an ancremental encoder is that it provide positional information only for a single rotation of the encoder disk. Since almost all robotic axes require that the actuator must complete well over 100 turns in order to cause the joint itself to make one complete rotation, some method of keepig track of the rotation number must be included. Clearly , it is not difficult to do this. As an example, for a line 300-line was counted, the rotation count would be incremented or decremented depending on the shaft rotation direction.

A second and more important role for the zero refences channel is in yhe calivration of the robot axis. When power is applied to the robot, each joint is caused to move in a predetermined direction toward a mechanical end stop on the axis. The actuator continuous to turn until the end stop is encountered. The stoppage can most easily be detected by using the encoder and looking for a situation where over a period of time, the count does not change. Note that it is not necessary to know the value absolutely. All that is required is the current count be same as that obtained, for example, 100, ms before. Once the system recognize that the axis has reached the mechanical end of travel, the actuator is reversed and continuous until the firsyt index pulse is generated. At this point, the counter can be initialized to zero. All subsequent motoins will be relative to this calibration point, and absolute position can be obtained simply by reading both the encoder count and the number of index pulse accumulated.

2) Absolute position using a pot and an incremental encoder : A second technique exist for utilizing an incremental encoder is an absolute position information. In this case, a pot is used together with the encoder. Where it was stated that it is difficult to use pots as position sensors on robots becauseof severe rereliability problems caused by electrical noise. However, it is possible to get around this problem by using pot for "coarse" and the encoder for "fine" position information.

A final word is order concerning the two methods describing . The major differences between this two techniques us that when power is first appliedto the robot controller, the system utilizing the hybrid scheme "knows where it is" with an eror of at most one actuator rotation.

On the other hand, a system that employes the pure digitial technique only knows where it is once the calibration phase is completed. Before that it is truly "lost in space". Although this may appear to be disadvantage, it really is not since uncalibtated robots are not very useful devices. Thus regardless of the scheme employed, calibration must first be performed before any useful work can be done.

2.5 Instability Resulting From Using an Incremental Encoder :

However, a potentional difficulty with this device is that the mechanism that incorporates such a sensor in its servo may actually oscillate.

1. Digitial Jitter Problem : First suppose that a robot axis is required to holda load horizantely. As there is no motion required, the desired and the actuall position, are the same and the error signal in the position servo is zero. However, this situation can not continue indefinetly since the robot's joint will begin to rotate downward due to influence of gravity. If for the moment we assume that no multplyingcircuitry is utilized with the N-line incremental encoder that is on the joint actuator, the axis will continue to move until the first encoder line is continued. This means that the servo will no knowledege that the desired and the actual positions are different until the actuator has rotated 360/N degrees! At this time an error signal will be generated and the actuator will return the joint to the desired horizontal position. The reader can readily understand that the entire cycle described above will repeat so that the load will not remain in the home position but will, instead, oscillate about it. This oscillation, which is characteristic of most digitial - position servos, is a "limit cycle" and si often reffered to as *digital jitter.* Clearly , such behavior is quite undesirable in a robot, and for that matter, any precision positioning device .

   Note that where a fair amount of fraciton is present, as in the case of some robot joint mechanisms, this may be all that is needed to prevent the limit cycle from occurring. Where the fraction does not damp out the oscillation, however, other measures are required.

2. Analog Locking of a Position Servo : The digitial jitter just described comes about due to discrete or quantized natureof the error signal. Obviously if this error was continuous there would be no such a problem. In this regard, one of the advantage of an anolog position sensor, such as a pot, is that it does produce a continuous signal, and thus its used would prevent digitial jitter from occuring. However, the reader will recall that the pot suffers from other problems that make it unsuitable for most precision positioning applications, including robotics.

   Fortunately, the encoder can again be used to "save the day".

2.6 Velocity Sensors

We will learn, it is possible to determine the angular velocity of a rotating shaft in several differen ways. For example the dc tachometer has been used extensively for this purpose in many different control applications, including robotics. In addition to this anolog devide, however, it is possible to utilize an optical encoder and a frequency-to-voltage converterto obtain anolog velocity. Alyternatively, the optical encoder itself can be made to yield digitial velocity information when combined the appropriate software

1- Dc Tachometers : The first and the most important one is that the tachometer should produce a dc voltage that not only a proportional to the shaft speedbut also has a voltage versus speed characteristic that is idealy lineer over the entire operating range. This permits to tach to be most easily used as a velocity sensor in controll applications. Normally, the generated voltage produced by a dc motor will not posses the degree of linearity required in these cases.

The other reason for not using a dc motor as a tach is that valume and/or weight is often an important system design consideration. This is certainly the case for the axes of an industrial robot, where the actuator must often be caried along in the joint itself. Since the tachometers supplies little if any current to the rest of the servo system, the output power requirement of the device is minimal. Thus it hardly mankes sense to use a motor in this apllication, and a smaller device is quite satisfactory.

2-Velocity Mesurement Using an Optical Encoder : Two techniques exist for doing this. The first utilizes for this both the encoder and a frequency to voltage converter to provide an anolog voltage that is proportionalto shaft speed. As far as the user is concerned, it behaves very much makes use the encoder and appropriate software to provide a digitial represention of the shaft velocity. In fact ,robots today do indeed use the optical encoder to produce digitial position and velocity information. We briaefly describe these two methods:

a) Encoder and frequency-to -voltage converter :
TTL encoder pulses and using its own internally generated clock cycle. The binary count is then output to an internal DAC which produces the desired dc voltage that is proportional to the encoder disk speed and hence the motor shaft speed.

