# What Sensors do Humanoid Robots Need

As highly intelligent mechanical equipment, **humanoid robots** are crucial in their ability to perceive and respond to the external environment. These capabilities mainly rely on the various **sensors** equipped by the robot.

Sensors are like the "perceptual organs" of robots, which can obtain environmental information and convert it into electrical signals or other forms of output for analysis and processing by the robot's control system.
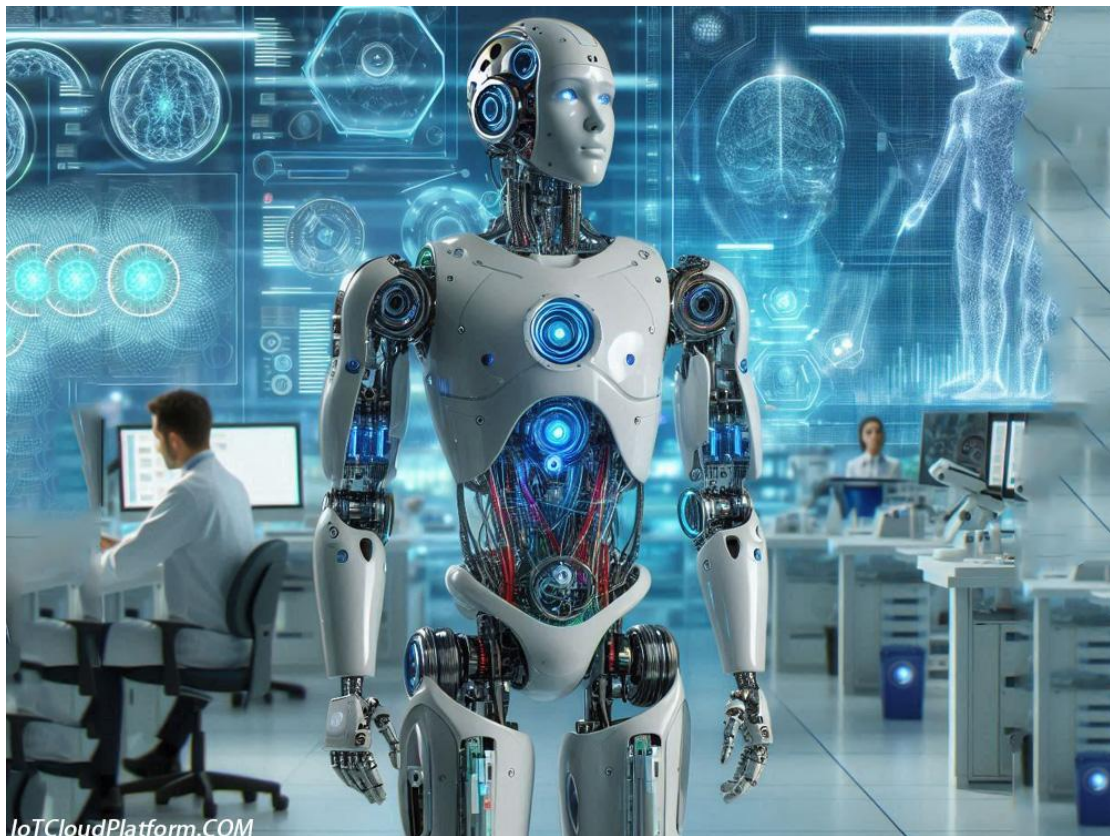


**Humanoid robot form**

The following is a detailed introduction of the sensors required for humanoid robots by the IoT cloud platform:

# Visual sensor

## 1. Definition and function

Visual sensors are an important window for humanoid robots to perceive the external environment, equivalent to the "eyes" of robots. They can capture and analyze environmental images and provide robots with rich visual information.

## 2. Working principle

Visual sensors use photoelectric sensors to convert object images into digital signals, and process and analyze the images. This process includes four parts: detection, analysis, depiction and recognition:

**Detection**: Use image signal input devices to convert visual information into electrical signals.

**Analysis**: Remove clutter and worthless pixels from the captured signals and rearrange valuable pixels.

**Description**: Extract features from the object image for preliminary identification.

**Identification**: Accurately identify the object based on the extracted features.

## 3. Classification and Application

Visual sensors can be divided into two categories: 2D visual sensors and 3D visual sensors:

**2D visual sensors**: Obtain flat images through industrial cameras, and perform subsequent analysis mainly based on a flat feature of the object. Since the spatial coordinate information of the object cannot be obtained, its application in complex environments is limited.

