An Introduction to Robotics

Dr. Bob Williams, williar4@ohio.edu

Mechanical Engineering, Ohio University

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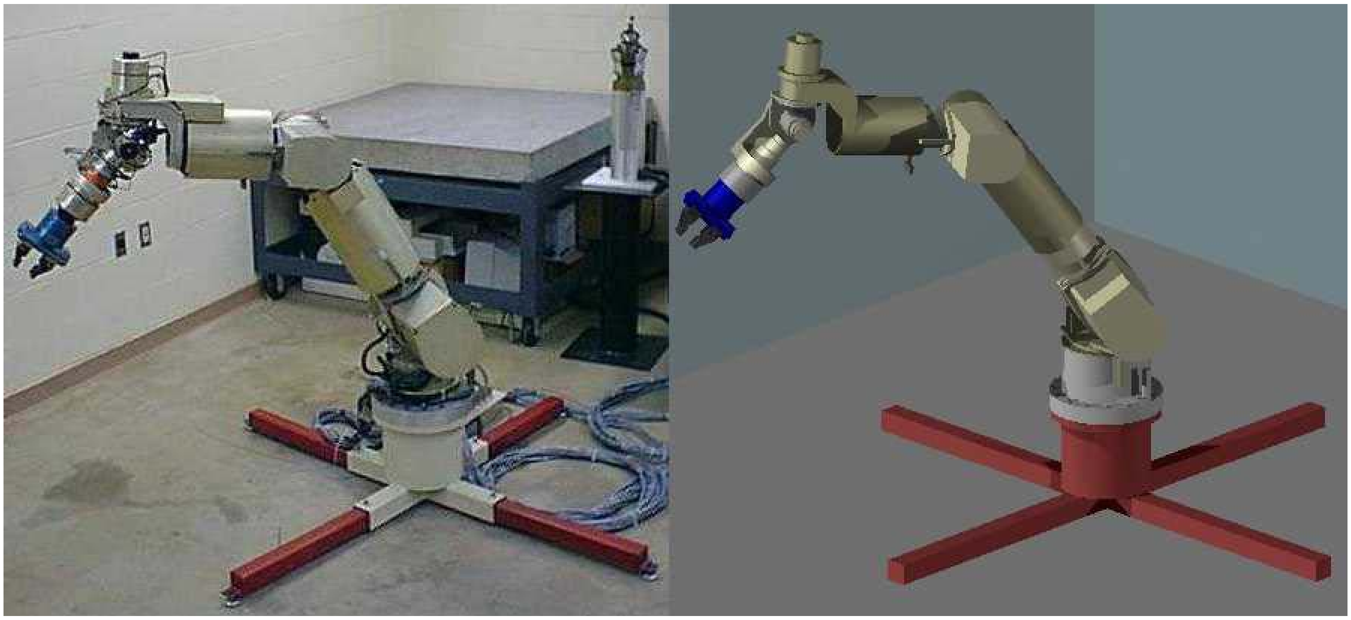


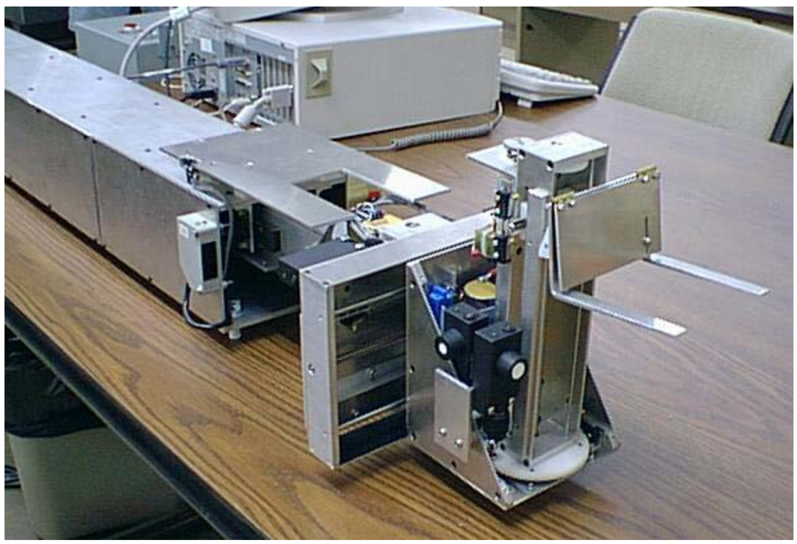
NASA LaRC 8-axis 8R Spatial Serial Manipulator

