Name: _____ Date: _____

Six Joints, Five Million Robots

Reading level 13 · 1997 words

Before the arm moves, Tomas reads its data sheet. He is an engineer who sets up work cells, and the arm in front of him is fixed to a steel base in a factory at night. The sheet lists six turning joints, a reach of 850 millimeters (33.5 inches) and a load of 5 kilograms (11 pounds). Those numbers say what the arm can do, and another says how well it does it: a pose repeatability of 0.03 millimeters, measured under ISO 9283. In plain words, if the arm is sent back to one point again and again, the hand should land no farther off than that each time. Everything he needs to know about the machine starts with those few lines.

Is it even a robot? The question has a careful answer. ISO 8373:2021, the world vocabulary for the field, defines a robot as a programmed, actuated mechanism with a degree of autonomy, one that moves itself around, handles objects or places them. A new edition is in draft. A factory machine of this kind is an automatically controlled, reprogrammable, multipurpose manipulator that can be programmed in three or more axes. An arm that a person steers from far away is a robotic device, not a robot. A guided cart that follows a path laid out for it is not a robot either, because it cannot choose its own path. Tomas's arm passes on every count.

Why six joints? A university textbook, Modern Robotics by Kevin Lynch and Frank Park, defines the degrees of freedom of a robot as the smallest number of real-valued coordinates needed to describe its configuration. A coin lying flat on a table has three: two for where it is, and one for which way it faces. A solid body in space has six, three for position and three for orientation. To put a hand at any point in reach, tilted any way, an arm needs at least six joints. George Devol's 1954 patent already described an arm with six degrees of freedom, and the first Unimate worked at General Motors in 1961.

From six joint angles, finding the hand is a sum called forward kinematics. For an arm built as an open chain, the sum has only one answer. The reverse is harder, because inverse kinematics asks which joint angles will put the hand at a wanted spot and tilt, and the book warns that there may be several answers, or none at all. Tomas's controller has to solve that problem again and again while the hand moves. A point beyond the arm's 850 millimeters of reach has no answer, so the program must stop short or refuse. In a controller, that calculation has to be repeated for every tiny step the hand takes along its path.

Each joint carries sensors. The book names encoders, which measure how far a joint has turned, and force-torque sensors, which measure the push and twist at a joint or at the hand. The data sheet gives the accuracy of its own such sensor as 4 newtons. Electric motors do the moving, and they spin fast with little twisting power, so gears slow them down and multiply

the torque. Gears bring a flaw called backlash, which the book defines as the amount of rotation available at the output of the speed-reduction device without motion at the input. The book says such devices should have zero or low backlash. At a repeatability of 0.03 millimeters, even tiny slack would matter.

A command alone cannot reach a target. The equations of motion depend on the mass and inertia of every link, and they miss friction, springiness and backlash. So, the book says, most practical control schemes make up for that by using feedback control: measure what the arm is doing, compare it with what is wanted, and adjust. It is the same idea that holds a drone level, with joint angle in place of tilt. The data sheet puts the arm's system update at 500 hertz, which is a new correction every 2 milliseconds. At the sheet's top joint speed of 180 degrees per second, a joint turns only 0.36 degrees between corrections. Both figures are our arithmetic.

Touch is harder than position. The book states a limit that no controller can escape: a machine cannot independently control motion and force in the same direction. If it sets the motion, the surroundings decide the force, and if it sets the force, the surroundings decide the motion. A gripper told only to close to a set width will crush anything wider than it expected, so a gripper that holds an egg has to sense how hard it squeezes. A Columbia lab built a system with pressure sensors that adjust the grip as they go; a university magazine reported that it picked up eggs and grapes in tests. Amazon says its Vulcan arm uses force sensors to stay below the point at which it risks doing damage.

How many arms like this exist? A count sounds simple until you ask what is being counted. The International Federation of Robotics published World Robotics 2026 on September 24, 2026, the newest edition as of November 2026. Factories installed 603,307 new industrial robots in 2025, up 11 percent and above the earlier record of 552,946 set in 2022. China installed 354,226. The United States installed 38,428, up 12 percent, second, ahead of Japan. The five-million figure is a different number: the stock, 5,079,078. It is an estimate. For most countries the federation adds up recent installations and has assumed a robot works about 12 years. A new edition has come out each September lately, and it replaces these figures.

Most readers would guess that car plants lead the list of buyers. In 2025 they did not. The electronics industry bought 142,235, and the car industry bought 138,429, a gap of only about 3,800. The count has limits too. It counts only machines that meet the factory definition from the second screen, and it rests on figures reported by suppliers and by national groups, so it is a count by the industry, not an independent audit. Other kinds of machines are counted separately. In 2025 about 250,000 professional service machines were sold, and 117,500 of them were for moving goods. Those made for consumers, mostly for the home, reached almost 34.2 million.

The standards expect a risk check before a cell like Tomas's runs. The main documents are

ISO 10218-1, which treats the robot as partly finished machinery, and ISO 10218-2, which covers robot applications and cells. Both appeared in February 2025. A3, the trade group for automation, called it the first major revision since 2011. The new Part 1 sorts robots by factors that include total weight per arm, top force and top speed. Class 1 machines have lower force and speed, and Class 2 covers most of them, with extra rules. In the United States, ANSI/A3 R15.06-2025 takes in both parts. Such standards are voluntary unless a law points to them. OSHA says it has no specific standards for the robot industry.

