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# Understanding Humanoid Robots

AI AND ROBOTICS

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# Introduction

In 1976, MGM released Futureworld, a science fiction movie. In the movie, Delo, an entertainment theme park, made robots that looked and acted just like humans. The park had a plan to make robots as human copies to replace their human originals.

Nearly half-century after the movie, we are entering humanoid robot era. Humanoid robots mimic humans to a limited extent, they are far from looking and acting like humans. Yet, rapidly advancing humanoid robot technologies have built the foundation for robots to improve in years to come, and they may eventually rival robots in Futureworld in a not so distant future.

Figure 1 – 1976 movie Futureworld poster

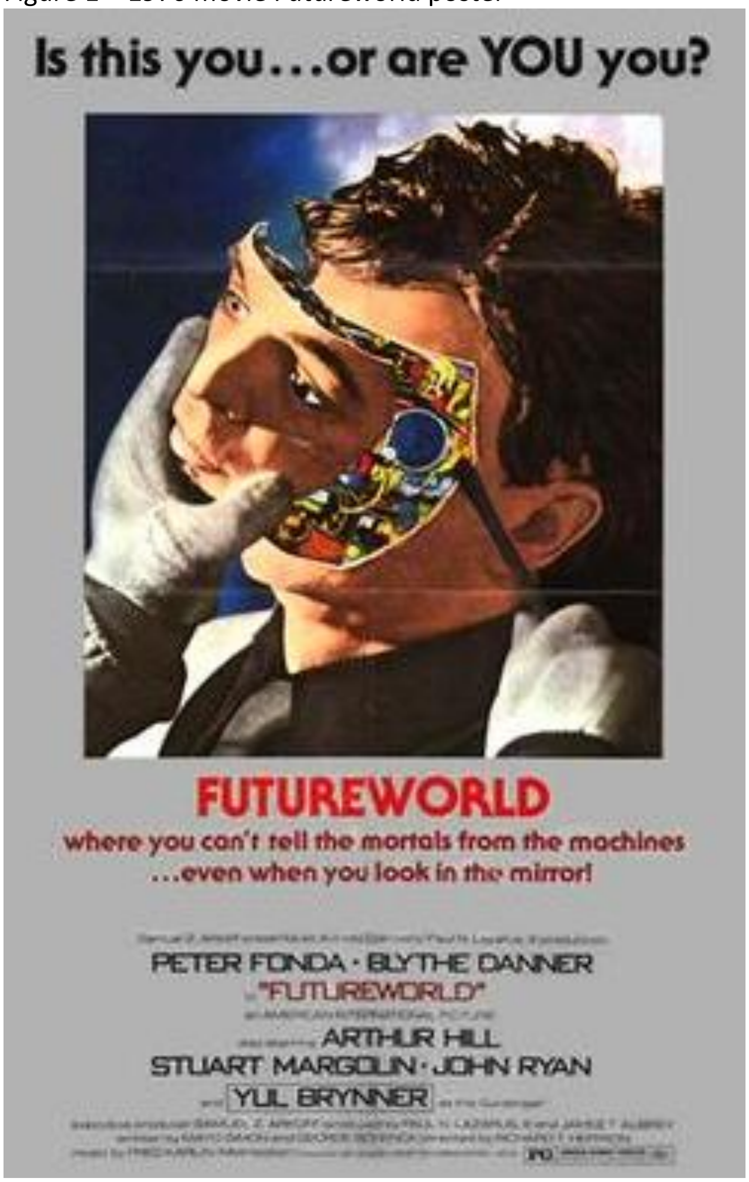