NASA LaRC 2 6-axis 6R PUMA Robots

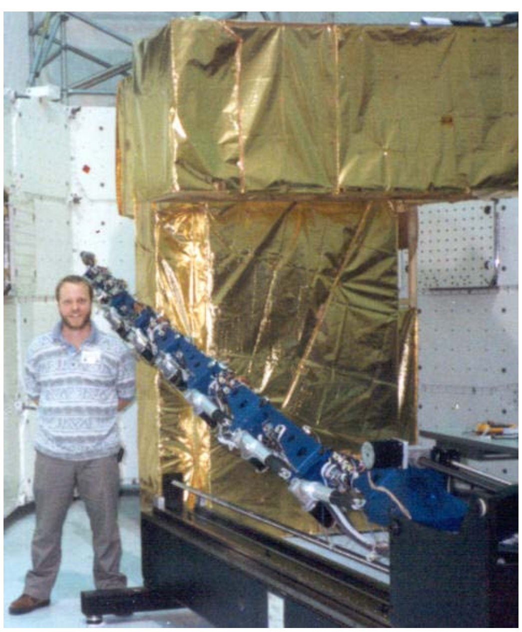
Rosheim Omni Wrist

R2-D2 and C3PO

NASA JSC RoboNaut

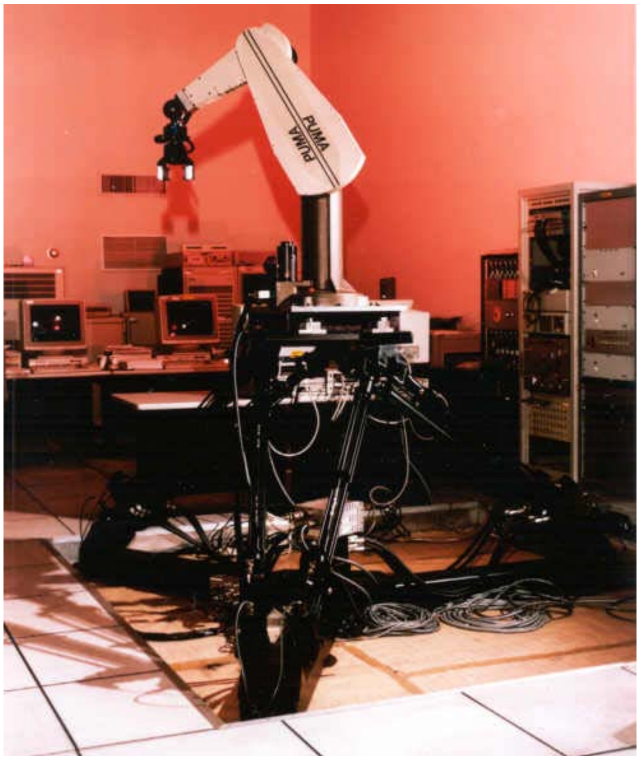


Stewart-Glapat 5-axis Trailer-Loading Robot

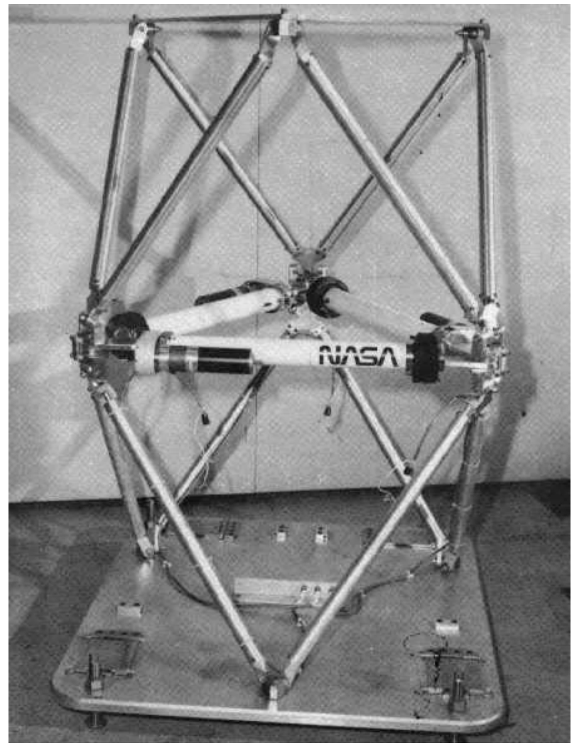


NASA KSC 18-dof Serpentine Truss Manipulator

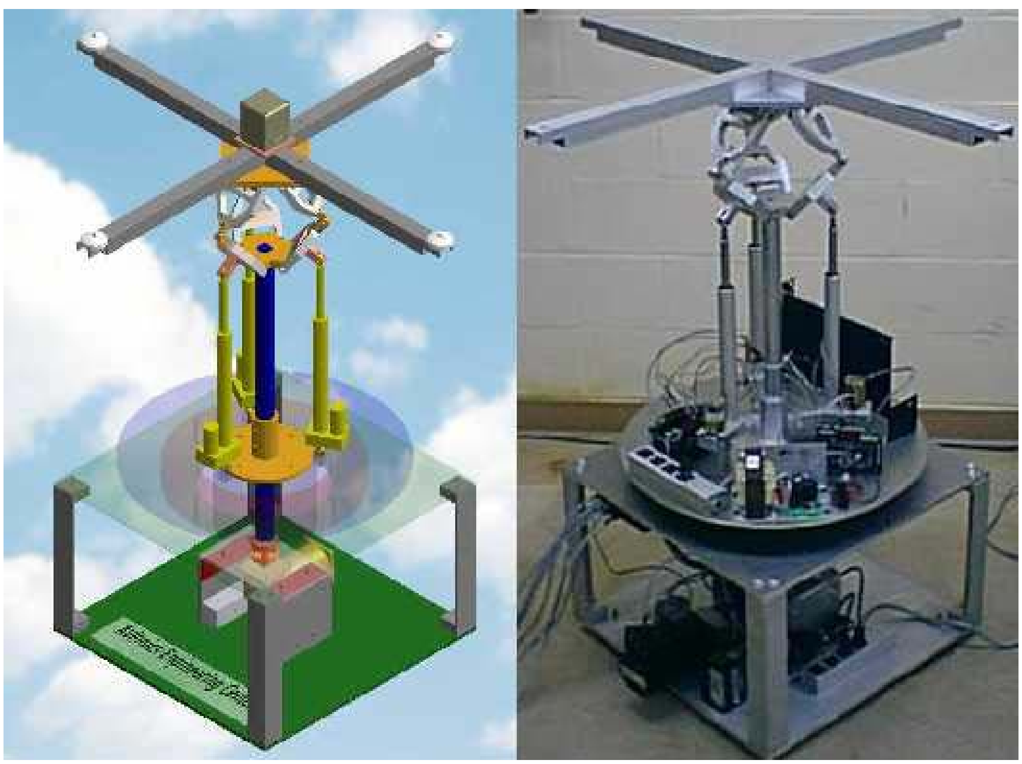
2 Modules (Rex Kuriger)



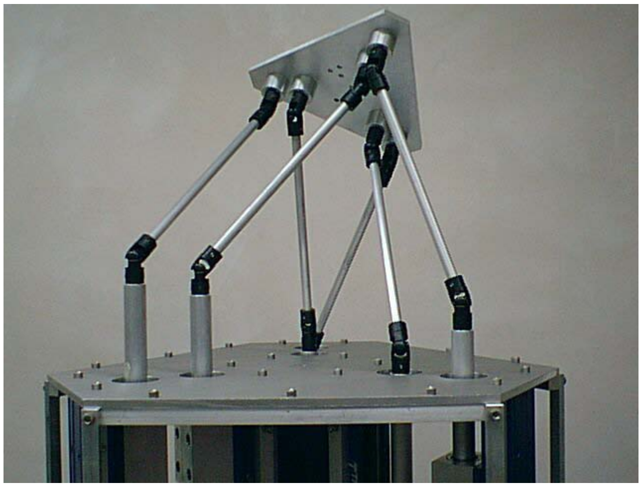
NASA LaRC 6R PUMA on Stewart Platform



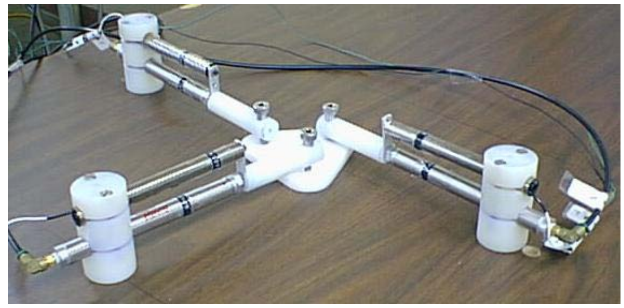
NASA Variable Geometry Truss



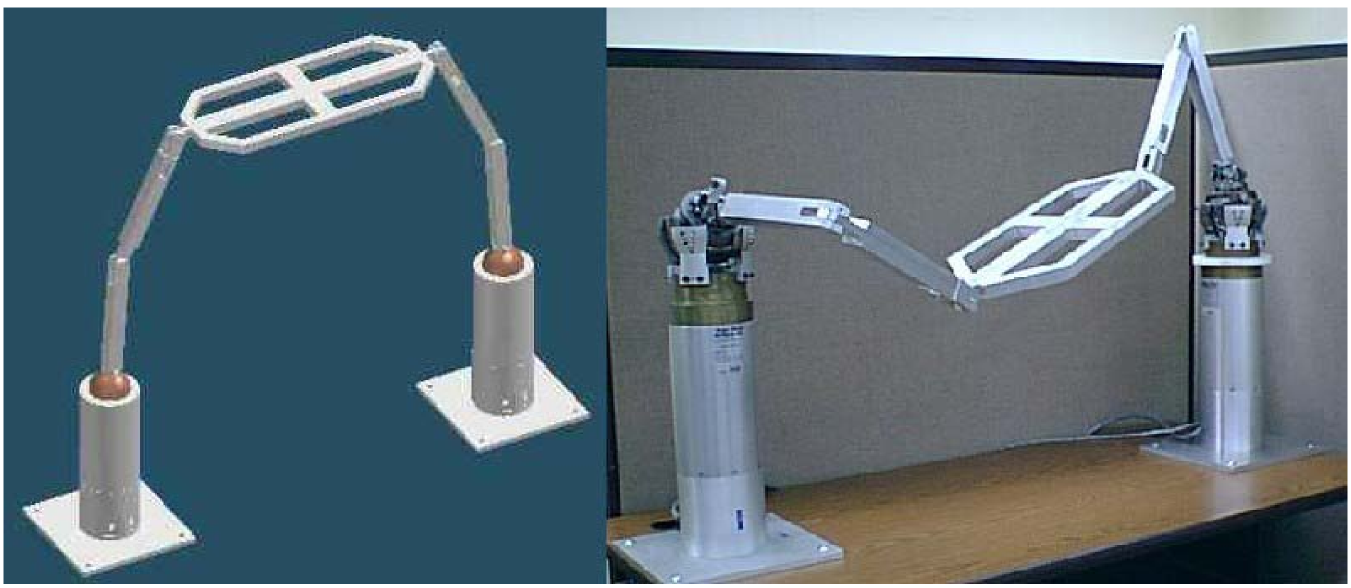
4-dof GPS/IMU Calibration Platform



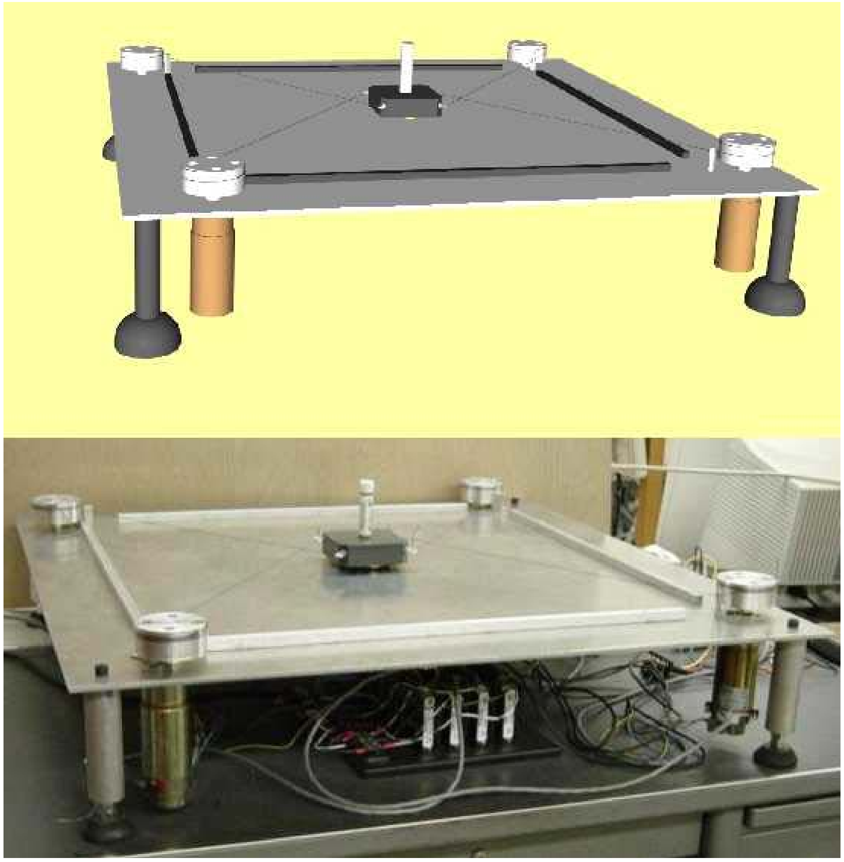
6-dof 6-PUS Parallel Platform Manipulator



