Deep Science Publishing
https://doi.org/10.70593/978-81-983916-1-2_3

Chapter 3

Advances in robotics technologies and implementations

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Abstract: This chapter may introduce robotics, from basic principles to the latest robot develop- ments in various branches. Robot actuation, coordination and control algorithms, power supplies, and the robots' sensors will be included here as part and parcel of the robotic system backbone. Such prin- ciples will then end with locomotion and manipulation, the two mechanisms by which robots move and interact with their environment. To continue, the chapter presents those aspects of kinematics that will give a basic understanding of and control over robots' movements. Sensor integration is articulated; the sensory inputs are critical concerning their contributions of helpful information for decision-making. Vision systems and feature extraction have covered the areas that help understand how robots perceive, interpret, and act concerning visual information about navigation between their environment and them- selves. Examples such as localization and mapping demonstrate how robots can perceive and create images of their environment. Applications of these robots in industry, agriculture, education, and other sectors show the different effects and impacts of robotics across fields. The chapter ends with ethical concerns with robots and calls for responsible design and deployment as they enter society.

Keywords: Robots, Components, Building robots, Kinematics, Sensors, Vision.

Citation: Singh, R., Singh, S., & Vidyalakshmi, K. (2025). Advances in robotics technologies and implementations. In *Advances in Robots Technologies and Implementations* (pp. 39-80). Deep Science Publishing. https://doi.org/10.70593/978-81-983916-1-2_3

Introduction

In the modern world, robots have become an important device that is changing businesses, and their applications are changing how individuals interact with technology. By immaculate means, a robot is a programmable mechanical device that can develop some shape of the task, from simple repetitive tasks to complex, speculative tasks that require common sense and adaptability. Essentially, these devices leverage mechanical engineering, electronics, computer science, and AI advances in performing most of their functions autonomously or with human intervention, as—figure 1 shows

Figure 1: Robot

The idea of robotics is not new to mechanical beings in ancient myths and folklore. However, it was not until the 20th century that practical robotics started to take off, driven primarily by industrial needs and technological advances. The word robot became popularized by Czech playwright Karel Č apek's 1920 play R.U.R. (Rossum's Universal Robots), where robots are portrayed as artificially created workers. Since then, the comprehension and application of robots have experienced a complete revolution due to advancements in automation and artificial intelligence. Today, there are a variety of sectors where robots have been recognized as significant players. They are utilized in manufacturing industries on assembly lines to perform actions that need accuracy and uniformity, such as welding, painting, and assembly processes. These industrial robots are designed as articulated arms with multipoint permutations and low output error rates. Figure 2 shows That they are a productivity monster that operates cheaply.

There has been a significant increase in the use of robots in the healthcare industry, particularly in the form of surgical robots for minimally invasive procedures. Patients may also benefit from rehabilitation robots' assistance, as exoskeletons help people with limited mobility. Moreover, autonomous robots are taking steps into new and uncharted territories. Mars rovers sent for space exploration and underwater robots deployed for marine ecosystems study illustrate that these' performance levels have increased remarkably through the introduction of artificial intelligence. With learning algorithms, robots can pro- cess vast volumes of data, put their input into patterns, and respond in real time. Robots also feature AI capabilities for service uses, allowing them to converse with humans through natural language or speech. They are ideally suited for customer care, caregiving, and educational uses. Mobile robots, like self-driving cars, are the best demonstration for the entire AI use of robots, where sensor appliances, cameras, and data-processing technology can help the robots navigate the unsafe world that lies ahead.

Thus, one of the ethical problems of introducing robots into society is that of job displacement.

Main Component of Robots

Robots are indeed sophisticated machines. These sophisticated machines are engineered to run tasks automatically or at least with minimal human interaction. Thus, integration would need to be such that all the parts are putting effort into making the robot fully functional. The main parts of robots can be categorized into different types. Among them, the following are:

