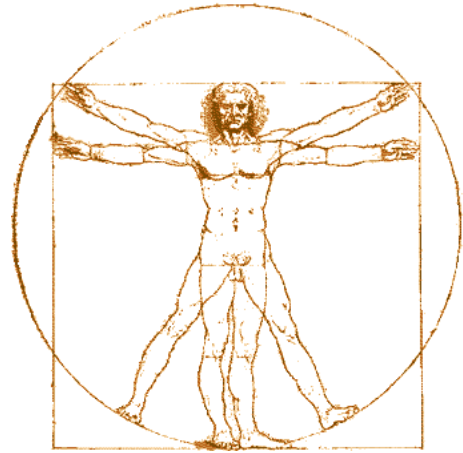


Anatomy Of A Robot

Stirling Paatz of robot integrators Barr & Paatz describes the anatomy of an industrial robot.

The term robot stems from the Czech word *robota*, which translates roughly as 'dull, repetitive labour'. Although robots are indeed often associated with performing highly repetitive, routine applications, today's flexible automation technology lends itself to much more than that, undertaking sophisticated precision tasks that a human cannot hope to emulate. But to understand quite what applications the technology is capable of and where it might be integrated into your own production processes, it is important to appreciate the anatomy of a robot, or more accurately an industrial robot, since that governs its functionality.



Let's start by defining an *industrial robot*. It is usually described as 'a reprogrammable, multifunctional manipulator designed to perform various automated tasks', to which the ISO standard adds that it must be 'programmable in three or more axes'. To make more sense of that, we need to consider a number of core terms that describe the robotic anatomy.

Axis/axes – an axis is a line across which a rotating body turns. Two axes are required to reach any point in a straight plane, while three axes (X Y Z) are needed to reach any point in space. Three further axes (roll, pitch and yaw) are needed to control the orientation of the end of the robot arm or wrist.

End effector – also known as *end of arm tooling*, this is the 'hand' attached to the end of the robot arm or wrist. End effectors include grippers, vacuum cups, sprayguns, welding tools and electro-magnetic pick-ups, their performance being vital to precision and repeatability.

Degrees of freedom – this is the number of independent movements the end effector can make along the axes of its coordinate system. For example, movement along the X Y Z coordinates only constitutes 3 DoF, whilst adding rotation around the Z axis equals 4 DoF. This term is often confused with degrees of mobility (see below).

Degrees of mobility – while DoF are often incorrectly determined by simply counting the number of independent joints on the robot, this is more accurately expressed as degrees of *mobility* (DoM). Thus, an industrial robot has a maximum of 6 DoF, but might actually have, say, 9 DoM.

Kinematics – is the actual arrangement of joints/axes and rigid links in the robot, as well as being the study of motion in robotics. Common robot kinematics, or configurations, include Cartesian, Articulated, Parallel and SCARA.

Manipulator – this refers to the arm mechanism, created from a sequence of joint and linkage combinations, including the wrist. Confusingly, it is often used to describe the robot itself, minus the power supply and controller.

Joints – robot joints are described as either *rotational* or *translational*. Rotational joints have a rotary action along the joint axis and are also referred to as *revolute*. Translational joints have a linear or sliding motion along the joint axis and are also known as *prismatic*.

Actuators – also referred to as *drives*, these are devices that convert electrical, hydraulic and pneumatic energy into robot motion. Nowadays, actuators are typically fast, accurate AC servo drives, while the robot base rotates using a harmonic drive or, less commonly, ring gear.

Work envelope – this is the total volume of space that the end effector of the manipulator can reach and is also known as *workspace* and *work volume*. The size and shape of the work envelope is determined by the robot kinematics and the number of DoF; it should be large enough to accommodate all the points the end effector needs to reach.

Having got to grips with the anatomical terms used in connection with industrial robots, we should next consider the operating and performance parameters against which any particular configuration and type is specified:

Payload (kg) – maximum load or carrying capacity, including weight of the end effector.

Reach (mm) – the maximum distance a robot can extend its arm to perform a task.

Speed (mm/sec) – how fast a robot can position its end effector or rotate an axis (deg/sec).

Acceleration (mm/sec) – defines how quickly an axis can accelerate to top speed.

Accuracy (\pm mm) – how closely a robot can move to specified place in the work envelope.

Repeatability (\pm mm) – how precisely a robot can return repeatedly to a given position.