3-dof 3-RPR Parallel Platform Manipulator

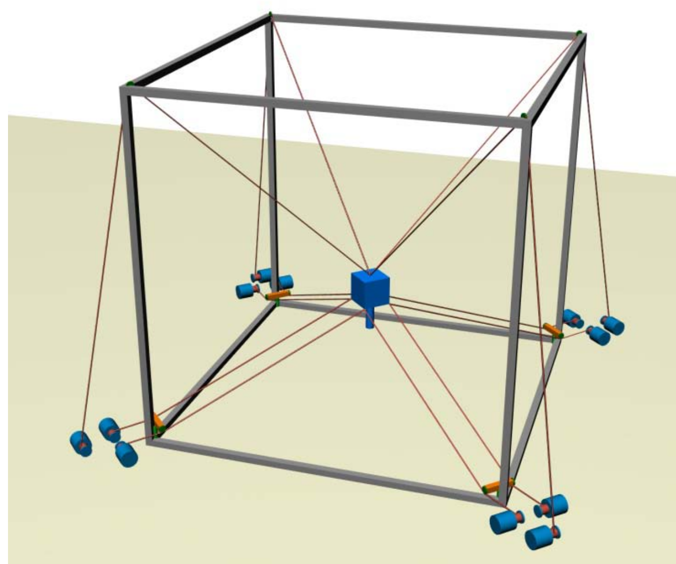


6-dof 6-SRU Spatial Parallel Platform Manipulator

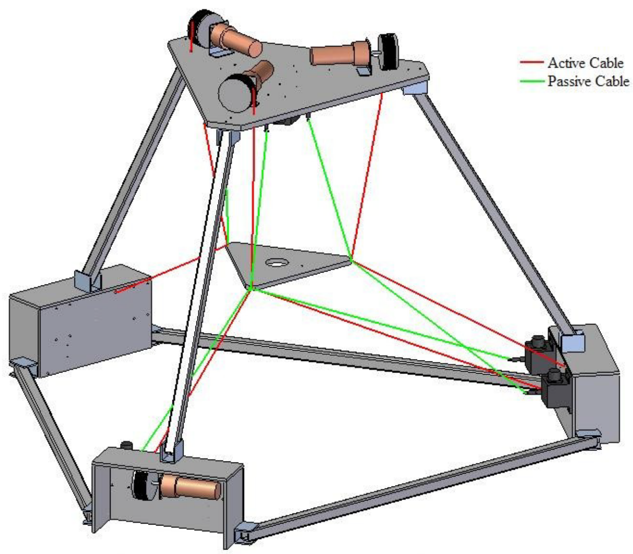


4-dof Planar Wire-Driven Robot

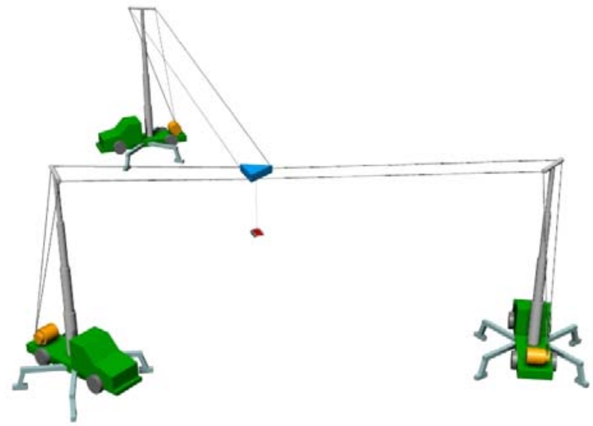
NIST 6-dof RoboCrane Cable Robot



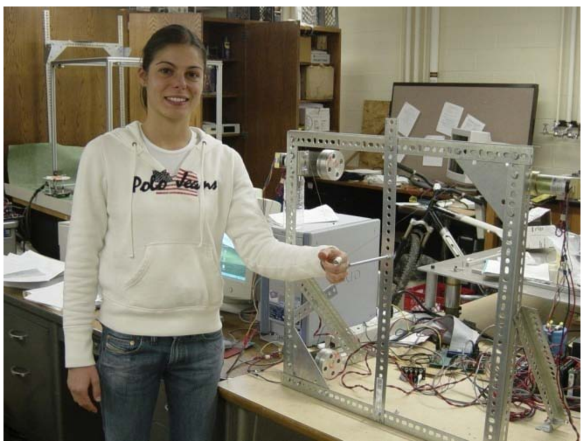
8-dof Cartesian Contour Crafting Cable Robot



