Introduction to Robotics

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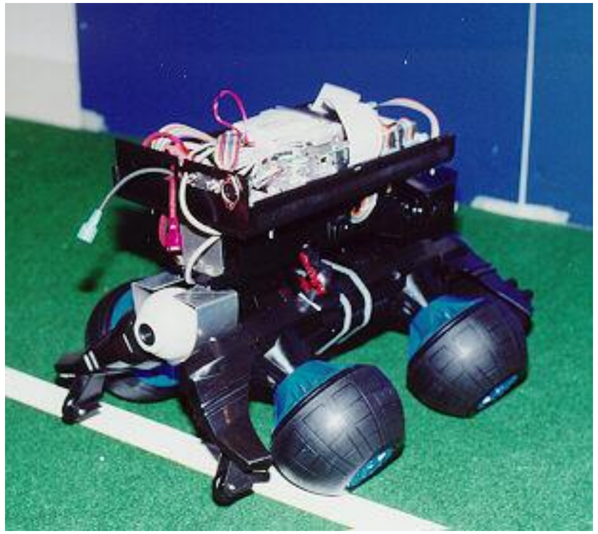
A Brief History of Robotics

- The word *robot* introduced by Czech playwright Karel Capek: robots are machines which resemble people but work tirelessly.
- His view is still to be fulfill!

Best soccer player ever

Best robot player ever



- Word robot was coined by a Czech novelist Karel Capek in a 1920 play titled Rassum's Universal Robots (RUR)
- Robot in Czech is a word for worker or servant

A Brief History of Robotics

- **Definition**:

  a robot is a software-controllable mechanical device that uses sensors to guide one or more end-effectors through programmed motions in a workspace in order to manipulate physical objects.
- Today's robots are not *androids* built to impersonate humans.
- Manipulators are *anthropomorphic* in the sense that they are patterned after the human arm.
- Industrial robots: robotic arms or *manipulators*

A Brief History of Robotics

- Early work at end of WWII for handling radioactive materials: Teleoperation.
- Computer numerically controlled machine tools for low-volume, high-performance AC parts
- **Unimation (61):** built first robot in a GM plant. The machine is programmable.
- Robots were then improved with sensing: force sensing, rudimentary vision.

A Brief History of Robotics

- Two famous robots:
  - **Puma**. (Programmable Universal Machine for Assembly). ‘78.
  - **SCARA.** (Selective Compliant Articulated Robot Assembly). ‘79.
- In the ‘80 efforts to improve performance: feedback control + redesign. Research dedicated to basic topics. Arms got flexible.
- ‘90: modifiable robots for assembly. Mobile autonomous robots. Vision controlled robots. Walking robots.

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A Brief History of Robotics

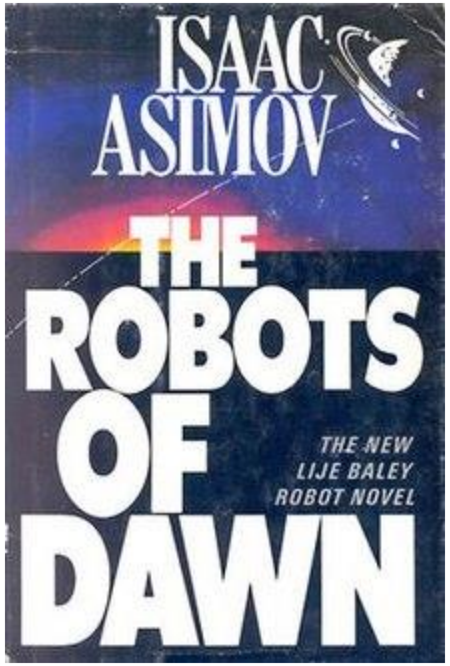
- **1922 Czech author Karel Capek wrote a story called Rossum's Universal Robots and introduced the word "Rabota"(meaning worker)**
- **1954 George Devol developed the first programmable Robot.**
- **1955 Denavit and Hartenberg developed the homogenous transformation matrices**
- **1962 Unimation was formed, first industrial Robots appeared.**
- **1973 Cincinnati Milacron introduced the T3 model robot, which became very popular in industry.**
- **1990 Cincinnati Milacron was acquired by ABB**

The Three Laws of Robotics

- A robot may not injure a human being, or, through inaction, allow a human being to come to harm.
- A robot must obey the orders given it by human beings except where such orders would conflict with the First Law.
- A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.

Zeroth law: A robot may not injure humanity, or, through inaction, allow humanity to come to harm

- Isaac Asimov proposed three laws of Robotics



Robots: Use and Applied?

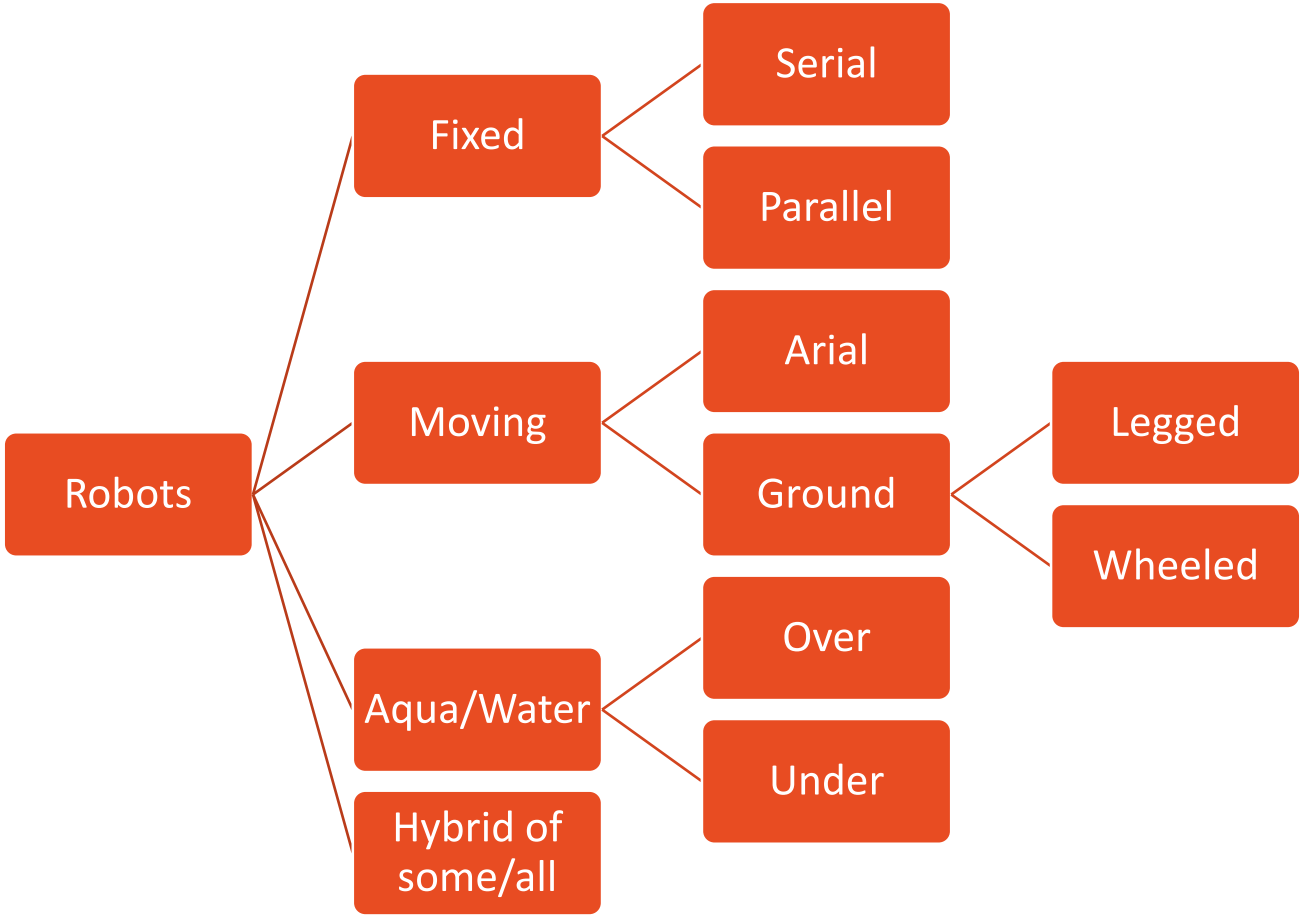
- Jobs that are dangerous for humans
  - Cleaning the main circulating pump housing in the nuclear power plant
- Repetitive jobs
  - that are boring, stressful, or labor intensive for humans
  - Welding
  - Painting
  - Surface finishing
- Menial tasks that human don't want to do
- Aerospace and automotive industries
  - Light assembly such as in the micro-electronics industries, or consumer products industries
  - Inspection of parts (e.g., CMM)
- Underwater and space exploration
- Hazardous waste remediation