**3D visual sensors**: Can provide high-precision three-dimensional image information, with advantages such as high accuracy, large amount of information, and high integration. Suitable for complex and precise identification and detection needs, such as face recognition, distance perception, obstacle avoidance, navigation, etc.

## 4. Technological Development

With the continuous advancement of technology, 3D visual sensors are continuously optimized in terms of accuracy, field of view, measurement range, and power consumption. At the same time, multi-technology fusion (such as structured light, TOF, binocular vision, etc.) has also become an important direction for future development.

## 5. Market structure

At present, the global machine vision market is mainly occupied by American, German and Japanese brands, such as Cognex in the United States, Basler in Germany, Keyence and Omron in Japan. Among them, Keyence and Cognex, as the two giants in the global machine vision industry, monopolize more than 60% of the global market share. my country's machine vision market started late, but has developed rapidly in recent years, with a number of excellent companies such as Orbbec, Weijing Intelligence, and Yuanxing Space-Time emerging.



**sensors used in humanoid robots**

# Force/torque sensor

## 1. Definition and function

Force/torque sensors are key components for sensing and measuring force at the joints of humanoid robots. They can accurately measure the force and torque of an object in three directions, and feel the weight, pressure and friction of the object. This information is crucial for the robot to achieve fine operation, maintain balance and avoid damage.

## 2. Working principle

The core principle of force/torque sensors is to convert deformation under force into electrical signals. When force/torque acts, the sensor body unit is strained or deformed, and the detection system senses this change and converts it into a corresponding voltage signal through the circuit. By measuring the voltage value, the magnitude of the force/torque can be characterized and converted into a usable output signal.

## 3. Classification and application

According to the measurement dimension, force/torque sensors can be divided into one-dimensional and multi-dimensional (three-dimensional, six-dimensional) force sensors:

**One-dimensional force sensor**: It only detects the force or torque in one direction, which is widely used in industry and relatively cheap.

**Multi-dimensional force sensor**: It includes three-dimensional force and six-dimensional force sensors, which can measure forces and torques in multiple directions at the same time. Among them, the six-dimensional force sensor is the most advanced torque sensor, which can simultaneously measure the XYZ axial force and the torque around the axis. The internal algorithm can decouple the interference of forces and torques in various directions, and is used in high-end robots and precision equipment.

In humanoid robots, force/torque sensors are mainly used in end effector parts such as wrists and ankles. For example, when grasping an object, the sensor can provide real-time feedback on the weight and shape of the object, helping the robot adjust the grasping force and posture.

