Electrical Engineering IV:
EE4009: MECHATRONICS AND INDUSTRIAL AUTOMATION

Masters in Mechanical Engineering (Manufacturing, Process & Automation Systems):
ME 6008 MECHATRONICS & ROBOTICS (TP1)
ME 6009 INDUSTRIAL AUTOMATION & CONTROL (TP2)

Teaching Period 1:

- ROBOTICS & RELATED TECHNOLOGIES:
  - Background/ Basic Configurations
  - Transformations
  - Palletizing and Depalletizing (ME6008 only)
  - Kinematics
  - Inverse Kinematics
  - Trajectory Following
  - Jacobians
  - Mathematica-based, Kinematic Analysis of Some Robots (Continuous Assessment for ME6008 only)

Teaching Period 2:

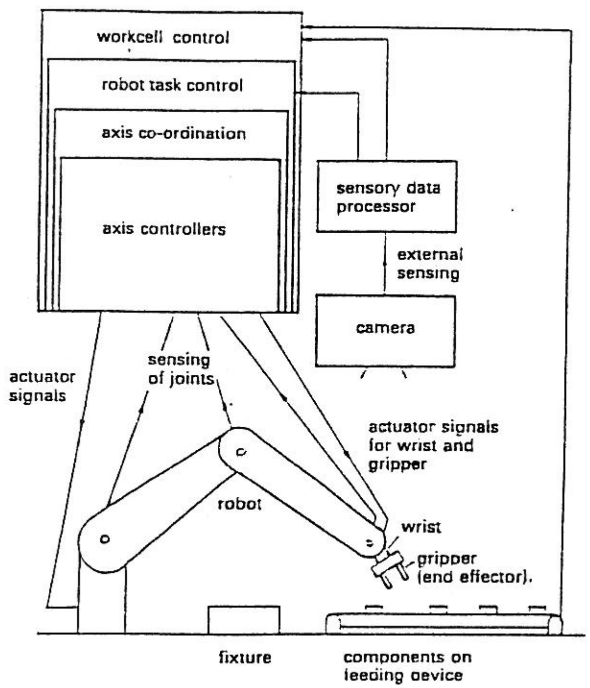
- AUTOMATION/ROBOTICS TECHNOLOGIES:
  - Sensors (Non-Vision)
  - Drive Technologies - Hydraulic (ME6009 only)
  - Control: Observers
  - Vision Systems
- OTHER INDUSTRIAL AUTOMATION TOPICS
  - Work Cells (ME6009 only)
  - PLCs (Programmable Logic Controllers)
  - Traffic Light Control using a PLC (Continuous Assessment for ME6009 only)
  - Industrial Communications

ROBOT: Term comes from Czech, Capek's play "Rossum's Universal Robots". "Robota" - Servitude or forced worker.

DEFN: A robot is a reprogrammable, multifunctional manipulator designed to move material, parts, tools or specialises devices through variable programmed motions for the performance of a variety of tasks.

Robotics is a multi-disciplinary subject encompassing: mechanics and mechanical devices, applied mathematics, actuators, sensors, real-time computing, programming and artificial intelligence, economics and sociology.

Fig 1 SCHEMATIC OF A TYPICAL ROBOTIC SYSTEM



ROBOTICS - SOME BASIC TERMS

Links, Joints: A robot may be thought of as a series of nearly rigid links which are connected with joints which allow relative motion of neighbouring links.

End Effector, Hand: The end effector is connected to the last link of the robot. It is typically a gripper, tool holder or tool. It is the part of the robot that acts on an external object.

Degrees of freedom Three degrees of freedom required to position an object in 3D space. ANOTHER three degrees are required to arbitrarily set the ORIENTATION of the end effector.

Arm, Major Axes: Grossly positions the robot tool. Usually three degrees of freedom.

Wrist, Minor Axes: Finely positions the end effector. Provides the correct orientation of the tool or grasped object. Requires up to three degrees of freedom.

Revolute Joint: Rotary joint; rotary motion about an axis Joint variable is the relative angular position of two consecutive joints.