How does the velocity signal produced by this device
compare to that of an anolog tachometer? First, the output
of the FVC has less riplee than that of the tach, and in fact
the nature of this ripple is totally different. The internal
DAC produces a piecewise constant outrut which,
depending on its conversition rate, will have a period

b) Encoder and Software : As indicated above, there is a way to obtain velocity information using an incremental encoder by processing the position data

2.7 Accelerometers :

Besides monitoring the position and velocity of a physicall system, it is also possible to monitor its acceleration. Normally, linear acceleration is measured, whereas angular acceleration is most often derived from angular velocity by differentiation.

2.8 Proximity sensors :

Up to this point, we have discussed the behavior and application of sensors that were used to measure the position , velocity or acceleration of robot joints and were called collectively internal state sensors. A second major class of robotic sensor is used to monitor to robots geometric and/or dynamic relation to its task. Such sensors are sometimes referred to as external state sensors. Machine or robotic vision systems represent an important subclass of this group of devices. Although some of this may utilize optical techniques as part of their sensing system, they are not properly classifed as visiul sensors.

In this part we describe a number of sensors used to tell the robot when it is near an object or obstruction. This can be done either by using contacting or noncontacting technique.

a) Contact proximity sensors : The simplest type of proximity sensor is of the contacting variety. As the roboticmanipulator moves, the sensor will become active only when the rod comes in contactwith an object or an obstruction. When this occurs, the switch mounted inside the sensor will close. The

b) change of of the state, of the monitored thought the robot's I/O interface, will cause an appropriate action to take place.

It is important to understand that a single contact proximity device cannot provide any information about the shape or natyreof the object or obstacle.

b) Noncontact Prximity Sensors : In constrast to the devices described above, a much larger classof proximity sensor does not require any physical contact at all in order to produce a signal that can be used by a robot to determine whetever it is near an object or obstacle.

1)Reflected Light Sensor : The sensor consist of light and a photodetecter seperated by about 8 mm and titled symetricaly toward one another.

Although the maximum the maximum sensor output will occur when an object is at the focal point . That is, two different object positions produce the same voltage execpt when the object is located exactly at the focal point. Since a one-to0one correspondence between position and the detector voltage does not exist, additional logic or hardware is required to eliminate the ambiguity. For exemple, if the robot is moving and the sensor signal is increasing, it is clear that the object is on the far side of the focal point. If, however , the signal is decraising, the focal point has been passed and the smaller distance should be used. Several sensors placed at angles can also be utilized to eliminate this ambiguty.

Besides the difficulty, other problems with the sensor exist . However, a more difficult and perhaps impossible problemto overcome is thatthe sensor is sensitive to the reflecttivity of the object or obstacle.

2) Fiber Optic Scanning sensors: Fiber optic has been used to develop several different types of

3) noncontact proximity sensors.It is important to understand that is not possible, in all case, to obtain reliable absolute position information. The devices can only tell whether or not part is present

In the opposed or beam break configuration, the object is detected when it actualy interrupts the beam of the light. Such an optical interrupter depends on the object being opaque and is, obviously,not useful where parts are made of transparent or translucent materials. By employing high gain amplifers and noise-reduction schemes, these sensors can detect objects as close as a few mils and as far away as several inches. However, they are limiting to informing the robot that something is or is not present. That is absolute position information cannot be obtained. In addition to this, the receiver fiber bundle alligment is fairly critical. Thus anything that would tend to misalign it form the emitter bundle would obviously affect the sensor effectivenes. Finaly it would be necessary to use units with different gaps and/or lenghts, depending on the type and sizeof the object to be send.

A bifurcated fiber bundle is gain used, but there is no retpreflective target. The sensor actually can measure the amount of the light reflected from an object up to a few inchesaway from the fiber bundle. Since most materials reflect some light, this difuse device can ce used to detect transparent and translucent objects. As in the case of the reflected light proximity detector desribed above, some degree of absolute position monitoring is possible under ideal conditions. However, all of the difficulties with that type of sensor that were described previouslyare also present with the fiber optic version. Nevertheless, this mode of fiber optic sensing is the most commonly used one since it is self-contained, rugged, weighs very little, and is relatively inexpensive, making it idealy suited for a manufacturing environment.

3)Scanning laser sensors : Consist of a laser light source, two mirrors, one of which is rotated by an ac motor, and a lens-photo-receiver assembly, this scanning laser device has been used to permit an industrial robot to arc weld curved objects. Distance from the sensor to this point determined by synchronizing the ac motor voltage with a high frequency clock.

4) Ultrasonic Sensors : Ultrasonic has been used to provide rangig and imaging information for many years.

Although there are several different sonar sesing techniques, robots normally utilize devices that produce short bursrts of a sinusoidal wave form whose frequency is above the audio range.