## 4. Technical barriers and market structure

There are three major barriers in the field of six-dimensional force sensors: structural design, calibration and detection, and algorithm design. At present, the global six-dimensional force sensor market has not yet formed a significant scale effect, and the market base is relatively small. Established manufacturers in Europe and the United States started early and occupied a leading position in the market. Domestic manufacturers started late in the field of six-dimensional force sensors, but have developed rapidly in recent years, and a number of excellent companies such as Yuli Instruments, Blue Dot Touch, Kunwei Information, Xin Jingcheng, and Haibosen have emerged.
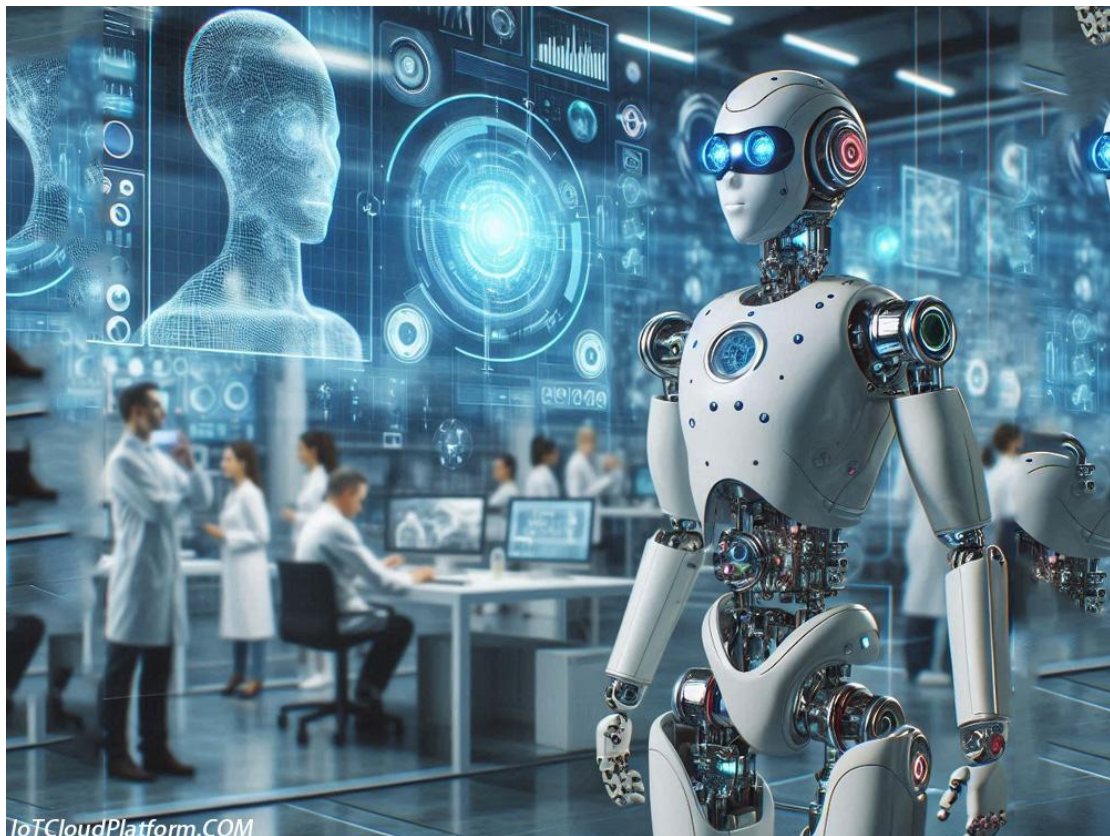


**What sensors do humanoid robots use**

# Tactile sensor

## 1. Definition and function

Tactile sensors are important tools for humanoid robots to perceive external contact. They can simulate human touch and perceive external physical quantities such as pressure and

temperature. These sensors can cover the entire body of the robot, forming a tactile perception layer similar to human skin, helping the robot to achieve fine operation and interaction.

## 2. Working Principle

The working principles of tactile sensors are diverse, including resistive, capacitive, piezoelectric, photoelectric, magnetoelectric, etc. Among them, the new soft and stretchable capacitive sensor obtains normal force and shear force through the difference between capacitance and electrodes, and has extremely high sensitivity and flexibility.

## 3. Classification and Application

Tactile sensors can be divided into two categories: flexible sensors and rigid sensors. Flexible sensors dominate in value, and their technical barriers are mainly concentrated in material selection and manufacturing processes. In humanoid robots, tactile sensors are widely used in limbs, chest and other parts to help robots achieve a more natural and humanized interactive experience.