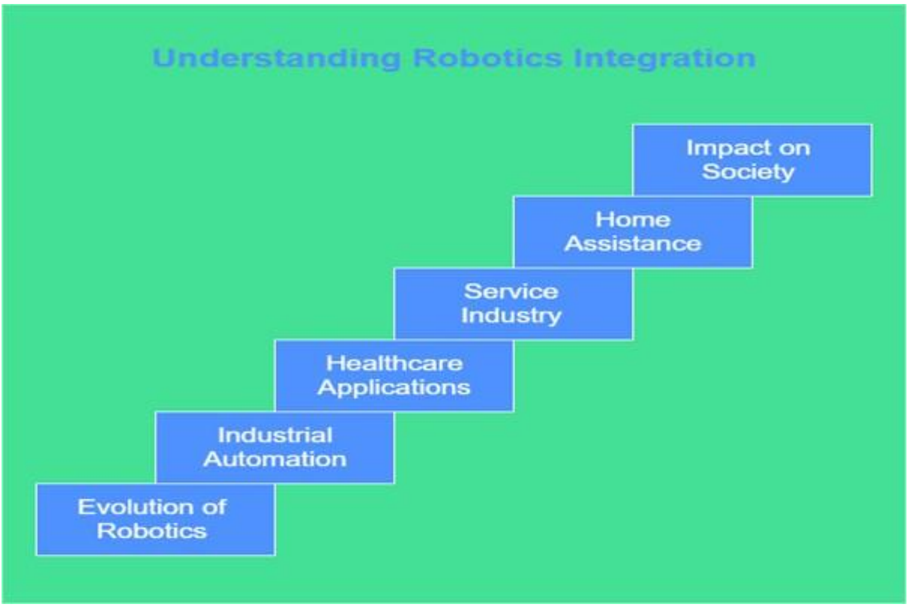


Figure 2: Integration Sector of robot

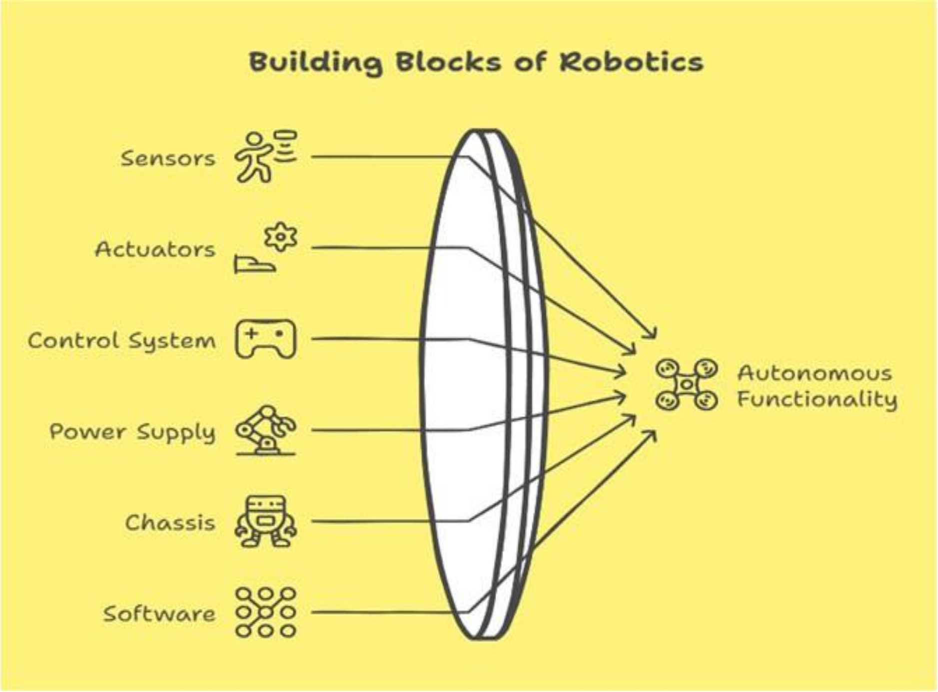


Figure 3: Main Component

Mechanical Structure

The mechanical structure forms the foundation of a robot. It includes components like chassis, joints, actuators, end effectors, etc. Typically, this structure is designed for a specific task and could be a humanoid structure to industrial robotic arms. For example, articulated arms are mainly used during processes undertaken by factories where much precision and consistency are required (Craig, 2005). To enhance performance, the materials used are typically very robust yet lightweight, such as aluminum or carbon fiber. Figure 3 shows all components of the robot.

Sensors

Robots' sensors are similar to human senses and are vital for feeding robots with input data that support ultimate decision-making. Sensors allow robots to perceive their surroundings and act dynamically. Common sensors include

Vision sensors

systems such as cameras or computer vision systems for object detection and navigation.

Tactile sensors

devices that sense pressure, texture, or force, which are important for grasping and manipulation (Dahiya et al., 2010).

Proximity sensors

Technologies such as lidar, radar, and infrared are used to detect and avoid obstacles.

Environmental Sensors

Equipment for recording external conditions like temperature, humidity, or presence of gases.