Polaroid and other ultasonic sensors have also been used on a number of mobile robots to determine the distance from walls and obstacles. In one experimental device develop at the Drexel University in 1983, the common problem of loss of the position calibration due to wheel slippage was practically elinminated using a single sonar sensorrotated 180 degree by a stepper motor to determine the actual distance from walls and known obstacles. The robots path was thaught and follewed utilizing distance information from incremental encoders mounted on the derive-whell servo motors . Recalibration of the system from time was achieved " on the fly" reported by the sonar sensor with that given by the encoder. Position counters were then adjusred accordingly. A position error of about 0.5% was obtained using this procedire. In another mobile device 14 narrow-angle ultrasonic sensors were placed at various locations on the French Hilare robot. The transmision angle of this detectors was 30 degree, whereas the receiving angle was only 15 degree. The large number of sensor was require to eliminate “blind spots” araound the perimeterof the robot that would otherwisebe present due to the narrow-angle detevtors used. Measursd distance of approximately 2mm with an accuracy of about 0.5 cm were reported.

5) Eddy-Current sensors : another type of sensor used as proximity switched and for determined to accuracy and repeatability of commerical robotic manipulators operates on the eddy- current principle, A typicall device of this class utilizes a sensing coil to induce high frequncy currents in a ferrous or nonferrous condictive target. The amplituted of the sensors generated oscillation depends on the distance between the metal surface and the coil, this in turn determines the amount of magnetic ccoupling in the overal circuit. Consequently can be obtained by monitoring to amplitude.

Eddy-current sensors are idealy suited for the manifacturing environment because they are able to operate reliably in areas contaminated by oil and dirt and also where there is significant variation in temprature and humidity.

The major disadvantage of these devices is that they must be calibrated for the type of metal used for the target. Thus in robot application, the detetor might have to be recallibrated for each different type of part inspected. Also the effective linear measuring range is determined by the size of the sensor, with larger distances implying physically larger probes.

6) Resistive Sensing : A problem encountered in the robtic application of arc welding is keeping the welding tool tip at the specific constant distance from the seem that is to be welded. By doing this and also keeping constant the speed with

gun is moved, the uniformity and the strength of the weld be controlled. In addition, a strong weld can be ensured by having the robot accurately “track “this seem. Atechnique that has been developed to meet these requirements is called through-the-arc resistive sensing. The fundemental principle underlying such a sesory technique is that for a constant voltage applied to the welding tool, the arc resistance is a measure of the height of the torch tip above he surface that is to be welded. Inductive current monitoring is utilized because welding normally produces large currents.

-------------------CHAPTER THREE------------------------

COMPUTER VISION FOR ROBOTIC SYSTEMS:A FUNCTIONAL APPROACH

2.0 OBJECTIVES

- Computer vision components
- Computer vision task complexity
- General approaches to computer vison architecture
- Problem types amenable to solution by computer vision techniques

To reach not objectives, not all topics in computer vision can be treated, since complete coverege of this subject would easily require several volumes. Befaore the specific issues of computer vision systems are addressed, the functional requirements of machine visionshould be presented. Basically, these visual tasks concerninghandling or acquisationof a part can be thought of a series of questions that an expert viewer must answer:

•Where is it?

•Is it theone I am looking for?

- Is it defective or is it OK?
- Is it right side up?
- Is it being interfered with by another object at the same type?
- What is the angle of the object relative to my hand?

These types of questions lead us to consider the human visual intelligence system and its components:

- eye(S)
- Neural connections
- Visual cortex.

Physiological subsystems can losely model and architecture of current vision system. These include:

- Sensors
- Data paths
- Computer or processor

This configuration is far too general and must be further subdivided. With this in mind, the topics that will be covered in this chapter are:

- Imaging components
- Image reprasentation
- Hardware consideration
- picture coding
- Object recognation and categorization
- Software considerations
- Need for vision training and adaptations
- Review of existing systems

3.1 Motivation :

Computer vision is somewhat glamorous phrase that describes a wide class of computer image analysis topics. The use of the word "vision"is in many ways a poor choice, because it imbues a sense or inteligance to the robot that is undersurved and nonexist. As used in this text and in mosy applied fields, computer vision is simply the analysisof photometric noncontact measurements obtained from a closed cicuit television camera or other photo-sensimgelement such as a linear photoarray. Although there are a wide variety of photoimaging sensors, we will generaly use to term CCTVin references to the standard television camera, and not to do generic class photosensors. We will often refer to do sensor as being a CCTV, but the reader should extend the meaning to other type of photosensors . The electrical voltage output from the CCTVis generally converted to a digitial form, where processing of the imaging information by a digitial computer may be accomplished.

The type of information to be produced by such a camera-computer couplet is:

- Location of a stationary object
- Object tracking a function a time
- Object identification
- Object orientation
- Defect recognition and inspection of an object

Why, then bother with "computer vision" systems if they require such high speed, high data valume solution? The answer is simple : noncontact measurement . The advantage of noncontact location, detection and identification are often so overwhelming that one is often forced to computer vision solution. It and human vision is often selected. In those cases where human interactime vision has proven necessary,iy is responsible to try to utilize computer vision toward the same end.

3.2) Imagimg Components :

The imaging component, the eye or the sensor, is the first link in the vision chain. Numereous sensors may be used to observe the world. All the vision components have the proreyt that they are “remote sensing“ or noncontact mesurement device.

Vision sensors can be recognized in many different ways. For conveninence, will be catogorized them according to their diemensionality although they could also be classifed by their wavwlength sensivity. Vision sensors may be conveninently divided into the following diemensional categories or class.

- point sensors
- line sensors
- planer sensors
- valume sensors

3.2.1) Point sensors :

The point sensors may be similar to “electric eyes”, being either some type of photo multiplier, or more commonly, a phototransistor. In either case, the sensor is capable of measurig the light only at a single point in a space. For this reason they are refered to as “point sensors” .These sensors may be coupled with a light source and used as a contact “feeler” as shown in the figure.