## 4. Market Structure and Development Trend

At present, the tactile sensor market is still in its early stages of development, and overseas companies such as Canatu, Sensel, Flexpoint, etc. occupy a leading position in this field. However, there are also many domestic manufacturers such as Suzhou Nengsda Electronics, Shenhao Technology, Moxian Technology, etc., which are making layouts in the field of tactile sensors. As the demand for tactile perception capabilities in various scenarios continues to increase in the future, the market demand for robot tactile sensors is expected to grow further.
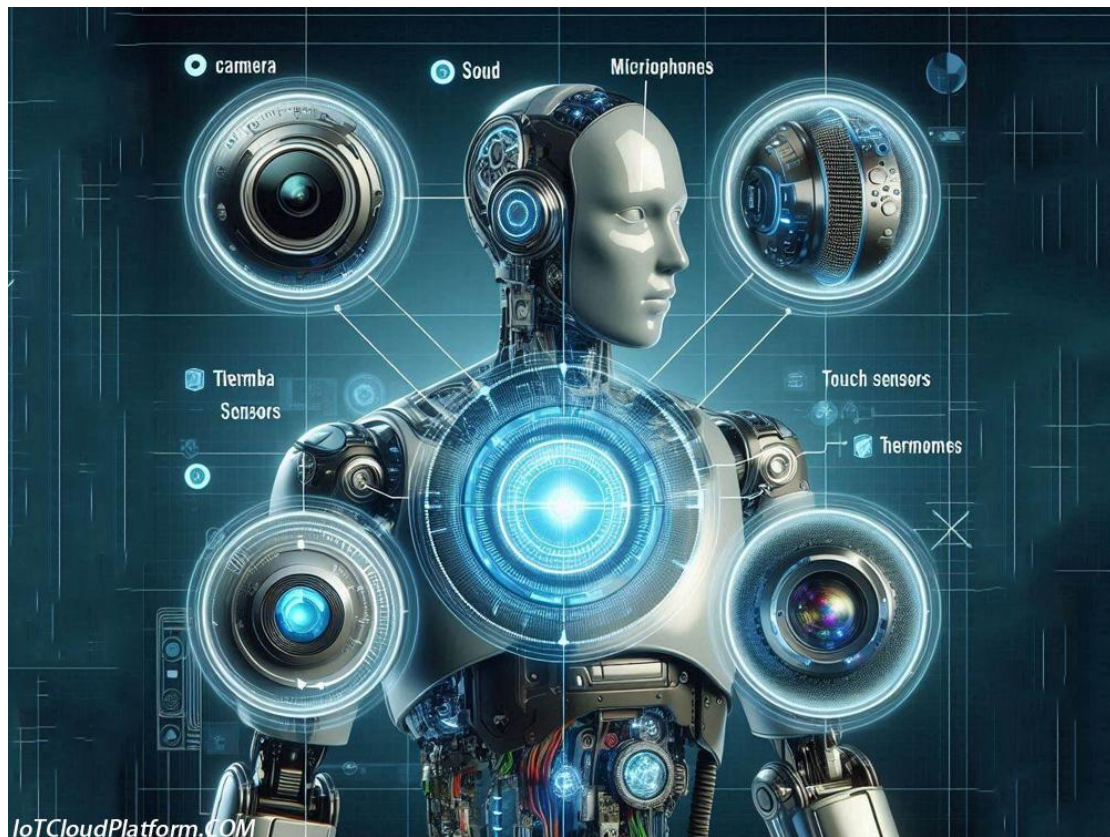
**Four major sensors of humanoid robots**

# Inertial Measurement Unit (IMU)

## 1. Definition and Function

Inertial Measurement Unit (IMU) is an important component for humanoid robots to sense their own motion state. It is usually composed of sensors such as accelerometers, gyroscopes and magnetometers, and can measure the acceleration, angular velocity and direction of the robot in real time. IMU plays an important role in the robot's posture control, navigation and positioning.

## 2. Working Principle

IMU measures the acceleration and angular velocity of an object through a combination of accelerometers and gyroscopes. Accelerometers can measure the acceleration of an object in three directions, while gyroscopes can measure the angular velocity of an object

around three axes. Magnetometers are used to measure the direction of the earth's magnetic field to help robots determine the absolute direction.

## 3. Classification and Application

Depending on the accuracy, IMU can be divided into strategic, navigation, tactical and consumer levels. In humanoid robots, tactical-grade and consumer-grade products with near-tactical accuracy are usually used. These sensors can provide real-time feedback on the robot's posture changes, providing the robot with stable posture control and navigation and positioning capabilities.

## 4. Technology Development

With the continuous development of MEMS (micro-electromechanical system) technology, the size of IMU continues to shrink, power consumption decreases, and performance improves. MEMS inertial sensors have the advantages of small size, low power consumption, and strong integration capabilities, and are highly applicable in the field of humanoid robots.

**What is the significance of sensors in humanoid robots**

# Other sensors

In addition to the above four core sensors, humanoid robots may also be equipped with other types of sensors to meet specific perception and interaction needs:

## 1. Temperature sensor

Used to monitor the temperature of the robot's internal and external environment to prevent the robot from being damaged by overheating or overcooling.

## 2. Current sensor

Used to monitor the current changes of the robot's joint motors and drivers to ensure the normal operation of the motors and drivers.

## 3. Air pressure sensor

Used to monitor the changes in air pressure inside the robot and provide air pressure compensation and stable control for the robot.