Mounting – robots can also be ceiling or wall mounted, freeing up effective workspace.

Footprint (m²) – installation space required, often minimised by overhead or wall mounting.

Cycle Time (secs) – cumulative time for completing one full set of process operations.

Given all of these structural and specifying parameters, we can now evaluate the main industrial robot configurations, which for simplicity's sake I have limited to the four mainstream types, in more or less descending order of complexity and flexibility:

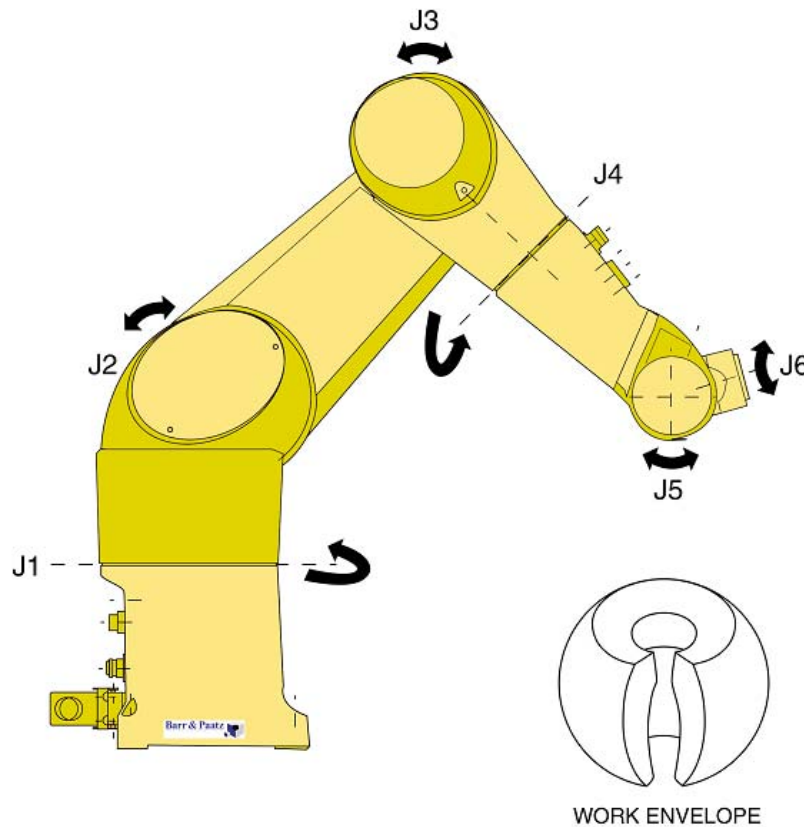
Articulated robot – or *Jointed Arm* robot, is the most versatile type and closely resembles the kinematics of the human arm. It has three concurrent prismatic or rotary joints, with a further 3 axes in the wrist, giving 6 DoF. Its end effector can be manipulated to any orientation in the work envelope, which is almost spherical. The capacity to reach over and around constructions and twist or tilt the end effector, make it ideal for complex part removal/installation, processing, arc and spot welding, paint spraying, mould unloading and machine tending tasks.

Benefits

- Large work envelope
- Small footprint
- Highly flexible
- Fast operating speed

Drawbacks

- More expensive
- More components
- Complex algorithms
- Less rigid at full reach



Articulated robot (6 DoF)

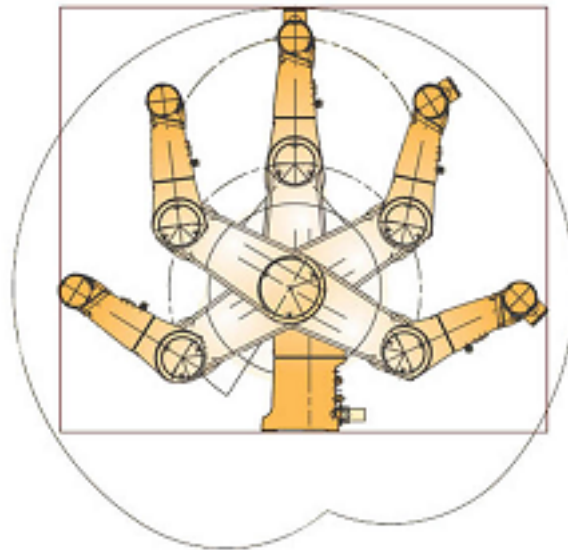
SCARA robot – an acronym of *selective compliance assembly robot arm*, this has 4 DoF, with two parallel rotational joints, a translational joint for vertical positioning, and a simple rotating wrist. This has a quasi-cylindrical work envelope, referred to as cardioidal, but the end effector is more restricted in orientation. It is commonly used for routine pick & place, assembly, packaging, palletising and machine loading applications and has arguably the best price/performance ratio.