7-dof Spatial Cable-Suspended Robot

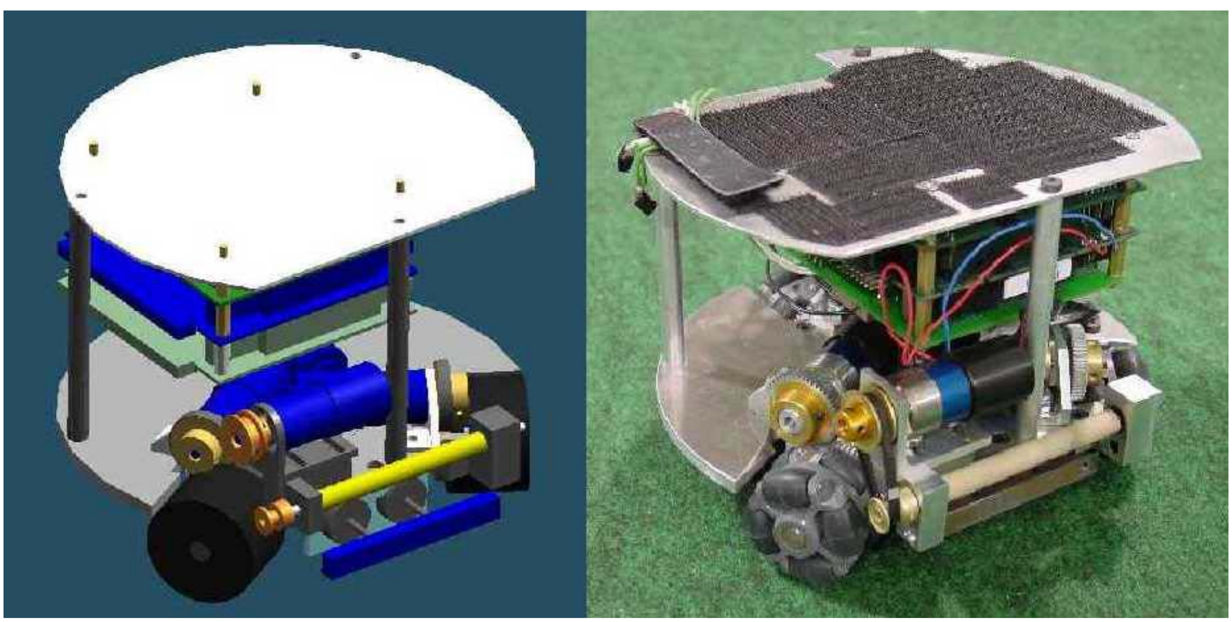


Deployable Search and Rescue Cable Robot

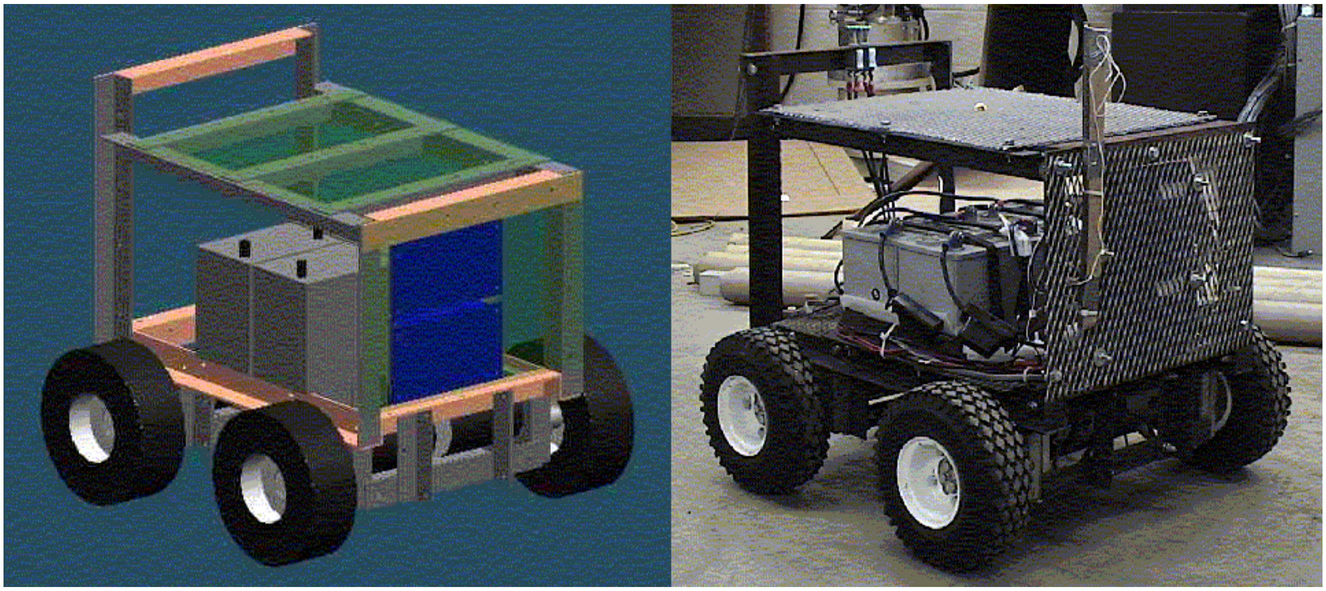


3-dof Cable-Suspended Haptic Interface

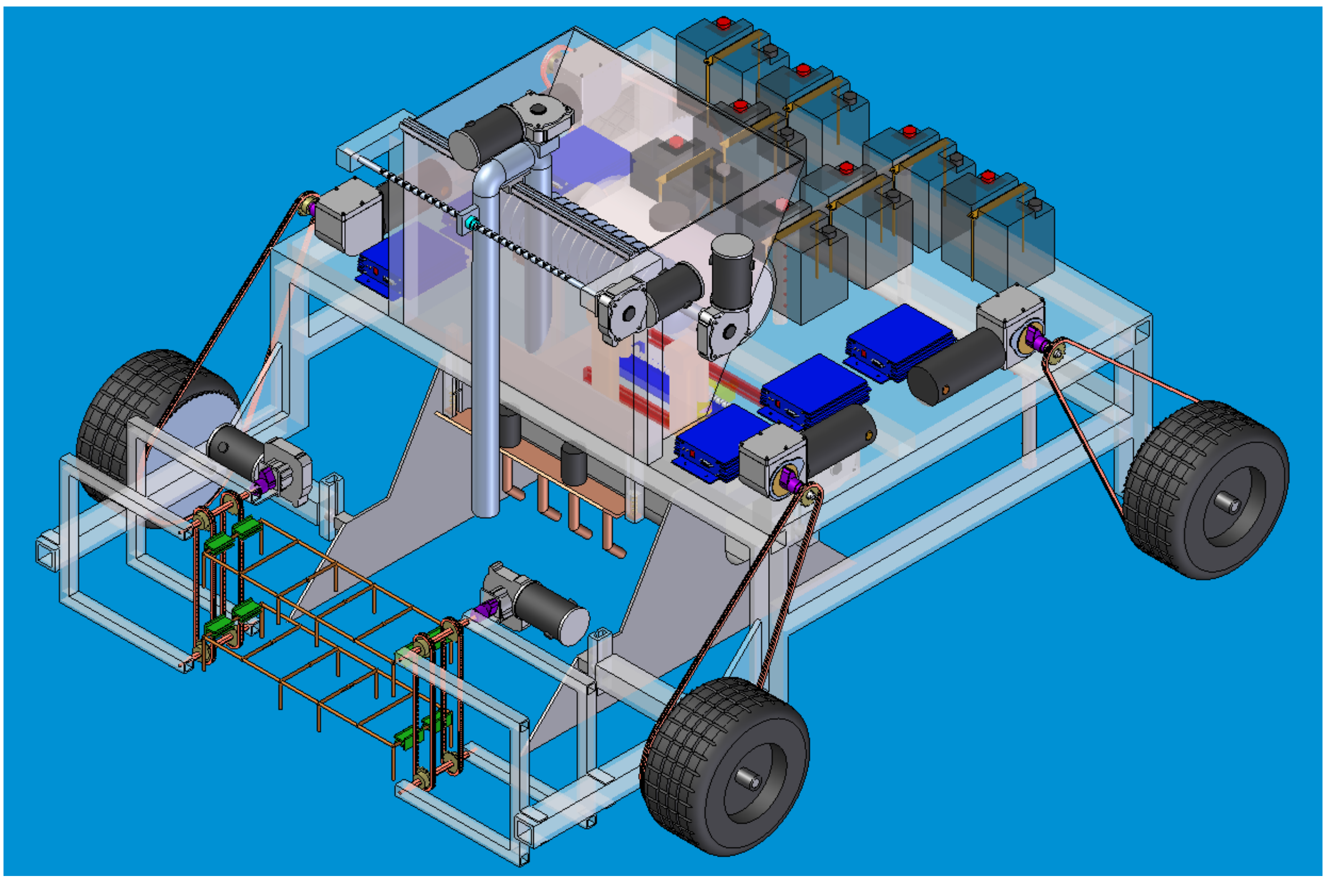
8-dof Cable-Suspended Haptic Interface



3-dof Omni-Directional RoboCup Wireless Autonomous Mobile Robot



4-dof Search and Rescue Mobile Robot



4-dof Autonomous Concrete-Paving Mobile Robot

History

- **Leonardo da Vinci** created many robot-like sketches and designs in the 1500's.

- The word **robot** first appeared in print in the 1920 play R.U.R. (Rossum's Universal Robots) by **Karl Kapek**, a Czechoslovakian playwright. **Robota** is Czechoslovakian for *worker* or *serf* (peasant). Typical of early science fiction, the robots take over and exterminate the human race.

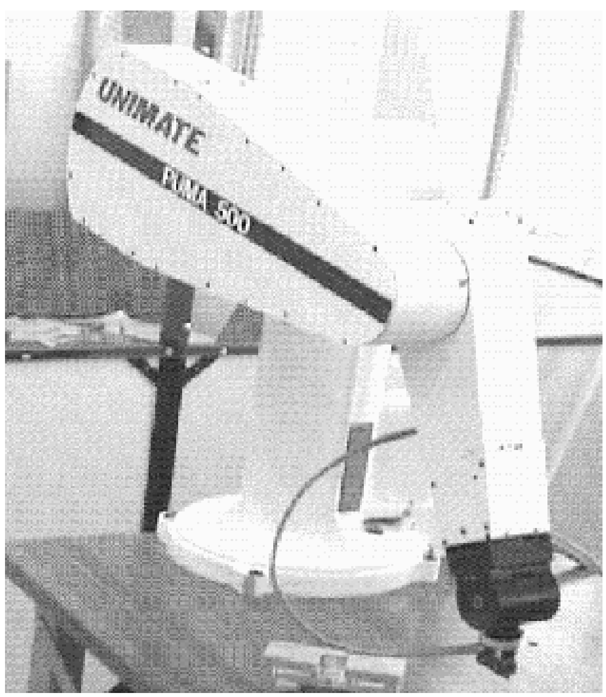
- **Isaac Asimov** popularized the term **robotics** through many science-fiction novels and short stories. Asimov is a visionary who envisioned in the 1930's the positronic brain for controlling robots; this pre-dated digital computers by a couple of decades. Unlike earlier robots in science fiction, robots do not threaten humans since Asimov invented the **three laws of robotics**:

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

  2. A robot must obey the orders given by human beings, except when such orders conflict with the First Law.

  3. A robot must protect its own existence as long as it does not conflict with the First or Second Laws.

- **Joseph Engleberger** and **George Devoe** were the fathers of industrial robots. Their company, Unimation, built the first industrial robot, the **PUMA** (**P**rogrammable **U**niversal **M**anipulator **A**rm, a later version shown below), in 1961.



PUMA Industrial Robot

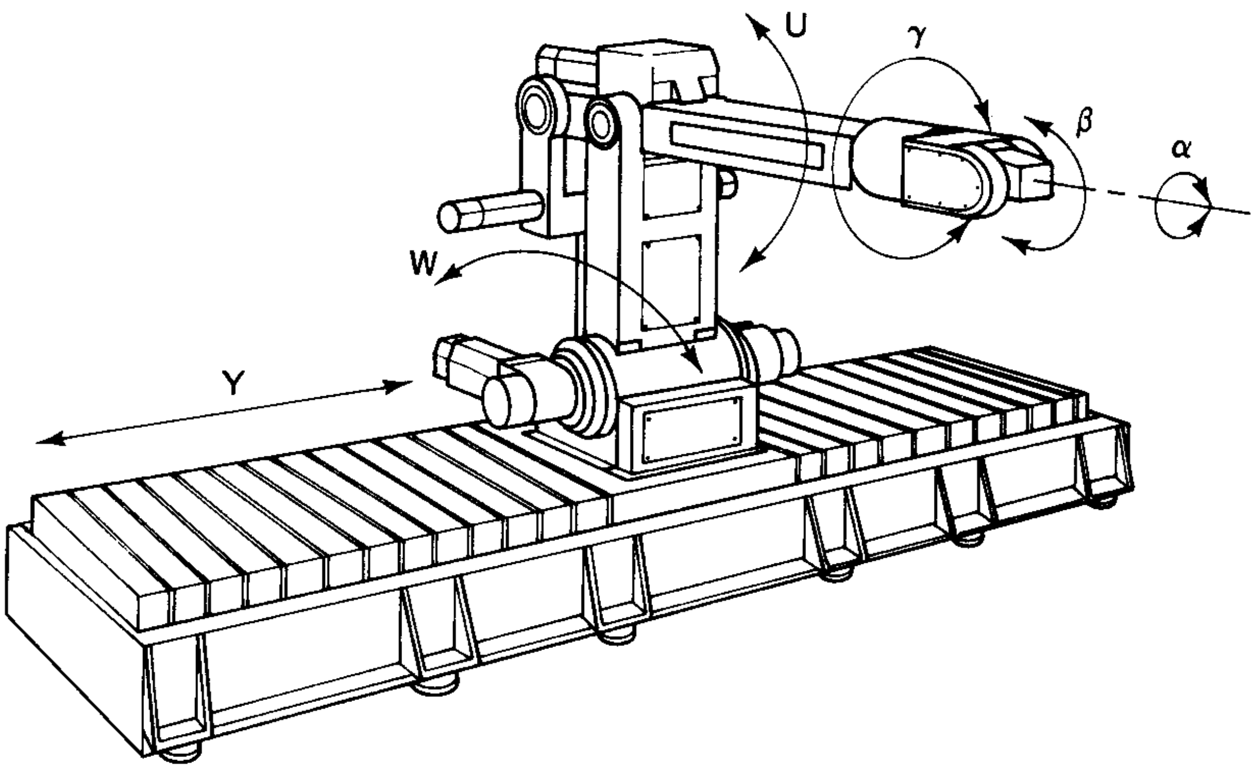
Definitions

robot An electromechanical device with **multiple** degrees-of-freedom (**dof**) that is **programmable** to accomplish a variety of **tasks**.