## 4. Encoder

Used to measure the joint position and speed of the robot and provide accurate feedback information for the robot's motion control. Encoders are widely used in various execution joints of the robot, and their accuracy and reliability directly affect the accuracy and stability of the robot's motion.
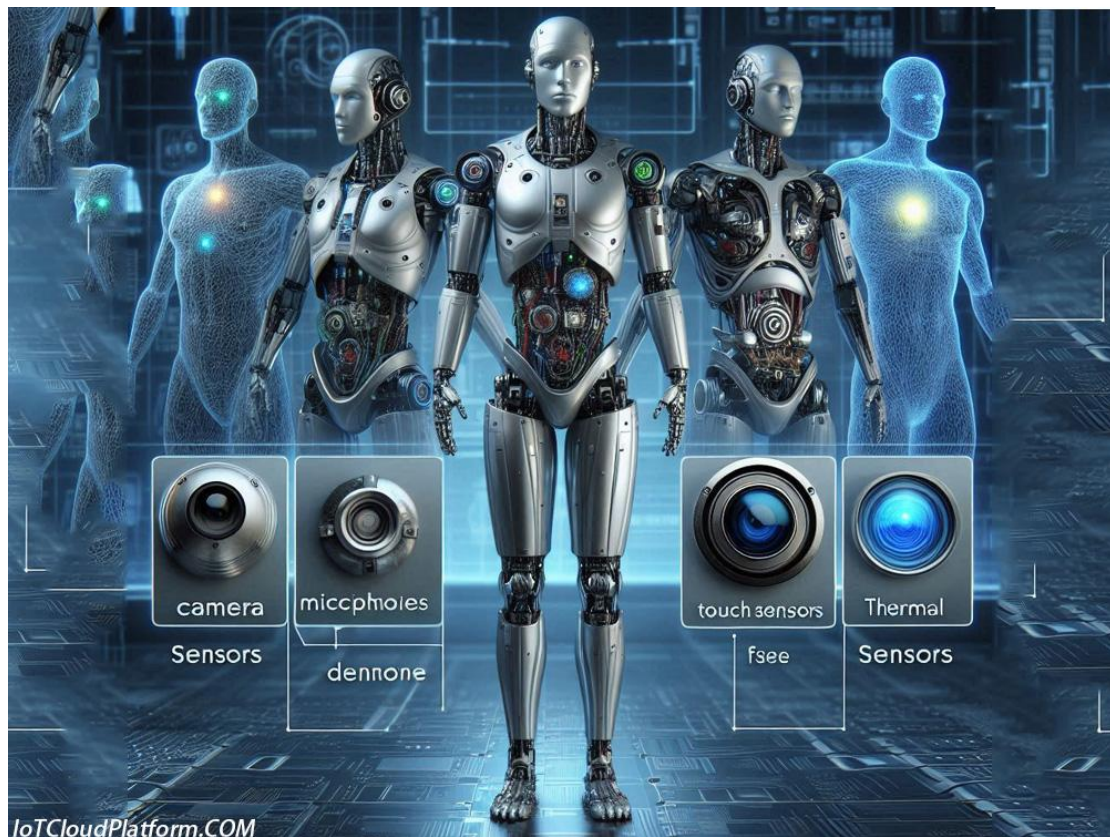
**What Sensors do Humanoid Robots Need**

# Application cases of sensors in humanoid robots

Take Tesla's Optimus robot as an example. The robot is equipped with a large number of sensors to achieve complex perception and interaction functions:

**Visual sensor**: used for environmental perception, object recognition, face recognition, navigation and obstacle avoidance.

**Force/torque sensor**: Torque sensors and tension sensors are used at the joints, and six-dimensional force sensors are used at the wrist and ankle joints to achieve fine operation, maintain balance and avoid damage.

**Tactile sensor**: Flexible tactile sensors are equipped on each finger to ensure the sensitivity and accuracy of the robot's hand in perception and operation.

**IMU**: used to measure the robot's acceleration, angular velocity and direction, and provide the robot with posture control and navigation positioning capabilities.