The standard does not judge the arm alone. A3 explains that a factory robot, strictly, is the arm and its controller. Add the tool at the end of the arm and it becomes a robot system. Add the part being worked on and the other equipment, and it becomes a robot application. Each piece can affect the safety of the whole. Fences and light curtains, whose beams stop a machine when something crosses them, are the classic answer and are still used. The standards now also describe hand guiding, speed and separation monitoring, and limits on power and force. None of these removes the need for a risk check. OSHA warns that many robot accidents happen during programming, maintenance, testing, setup or adjustment, when a worker may stand inside the robot's reach. That describes Tomas's own job.

The robot most people picture is not an arm like Tomas's. The newest figures, from September 2026, say about 7,000 full-size humanoids, taller than 140 centimeters, were sold in 2025 for commercial and professional work, not research or entertainment. Counts differ: the research firm IDC put all 2025 humanoid shipments, research and entertainment included, near 18,000. The federation says most current uses are narrow and often need a person to steer the machine from far away. It adds that most humanoids remain prototypes or pilot projects. At this stage, it says, industrial robots make more economic sense for factory work, and humanoids may eventually work beside them in selected jobs.

Real deployments exist. On October 26, 2026, a logistics company and a humanoid maker said they would expand a Digit humanoid to sites in North Carolina and Tennessee. They started with a trial in Georgia in late 2023, and they say it has moved more than 100,000 totes since. Those are the companies' own words. The group's 2025 paper says advances in AI have improved what humanoids can do. Its January 2026 report says AI-driven autonomy changes the safety landscape. Testing and human oversight become much more complex, it says, but also more necessary. Its 2026 summary says machine vision for guiding robots is already ready for factories, while general-purpose physical AI is not yet.

Where AI plans a robot's moves, people check the plan: NASA tested its first AI-planned Mars drives in a digital twin before sending them. One more caution is for readers. Robot toys come with apps, and the federation says consumer robots increasingly connect to smart home systems. The Federal Trade Commission counts a child's full name, address, phone number, email address, location, photos, videos and voice recordings as personal information. In September 2025 it alleged that one robot-toy maker's app let a third party collect children's

locations without parents' consent. Do not type your full name, address, school or photo into a robot's app. Say no if it asks where you are, and ask a parent to set it up.

Do robots take jobs? Careful studies can reach different answers, and both of these are about factory robots like the one Tomas is switching on. Daron Acemoglu and Pascual Restrepo studied how factories used robots across US commuting zones from 1990 to 2007. In the published version, one more robot per thousand workers cut the share of the population with a job by 0.2 percentage points and wages by 0.42 percent. Wolfgang Dauth and colleagues studied Germany from 1994 to 2014 and found no evidence that robots cause total job losses. In an earlier version they estimated that each robot destroyed two factory jobs, about 275,000 in all, but new service jobs fully made up for the loss. The cost fell on young workers just entering the labor market.

The industry makes a third argument. The federation, a nonprofit whose members come from the robotics industry, says labor shortages and population change keep demand for automation growing. None of this settles the question. The US study ends in 2007, the German study in 2014, and neither covers the years since. The two countries also differ. Two good studies can point in different directions, because they ask slightly different questions of different places. A fair summary is that both find robots cost some kinds of jobs, that they disagree on whether the total fell, and that nobody can state the future as fact.

Tomas ticks the last line of his checklist and starts the first cycle. The arm lifts, swings and stops at its first point. On his screen six joint angles update 500 times a second, six numbers that together say where the hand is and which way it faces. He keeps one hand near the stop button and watches the readings settle. Behind him the factory is quiet. The other cells in the building are dark, and this one is the only machine awake. The fence door is shut, and a light curtain, which stops the arm if anything crosses its beams, glows across the gap.

Questions

1. Why does an arm need at least six joints to put its hand anywhere in reach, tilted any way?

A. A rigid body in space has six degrees of freedom
B. Six is the legal minimum
C. Each joint can only hold one tool

2. In this book, "backlash" is

A. a sudden power loss
B. slack in a gear train between input and output
C. a failed encoder reading

3. Why is a guided vehicle that follows a laid-out path not a robot under the standard?

A. It is too heavy
B. It has no wheels
C. It cannot determine its own path

4. Which industry bought the most industrial robots in 2025, according to the federation?

A. Electronics
B. Automotive
C. Food

5. Why do the two job studies not settle the question?

A. Both used the same data
B. They cover different countries and years, and both end years ago
C. Neither mentions wages

6. When does OSHA say many robot accidents occur?

A. Only during a power failure
B. When robots are first shipped
C. During programming, maintenance, testing, setup or adjustment

Words to know

kinematics: motion geometry
backlash: gear slack
torque: twisting force
repeatability: same-spot accuracy
autonomy: self-direction

Answer key: Six Joints, Five Million Robots

1. A. A rigid body in space has six degrees of freedom
2. B. slack in a gear train between input and output
3. C. It cannot determine its own path
4. A. Electronics
5. B. They cover different countries and years, and both end years ago
6. C. During programming, maintenance, testing, setup or adjustment