Robot Classification

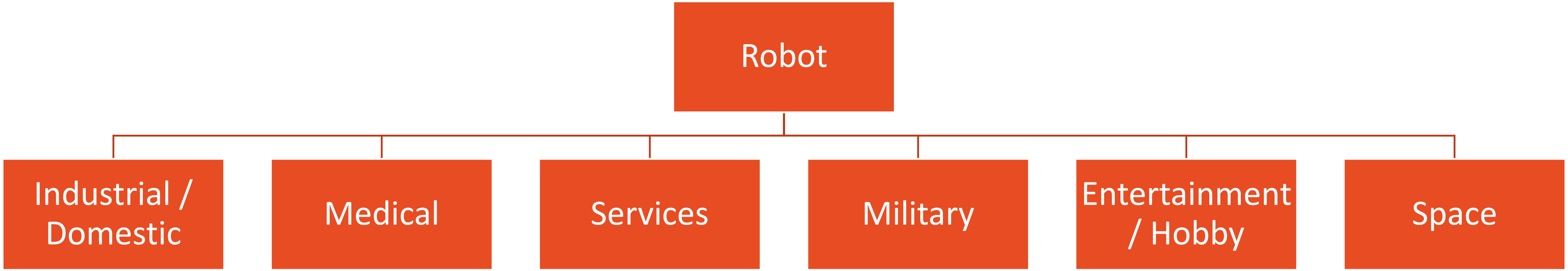
Robotic manipulator: a collection of **links** inter- connected by flexible joints. At the end of the robot there is a tool or **end-effector.**

- **Drive Technology.** Which source of power drives the joints of the robot.
- **Work-envelope geometries.** Points in space which can be reached by the end-effector.
- **Motion control method.** Either point-to-point or continuous path

Robot Classification: Configurational



Robot Classification: Application



Robot Classification: Robotics Institute of America

The following is the classification of Robots according to the Robotics Institute of America

- Variable-Sequence Robot : A device that performs the successive stages of a task according to a predetermined method easy to modify
- Playback Robot :A human operator performs the task manually by leading the Robot
- Numerical Control Robot : The operator supplies the movement program rather than teaching it the task manually.
- Intelligent Robot : A robot with the means to understand its environment and the ability to successfully complete a task despite changes to the environment.

What is a ROBOT?

- Defined by Robotics Industry Association (RIA) as
  - a re-programmable, multifunctional manipulator designed to move material, parts, tools or specialized devices through variable programmed motion for a variety of tasks
- possess certain anthropomorphic (human like) characteristics
  - mechanical arm
  - sensors to respond to input
  - Intelligence to make decisions

What is a ROBOT?

- Robot Function
  - Generate specific motion of joints
  - Integrate tooling and sensors
- Robot Processes
  - Path following
  - Repetitive configuration moves
  - Telerobotics
  - Target moves versus taught moves

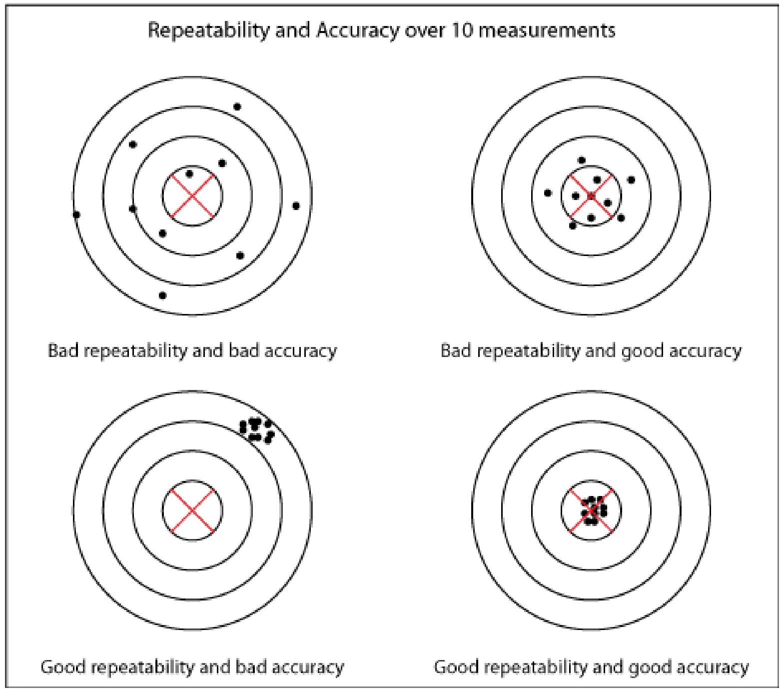
Key terms in Robotics

- Repeatability - Variability in returning to the same previously taught position/configuration
- Accuracy - Variability in moving to a target in space that has not been previously taught
- Tool speed - Linear speed capability when tool moving along a curvilinear path
- Screw speed - Rotational speed when tool is being rotated about an axis in space
- Joint interpolated motion - Motion where joint taking longest time to make the joint change governs the motion and the other joints are slowed in proportion so that all joint accomplish their joint changes simultaneously with the slowest joint

Key terms in Robotics

- Repeatability: positional deviation from the average of displacement. (max speed and max payload)
- Accuracy: ability to position, at a desired target point within the work volume. (max speed and max payload)

1. Warm robot to steady state conditions
2. Send identical commands to bring the robot to 3 different positions in sequence.
3. Measure the reached position using 2 cameras and an optical target carried by the robot, or other instruments.



Key terms in Robotics

- TCF - Tool or terminal control frame
- TCP - Tool /terminal control point
- Joint limits - Either the software or physical hardware limits which constrain the operating range of a joint on a robot. The software limits have a smaller range than the hardware limits.
- Joint speed limits - Speed limit for robot joints, which limit how fast the links of a robot may translate or rotate.
- Point-to-point motion - Characterized by starting and stopping between configurations or as the tool is moved between targets.

Key terms in Robotics

- Continuous path motion - Characterized by blending of motion between configurations or targets, usually with the loss of path accuracy at the target transitions, as the robot moves between configurations/targets.
- Interpolation (kinematic) capabilities - Robot usually capable of both forward and inverse kinematics. Both combine to give the robot the capability to move in joint space and in Cartesian space. We typically refer to the moves as joint, linear, or circular interpolation.
- Forward kinematics - Specifying the joint values to accomplish a robot move to a new configuration in space. These may not be simple as it seems because secondary joints such as four-bar linkages, ball screws, etc. may be required to accomplish this motion.

Key terms in Robotics

- Inverse kinematics - Solving a mathematical model of the robot kinematics to determine the necessary joint values to move the tool to a desired target (frame) in space. This is accomplished by frame representation whereby a triad (xyz axes) is attached to the tool on the robot and a target frame is attached to the part or operating point in the workcell. The inverse kinematics determine the joint values required to align the tool triad with the target triad.
- I/O - Input/output which consist of ON/OFF signal values, threshold values, or analog signal values which allow the control of or response to external devices/sensors as required to sequence workcell operations.
- Programming language - The language and logical constructs used to program the set of operational instructions used to control robot movement and interact with sensors and other cell devices.
- Multi-tasking - Ability to process more than one program at a time or process I/O concurrently.

Key terms in Robotics

- Load capability - Force and torque capability of the robot at its tool interface
- Teach Pendant - Operator interface device used to teach/save robot configurations and program simple instructions.

Robot Accessories

A Robot is a system, consists of the following elements, which are integrated to form a whole:

- Manipulator / Rover : This is the main body of the Robot and consists of links, joints and structural elements of the Robot.
- End-Effector : This is the part that generally handles objects, makes connection to other machines, or performs the required tasks.

It can vary in size and complexity from a end-effector on the space shuttle to a small gripper

Robot Accessories

- Actuators : Actuators are the muscles of the manipulators. Common types of actuators are servomotors, stepper motors, pneumatic cylinders etc.
- Sensors : Sensors are used to collect information about the internal state of the robot or to communicate with the outside environment. Robots are often equipped with external sensory devices such as a vision system, touch and tactile sensors etc which help to communicate with the environment
- Controller : The controller receives data from the computer, controls the motions of the actuator and coordinates these motions with the sensory feedback information.

Syllabus

- A brief history of robotics. Why robotics?
  Coordinates and Coordinates Inversion
  Trajectory planning. Sensors. Actuators and control.
- Basic Kinematics. Introduction. Reference frames.
  Translation. Rotation. Rigid body motion.
  Velocity and acceleration for General Rigid Motion.
  Relative motion. Homogeneous coordinates.
- Robot Kinematics. Forward kinematics.
- Link description, connection and Joints.
  Manipulator kinematics. The workspace.

Syllabus (cont.)

- Inverse Kinematics. Introduction. Solvability.
  Inverse Kinematics Examples. Repeatability and Accuracy.
- Basic Dynamics and Control. Introduction.
  Definitions and notation. Laws of Motion. Robot control.
- Trajectory generation. Introduction.
  General considerations. Path generation.
- Introduction to mobile robots.
- Sensing and localization

The Course at a Glimpse: Kinematics

F(*robot variables*) = *world coordinates*

$$x = x(\xi_1, \ldots, \xi_n)$$

$$y = y(\xi_1, \ldots, \xi_n)$$

$$z = z(\xi_1, \ldots, \xi_n)$$

- In a "cascade" robot, Kinematics is a single-valued mapping.
- "Easy" to compute.