What are examples of robots?

robotics The science of **robots**. Humans working in this area are called **roboticists**.

dof **degrees-of-freedom**, the number of independent motions a device can make. Also called **mobility**.



How many **dof** does the human arm have? The human leg?

manipulator Electromechanical device capable of interacting with its environment.

anthropomorphic Designed or appearing like human beings.

end-effector The tool, gripper, or other device mounted at the end of a **manipulator**, for accomplishing useful tasks.

workspace The volume in space that a robot's end-effector can reach, both in position and orientation.

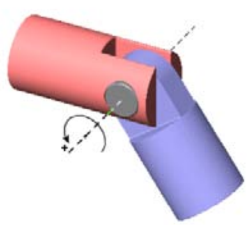
position The translational (straight-line) location of an object.

orientation The rotational (angular) location of an object. An airplane's orientation is measured by **roll**, **pitch**, and **yaw** angles.

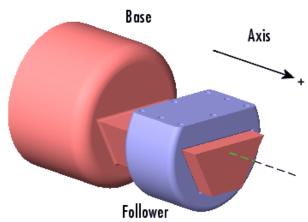
pose **position** and **orientation** taken together.

link A rigid piece of material connecting joints in a **robot**.

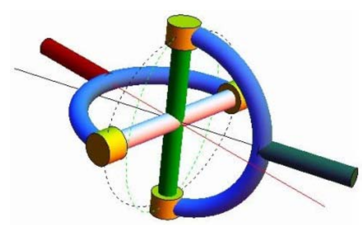
joint The device which allows relative motion between two links in a **robot**.



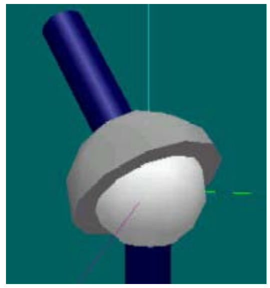
revolute (R)



prismatic (P)



universal (U)



spherical (S)

kinematics The study of motion without regard to forces/torques.

dynamics The study of motion with regard to forces/torques.

actuator Provides force/torque for robot motion.

sensor Reads actual variables in robot motion for use in control.

haptics From the Greek, meaning **to touch**. Haptic interfaces give human operators the sense of touch and forces from the computer, either in virtual or real, remote environments. Also called **force reflection** in telerobotics.

Applications

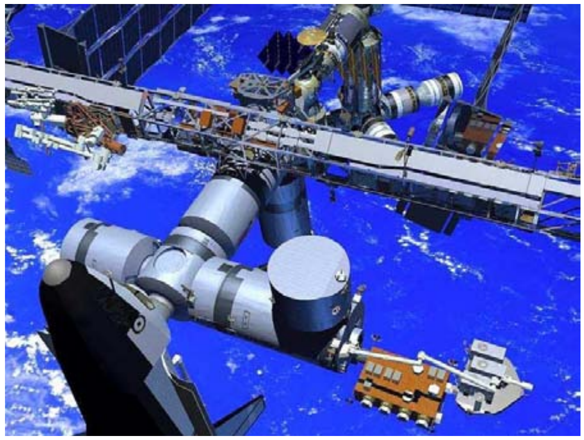
Traditionally, robots are applied anywhere one of the **3Ds** exist: in any job which is too: **Dirty**, **Dangerous**, and/or **Dull** for a human to perform.

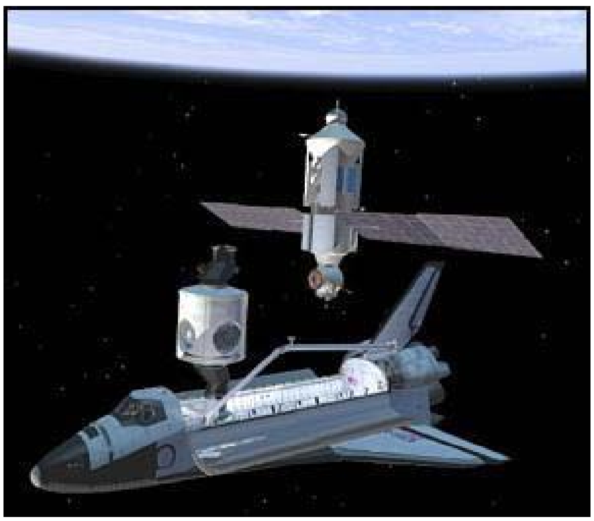
Industry

Industrial robots are used in manufacturing, assembly, welding, spray painting, deburring, machining.

Remote operations

Remote applications for robotics include undersea, nuclear environment, bomb disposal, law enforcement, and outer space.





NASA Space Shuttle and International Space Station Robots

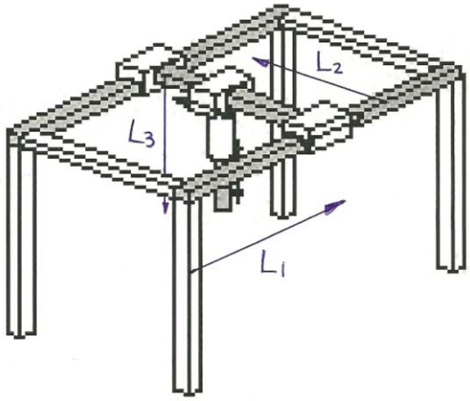
Service

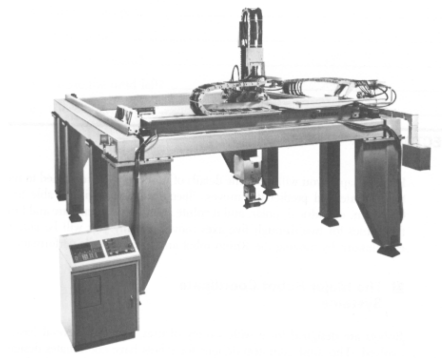
Service robots have been implemented as hospital helpmates, handicapped assistance, retail, household servants, and lawnmowers.

Common Robot Designs

Cartesian Robot

Cartesian robots have three linear axes of movement (X, Y, Z). They are constructed of three mutually-orthogonal prismatic joints, with variable lengths L_1, L_2, L_3. Used for pick and place tasks and to move heavy loads. Also called Gantry Robots, they can trace rectangular volumes in 3D space.



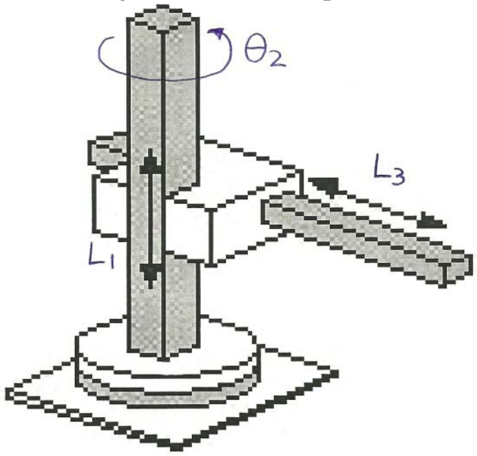


Gantry Robot.

Photo used with permission of Cybotech.

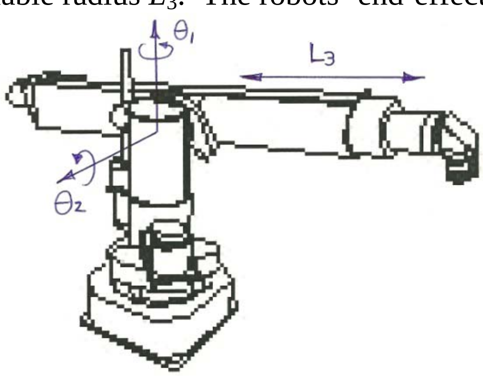
Cylindrical Robot

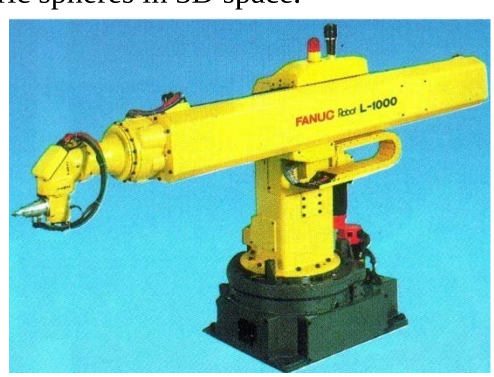
Cylindrical robot positions are controlled by a variable height L_1, an angle θ_2, and a variable radius L_3 (P joint, R joint, P joint). These robots are commonly used in assembly tasks and can trace concentric cylinders in 3D space.