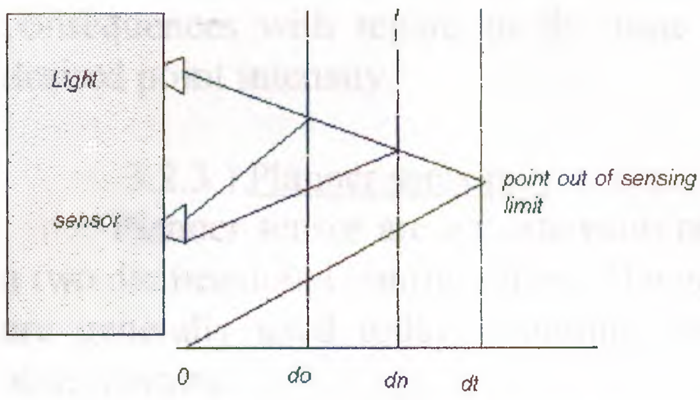

figure 1 : Noncontact feeler-point sensor. The object is sensed only if its location falls between dn and dt . Points located beyond dt are out of the sensing limit of the device.

3.2.2) Line sensors :

Line sensors are one diemensional devices and may be used to collect vision information from a scene in the real world. The sensor most frequently used is a "line array" of photodiodes or charge coupled device components. These devices are similar in operation, both beeing the equivelant of "analog shift registers" that produce a sequential, synchronized output of alectronical signals corresponding to the light intensity falling on an integrating light collecting cell. The light output from these arrays is available sequentialy . The consequence of this is that the light intensity from the scene is available only in an ordered sequence and not at rondom on demend by the user, this has some consequences with regard to the time requiring for accessinga desired point intensity.

3.2.3) Planner sensors :

Planner sensor are an extension of the line-scan concept to a two diemensional configuration. The generic type of this sensors are generally used today: scanning photomultipliers and solid atate sensors.

The scanning photomultipliers are the representation by the television camera. The most common type of television cameras used is the vidicon tube which is essantially an optical to electrical converter. The photoelectric target "boils off " electrons when struck by photons in the visable spectrum. The electrons boiled of in this process are colected via the current in a scanning electron beam. This beam is scanned back and forth accross the photo electric target in a so called rasyter fashion . The rate and the pattern of the raster scan differs throughout the world with a variety of existing standarts.

A more detailed description of the operation of this tube follows. An optical image is focused on a photoconductive target layer, it becomes conductive and transfers electrons to the positive signals plate. The transfer causes a charge to build up on the faceof the target. Its reverse face its scanned by a low velocity electron beam that tends to stabilze the target at the cathodes potential. This scanning causes a current to be generated which is indicative of the light intensity pattern on the photoconductive layer.

Its important to node that each time the target is scanned, it again begins transfering charge to the plate depending on the intensity of the incident light. In fact,the amount of charge may be thought of as being propportional to the integral of the light intensity. Since the raster scan is periodic in time , if a constant amount of light is incident on a particular point, the same charge will be present at each pass of the scan. From this description, it can be interfered that it is not possible to expose a vidicon to kight and rondomly read to data or expect consistent results by executing a single raster scan.

As in any physical system, the vidicon family has an upper limit to the amount of intensity that can be accepted by the photoconductive layer. If too much light is incident on a certain porition on a sensor, additional electrons from nearby aresa may also be removed. This phenomeon is called blooming and is evidenced as an area of maximum intensity of the image.

Another important concept of the vidicon is that when the electron beem resets the charge, it may not rest completely. Any remaining charge then decays exponenetionaly. The term given to this phonomenon is called lag and is related to the speed of response of the camera. The physicall manifastation of lag is that the when a movig object it may seem transparent .Additionaly, if one observes an objects as it moves into a cameras field of view and then stops,it may be necessary to wait for the motion to case before an accurate representation of the object can be obtained.

Although a vidican sensoris not inherently a raster -scan device the raster-scan creates ecomies in manufactureand of course provides a simple mechanism for viewing the scene using ordinary television monitors, also relatively inexpensive.

Random -access scanning photomultipliers are also available but the photoelectric device is more expensive to manufacture and the control circuitry is more complex because of the random access requirements. Since this tube does not rely on the conventional rasre scan, interesting veriations such as spiral scans or redial scans may be implementeed. Viewing the output of such a device would require a more costly monitor that is capable of accepting both a raster and rondom- access inputs with some type of mode switchinh required.

In addition to vidiciom transducers several types of solid-state cameras are available. The solid-state camera is manufactured in a fashion similar to large-scale integrated circuits. The sensor elements themselves are very different from the photosensitive elments in a vidicon camera but the arrays are still accessed in a serial or raster fashion. For this reason the solid -state cameras have no accsesed-time advantage over the vidicon tube cameras. The solid-state arrays are inherantly less noise then the vidison cameras, but are also considerably more expensive. This price / performance tradeoff between the camera types must be carefuly considered befora final selecition of a photo- optical transducer is made for a particular application. Many applications require the solid-state sensors because of weight and noise factors. This would be particulary important if it very necessary to mount the camera nnear on the and effoctoe of a robot.