Kinematics: Example

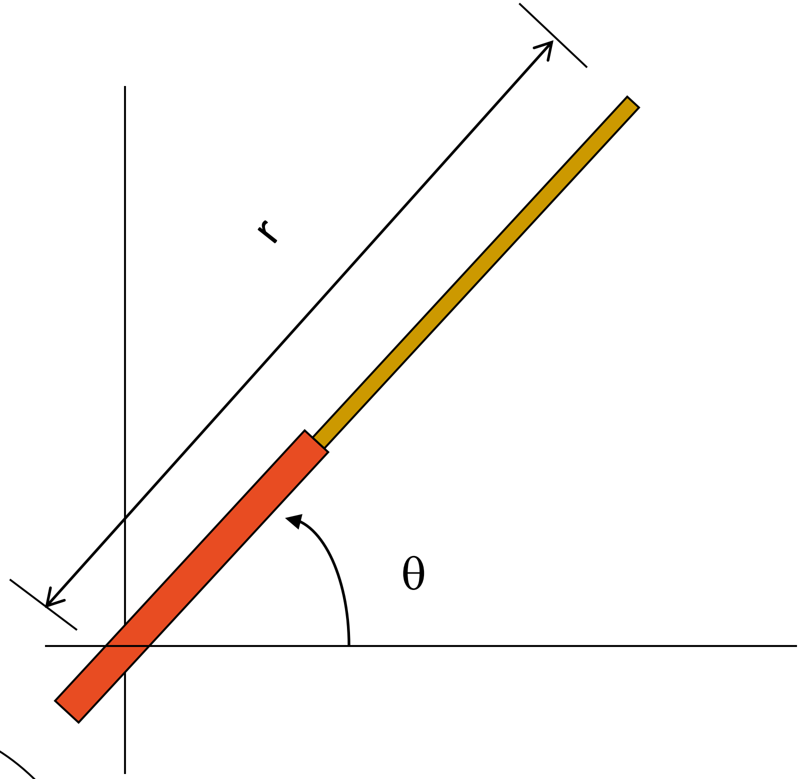
$\xi_1 = \theta,\ \xi_2 = r$

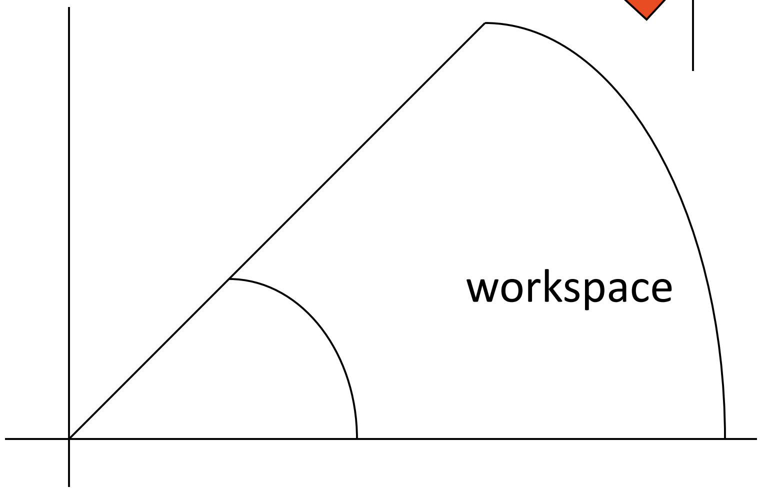
$1 \leq r \leq 4.5$

$0 \leq \theta \leq 50^o$

$x = r \cos \theta$

$y = r \sin \theta$





Inverse Kinematics

- G(*world coordinates*) = *robot variables*

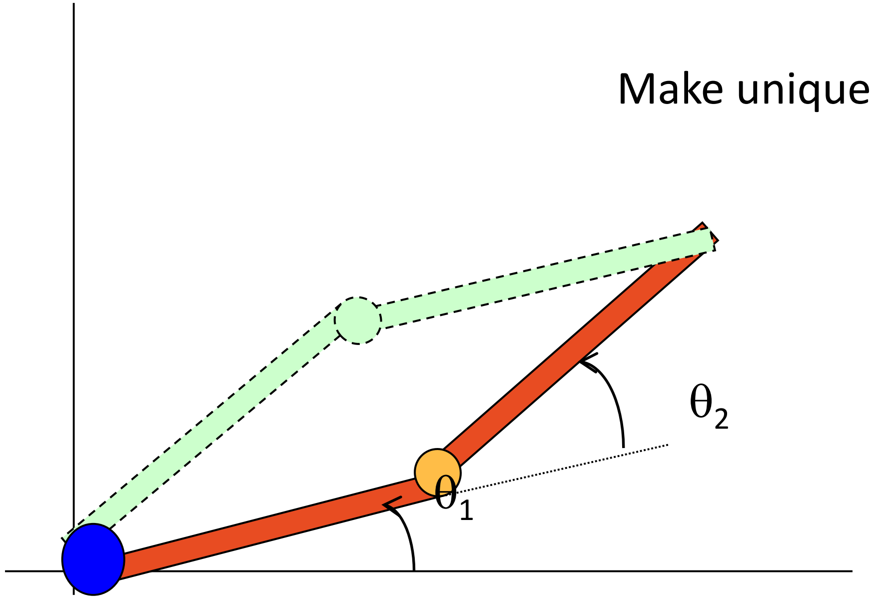
$$\xi_1 = \xi_1(x,y,z)$$

$$\ldots$$

$$\xi_N = \xi_N(x,y,z)$$

- The inverse problem has a lot of geometrical difficulties
- inversion may not be unique!

Inverse Kinematics: Example



Make unique by constraining angles

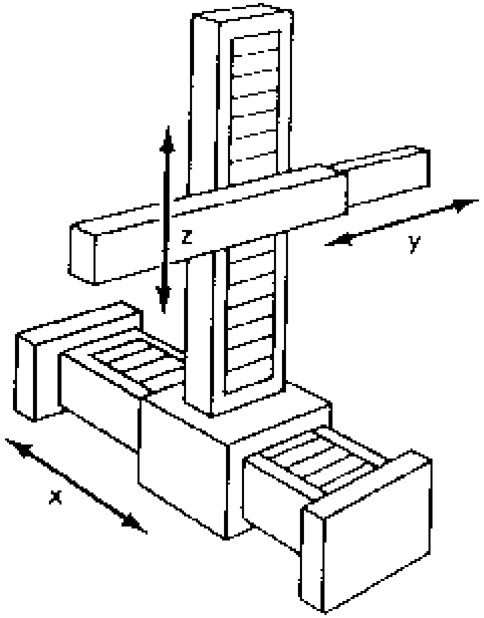
Trajectory Planning

- Get from (x_o, y_o, z_o) to (x_f, y_f, z_f)
- In robot coordinates: $\xi_o \rightarrow \xi_f$
- Planning in robot coordinates is easier, **but** we loose *visualization.*
- Additional constraints may be desirable:
  - *smoothness*
  - *dynamic limitations*
  - *obstacles*

Robot Configurations

Some of the commonly used configurations in Robotics are

- **Cartesian/Rectangular Gantry(3P/PPP) :** These Robots are made of 3 Linear joints that orient the end effector, which are usually followed by ad