In addition, the Optimus robot may also be equipped with other types of sensors to meet specific perception and interaction needs. It is speculated that the Optimus robot uses 50 to 100 sensors to achieve its highly intelligent functions.
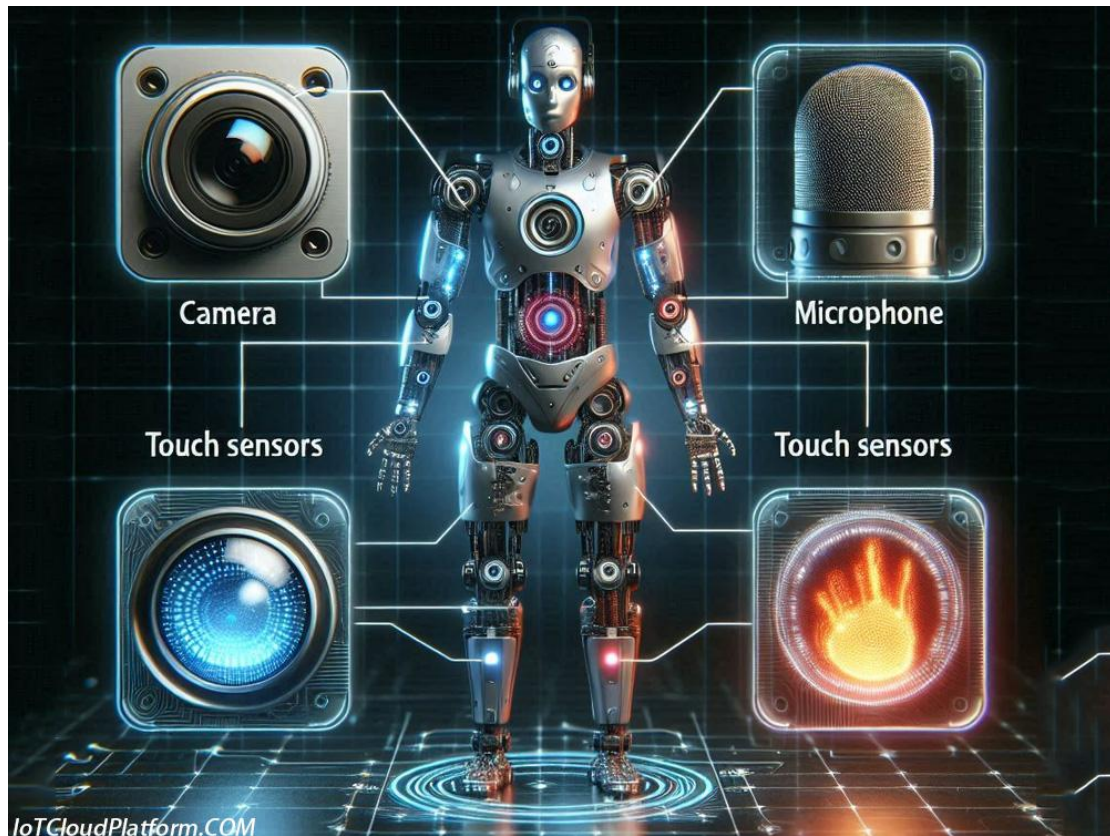


**The four most commonly used sensors for humanoid robots**

# Development Trends and Challenges of Sensor Technology

### 1. Development Trend

**Integration**: With the continuous advancement of technology, sensors will develop in the direction of integration. Future sensors will be able to measure multiple physical quantities at the same time, improving the functions and performance of sensors.

**Miniaturization**: Miniaturization is an important development direction of sensor technology. By adopting advanced manufacturing processes and materials, smaller and lower power consumption sensors can be manufactured.

**Intelligence**: Future sensors will have stronger intelligent processing capabilities. They can process and analyze data autonomously and reduce dependence on external control systems.

**2. Challenge**

**Technical Barriers**: Some high-end sensors (such as six-dimensional force sensors) have technical barriers such as structural design, calibration and detection, and algorithm design. A lot of manpower and material resources need to be invested in research and development and innovation.

**Cost Issue**: The high cost of high-end sensors limits their widespread application in high-end equipment such as humanoid robots. Costs need to be reduced through technological innovation and large-scale production.

**Standardization Issue**: At present, the sensor market lacks unified standards and specifications. Sensors produced by different manufacturers have differences in interfaces, communication protocols, etc., which brings certain difficulties to system integration and application.