Figure 2 – Unitree G1 robots available for sale at $16,000

Figure 3 – Tesla Optimus, not available for sale yet

Figure 4 – Boston Dynamics Atlas, not available for sale yet

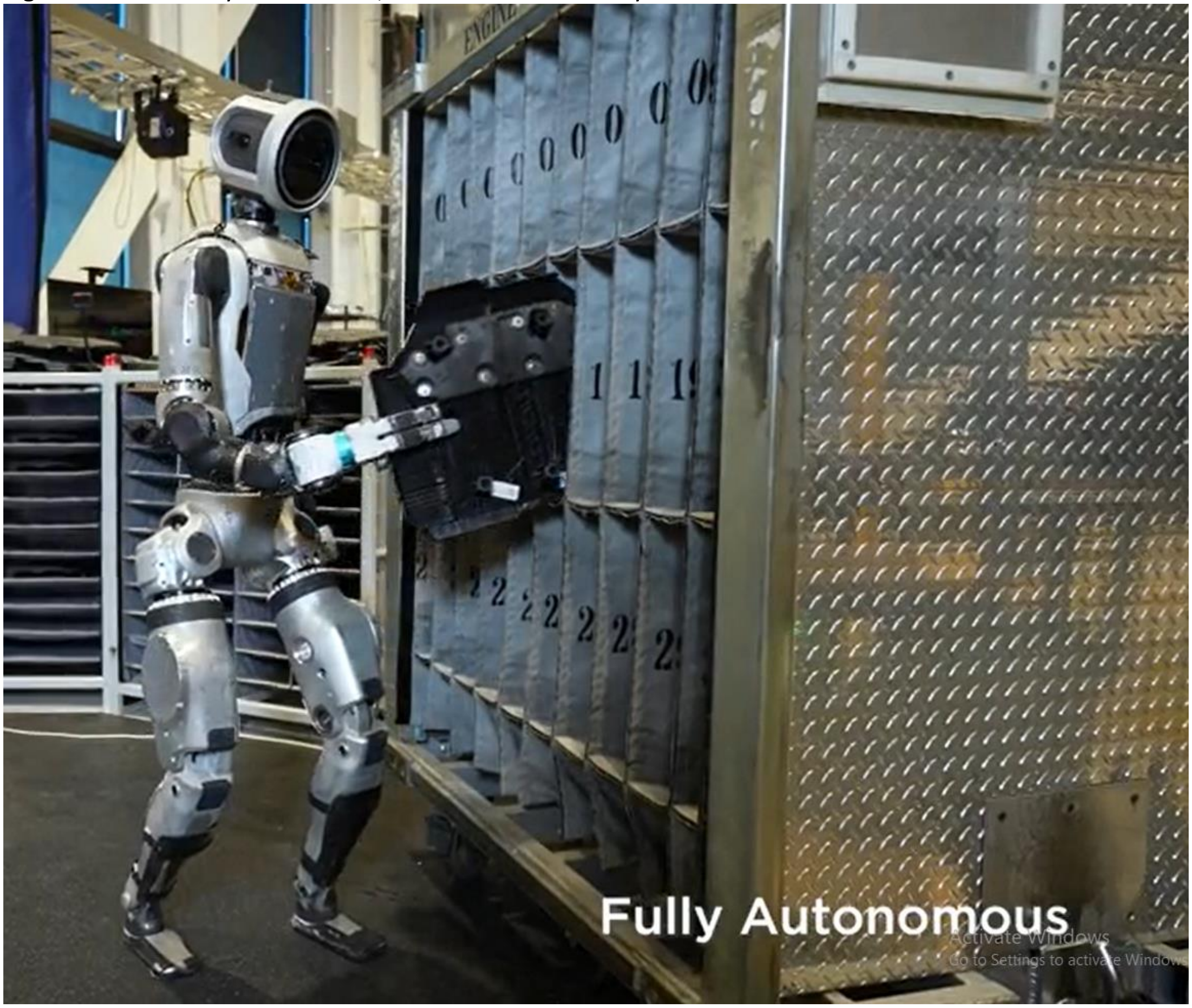


Figure 5 - Fourier GR-2, available for sale in China at 900,00 RMB or approximately $128,571


# Making of Humanoid Robot

A humanoid robot is assembled from core components into a complex and integrated system. The core components include the following:

## Physical body frame

- The robot body simulates the human skeletal system. It is a mechanical structure with head and torso that houses sensors, cameras, and processors
- In addition, the body has arms and legs that enable movement and interaction with the environment
- Further, the body includes joints and actuators that provide flexibility and motion, mimicking human joints, such as shoulders, hips, knees, and elbows.