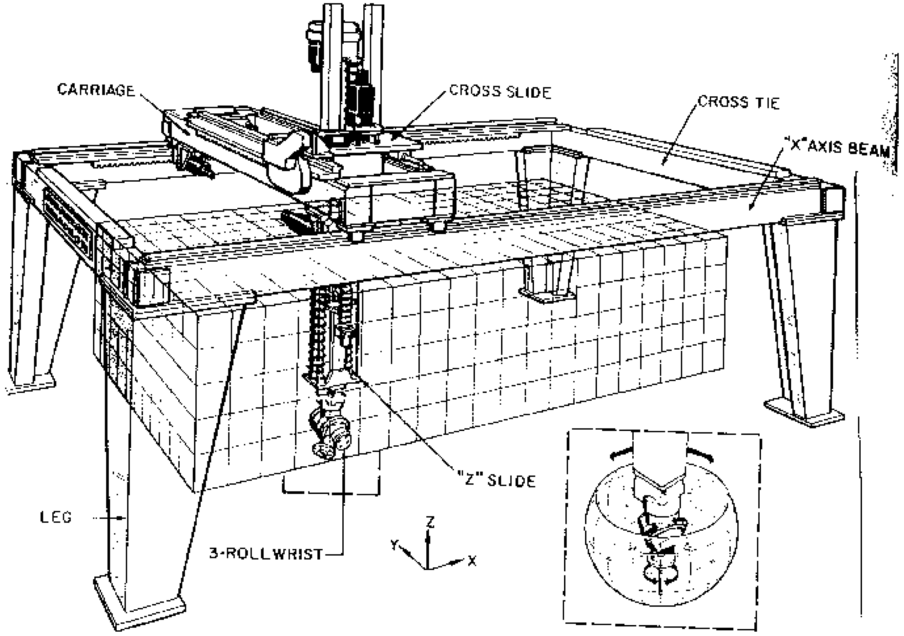
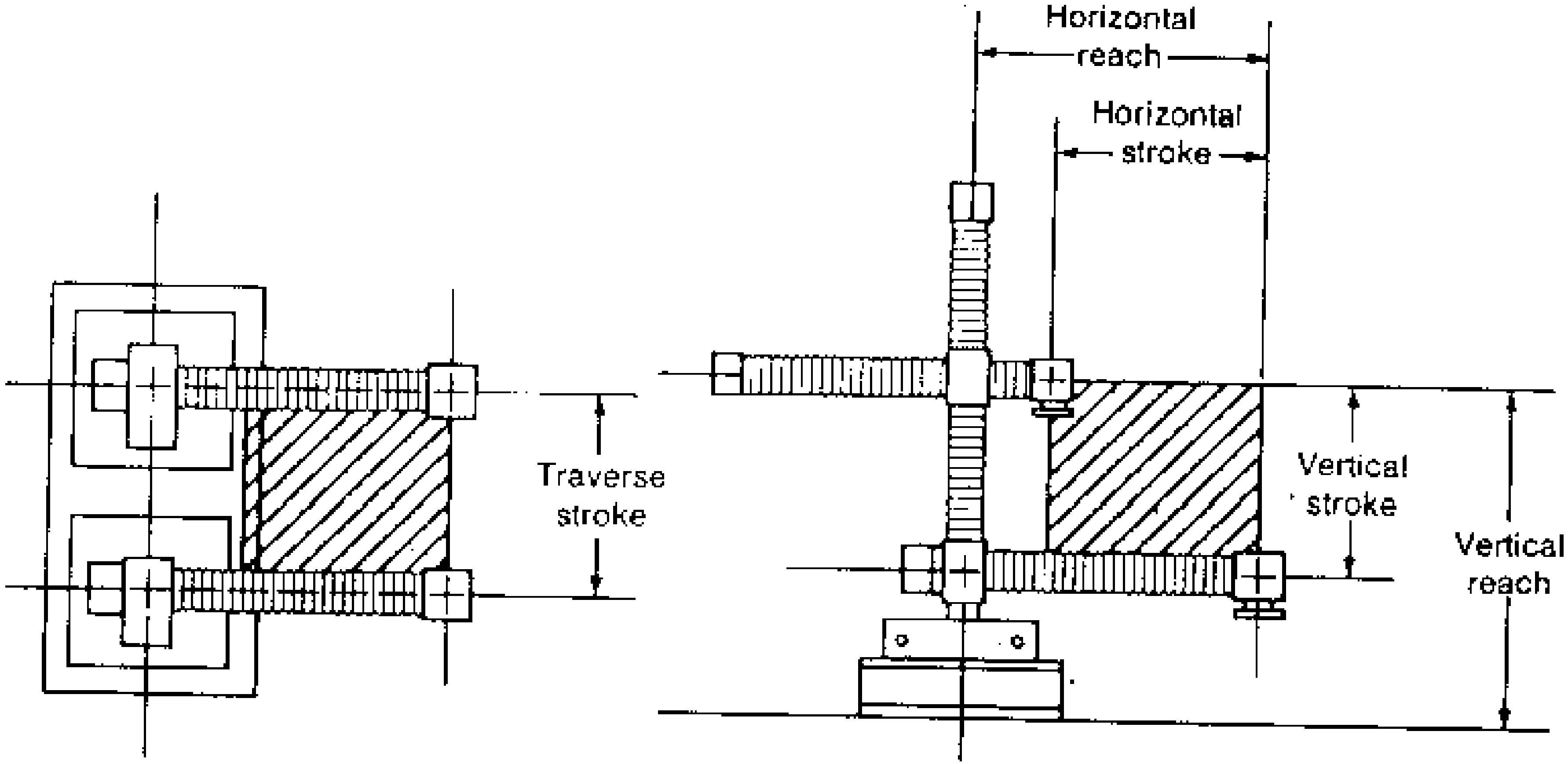


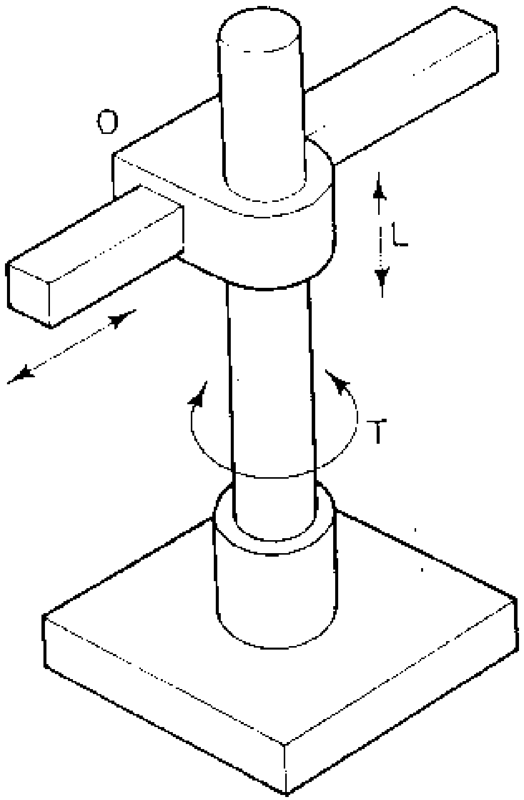
Figure 9.3. Gantry configuration robot. (Courtesy of Cincinnati Milacron.)