Prismatic Joint: Linear, or sliding motion along an axis. Joint variable is the 'Offset'.

ROBOTICS - SOME BASIC TERMS

Non-Servo Controlled: Joint is moved until the link hits an end-stop. This is open loop control without sensory feedback. Common for pick-and-place machines.

Servo Controlled: The position and/or velocity of the robot links are accurately controlled using a feedback control system.

Point-to-point Motion: A servo controlled system in which only the initial and final points of the motion are important and need be accurately specified.

Continuous-Path Motion: The entire motion is accurately controlled, e.g. to ensure straight line motion or collision avoidance.

Work Envelope, Work Space: The locus of points in 3D space that can be reached by the end effector. 'Dextrous work envelope' : the smaller volume in which the robot has its full degree of freedom. 'Gross work envelope': where the wrist can be positioned to.

Actuators: Electric, Hydraulic, Pneumatic:
Electric: DC Motors, Brushless Motors, Stepper Motors, etc. Hydraulic: Based on pistons compressing fluid - high power possible but dirty. Pneumatic: Air - Compressible; useful for compliant grippers.

Workcell: A collection of robot(s), fixtures, feeding devices and other machines which are combined to perform one or more operations on some object(s).

Fig 2 SUBSYSTEMS OF ROBOT COMPONENTS

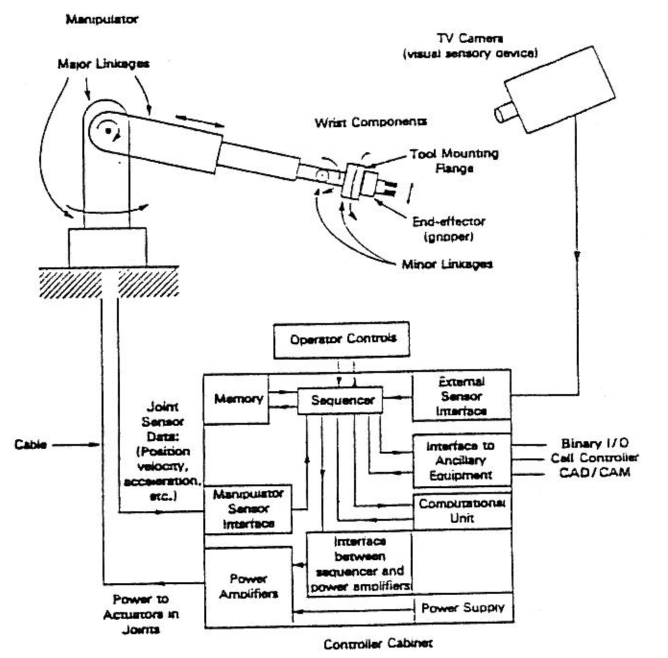


Fig 3 POSSIBLE IMPLEMENTATION OF A ROBOT CONTROLLER

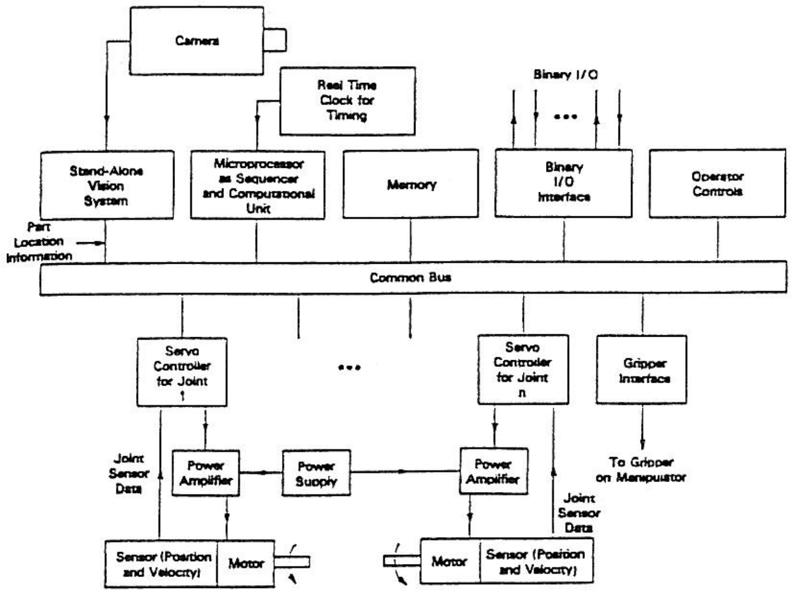


Fig 4 THE ROBOT AS A CELL CONTROLLER

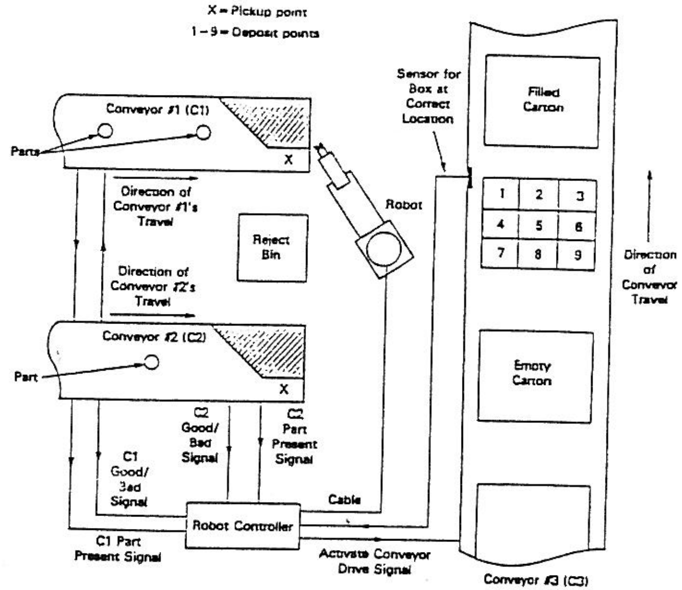
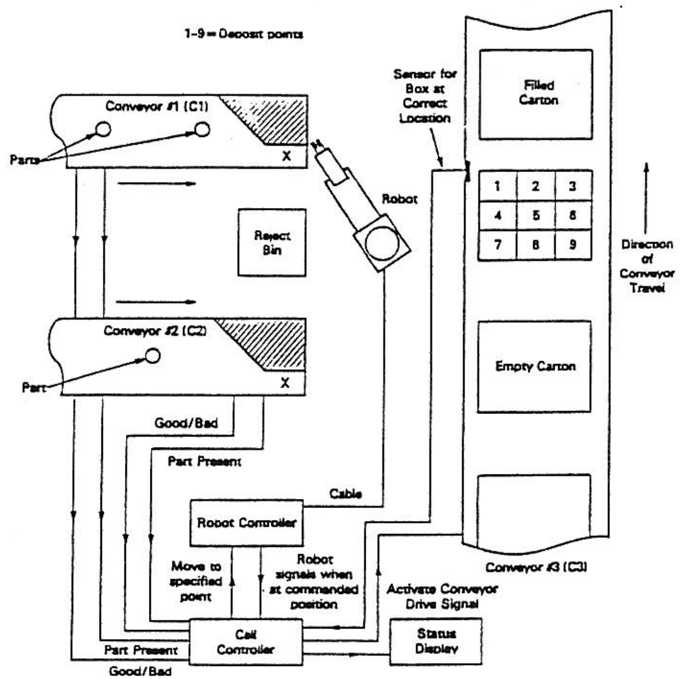


Fig 5 THE ROBOT AS A PERIPHERAL DEVICE



WHY ROBOTS?

Stronger than humans; Tireless; Consistent and highly precise; Insensitive to hostile environments (toxic, heat, dark, etc.)

WHY NOT?

High initial cost; No independent thought (e.g. in emergency); Cause unemployment ??