Spherical Robot

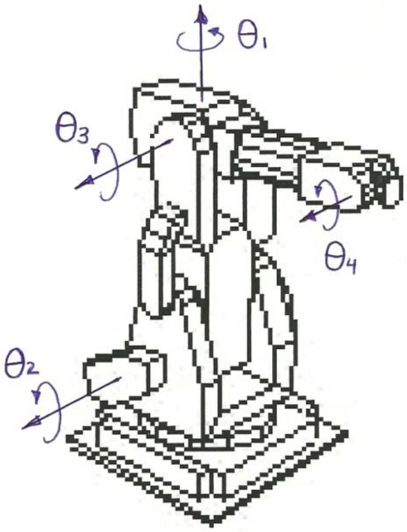
Spherical robots have two orthogonal rotational R axes, with variables θ_1 and θ_2, and one P joint, variable radius L_3. The robots' end-effectors can trace concentric spheres in 3D space.

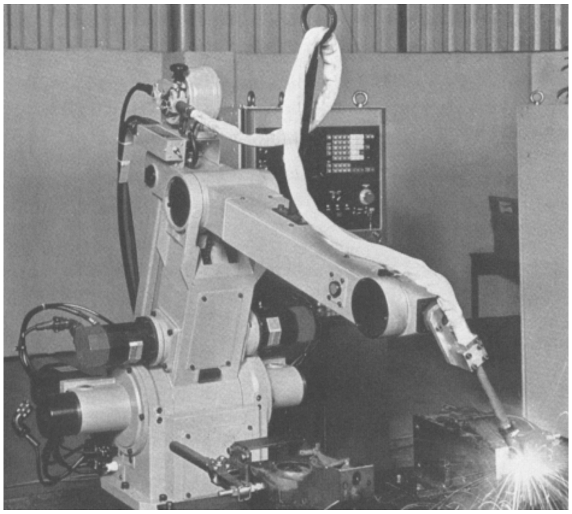




Articulated Robot

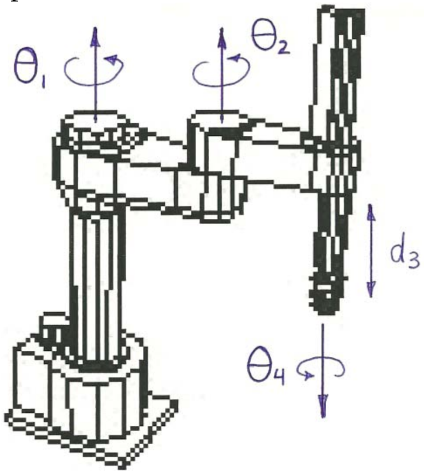
Articulated robots resemble the human arm in their 3D motion (they are anthropomorphic). They have three R joints, with three variable angles θ_1, θ_2, and θ_3, representing the human body waist, 1-dof shoulder, and elbow joints. They are versatile robots, but have more difficult kinematics and dynamics control equations than other serial robots. All of these robot architectures may be used with a variety of robot wrists to provide the orientation dof. A wrist pitch, with variable angle θ_4, is shown with the articulated robot below.





SCARA (<u>S</u>elective <u>C</u>ompliance <u>A</u>rticulated <u>R</u>obot <u>A</u>rm) Robot

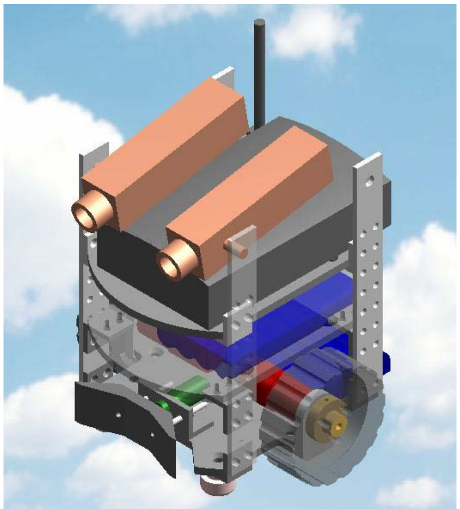
SCARA robots have three revolute joints θ_1, θ_2, and θ_4, plus a prismatic joint d_3 perpendicular to that plane of motion, to achieve a 3D workspace. These are common table-top assembly robots.



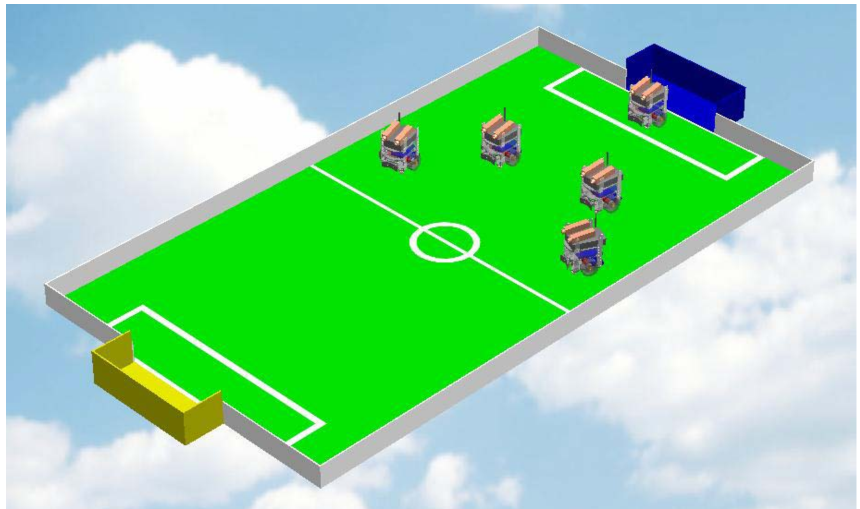
We will mostly deal with serial robotic arms; some other interesting types of robots are mobile robots, humanoid robots, and parallel robots.

Mobile Robots

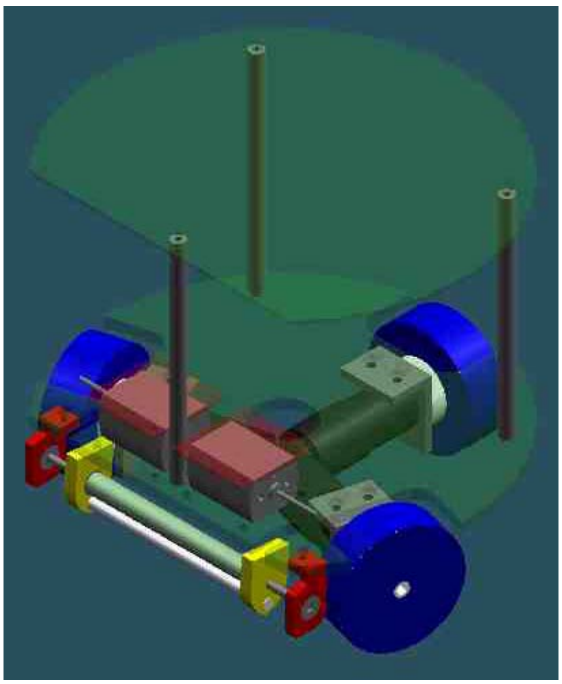
Mobile robots have wheels, legs, or other means to navigate around the workspace under control. Mobile robots are applied as hospital helpmates and lawn mowers, among other possibilities. These robots require good sensors to see the workspace, avoid collisions, and get the job done. The following six images show Ohio University's involvement with mobile robots playing soccer, in the international *RoboCup* competition (robocup.org).



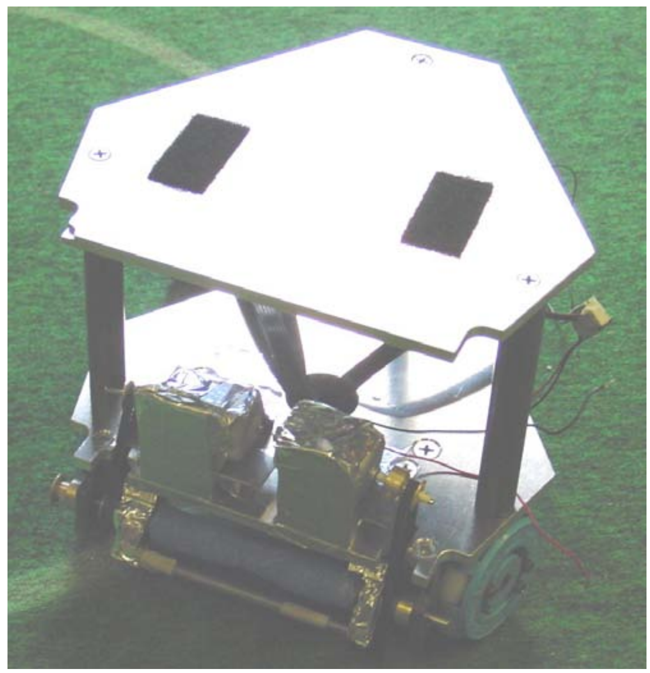
Early Conceptual Design



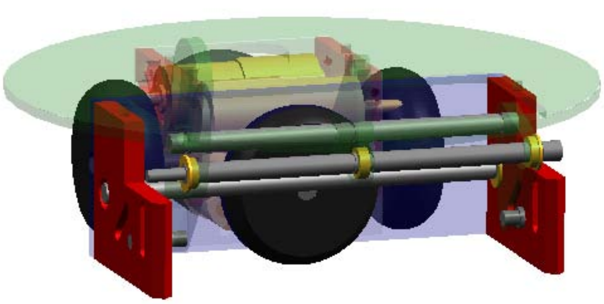
RoboCup Playing Field; 4 Players and 1 Goalie