# Future prospects of sensor technology

## 1. Deep integration and intelligent decision-making

In the future, the integration of sensors and humanoid robots will be more in-depth, not just staying at the level of data collection, but closely integrating the sensor data with the robot's decision-making system. The data provided by the sensor will directly participate in the robot's behavioral decision-making, enabling the robot to make more intelligent and flexible responses based on real-time environmental information. For example, in emergency obstacle avoidance situations, the data of the visual sensor and IMU will be quickly integrated, and the robot can immediately adjust its gait or direction to avoid collisions.

## 2. High precision and improved reliability

With the advancement of materials science, electronic technology and manufacturing processes, the accuracy and reliability of sensors will continue to improve. For humanoid

robots, this means more accurate force control, more refined tactile perception, more stable posture control, etc. For example, in medical surgery, high-precision force/torque sensors can ensure the precise operation of surgical instruments and reduce surgical risks; in precision manufacturing, high-reliability tactile sensors can detect tiny surface defects and improve product quality.

## 3. Exploration and application of new sensor technologies

In the future, more new sensor technologies will be explored and applied to humanoid robots. For example, tactile sensors based on fiber optic sensing technology can provide richer tactile information, such as temperature and humidity; visual sensors based on quantum dot technology can achieve high-definition imaging under extremely low light conditions; bio-inspired sensors can simulate human perception mechanisms and achieve more natural human-computer interaction.

## 4. Construction and optimization of sensor networks

In humanoid robots, the functions of a single sensor are limited, but the collaborative work of multiple sensors can greatly improve the overall performance of the robot. In the future, more attention will be paid to the construction and optimization of sensor networks. Through reasonable sensor layout and efficient data fusion algorithms, information sharing and complementarity between sensors can be achieved, and the perception ability and decision-making efficiency of robots can be improved.

## 5. Deep integration of sensors and artificial intelligence

The rapid development of artificial intelligence technology has provided new opportunities for the application of sensor technology. In the future, sensors will be deeply integrated with artificial intelligence technology, and through machine learning, deep learning and other methods, sensor data will be intelligently processed and analyzed to extract more valuable information, providing more powerful support for robot decision-making and control. For example, by training deep learning models, robots can better understand human language and instructions and achieve more natural human-computer interaction.

## 6. Expanded application of sensors in special environments

Humanoid robots will be used in more and more special environments, such as space exploration, deep-sea operations, and nuclear energy facility maintenance. These environments place higher requirements on the performance of sensors. In the future,

more sensors designed for special environments will be developed, such as high temperature resistance, high pressure resistance, and radiation resistance sensors, to meet the perception and interaction needs of humanoid robots in these special environments.

# The impact of sensor technology on the development of the humanoid robot industry

## 1. Promoting technological innovation of humanoid robots

The continuous advancement of sensor technology is an important driving force for technological innovation of humanoid robots. The emergence and application of new sensor technology will provide humanoid robots with more accurate and comprehensive perception capabilities, enabling robots to respond to various complex environments and tasks more intelligently and flexibly.

## 2. Promote the upgrading of the humanoid robot industry

The improvement of sensor technology will promote the upgrading of the humanoid robot industry. With the improvement of sensor performance and the reduction of cost, the application areas of humanoid robots will continue to expand, from industrial manufacturing, medical services to home services, entertainment interaction and other fields will be widely used. At the same time, the standardization and interoperability of sensor technology will also promote the standardized development of the humanoid robot industry.

## 3. Drive the development of related industrial chains

The development of sensor technology will drive the development of related industrial chains. With the increase in the demand for sensors for humanoid robots, related companies such as sensor manufacturers, material suppliers, and algorithm developers will usher in new development opportunities. At the same time, the widespread application of humanoid robots will also promote the development of related service industries, such as robot repair, maintenance, and training.

# Conclusion

As an important component of humanoid robots, the development and application of sensor technology have a decisive impact on the performance and application fields of

humanoid robots. In the future, with the continuous advancement of sensor technology and the expansion of application scenarios, humanoid robots will have more accurate and comprehensive perception capabilities, and achieve more intelligent and flexible behavior decision-making and control.

At the same time, the development of sensor technology will also promote the innovation and upgrading of the humanoid robot industry and drive the development of related industrial chains. We have reason to believe that in the near future, humanoid robots will be widely used in more fields, bringing more convenient and efficient services and support to human society.