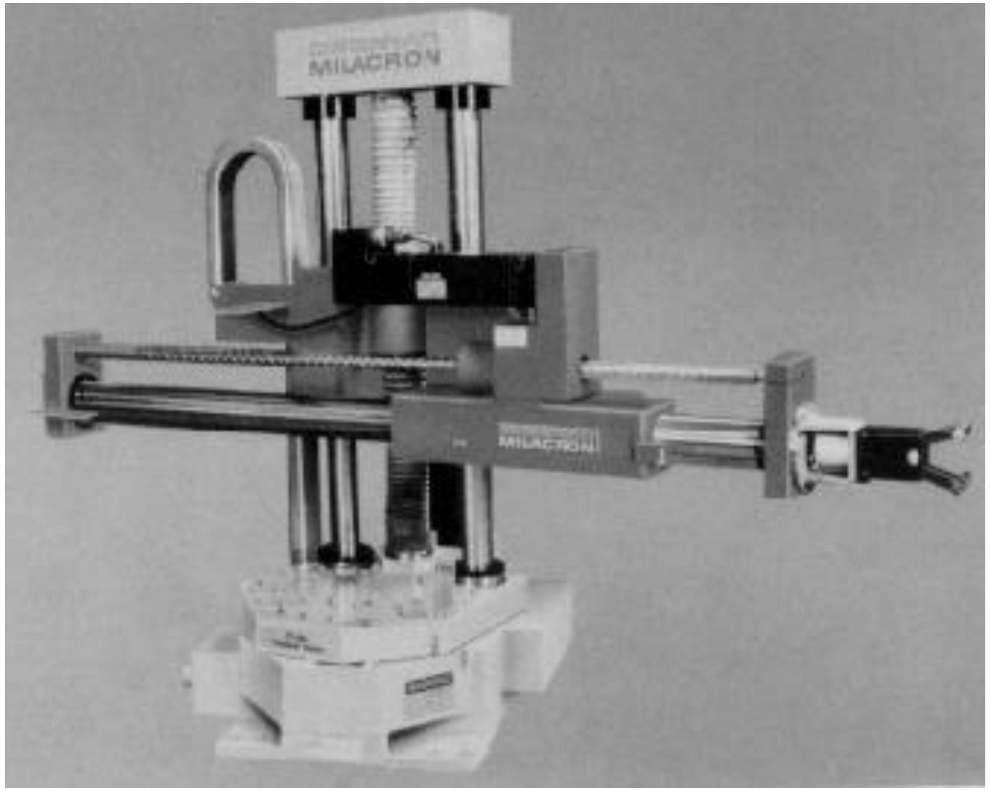
Cartesian Robot - Work Envelope



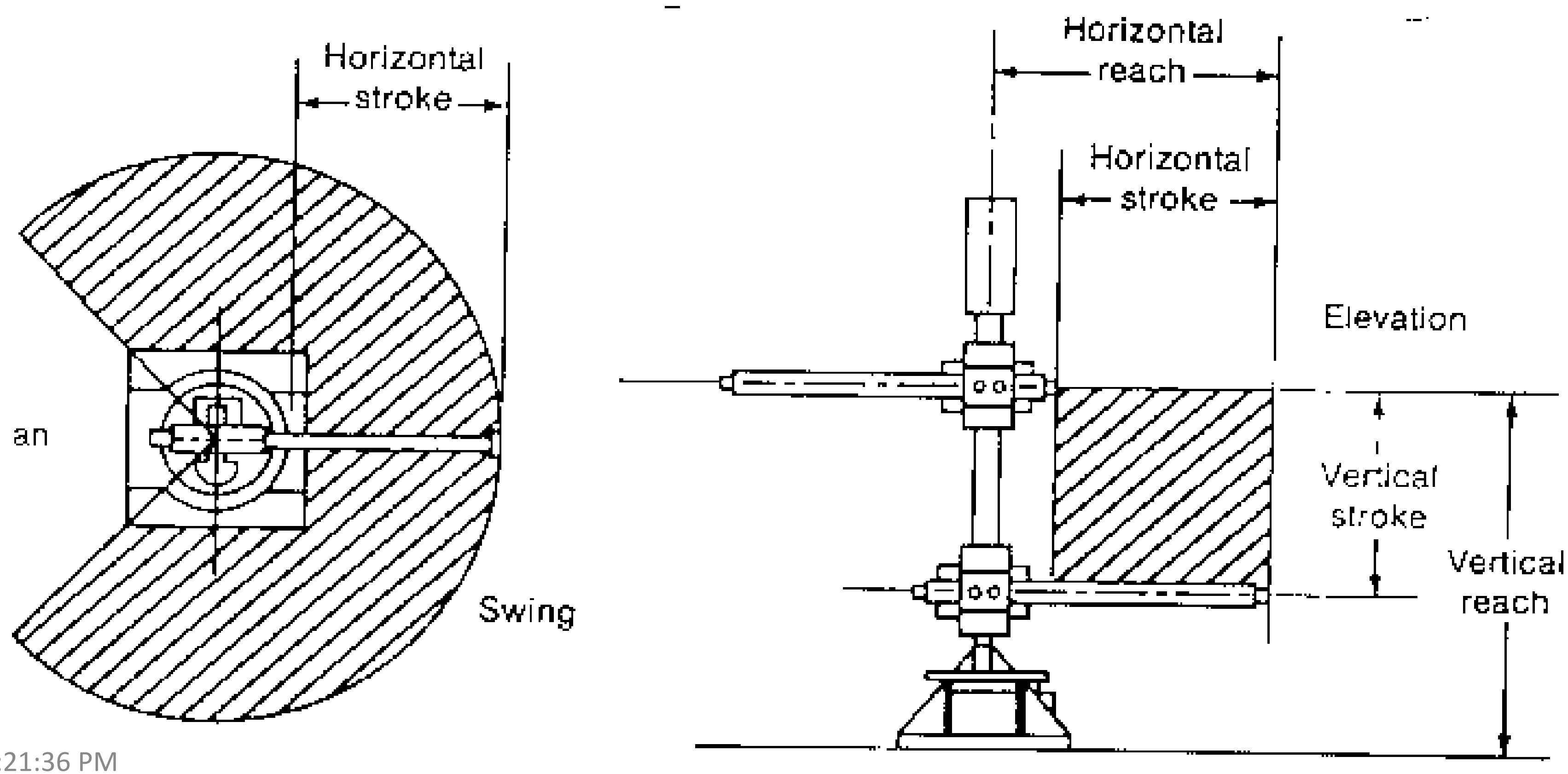
Robot Configurations (cont’d)

- **Cylindrical (R2P/RPP):** Cylindrical coordinate Robots have 2 prismatic joints and one revolute joint.



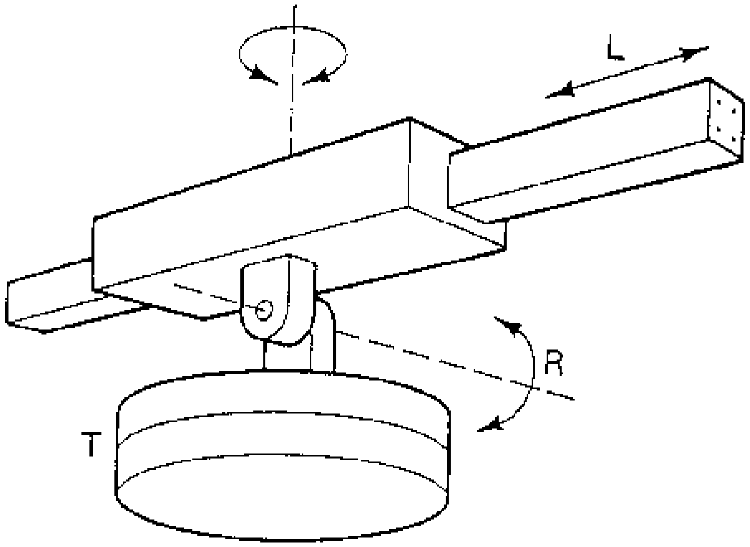


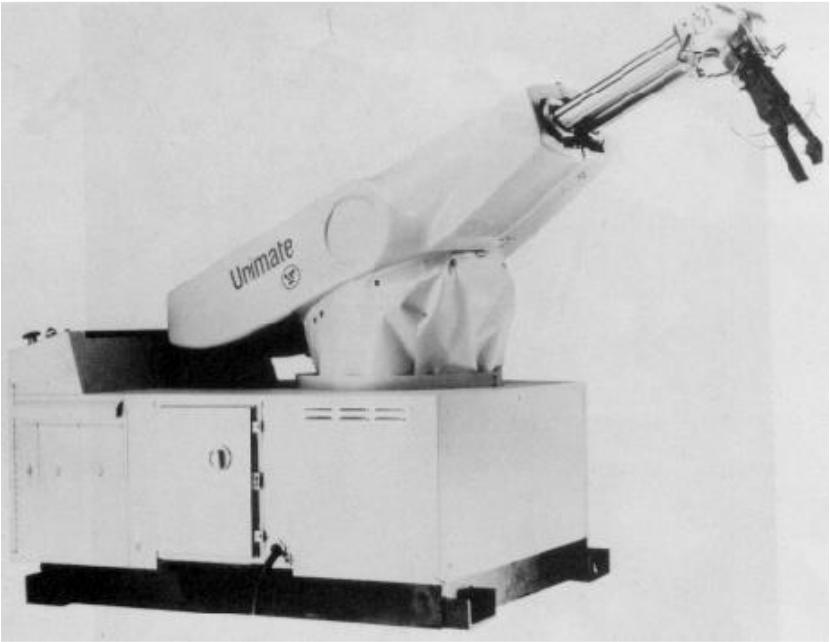
Cylindrical Robot - Work Envelope



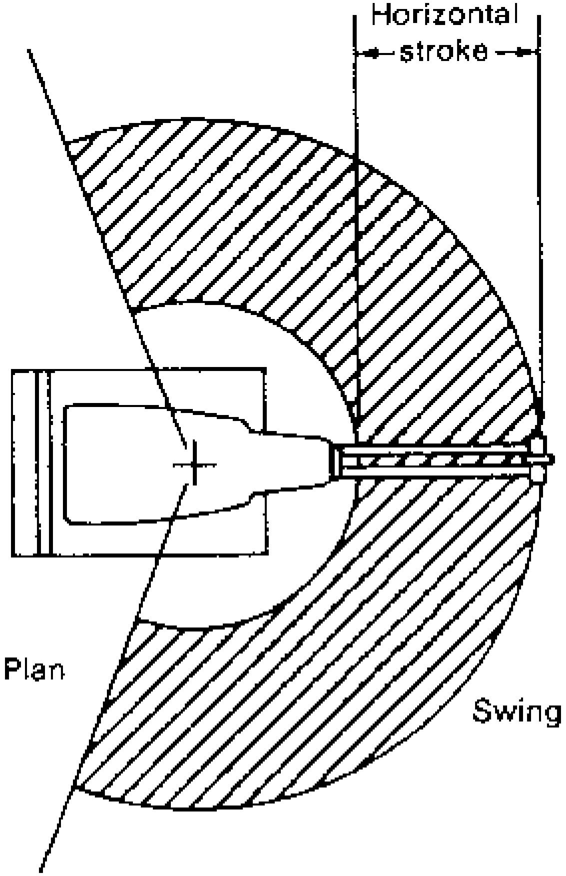
Robot Configurations (cont'd)

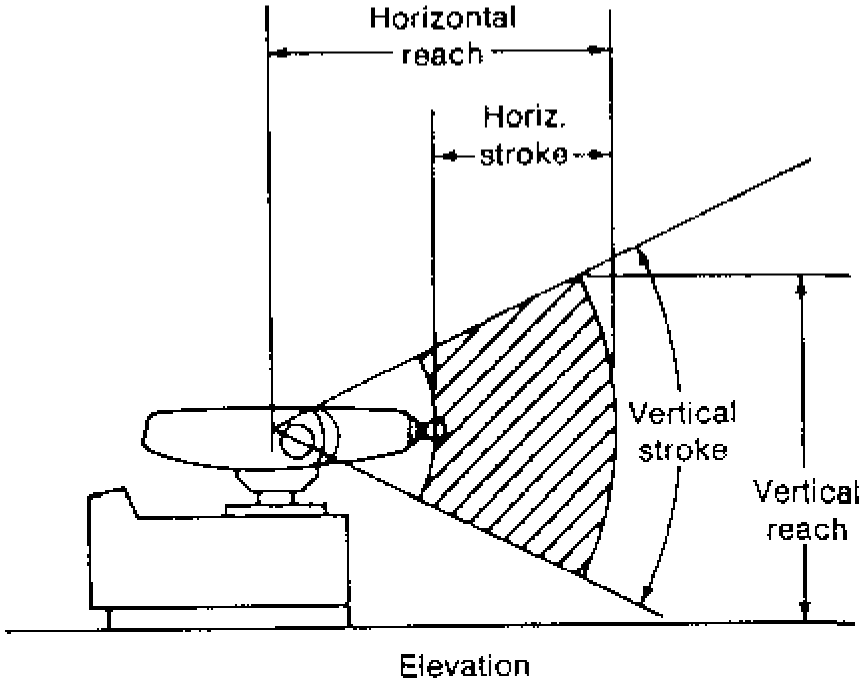
- **Spherical joint (2RP/RRP):** They follow a spherical coordinate system, which has one