## Sensors

Enable the robot to gather surrounding data for perception, navigation, and interaction

- Vision sensors – Cameras for object recognition and mapping. The more cameras and higher camera resolution the robot has, the more capable the robot is of navigating and handling objects
- LIDAR (Light detection and Ranging) – Laser-based sensors for 3D surrounding mapping
- Infrared sensors – For proximity or heat detection
- Tactile sensors – On hands or feet for touch feedback, important for object handling and maintaining balance
- IMUs (Inertial Measurement Units) – Accelerometers and gyroscopes for balance and orientation
- Microphones – For sound detection and voice recognition
- Speakers – For voice interaction with humans, though speakers by themselves are not sensors.

## Actuators (Motors/Joint Motors)

Enable movement by driving joints, simulating human muscle action.

- Servo Motors - Common in smaller robots, offering precise control.
- Brushless DC (BLDC) Motors - Used in advanced robots like Tesla’s Optimus for high torque and efficiency.
- Linear Actuators - For extending or contracting parts (e.g., knee flexion).
- Pneumatics/Hydraulics - For high-strength tasks in larger robots (e.g., Atlas).
- Integrated with gearboxes to convert high-speed, low-torque output into low-speed, high-torque motion. High torque density is critical for tasks like walking or lifting.

## Gearbox and Power Transmission

Transmits and amplifies motor power to joints.

- Gears (e.g., planetary, bevel) reduce motor speed while increasing torque.
- Timing belts or chains may be used to distribute power (e.g., in LOLA’s ankle joints). The ankle joints of the humanoid robot LOLA are designed with a focus on dynamic performance and reduced leg inertia. Instead of placing actuators directly at the ankle joint, LOLA uses a **spatial**

**slider-crank mechanism** to actuate its two degrees of freedom (DOF) ankle joint. This design minimizes the weight at the ankle, bringing the actuators closer to the hip, which improves balance and agility during bipedal locomotion

- Minimizing backlash (play between gears) is key for precise movement.

## Joints and Degrees of Freedom (DOF)

Allow human-like movement and flexibility

- Each joint (e.g., shoulder, elbow, ankle) has rotational or linear motion, measured in DOF.
- Higher DOF increases flexibility but complicates control.
- Mimics human joints like hips (3 DOF), knees (1 DOF), and wrists (2-3 DOF).

## End-Effectors (Hands/Grippers)

Enable robots to interact with objects, mimicking human hands.

- Range from simple grippers to multi-fingered hands with multiple degrees of freedom (DOF).
- Often equipped with tactile sensors for dexterity (e.g., grasping delicate items).
- Actuated by small motors or pneumatics for fine movements.

## Control System (Brain/Processor)

Processes sensor data, executes AI algorithms, and controls actuators.

- Microcontrollers - For basic tasks (e.g., Arduino-like OpenCM9.04 in ROBOTIS MINI).
- Onboard Computers - High-performance CPUs/GPUs (e.g., NVIDIA Jetson for real-time AI in modern humanoids)
- Runs software for motion planning, balance, and human-robot interaction.

## Software and AI

Enable robots for decision-making, learning, and interaction.

- Operating Systems - Often ROS (Robot Operating System) for modularity. ROS1 and ROS2 are both open-source ROS operating systems with supporting drivers for various robot components
- AI Algorithms - Machine learning, imitation learning, or reinforcement learning for tasks like walking or grasping. VLA (Vision-Language-Action) AI models are used in robots, which are different from LLMs (Large Language Models) primarily for natural language processing only
- Programming - Python, C++, or graphical tools (e.g., RoboPlus for beginners).
- Handles speech recognition, facial expression analysis, and task planning.

## Power Supply

Provides energy to all components.

- Lithium-ion batteries
- Advanced robots may use tethered power for continuous operation during development.
- Energy efficiency is critical, with battery life extended by optimized motor control

## Cooling Systems (Advanced Models)

Manages heat from motors and electronics.

- Passive (heat sinks) or active (fans, liquid cooling) systems.
- Critical for high-performance robots like Atlas during dynamic tasks.