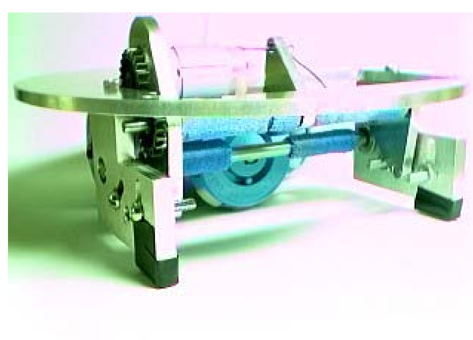
RoboCup Player CAD Model



RoboCup Player Hardware



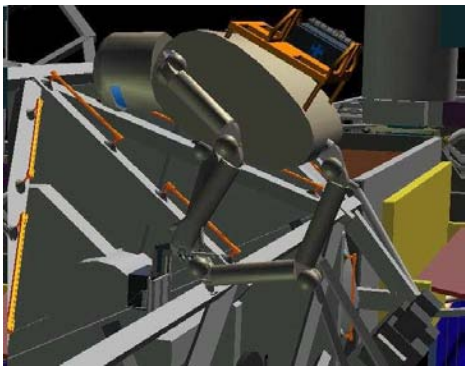
RoboCup Goalie CAD Model



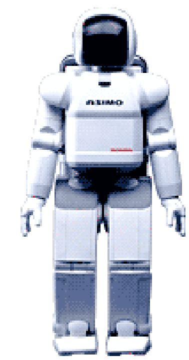
RoboCup Goalie Hardware

Humanoid Robots

Many students (and U.S. Senators) expect to see C3PO (from Star Wars) walking around when visiting a robotics laboratory. Often they are disappointed to learn that the state-of-the-art in robotics still largely focuses robot arms. There is much current research work aimed at creating human-like robots that can walk, talk, think, see, touch, etc. Generally Hollywood and science fiction lead real technology by at least 20 or 30 years.



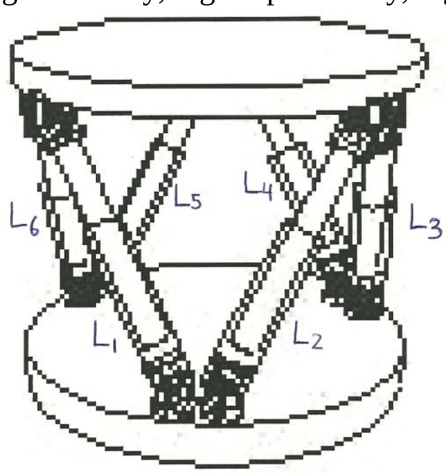

NASA JSC Robonaut



Honda Humanoid Robot

Parallel Robots

Most of the robots discussed so far are serial robot arms, where joints and links are constructed in a serial fashion from the base, with one path leading out to the end-effector. In contrast, parallel robots have many arms with active and passive joints and links, supporting the load in parallel. Parallel robots can handle higher loads with greater accuracy, higher speeds, and lighter robot weight; however, a major drawback is that the workspace of parallel robots is severely restricted compared to equivalent serial robots. Parallel robots are used in expensive flight simulators, as machining tools, and can be used for high-accuracy, high-repeatability, high-precision robotic surgery.



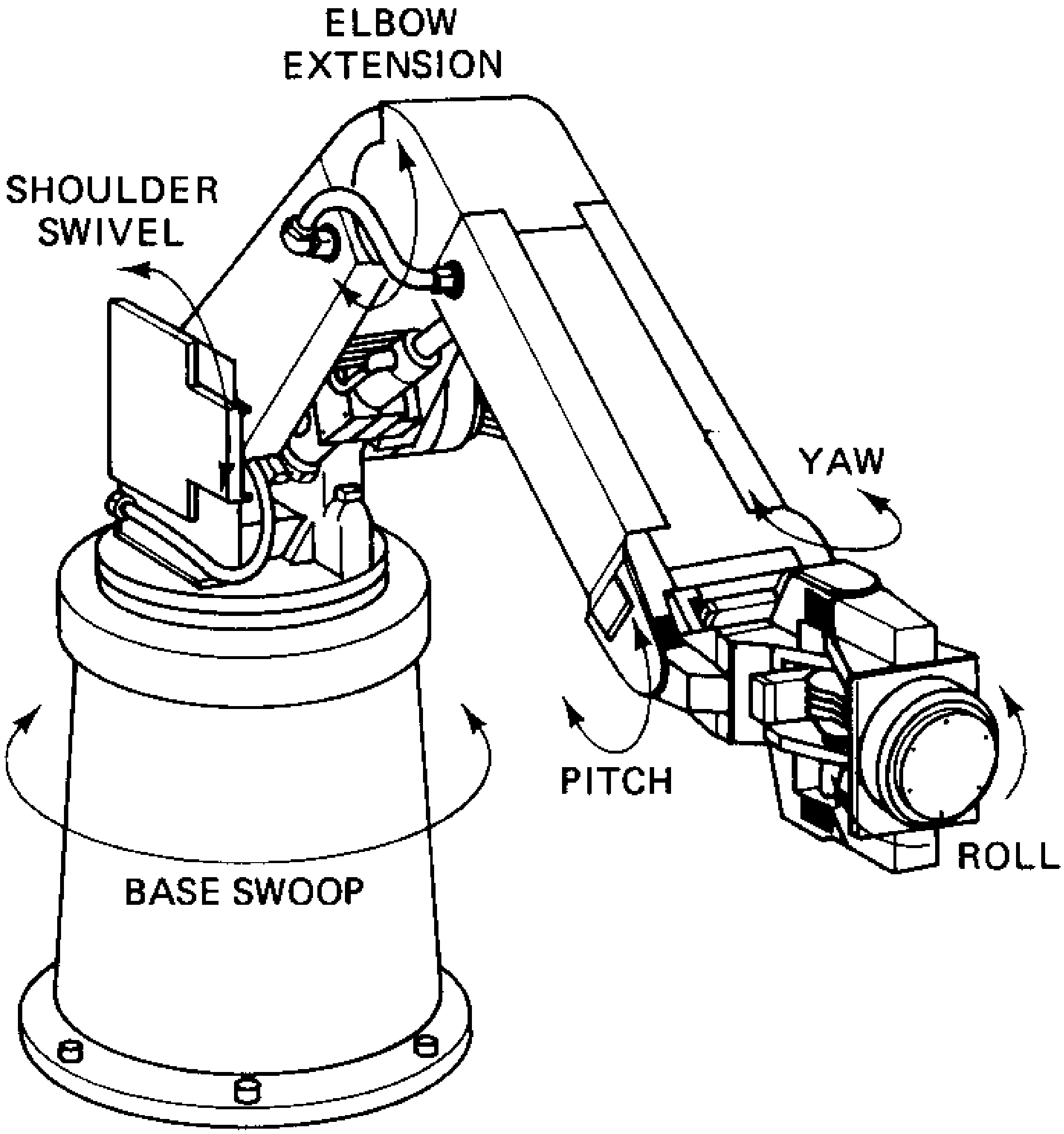
Stewart Platform Parallel Robot

Parallel Platform Robot at Ohio University

Cable-Suspended Robots

Cable-suspended robots, pictured in the Photo Gallery earlier, are a special kind of parallel robot where lightweight, stiff, strong cables are both the actuators and structure for the robot. Though a disadvantage is you cannot push on a cable (you can apply only tension), cable-suspended robots have large, even huge, translational workspaces, unlike most parallel robots.

Robot Parts



- base
- shoulder
- elbow
- wrist
- tool-plate
- end-effectors (not shown)

Technical Robotics Terms

Speed

Speed is the amount of distance per unit time at which the robot can move, usually specified in inches per second or meters per second. The speed is usually specified at a specific load or assuming that the robot is carrying a fixed weight. Actual speed may vary depending upon the weight carried by the robot.

Load Bearing Capacity

Load bearing capacity is the maximum weight-carrying capacity of the robot. Robots that carry large weights, but must still be precise are expensive.