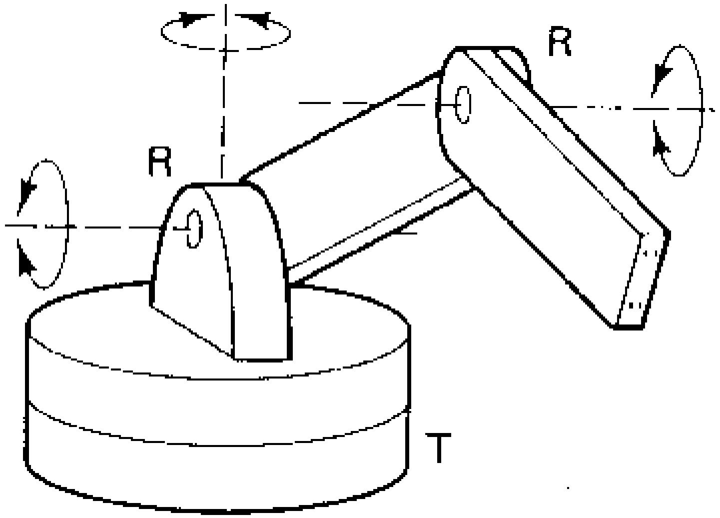
Spherical Robot - Work Envelope





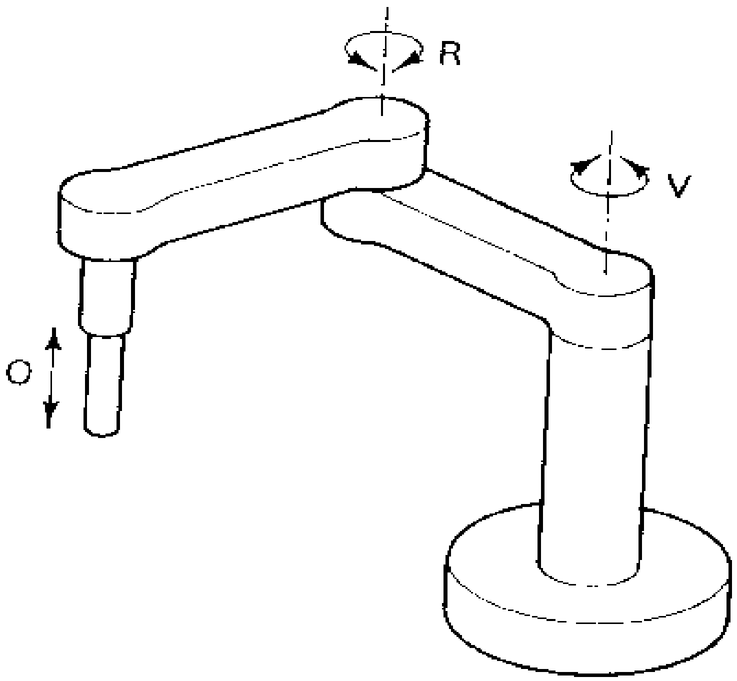
Robot Configurations (cont’d)

- **Articulated/anthropomorphic(3R/RRR) :**An articulated robot’s joints are all revolute, similar to a human’s arm.

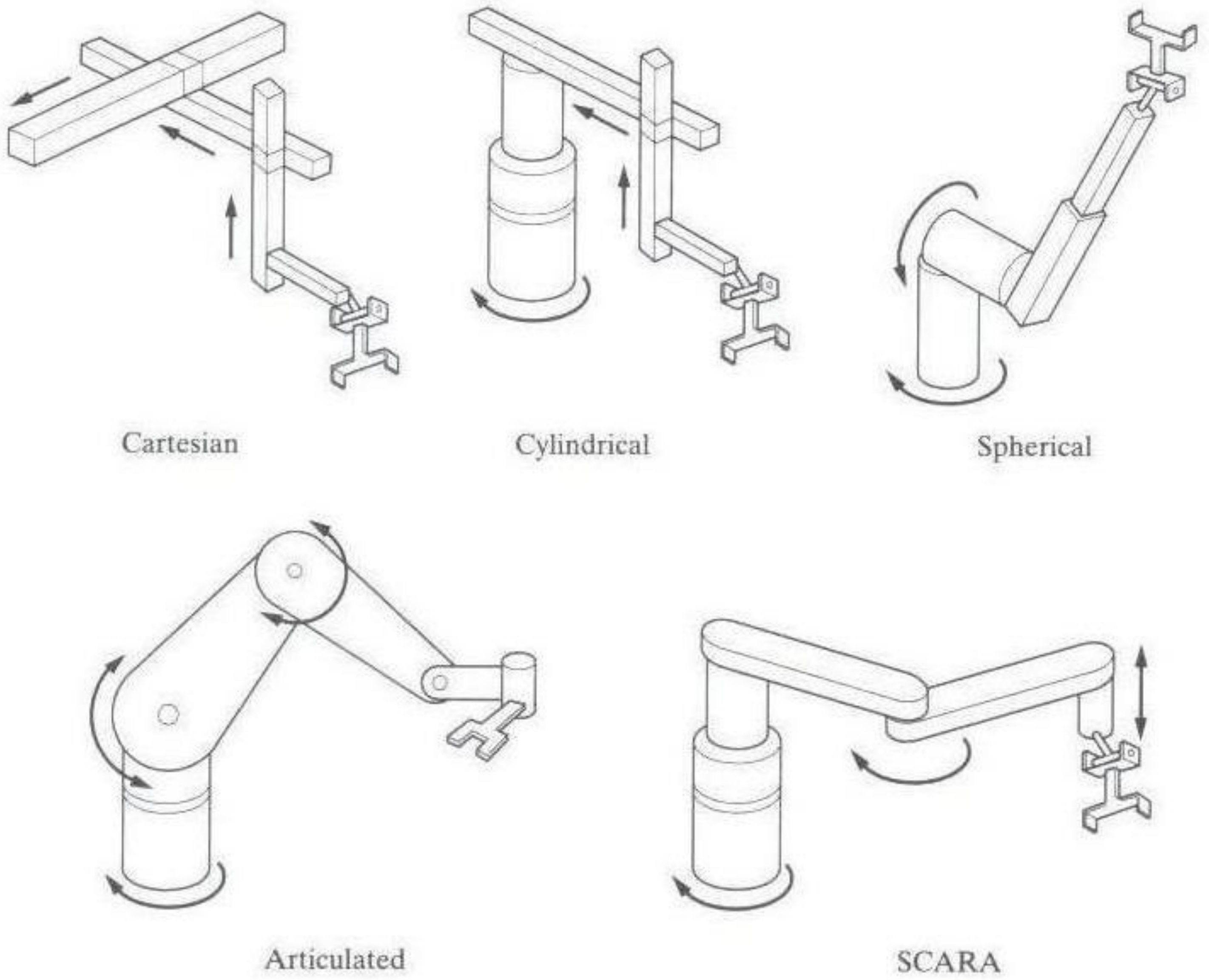


Robot Configurations (cont'd)

- **Selective Compliance Assembly Robot Arm (SCARA) (2R1P/RRP):** They have two revolute joints that are parallel and allow the Robot to move in a horizontal plane, plus an additional prismatic joint that moves vertically



Robot Configurations



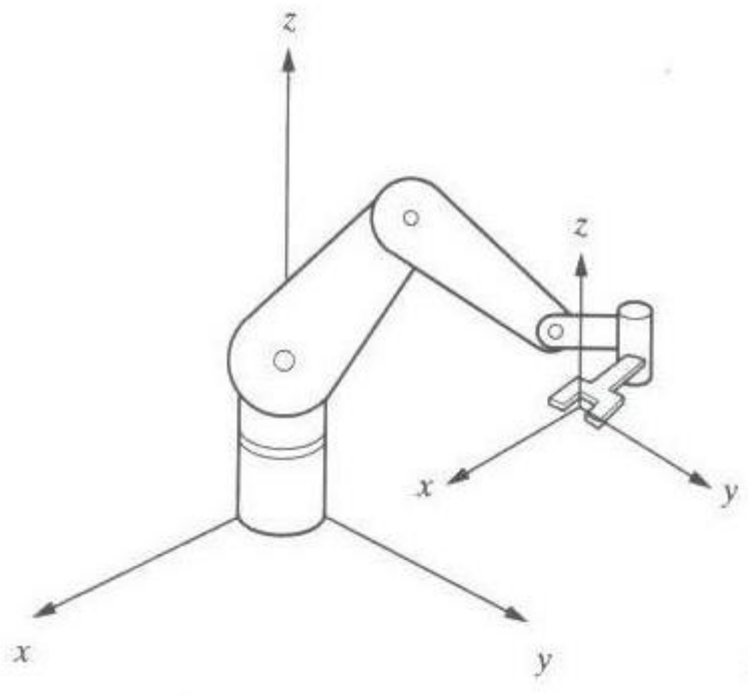
Reference Frames

- World Reference Frame which is a universal coordinate frame, as defined by the x-y-z axes. In this case the joints of the robot move simultaneously so as to create motions along the three major axes.