INDUSTRY'S REASONS:

Labour Saving; Improved Quality; Improved Productivity; Improvement of working conditions; Increased Flexibility; Ease of Production Control

MAIN ROBOT APPLICATIONS

U. S. ROBOT MARKET (1986)

Application	Percent
Material handling	24.4
Spot welding	16.5
Arc welding	14.5
Spray painting and finishing	12.4
Mechanical assembly	6.2
Electronic assembly	4.8
Material removal	4.5
Inspection and testing	2.9
Water jet cutting	2.7
Other	11.1

Industrial, medical, dental & pharma. have grown considerably

≈ 1 million units installed in 2004

SOME MEASURES OF PERFORMANCE

The *working volume* of the robot obviously needs to be sufficient so that all parts of the working area can be reached.

The *speed* and *acceleration* of the robot must be large enough so that the task can be accomplished within an acceptable time. Maximum speed is only a guideline, particularly when small movements are being made. In this case, the accelerations will dominate the time to accomplish the movement.

The *repeatability* of the robot is a measure of the tolerance within which the end effector can be returned to a pre-recorded point.

The *resolution* of the robot is the smallest step move that can be made at a given position. Typically, the worst case is quoted over the whole of the working volume.

The *accuracy* of the robot is different from that of repeatability. In this case, the robot may have been programmed offline to move to a given location 10 mm above a reference point. In practice, it will not get exactly to that point, not only because of frictional effects and discrete data effects in sensors and computers, but also because of calibration errors. The accuracy may be improved by additional sensory feedback.

CLASSIFICATION BY CO-ORDINATE SYSTEM

TABLE 1-1 TYPES OF ROBOT JOINTS

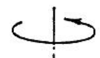
Type	Notation	Symbol	Description
Revolute	R		Rotary motion *about* an axis
Prismatic	P		Linear motion *along* an axis

TABLE 1-2 ROBOT WORK ENVELOPES BASED ON MAJOR AXES

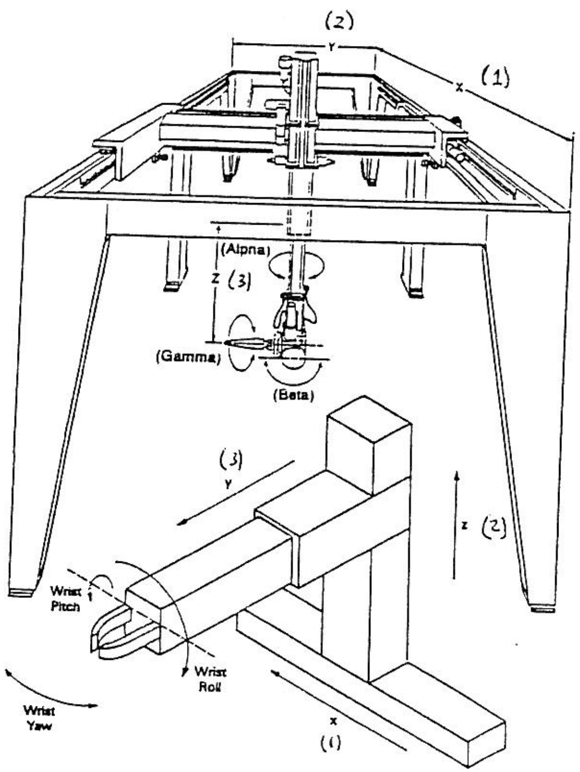
Robot	Axis 1	Axis 2	Axis 3	Total revolute
Cartesian	P	P	P	0
Cylindrical	R	P	P	1
Spherical	R	R	P	2
SCARA	R	R	P	2
Articulated	R	R	R	3

P = prismatic, R = revolute.