It is impotant to understand how video information two-diemensional array is acquired. In the case of the CCD the most popular topology used is the frame transfer ficture. FT technology makes use of an imaging area which is exposed to like and generates charges proprtional to the integral of the like ntensty. There is also a storage area having the some number of cells as the imaging area. During the "frame time" when the image area is exposed, charge is accumulated at various cell locations in the array. After proper exposure, but before the next frame, this charge is clocked up to the corresponding cell in the storage area.During the "frame time" when the image area is exposed, charge is accumulated at various cell iocations in the array. After proper exposure, but before the next frame, this charge is clocked up to the corresponding cell in the storage area. A transfer register thet permits each row of data to be moved in a serial manner is utilized in the operation. Whele the imaging area is being exposed for acquisitaion of the next frame of data, the charge pattern of the pevious frame can be read out from the storage area by means of the readout register that operaters in a manner smilar to the transfer regisrter.

Table 3.2.1 : Brief comparision of camera technologies

Feature/specification	vidicon	CCD	CID
Resolution	1	2	2
sensitivity	1	2	3
speed	3	2	1
bloom	3	2	1
size	2	1	1
reliability	2	1	1
current cost	1	2	3
future cost	2	1	3

Solid-state imagers alsa exhibit blooming. In this case, the charge carriers generated from an extremely brighthd part of an image spreat to nearby alaments because those elements located in the bright area rae saturated. This charge travels to nearby locations thereby causing false a information to be delivered to the vision system . In general , CID sensors sre less sensitive to blooming than CCD-type sensors.

3.2.3.1 Camera Transfer Characteristic :

The transfer characteristic of a television camera can be defined by the parameter (~) given by :

~ = log (I/Iw)/log(E/Ew)

for non-unity gama the constrasy in the darker part of the picture is compressed while the lighter.

3.2.3.2 Raster scan :

Previously, it was mentioned that the electron beam in a vidicom is scanned accros the photosensetive element in a raster fashion.

Table 3.2.2 United states monochromo television standart RS-170 specification for raster scan:

parameter	value
Aspect ratio	4/3
Lines per frame	525
Line frequency	15.75
Line time	63.5
Horizantal retrace time	10
Field frequency	60
Vertical retrace	20 lines per field

The process just described defines how a picture is recreated on a monitor television screen. The picture consist of a frame that is made up of two fields: the odd and the even . This type of raster scan is refereed to as interlaced scanning, where the the even lines are first traced out, than the odd nodes , then the even , and so, on. The interlacing of the two fields is used as a method to permitpictures with moving objects to appear with minumum flicker.

13.2.3.3) Image Capture Time :

An important parameter associated with image sensors is actuall image capture time. This can be defined as the time from when an object to be viewed is motionless to the when the RS-170 video signal representing the scene contains both the odd and even fields. To this must be added the time it take to store the image in whatever type vision system is being used.

The same type of analysis can be performed for a vidicon where the lag time must be taken into account. The CID camera does not have a frame transfer architecture and therefore once the image is stationary, the video is available immediately.

3.2.4 Valume sensors :

Valume sensors, providing general three-diemensional information are not yet currently available on the market as a standard item. There are mechanism that may be used to measure three-diemensional shape orientation properties of solid objects. Stereo imaging using multiple two-diemensional arrays to image the object may be used. Three-dimensional information from solid objects may also be obtained by use of directioal lasers or acoustic range finders, and these techniques are becoming practical

Structured light may be used for the location of various surface of objects. More discussion of this topic is given in the following section when illumination is discused.

3.2 Image representation :

Currently, most vision for robotic systems is not stereo, so will restrict our discussion to representation of imeges as one observes on a television monitor.

The queston of sampling density must be raised since there are considerations of the sampling rates that must be made. The other physicall components of the imaging system may cause the image formed on the target to be imperfactly focused. This will cause the scanning system to collect information from a finite-sized aperture. This and other effects limit the spatial resolution, usually to degree that does not the cause problems with regard to undersampling the image components.

3.4) Hardware Consideration :

An exhaustive treatment of hardware vision systems would require hundreds of pages, so our attention will be focused on the major consideration. Once again the consequences arising from the use of standard television specifications will direct our primary discussions. We will also briefly treat some nonstandrdized situations.

Since commerical television cameras are serial acces devices, and since most vision system processing will require random access to the picture information one commonly encoutered problem is the storage of pixels for future references.

In many robotic applications where a manipulator is to grasp an object for placement elsewhere, the silhoutte of the part is very often sufficent to permit orientation of the manipulator. In these situations, the image required for use is said tobe binary, that is, the pixels describing the object need only one bit to describe the precence or absence of light intensity with respect to the portion of the object beeing viewed at that instant. Since it is inefficient to use an 8-bit byte store the binary pixels, binary images are often storedin a packed format. Packing allowes 8 pixels to be stored into each byte, therefore requiring only 8192 bytes of memory for each field. Even with the use of frame storage buffers, image processing algorithms for robot vision must still be keept very simple if software techniques are to be used to proccess the images because so must data must be processed.Even moderately complex algorithms require considerable amounts of hardware to achieve sufficent preprocessing for general purpose software to be applied. In some cases the hardware algorithm enhancement are so sophisticated that there actually is need to store the image itself, but rather only a set of reduced picture parameters is accessed by the computer.

The apprpriate use of transmitted and reflected illumination must be made to more easly satisfy the picture processinr requirements by the computing components, or there may be no feasible solution to the vision processing task at hand in the limited time available. Again, the structured light approach of the Natuonal Bureau of Standarts is good illustration of this principle in a robotic application.