## Skin/Exterior (Optional)

Enhances aesthetics or functionality (e.g., grip, protection).

- Synthetic materials like silicone for androids
- May include sensors for touch sensitivity.
- Often absent in research models to prioritize mechanics.

# Manufacturing of Humanoid Robot

Computer Numerical Control (CNC) machining is widely used across industries like automotive, aerospace, medical, and electronics due to its ability to produce high-quality, reliable components.

CNC machining is a subtractive manufacturing process. This process involves the precise removal of material from a workpiece to achieve the desired shape and specifications. Here's an overview of CNC-machined components:

Common CNC-Machined Components:

- Engine Parts: Pistons, cylinders, and crankshafts for automotive and aerospace industries.
- Medical Devices: Surgical instruments, implants, and prosthetics.
- Electronic Housings: Enclosures for electronic devices, ensuring durability and precision.
- Gears and Bearings: Used in machinery for smooth and efficient operation.
- Custom Prototypes: Rapid production of prototypes for testing and development.
- Aerospace Components: High-precision parts like turbine blades and structural components.
- Industrial Tools: Cutting tools, molds, and dies for manufacturing processes.

Materials Used:

- Metals: Aluminum, steel, titanium, brass, and copper.
- Plastics: ABS, polycarbonate, and nylon.
- Composites: Carbon fiber and fiberglass.

Advantages of CNC-Machined Components:

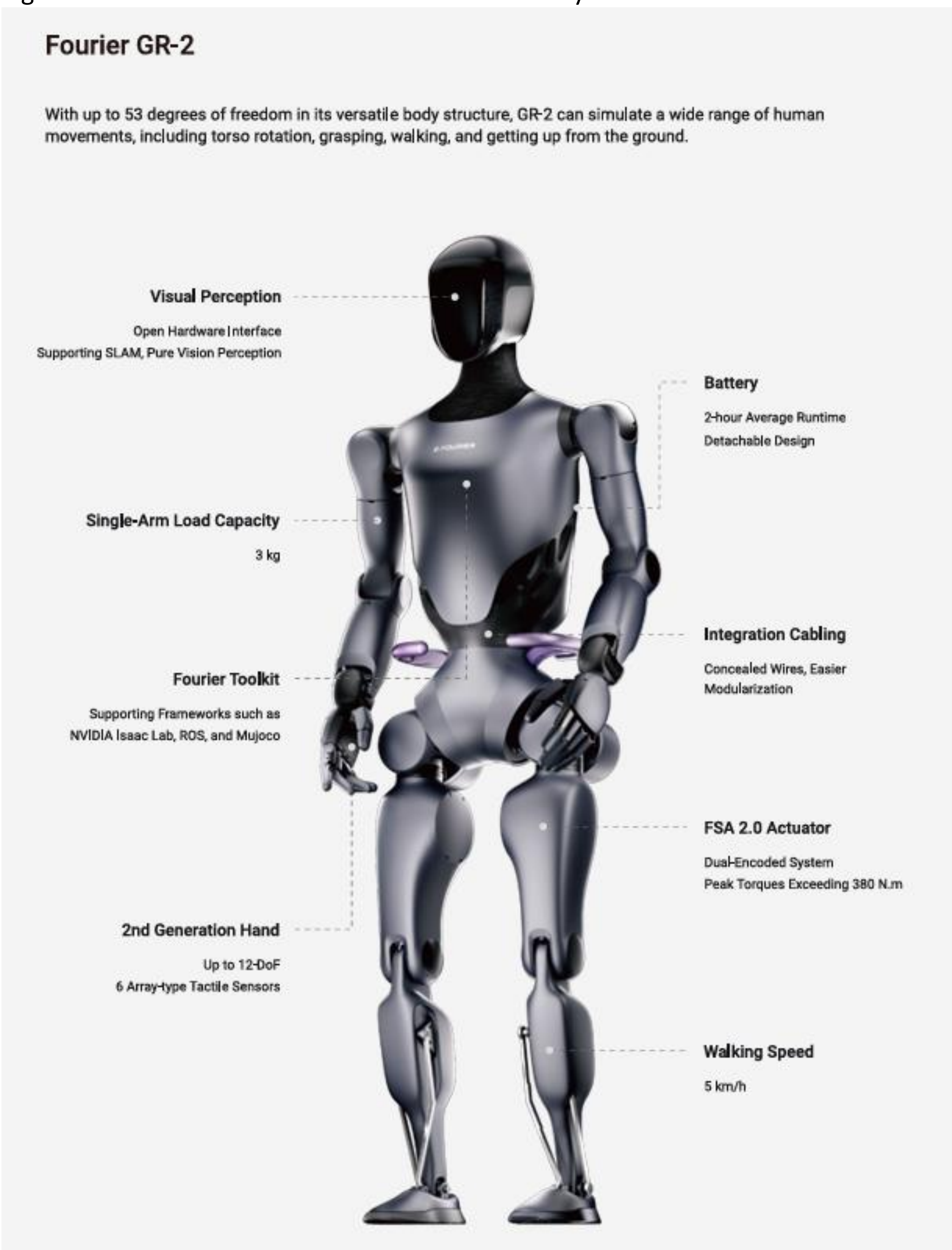
- High Precision: Achieves tight tolerances and intricate designs.
- Consistency: Ensures uniformity across multiple parts.
- Versatility: Works with a wide range of materials.
- Efficiency: Reduces production time for complex parts.