CARTESIAN ROBOTS

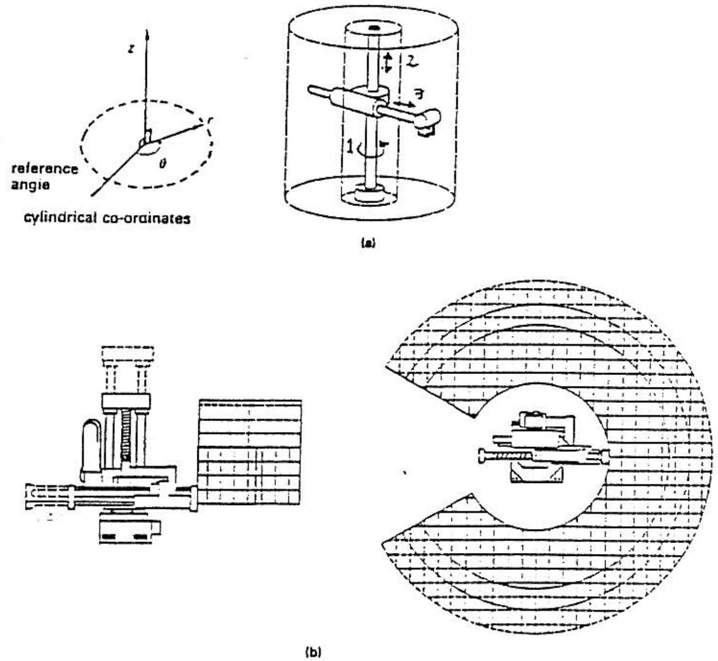
Simple 'real-world' configuration;
Cantilevered: Good Accuracy & repeatability; Easily Programmed; Limited extension; Poor Rigidity; Often limited types of motion. Gantry: Heavy loads; Rigid; Poor access to workspace.

Geometry of a Cartesian gantry style robot. (Courtesy of CIM-CORP, Inc., St. Paul, MN.)



Cantilevered Cartesian robot geometry.

CYLINDRICAL ROBOTS



A cylindrical coordinate robot: (a) a general view of the geometry of the robot's major axes; (b) vertical and top views of the workspace of such a robot. (Courtesy of J. Cosnnitzke. Cincinnati Milacron. Cincinnati. OH).

SPHERICAL ROBOTS

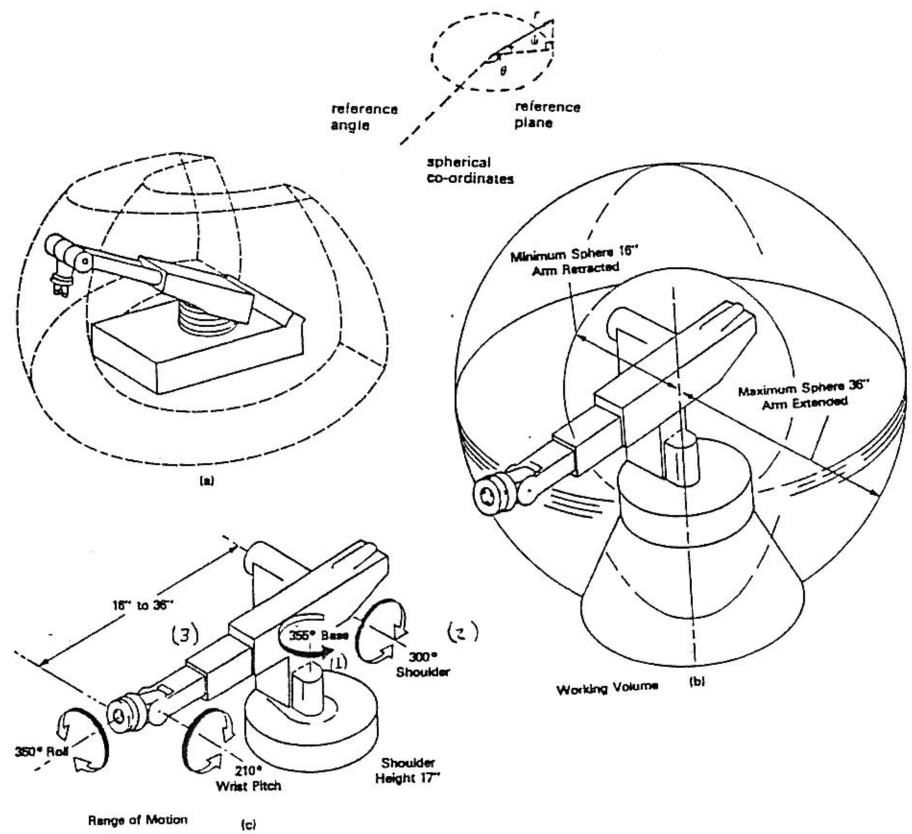
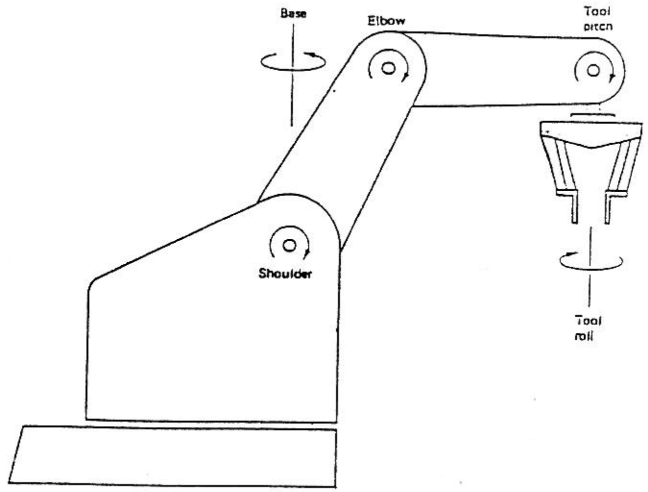