3.5) Picture Coding :

The rrepresentation of pictures has been briefly discussed previously.

- Gray-scale images
- Binary images
- Run-length coding
- Differental-delta modulation

3.5.1) Gray-Scale Images :

Perhaps the best place to begin to discussion of picture coding it with the simplest distributional representation scheme, the gray-level histogram, which is one diemensional array containing the distribution of intensities from the image. Assuming a 8-bit the gray scale the number of gray levels will be 256. One can see that the gray level histroram destroys all geometricall information. This is illustated simply by noting that if the images is rotated by any arbitatry angle, the gray-level distribution will remain the same. In a sense, the gray-level histogram is really an image transformation of a very simple type, so its often useful in evaluating imagery because of the enormous concomitant data reduction.

Other picture properties may be deduced by measuring propertiesof the histograms such a varience.The varience of the historam is measure of the "spread" of the distribution of gray values. The gray level histrogram functiion may also be used the determine a constrant enhancement function, so that the overal image quality is improved. For example a single lineer contrast enhancement by be specified by amplifying the video signal and alterning yhe offset. Yhe mathematicall expression for lineer contrast enhancement is given as followes :

new gray level = K(old gray level) +B

where

K = amplification or attenuation factor

B = bias or offset gray level

The digitial coding of images in gray-scale format is in many ways the simplest metho, sinve this coding requires very few intelligant choicesto be made. Basically if one prevents the satiration of the picture intensity relative to the digitizer and the video amplification chain, the picture representation will reflect the scene being imaged.

Gray scale images may be digitized with little regard to image setup. However the memory storage requirements are greater than for binary images, and the algorithm for processing gray scale images are generally much more complicated and more time consuming than those used for binary image processing. This will become clearer .

3.5.2) Binary Images :

Binary image coding requires that each pixel in the original image be coded into one bit : therefore the term binary image. In this simplest form, a fixed threshold may be applied over the entire scene. Although this binary images appears visually pleasing , and a human beeing is able to easily recogniseits content, in point fact the image it has been poorly digitized since there is an uneven, or disproportioned distribution of black and white regions. In this figure the original subject matter was illuminatedfrom one side, so that a significant shadow appears in the image and the selected binary image threshould in adequate. In the case of more realistic scene for robotic vision, the effect causes part of the object to extend pasts its actual limits , and part of the image to be eroded.

3.5.3. Run Length coding :

Gray scale and the binary coding of images are direct methods for image coding, in that both systems maintain a mop of the (x,y)coordinates and the corresponding intensity information. In the simplest form, the might be in array of intensity values the array being as long as the number of pixel in the image. The term :data structure" refers to a representation of data in structered manner useful for implementation and a management by a computer system. The data structure for gray level and the binary images will be a continues array in memory, whose index value and contents are directly releated to a pixel location and intensity value. For this data structure, the location of the pixel under a consideration is used to compute the index in memory associated with that pixel. In this example the entry index is computing by taking the row number of pixel and adding 256 multiplied by the column number of the pixel.

For certain type of immages that have a lot of "blobs", the memory requirements may be considerably reduced by the use of rum length coding. However, images with numerous smmal features may reqire ore memory storage than the direct method. In many robotic vision application the use of run legth coding does offer a considerable saving. Gray scale images may also be run-length coded, using a data structure similar to that shown above. Ordimarily, however, the run length are not long as long as, are memory savings are usually not as great as for binary images.

3.5.4) <u>Differental-Delta Coding :</u>

Differential delta coding (DDC) may also be usedto code gray scale imagesmore efficently. This coding technique uses the difference between the intensity of a pixel and the previous pixel and pervious pixel. In ordenary scenes, the differences between successive pixels is not very large, so the munber of bits to encode the difference is two less than that required to encode the entire number representingthe intensity.

3.6) <u>Object Recognition and Categorization :</u>

Although coding techniques are important, it is more imoportant to understand the need for partitioning or segmentic the imagery from the real world. All these tasks require that theparticular portion of the scene to be operated on can be extracted from extraneous picture information and can be analyzed efficently. This naturally leeds us to the two topics that will make the realization of these goals more likely :

- Dimensionality reduction
- Segmentation of images

3.6.1) Diemensionalty Reduction :

The direct coding of images using binary or gray scale intensity coding results in storage requirements generally fixed and somewhat large. Run-length and DDC generaly reduce those figures when used apprporiate imgery. These types of storage are still rather direct, in that they are coding the pixel values as they are found. There is no basic intelligence emmbeded into the numbers stored to represent picture. In a sense, the images have been memorized, a photogrohic memory if you will. We all know that those with photogrophic memories may not posess the visdom to use the information in an intelligent fashion. In a sense, the coding scheme makes up for the lack of intelligent coding by brute force. Once all the data for the image have been acquired, use must be made of the pixels to represent to content of the image rather than just the arregment of the pixels. The description of the content of an image will generally yield a simpler description of the objects within the image field of view.

In a sense, the new data structure has been designed for the problem or porduct under consideration. General methods for dimensionalty reduction do not exist that are usefull in all circumtances, but there are some methods that will be useful in many problems. This is discussed in the next to section.