Benefits

Good vertical stiffness
Fewer joints/components
Small footprint
High speed operation
Good payloads
Excellent repeatability

Drawbacks

Restricted motion
Less flexibility
Horizontal compliance



Vitruvian Robot - after Leonardo



Parallel robot – the best known of this type is the *Delta Robot*, also known as a high speed picker; it looks less like a conventional robot and more like a three- or four-legged spider, with a fourth moving element extending from the centre to manipulate the end effector, within a hemispherical work envelope. It has 4 DoF, three translational and one rotational, and because the actuators are mounted off the lightweight arms on the overhead chassis, there is less mass to accelerate and very high speeds are possible (up to 150 picks per minute compared to 60-65 ppm for a SCARA). Its key applications are picking and packaging lighter payloads in the food, pharmaceuticals, plastics and life sciences industries.

Benefits

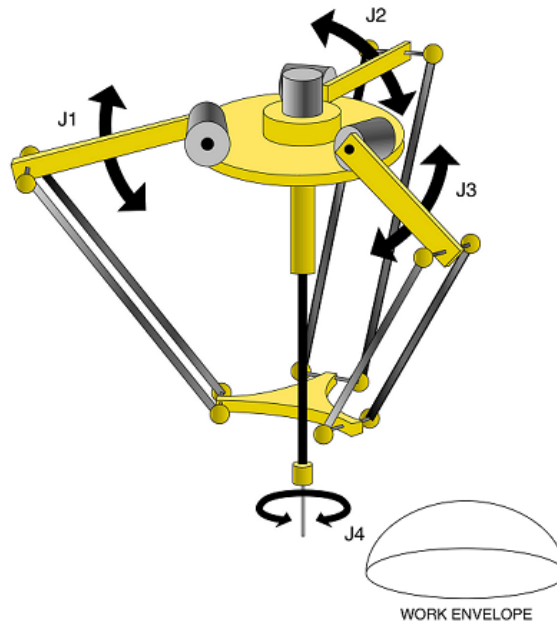
Very high speeds
Low installation profile

Drawbacks

Smaller payloads
Less flexibility

Low gross weight
Long term reliability
Very accurate

Restricted workspace
Complex algorithms



Parallel/Delta robot (4 DoF)

Cartesian robot – also commonly known as a *Gantry robot*, it features only three prismatic joints, often with an attached wrist to enable rotational movements (4 DoF), and can reach any position within its rectangular work envelope, through linear motion of the axes. It is typically suspended from an overhead grid and the installation footprint is often larger than the workspace, but the rigid structure means very heavy payloads can be carried. Typical applications include materials handling, pick & place, machine loading/unloading, stacking and palletising, usually performed with considerable speed and accuracy.

Benefits

Very high payloads
Speed and accuracy
Relatively low cost
Overhead mounting
Simple algorithms

Drawbacks

Little flexibility
Restricted workspace
Big footprint

Having considered the different robot kinematics, you will appreciate that all are capable, for example, of pick & place tasks, but with quite different speeds, payloads and complexity of motion. As with any mechanical installation, however, it is important not to over-engineer the solution, with more DoFs, faster cycle times and higher payload capacities than are needed for the application, because that factors in increased cost. That's where specialist robot integrators like ourselves enter the equation. We consider the application as a whole, taking into account the exact process, required kinematics, the workpiece and end effector, then specify the right manipulator and the right model, with the appropriate performance characteristics for the task in hand.

Not only that, we will construct the algorithms for accomplishing that particular task, program the robot controller and integrate any associated processes, feed mechanisms and other manipulators into the operating cycle, then design the mechanical and electronic barriers for safeguarding personnel and the fast-moving machinery. Then using advanced 3D modelling software, we'll simulate the entire robot workcell or production line, in order to prove to you, the customer, that it will actually work in practice, before anything's built.

Nevertheless, I hope that this brief guide to the anatomy of a robot means that when talk next turns to kinematics, manipulators, end effectors and work envelopes, you can smile knowledgeably – then call someone who knows!

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