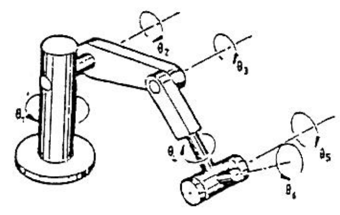
Figure 1.3.6. A spherical coordinate robot: (a) general view of the geometry of the robot's major axes: (b) working volume (workspace) of such a robot: (c) range of motion for each of the five axes of a typical spherical coordinate robot. (Courtesy of G. Heatherston and U.S. Robots, a Square D Company.)

ARTICULATED ROBOTS

Example: PUMA robot (Programmable Universal Machine for Assembly) - Unimation

Advantage: Wide reach (near base & over obstacles); Trunk, Shoulder, Elbow joints - Anthropomorphic.

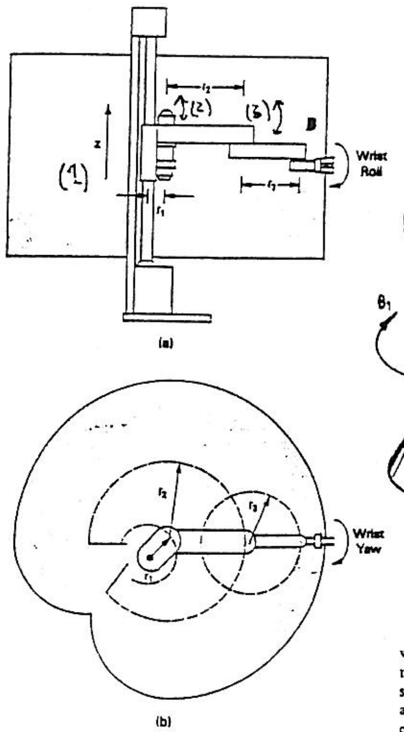


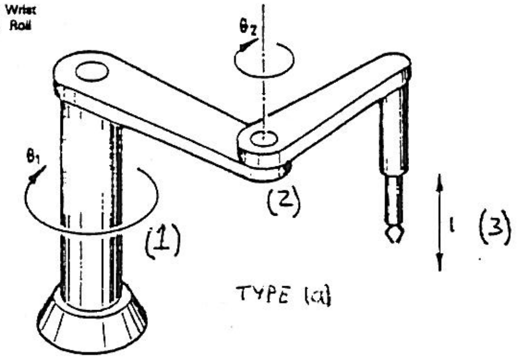


The six degrees of freedom of a manipulator.