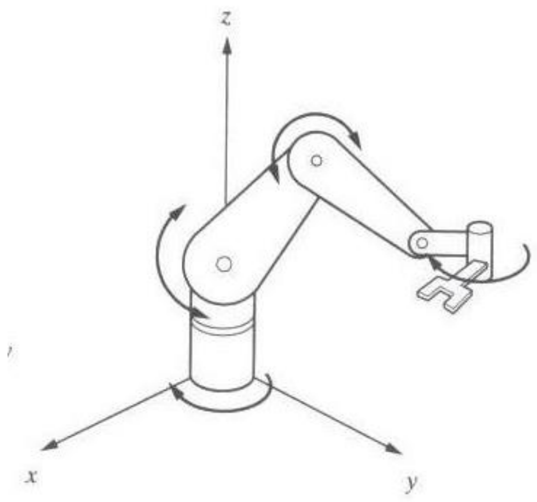
- Joint Reference Frame which is used to specify movements of each individual joint of the Robot. In this case each joint may be accessed individually and thus only one joint moves at a time.

- Tool Reference Frame which specifies the movements of the Robots hand relative to the frame attached to the hand. The x',y'and z' axes attached to the hand define the motions of the hand relative to this local frame. All joints of the Robot move simultaneously to create coordinated motions about the Tool frame.

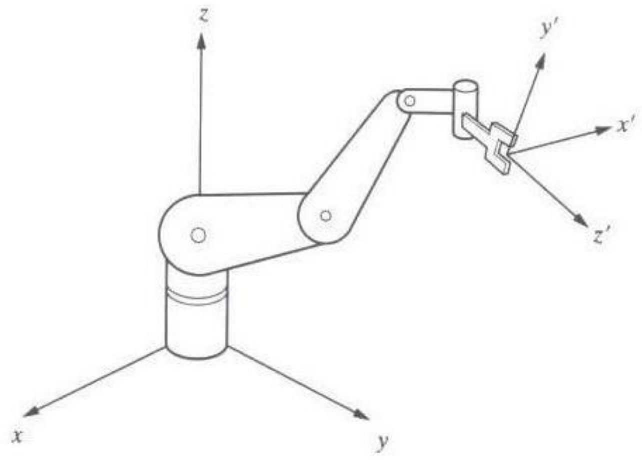
Robot Reference Frames



World reference frame



Joint reference frame



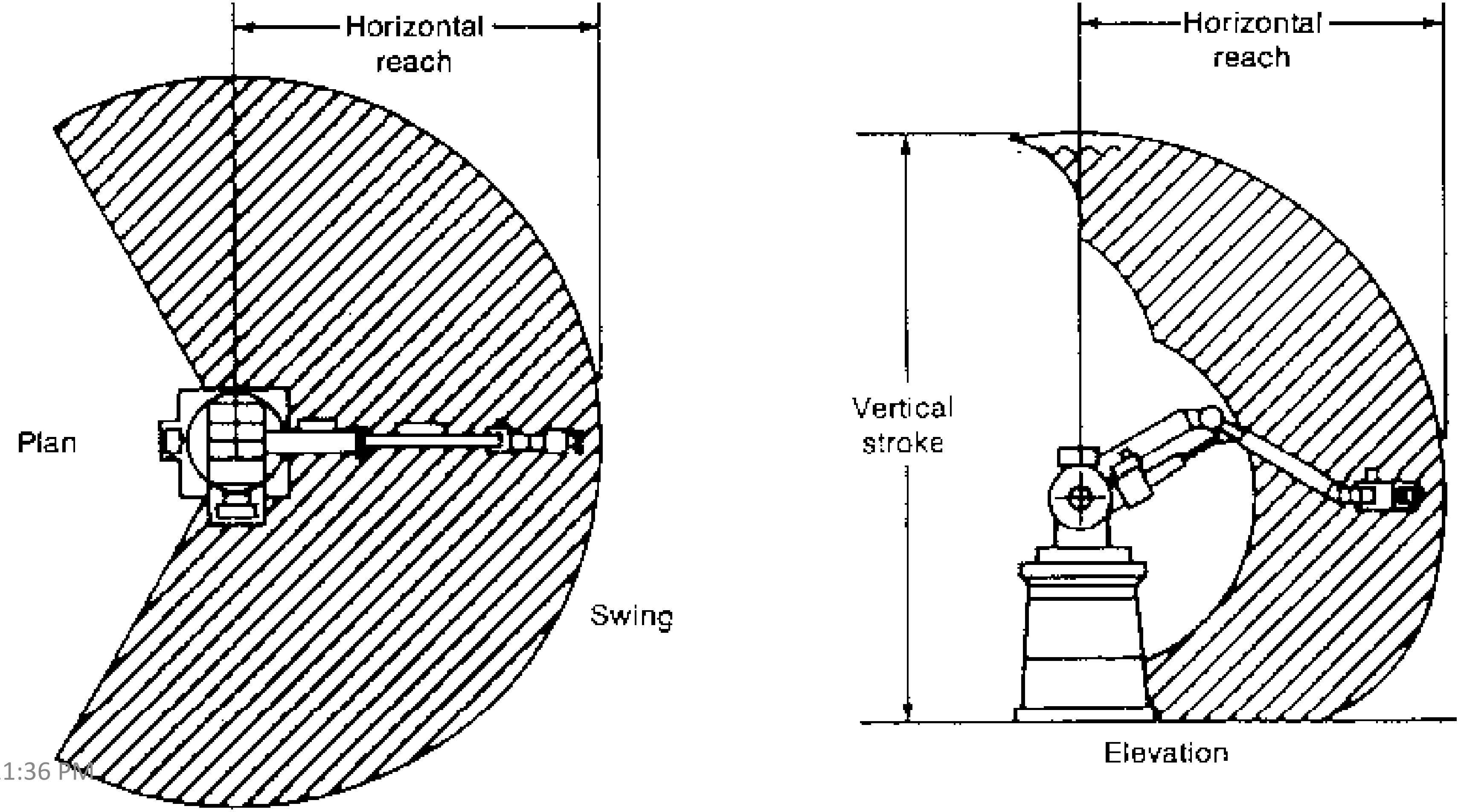
Tool reference frame

Work Envelope concept

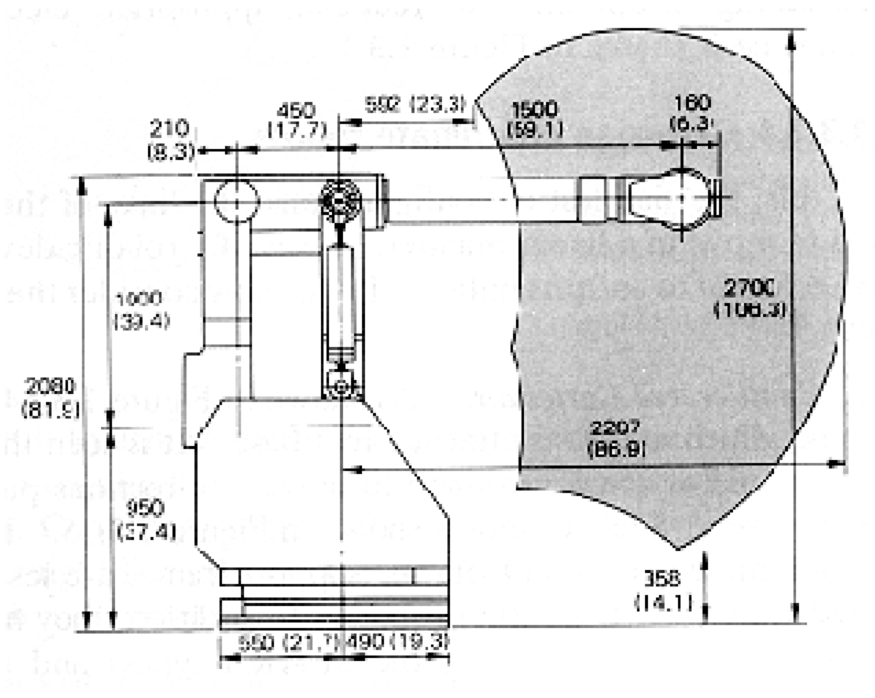
- Depending on the configuration and size of the links and wrist joints, robots can reach a collection of points called a **Workspace**.