Computer Numerical Control (CNC) machining is also used in the manufacturing of humanoid robots because it meets the requirements of many robot components.

Additionally,

- For prototyping, 3D printing is also used.
- Body framework/structure/chassis: lightweight yet strong materials like aluminum, steel, or carbon fiber composites are typically used.
- End Effectors and Hands: These are the parts that interact with the environment and manipulate objects. Advanced humanoid robots are equipped with multi-fingered hands with dexterity close to human hands. Those hands can be two-fingered, three-fingered, or five-fingered hands

Figure 6 – Fourier GR-2 Humanoid Robot Assembly



# Application Contexts of Humanoid Robots

Humanoid robots are becoming increasingly valuable across various industries due to their ability to mimic human movements and interactions. Here are some industries where they are most needed:

Healthcare:
- Assisting in elderly care by providing companionship and performing routine tasks.
- Supporting physical therapy and rehabilitation programs.
- Acting as surgical assistants for precision tasks.

Manufacturing and Warehousing:
- Performing repetitive or physically demanding tasks.
- Assisting in logistics, such as sorting and transporting goods.

Service Industry:
- Acting as receptionists, guides, or customer service representatives in hotels, airports, and malls.
- Enhancing customer experiences with interactive and personalized services.

Education:
- Serving as teaching assistants or tutors, especially for STEM education.
- Engaging students with interactive learning experiences.

Entertainment:
- Performing in theme parks, shows, or events.
- Acting as interactive characters in gaming or virtual reality setups.

Public Safety and Security:
- Assisting in surveillance and patrolling.
- Supporting search and rescue missions in hazardous environments.

Space Exploration:
- Performing tasks in environments unsuitable for humans, such as space stations or planetary surfaces.

Retail:
- Assisting customers with product information and navigation in stores.
- Managing inventory and restocking shelves.

Research and Development:
- Acting as test subjects for studying human-robot interaction.
- Supporting experiments in robotics and AI.

In addition to many industries that need humanoid robots, the household is perhaps the place where humanoid robots can most value and yet it is also the most challenging environment for robots to perform well. Humanoid robots need to be
- house maid doing housekeeping chores
- home-based care provider to care for the elderly

Unlike in any industrial setting, homes lack standards and patterns, objects that humanoid robots encounter in a home are highly unpredictable, they come in all shapes, sizes, and colors. Home appliances, furniture, floor layouts, downstairs, upstairs, garage, basement, attic, rooms for different purposes, etc., further complicate the environment for humanoid to know what to do where and when as it is expected to.

We are now at the beginning of the humanoid robot era. Technology is advancing fast. However, only when a humanoid robot can truly function as a human house maid or a house care provider in a home, can we declare humanoid robot technology has matured.