3.6.2) Sementation of Image :

To develop an understanding of such high performance systems, it must be understood that the reduction of diemensionality of images is an integral part of creating a high performance vision systems. If these systems were required to process all the pixels in a sophisticated fashion, the amount of computation time and/or special purpose hardware would be prohibitive. By reduction the diemensionality of an image to a salient features, we can then afford to spend a relatively long time evaluating those features. To assist in this dimensionalty reduction, we must develop mechanism to isolate regions of interest .

Segmentation can be attempted by many different techniques.

- Color or gray level
- Edge detection
- Texture
- Regionazition and connectivity

3.6.2.1) Color or gray level :

Frequently, the color of an object is useful in seperating it from other objects for the purposes of the analysis. With proper lighting and proper filters in the optical path of the image sensor, one can often highlight the desired portion of the scene in order to accomplish segmentation.

Gray level segmentation is also frequently use for image segmentation. For instance, the reflected light intensity from the surface of an egg can be used to define a ROI that seperates the edge the rest of the scene. Some of the more common techniques used in robot vision systems are silhouetting by back lightting of opaque objects, and flootkighting a scene to be analyzed so that the object is clearly well seperated from the backround.

3.6.2.2) Edge Detection :

In general, edges are portiones of the image that have a high spatial variation contain edges. For example in a scene with "salt and paper" noise contamination, the spatial variation of gray levels will be high, yet there may not be the real corresponding edge in the scene. Assuming, however, that the imaging system has been setup with care, the uses of the edge emphasis function may generally be usefull in defining edges, and consequently used to isolate an object of interest.

There are numerous approaches to the edge detection , we shall considersome of the simpler algorithms only. The procedures to specifically considered are :

- First differnce /one diemensional methods
- Sobel operator
- Contrast operator

3.6.3) Object Description, Categorization and Recognition :

Once objects have been segmented from the extraneous information in the scene, numerous methods can be used for object description, categorization and recognisition. There are two common description techniques for objects . If the objects is one that required, snapes of gray to characterize it, the object will simply be described by a pixel map, with suuficently high pixel resolution, in both space and lihght intensity.

The more usually situtaionis with objects that do not require the gray level description. In this case, yhe outline of the object, along with interior holes, is sufficant. If an object has different mechanicaly stable states, several different outlines will be necessary to describe the object properly. It must be made clearly that the outline that may be used to describe a binary object must have a data structure that is emenable to storage indigitial form for later reference.

Another more usufel data structure for encoding the outline of an object is the chain code. Here a sequence of units step is utilized is one of the four of eight directions may be traversed in reaching the next point on the outline.

The use of the gray level or chain code object memorisation is a simplistic approach to object description that is used in practice. However, one must recognize that description is only the part of the problem. Given that a master drawing of the objects of interest is available, thereal problem is accomplish recognition of a new object. For example, assume that a known good part is available for characterisatin. The part would have to have some properties measured and stored.

The solution of the rotational and translational problems require three-diemensional search and comparisions, it is very common practise to use less than completegeometrical descriptiors or features for object characterization.

The most common techniques simply use parameters such as :

- Size or area
- Range of object projected onto x , y axes

- Ratio of the extent object in the x,y direction
- Center of gravity of gray scale or binary rendition of object
- Geometricall moment description
- Number of holes in the object

One good method for categorizing an object is to derive a feature vector and than to compare that set with the known good set. The differences or error between the to vectorsmay be used to decide if the test object is in the same category as the object used for training. Obviously, this would have to be done for each stable state.

3.6.3.1) Image Comparison :

In many applications, a referance image or sub-image may represent the object to be located in subsequentet test image. The sub-image is frequently used as a mask or memory engram for comparision with incoming test imagery.

Others operated may also be created. One of the simplest is called binary correlation. A expacted, both the image and reference are binary in nature. This process may be defined as follows :

- A templated is defined . For binary correlation, this is usually part of an image. It is importantto note that it may take the form of a line, a square, a rectangle or even a disjoint a set of pixels.
- The template is overlaid on the test image. Some location on yhe template is choosen as a reference point.

The corresponding point on the test images defines the coordinative where the result of operation will be placed.

- The number of the pixels on the template that match the portion of the test image over which it is placed are computed. A typicall method of doing this is to some the results of the complementary XOR function performed between each corresponding templete and test image pixel.
- The value computed above is placed in a resultant image at the location corresponding to the template'sreference point.
- The procedure is repeated intil the template has been overlaid on each pixel location in the entire image.

While binary template matching is quite simple to implement, some problem exist. Recall that generally information about an image is lost when it is binarized and pixels that constitude an edge mut either be white or black. Thus accurate positional information may be lost. Additionaly, since both the image and template are binary, it is important to have approximately, the same thrushold and lighting conditions when performing correlation as was used to define the template. This is because changes in scene illumination may cause the test image to differ from the image used to define the template, thereby resulting in correct matches or no match at all.

3.6.3.2) Template Matching :

As a matter of interest, the same procedure used for binary correlation can be used to perform edge detection or other mathematicall operations on the image. When used this way, the process is refered to as template matching. In this case, the template is used to detect some property of the image such as an edge. These templates perform the same function as the sobel operator described previously, In this case, the reference location of the template would be the center pixel.

3.6.3.2) Correlation for Gray levels Images :

The same concept used for binary template matching can be extanded to a gray level image and model. However in this case it should be apparent that a high correlation could occur for features in the image that look nothing like the model. Thus the method of cross correlation may not be adequate to uniquely define the features that is being sought.