SCARA ROBOTS Selective Compliance Assembly Robot Arm

Special case of Articulated (Jointed arm) robot
Three axes are vertical; Fast; Smooth; Very stiff in vertical direction; Lateral 'give' (compliance) - programmable; Useful for inserting objects in holes



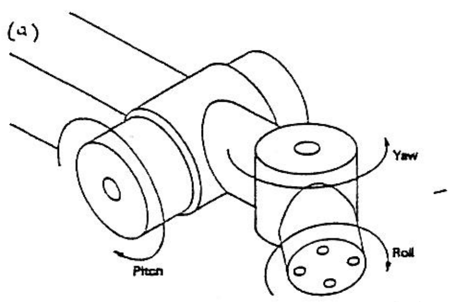


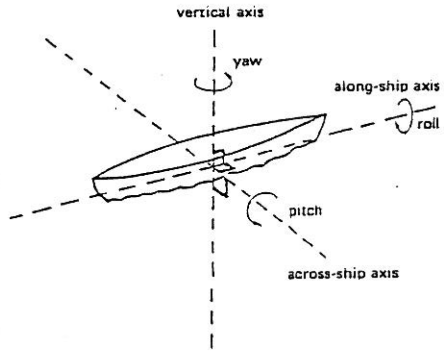
TYPE (b)

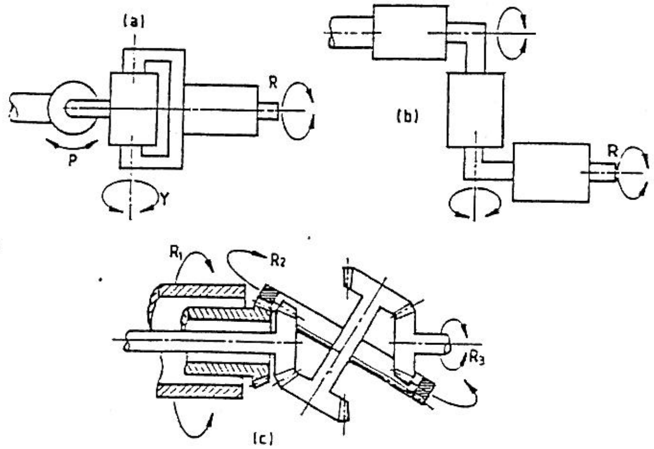
Jointed cylindrical workspace and geometry robot: (a) vertical cross-section; (b) top view. In some SCARA robots, $r_1 = 0$ and the z axis is located at the wrist. Also, wrist could have a pitch axis.

MINOR AXES - WRISTS

In (b), first two joints together produce pitch and yaw motion
In (c), Concentric drive shafts used,; compact intersecting axes - like ball and socket joint.
Note: If tool is symmetrical, roll axis not needed.



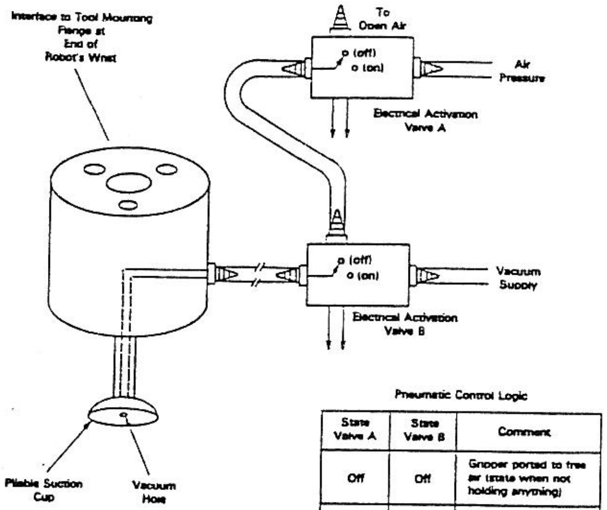




Wrists: (a) all axes mutually perpendicular (b) all elements capable of continuous rotation (c) a design that allows remote drive.

END EFFECTORS - GRIPPERS

Unilateral Grippers



Pneumatic Control Logic

State Valve A	State Valve B	Comment
Off	Off	Gripper ported to free air (state when not holding anything)
On	Off*	Air pressure applied to cup (used to release part, i.e., neutralize residual vacuum)
On/Off	On	Vacuum applied to cup (used to pick up part)

Figure 3.7.1 End effectors with unilateral gripping action.

END EFFECTORS - GRIPPERS

Bilateral, Multilateral Grippers