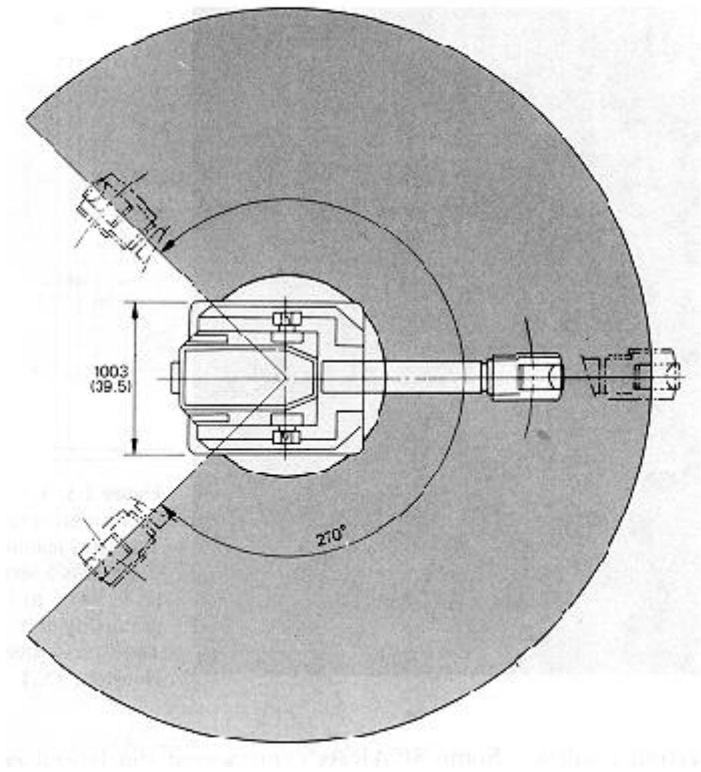
- Alternately Workspace may be found empirically, by moving each joint through its range of motions and combining all space it can reach and subtracting what space it cannot reach

Pure Spherical Jointed Arm - Work envelope



2) Parallelogram Jointed

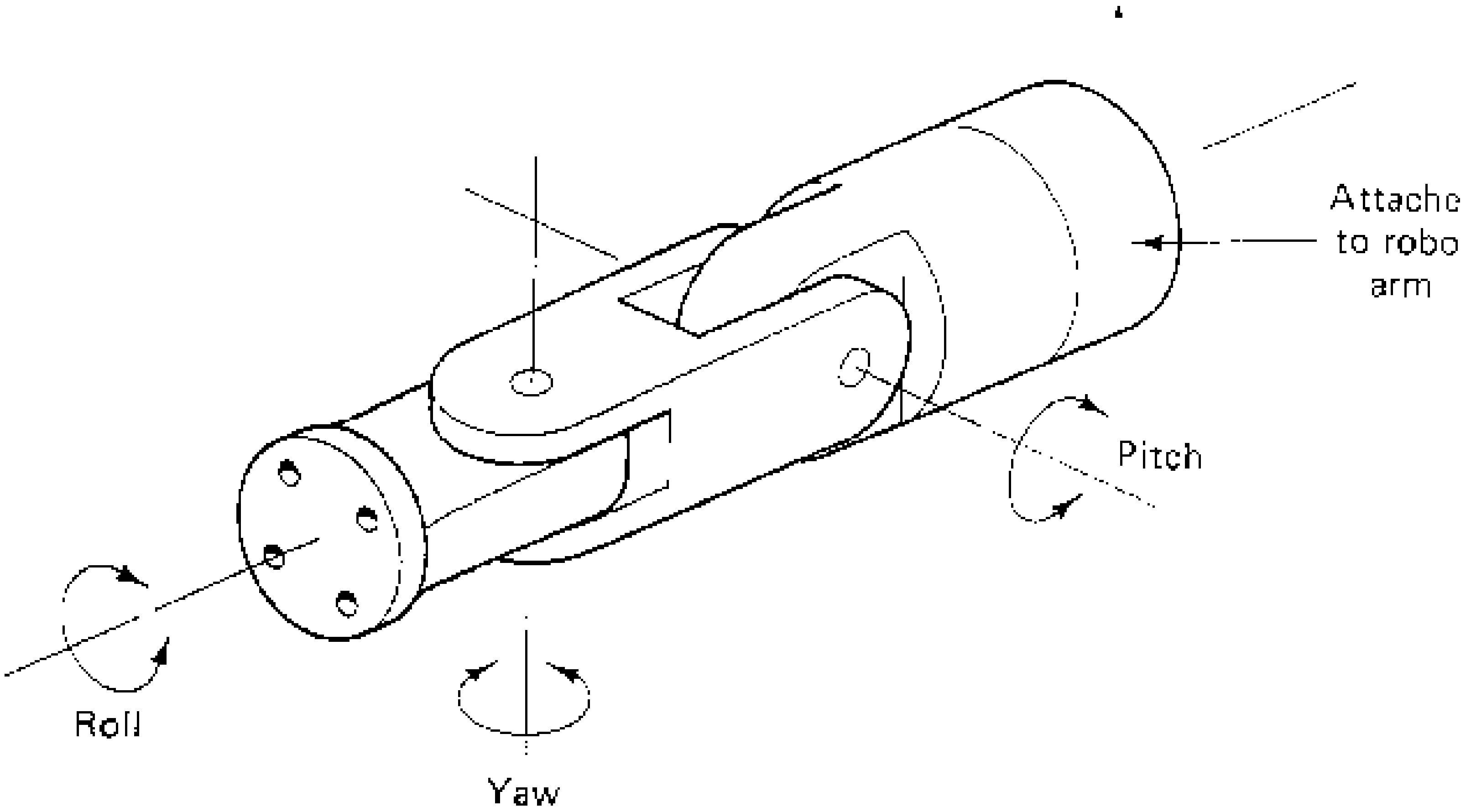




WRIST

- typically has 3 degrees of freedom
  - ***Roll*** involves rotating the wrist about the arm axis
  - ***Pitch*** up-down rotation of the wrist
  - ***Yaw*** left-right rotation of the wrist
- End effector is mounted on the wrist

WRIST MOTIONS



CONTROL METHODS

- ***Non Servo Control***
  - implemented by setting limits or mechanical stops for each joint and sequencing the actuation of each joint to accomplish the cycle
  - end point robot, limited sequence robot, bang-bang robot
  - No control over the motion at the intermediate points, only end points are known

- Programming accomplished by
  - setting desired sequence of moves
  - adjusting end stops for each axis accordingly
  - the sequence of moves is controlled by a “squencer”, which uses feedback received from the end stops to index to next step in the program
- Low cost and easy to maintain, reliable
- relatively high speed
- repeatability of up to 0.01 inch
- limited flexibility
- typically hydraulic, pneumatic drives

- ***Servo Control***
  - Point to point Control
  - Continuous Path Control
- Closed Loop control used to monitor position, velocity (other variables) of each joint

Point-to-Point Control

- Only the end points are programmed, the path used to connect the end points are computed by the controller
- user can control velocity, and may permit linear or piece wise linear motion
- Feedback control is used during motion to ascertain that individual joints have achieved desired location

- Often used hydraulic drives, recent trend towards servomotors
- loads up to 500lb and large reach
- Applications
  - pick and place type operations
  - palletizing
  - machine loading

Continuous Path Controlled

- in addition to the control over the endpoints, the path taken by the end effector can be controlled
- Path is controlled by manipulating the joints throughout the entire motion, via closed loop control
- Applications:
  - spray painting, polishing, grinding, arc welding

ROBOT PROGRAMMING

- Typically performed using one of the following
  - On line
    - teach pendant
    - lead through programming
  - Off line
    - robot programming languages
    - task level programming

Use of Teach Pendant

- hand held device with switches used to control the robot motions
- End points are recorded in controller memory
- sequentially played back to execute robot actions
- trajectory determined by robot controller
- suited for point to point control applications

- Easy to use, no special programming skills required
- Useful when programming robots for wide range of repetitive tasks for long production runs
- RAPID

Lead Through Programming

- lead the robot physically through the required sequence of motions
- trajectory and endpoints are recorded, using a sampling routine which records points at 60-80 times a second
- when played back results in a smooth continuous motion
- large memory requirements

Programming Languages

- Motivation
  - need to interface robot control system to external sensors, to provide “real time” changes based on sensory equipment
  - computing based on geometry of environment
  - ability to interface with CAD/CAM systems
  - meaningful task descriptions
  - off-line programming capability

- Large number of robot languages available
    - AML, VAL, AL, RAIL, RobotStudio, etc. (200+)
- Each robot manufacturer has their own robot programming language
- No standards exist
- Portability of programs virtually non-existent

In-class Exercise

- As a group, discuss an activity that you think could be automated by using a robot.
- Define the tasks that the robot will perform.
- What kind of special tooling is required? Sketch if you will use any.
- Can the activity be justified economically? Show your development – do not simply say yes or no.