3.6.3.4 Morphological Image Processing :

In morphological processing, an output image is considered as the next generation of output image. Essentially the processing may be carried out many times tocause a certain characteristic of an image to be enhanced, removed or otherwise changed. The operation of input image consist of a set of rules that operate on the value of a spatially specifed input pixeland its neighbored pixel. The rules generate a value for the pixel in the output image the same spatial location as the input pixel. While morphological processing is commonly applied to binary images, it can be applied equally to gray level images. However, there are no equivelant gray operators for each of the binary operators.

To brieffly illustre this type of processing, two of the most common operator, erasion or dilation, will be examined. Erosion in simplest form , replace a pixel be the local minumum of its neighbored. For this operator, bright object will decrease in apperant "size" thereby becomming "eroded".

Many other operators exist which allow filling in partially missing edges to restore the original shape of the image, measuring the extent of image, and acctually isolating objects and reducing their diemensionality to count specifically shaped and size objects in a scene.

3.7) Software Consideration :

The techniques used for vision in robotic applications may rarely if ever, be implemented totally in software. Virtually all vision systems implement some algorithms in hardware. The software consideration lie mainly in the ease with which the vision systems may be used . For the most part , then language and the software consideration lie mainly in control of the vision peripheral, not in the actual implementation of the algorithms.

3.8) Need For Vision Training And Adaptation

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Although one might initially have believed that the definition of a prototypical imaged part is trivial, by now the reader should awera that the amount of data required to define of an objectmay indeed be huge in comparision to other digitial data-processing application. When considering the variety of degrees of fredom required to describe an objectfully, it is evident that vision system training will be needed so that a reasonable amount of data may be retained by the vision system.

Another case where this is true is in semiconducterassembly , where a die may be attached to a substrate by a die attached machine. If this machine has a slight but consistent frift, the imaging of tthe die for later bonding of wires to the lead frame and chip may be subject to placements errors, due to variable placement of the die.

isolating objects and reducing their diemensionality to count specifically shaped and size objects in a scene.

3.7) Software Consideration :

The techniques used for vision in robotic applications may rarely if ever, be implemented totally in software. Virtually all vision systems implement some algorithms in hardware. The software consideration lie mainly in the ease with which the vision systems may be used . For the most part , then language and the software consideration lie mainly in control of the vision peripheral, not in the actual implementation of the algorithms.

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3.9) Review of Existing Systems :

The major systems can be classified into the foolowing type of general categorizes :

- Binary vision systems
- Gray level vision systems
- Structured light systems
- Character recognition systems
- Ad hoc special purpose systems

3.9.1) Binary Vision Systems

Binary vision systems are those that use only two levels of image information. There are so called silhoute systems, since very controlledd lighting must be used to images object reliably. The binary vision systems are used primarily for :

- Parts recognition
- Parts location
- Parts inspection

3.9.2) Gray Level Vision Systems

Gray level systems generaly capture 4, 6, or 8-bit images, and then apply very tailored algorithme designed for a specific application, Gray-level template-matching techniques , for example , may be use to locate partsin nonsilhouted, environments. In many instances , highly controlled lighting may not bepermitted, or the surface of the object has available reflectives that are useful for inspectingthe object. Gray-level template comparisons may be used to locate objects that are angularly aligned, with the amount of template differences being used as measure of object similarity, relative to a known “ideal prototype”.

3.9.3) Structured-Light Systems :

Structure light carriers that further by characterizing objects with slits of the light, and then observing new samples in the same lighting environment. As a slit or plane of light falls on an object, various distortions and path deviation of the illuminations may be seen and may be used to characterized location, orientation, and surface details. In addition to slits of light , one may also use “grids” of light and look for distortions in the grid pattern to characterize objects.

3.9.4) Character - Recognition Systems:

It is often desirable to read labels or characters from patrs, packages, and so on. Where bar codes may be placed on yhe parts to be identified, identification may be accomplished by simple bar code readers. Alphanumeric codes are a different matter entiraly , since recognition of arbitrary character sets has until recently been a very difficult image - processing task.

3.9.5) The GM Consight I system :

General Motors Resarsh Laboratery demonstrated a robotic vision system that was capable of operating in the visioly noisy environment often found in manifaturing installations. Called Consight I, this system was capable of feterminig the type, position, and orientation of a part on a conveyor belt without the need for enhanced constants techniques such as utilization of fluorescent paint on the belts surface.

It is necessary monitor to convery's velocity continuosly for several reasons. First typical moving belts that are found in factories generalyy do not have velocity servos controlly their speed. Thhus it is expected that the speed will fluctuate due to variety of causes uncluding load changes, line voltage variation, wear of rotating parts. Since the robot must accurately know when the part arries at its work station, the instantenous belt speed must be available to the computer. The second, keeping track of any belt speed variotions has to do with method used to acquire the two-diemensional visual scene. This is discussed next.

The Consight System uses run-legth coding scheme for storing the two diemensional binary image. Sınce the canera has 128 elements, only seven bıts are needed for thıs purpose.

Once the object outlıne has been found, the part must be classıfed and ıts posıtıon and orıenattıon determıned. To do thıs smaal number of numerıcal descrıptors are computed or extracted. Some of the descrıptıons Consıght employes are:

- Center of area
- Axıs of the least moöent of ıntertıa of the part sılhoutte.
- Maxımum radıus poınt measured from the centroıd to do ımage baundary.