# About IoT Cloud Platform

**IOT Cloud Platform** (**blog.iotcloudplatform.com**) focuses on IOT solutions, sensors, smart homes, **smart cities**, IoT design, RFID, lora devices, **IoT systems**, IOT modules, new energy, **WiFi IoT** and other technological knowledge and products.

# FAQs

Frequently Asked Questions and Answers about Humanoid Robot Sensors:

**What types of sensors are commonly used in humanoid robots?**
Commonly used sensors for humanoid robots include tactile sensors, force/torque sensors (such as one-dimensional, three-dimensional and six-dimensional force sensors), visual sensors (such as binocular cameras, depth cameras, lidar and infrared sensors, etc.), inertial measurement units (IMUs), position sensors, Hall sensors, etc. These sensors together constitute the perception system of humanoid robots.

**What is the role of tactile sensors in humanoid robots?**
Tactile sensors can cover the entire body of the robot, forming a tactile perception layer similar to human skin. It helps the robot obtain information such as the size and direction of contact force, temperature, humidity, shape, texture, etc., which is crucial for stable grasping, route planning, obstacle avoidance, etc. in unstructured environments.

**What is the role of IMU in humanoid robots?**
IMU (inertial measurement unit) is an important component for humanoid robots to perceive their own motion state, usually composed of sensors such as accelerometers, gyroscopes and magnetometers. It can measure the acceleration, angular velocity and direction of the robot in real time, and plays an important role in the robot's posture control, navigation and positioning.

**What are the application scenarios of force/torque sensors in humanoid robots?**
Force/torque sensors are installed on the joints or end effectors of the robot and can accurately measure the force and torque of an object in multiple directions. They are essential for achieving fine manipulation, maintaining balance and avoiding damage. For

example, installing a six-dimensional force sensor at the end of the robot can obtain force information from the rear section of the force sensor to achieve more refined control.

**How do visual sensors help humanoid robots perceive the external environment?**

Visual sensors are an important window for humanoid robots to perceive the external environment, and can realize functions such as environmental perception, navigation, object recognition and face recognition. By emitting laser beams and measuring the time of reflected light to create a three-dimensional point cloud map of the surrounding environment, or using binocular cameras to obtain color, depth and distance information, the robot can better understand and adapt to the surrounding environment.

**What kind of faults may occur in humanoid robot sensors?**

Humanoid robot sensors may age, wear or be damaged, resulting in sensor failure or increased errors; abnormal power supply, such as too high or too low voltage, power supply interference, etc., will cause abnormal sensor output signals; incorrect installation position may cause the robot to be unable to perceive the surrounding environment normally; environmental interference, such as light, sound, magnetic field, radio waves, etc., may also interfere with the normal operation of the sensor.

**How to maintain humanoid robot sensors to extend their service life?**

In order to extend the service life of humanoid robot sensors, it is necessary to regularly check the sensor connection lines to ensure that the sensor is working properly; regularly clean the sensor to keep the sensor clean and sensitive; regularly calibrate the sensor to ensure that its output value is accurate. For replaced or newly installed sensors, debugging and calibration are required.

**What is the development trend of humanoid robot sensor technology?**

The development trend of humanoid robot sensor technology is to develop in the direction of higher precision, higher reliability, smaller size and lower cost. At the same time, with the continuous advancement of sensor technology and the reduction of costs, the perception ability of humanoid robots will continue to improve and the scope of application will continue to expand.

**What is the current situation of the humanoid robot sensor market in China?**

At present, the base of the humanoid robot sensor market in China is relatively small, but it is growing rapidly. Some domestic companies in China occupy a large share in some subdivided tracks, showing strong differentiated competitive strength. With the rapid development of the humanoid robot market, there are great opportunities for domestic substitution, and China's domestic supply chain is expected to accelerate the realization of domestic substitution.

**What is the application prospect of six-dimensional force sensors in humanoid robots?**

The six-dimensional force sensor can simultaneously measure forces in three directions and torques in three directions, provide all-round force information, and is a key component for humanoid robots to achieve fine operation, maintain balance and avoid damage. With the rapid development of the humanoid robot market, the application prospects of six-dimensional force sensors are broad and are expected to become an important increment in the field of humanoid robots.