Accuracy

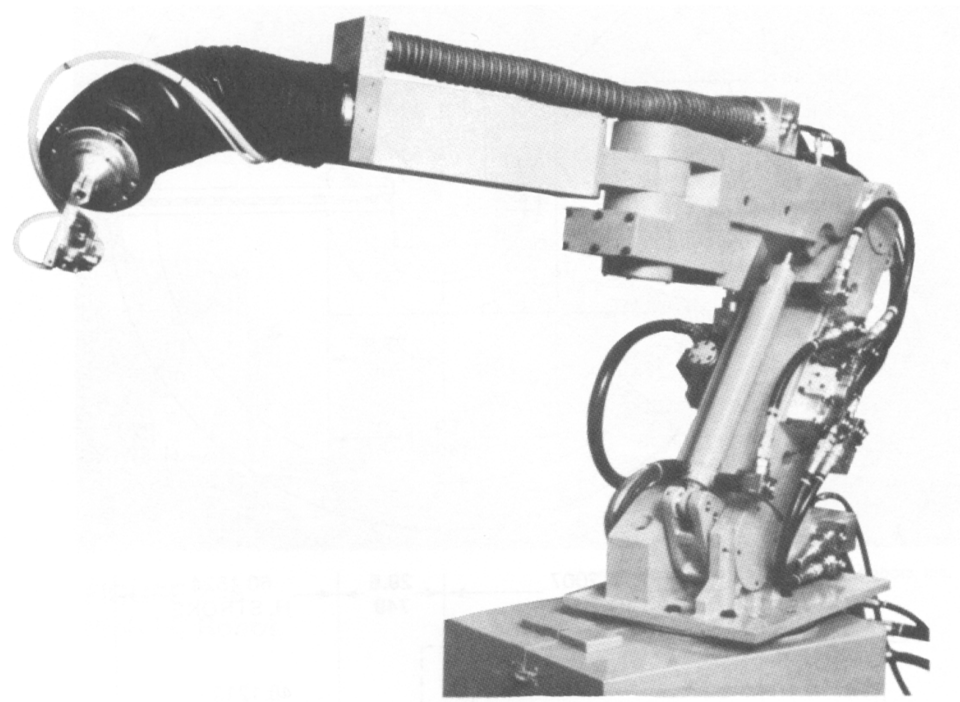
Accuracy is the ability of a robot to go to the specified position without making a mistake. It is impossible to position a machine exactly. Accuracy is therefore defined as the ability of the robot to position itself to the desired location with the minimal error (usually 0.001 inch).

Repeatability

Repeatability is the ability of a robot to repeatedly position itself when asked to perform a task multiple times. Accuracy is an absolute concept, repeatability is relative. Note that a robot that is repeatable may not be very accurate. Likewise, an accurate robot may not be repeatable.

Work Envelope

Work envelope is the maximum robot reach, or volume within which a robot can operate. This is usually specified as a combination of the limits of each of the robot's parts. The figure below shows how a work-envelope of a robot is documented.



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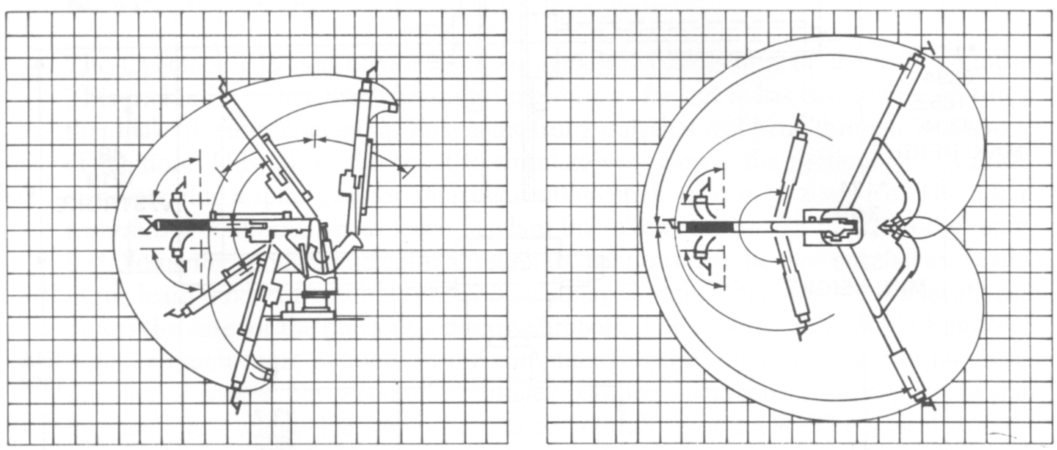

1 SQUARE = 1 FOOT

Cybotech P15

Workcells

Robots seldom function in an isolated environment. In order to do useful work, robots must coordinate their movements with other machines and equipment, and possibly with humans. A group of machines/equipment positioned with a robot or robots to do useful work is termed a **workcell**. For example, a robot doing welding on an automotive assembly line must coordinate with a conveyor that is moving the car-frame and a laser-positioning / inspection robot that uses a laser beam to locate the position of the weld and then inspect the quality of the weld when it is complete.

Robot Power Sources/ Actuators

The robot drive system and power source determine characteristics such as speed, load-bearing capacity, accuracy, and repeatability as defined above.

Electric motors (DC servomotors)

A robot with an electrical drive uses electric motors to position the robot. These robots can be accurate, but are limited in their load-bearing capacity.

Hydraulic cylinders (fluid pressure)

A robot with a hydraulic drive system is designed to carry very heavy objects, but may not be very accurate.

Pneumatic cylinders (air pressure)

A pneumatically-driven robot is similar to one with a hydraulic drive system; it can carry less weight, but is more compliant (less rigid to disturbing forces).

McKibben Artificial Muscles (air pressure)

The McKibben artificial muscle was invented in the 1950's, but was too complicated to control until the 1990's (computers and nonlinear controls technology have greatly improved). Like the human muscle, these artificial muscles can only contract, and cannot push. They have natural compliance and a very high payload-to-weight ratio.

McKibben Muscle

Human Arm Model with McKibben Muscles

Piezoelectric materials

A piezoelectric material can be used as an actuator since it deflects when a voltage is applied. These are not very useful in robotics since the motion and forces are so small. Conversely, a piezoelectric material may be used as a sensor, reading the resulting voltage when the material is deflected by outside forces.

End Effectors

End-effectors are the tools attached to the end of the robot arm that enable it to do useful work. Most robot manufacturers either do not include end-effectors with their robots or include a general-purpose gripper to allow you to do simple tasks. Typically, the end-effectors must be purchased or designed separately.

Grippers

Grippers are the most common end-effectors. They provide the equivalent of a thumb and an opposing finger, allowing the robot to grasp small parts and manipulate them.

Machine Tools

Robot end-effectors can also be machine tools such as drills, grinding wheels, cutting wheels and sanders.

Measuring Instruments

Measuring instruments are end-effectors that allow the robot to precisely measure parts by running the arm lightly over the part using a measuring probe or gauge.

Laser and Water Jet Cutters

Laser and water jet cutters are robot end-effectors that use high-intensity laser beams or high-pressure abrasive water jets to cut sheet metal or fiberglass parts to shape.

Welding Torches

Welding torches are robot end-effectors that enable robots to weld parts together. These end-effectors are widely used in the automotive industry.

Can you think of additional end-effectors that may be available or designed for robots?

Robot Control Methods

All robot control methods involve a **computer**, **robot**, and **sensors**.

Lead-Through Programming

The human operator physically grabs the end-effector and shows the robot exactly what motions to make for a task, while the computer memorizes the motions (memorizing the joint positions, lengths and/or angles, to be played back during task execution).

Teach Programming

Move robot to required task positions via teach pendant; computer memorizes these configurations and plays them back in robot motion sequence. The teach pendant is a controller box that allows the human operator to position the robot by manipulating the buttons on the box. This type of control is adequate for simple, non-intelligent tasks.

Microbot with Teach Pendant

Off-Line Programming

Off-line programming is the use of computer software with realistic graphics to plan and program motions without the use of robot hardware (such as IGRIP).

Autonomous

Autonomous robots are controlled by computer, with sensor feedback, without human intervention. Computer control is required for intelligent robot control. In this type of control, the computer may send the robot pre-programmed positions and even manipulate the speed and direction of the robot as it moves, based on sensor feedback. The computer can also communicate with other devices to help guide the robot through its tasks.

Teleoperation

Teleoperation is human-directed motion, via a joystick. Special joysticks that allow the human operator to feel what the robot feels are called *haptic interfaces*.

Force-Reflecting Teleoperation System at Wright-Patterson AFB

Telerobotic

Telerobotic control is a combination of autonomous and teleoperation control of robot systems.

Robot Sensors

Robots under computer control interact with a variety of sensors, which are small electronic or electro-mechanical components that allow the robot to react to its environment. Some common sensors are described below.

Vision

A vision system has a computer-controlled camera that allows the robot to see its environment and adjust its motion accordingly. Used commonly in electronics assembly to place expensive circuit chips accurately through holes in the circuit boards. Note that the camera is actually under computer control and the computer sends the signals to the robot based upon what it sees.

Voice

Voice systems allow the control of the robots using voice commands. This is useful in training robots when the trainer has to manipulate other objects.

Tactile

Tactile sensors provide the robot with the ability to touch and feel. These sensors are used for measuring applications and interacting gently with the environment.

Force/Pressure

Force/pressure sensors provide the robot with a sense of the force being applied on the arm and the direction of the force. These sensors are used to help the robot auto-correct for misalignments, or to sense the distribution of loads on irregular geometry. Can also measure torques, or moments, which are forces acting through a distance. Can be used in conjunction with haptic interfaces to allow the human operator to feel what the robot is exerting on the environment during teleoperation tasks.

Proximity

Proximity sensors allow the robots to detect the presence of objects that are very close to the arm before the arm actually contacts the objects. These sensors are used to provide the robot with a method of collision avoidance.

Limit Switches

Limit switches may be installed at end-of-motion areas in the workspace to automatically stop the robot or reverse its direction when a move out-of-bounds is attempted; again, used to avoid collisions.

Other Sensors

- encoder — measures angle
- potentiometer — measures angle or length
- LVDT — measures length (linear variable displacement transducer)
- strain gauge — measures deflection
- ultrasonic sensor — measures distance
- infrared sensor — measures distance
- light sensor — detects presence