Actuators

Actuators enable a robot to have freedom of movement and interaction with the environment. Actua-tors allow the transformation of energy into mechanical movement. Thus, every actuator has its distinct ap- plication among such actuators, including the electric motor actuator, hydraulic actuator, and pneumatic actuator. For example, articulated arms are often used in manufacturing processes requiring high preci- sion and consistency (Craig, 2005). Robust and lightweight materials like aluminum or carbon fiber are often used to increase performance.

Power Supply

The power supply is a crucial factor continuously driving the robot into operation. Robots mainly depend on batteries, solar energy, or direct electricity for their energy supply. The battery utilized in such mobile robots is an imperative battery technology that is usually lithium-ion batteries manufactured for high energy density and effectiveness (Gonzalez-Gil et al., 2014).

Control System

This is a computer that could process information in a robotic environment that is concerned with actions through a system. The above systems are integrated controllers through microcontrollers, digital signal processors, or embedded systems. Moreover, advanced control would be provided through features of machine learning and artificial intelligence to support adaptability and decision-making powers further (Siciliano & Khatib, 2016)

End Effectors

End effectors are devices mounted on robotic arms interacting with the surrounding environment. Grip- pers for handling workpieces, welding machines, and surgical tools are all examples of end-effectors. End effectors are designed for a particular task and often come with sensors to improve the user's preci- sion (Mason, 2001).

Software and Programming

software and programming software connect hardware to operational capabilities through interfaces that enable a robot to work effectively. The programming tools mostly used by programmers include the languages Python and C++ and frameworks like ROS, which provide the basic framework under which robotic functionalities such as building and implementing may be organized (Quigley et al., 2009).

Communication Systems

The information exchange may be between the robot and the outside system, or different robots can process it. Various technologies in data communication, such as Wi-Fi, Bluetooth, and Zigbee, prove expensive in terms of real-time monitoring and coordination for multi-robot systems (Luo et al., 2000).

Building Robots: Locomotion and Manipulation

Positioning and interaction are crucial functionalities of robots concerning their environment, and these become possible through locomotion and manipulation systems. Locomotion and manipulation would be critical for performing tasks ranging from industrial automation to exploration and caregiving. Fol- lowing are these two mandatory features of robot designs:

Locomotion

The motion of a robotic entity is referred to as locomotion concerning its environment. Depending on the application and terrain, locomotion can take various forms.

Wheeled Locomotion

Wheeled robots are the most preferred among their different types, courtesy of their efficiency and simplicity. They perform well on flat, structured surfaces and are typically deployed in warehouse automation or service robots. They are usually configured with differential drive and omnidirectional wheels. This gives them navigation flexibility (Siegwart et al., 2011).

Legged Locomotion

An objective of research in legged locomotion robot designs has been to create models that show realistic behavior when it comes to walking upon uneven or rugged terrain, mimicking the capability of insects or mammals for standing and moving in various orientations. These include bipedal robots, such as Atlas, as well as those involving four-legged robots, such as Spot, which demonstrate the utility potential for agility and balance in complex environments. Accomplishing stable-legged locomotion requires control algorithms and sensors that are less simple (Raibert et al., 1986).

Tracked Locomotion

Tracked robots, like tanks, employ continuous tracks for movement and maneuver over loose or uneven terrain. Their special functions include assisting search and rescue operations or military applications where stability and traction are crucial (Muir & Neuman, 1987).

Flying and Swimming Robots

Drones and underwater robots show advanced locomotor systems. Drones rely on propellers and ad- vanced control systems for stability, whereas underwater robots have fins, thrusters, or buoyancy control for navigation (Antonelli, 2014).

Manipulation

Manipulation represents the ability of the robot to interact with objects in its environment. It is primarily important for performing tasks such as assembling products, handling materials, or helping human users.

Robotic Arms and End Effectors

Robotic arms are the most common manipulation systems, consisting of links and joints that specify the degrees of freedom by which they measure precise movements. These arms have end effectors, such as grippers, suction cups, and tools, attached to the end effector to perform their intended tasks (Craig, 2005).

Control and Dexterity

Robotic manipulation involves an accurate control system as well as an accurate set of sensors. Sensing, ranging, and gesturing, with force-torque and tactile sensors, are required touch-sensitive robots that adjust grip and apply highly sensitive forces. For example, robots like Baxter and UR5 are designed to work in collaborative environments wherein dexterity and safety are paramount (Mason, 2001).

Mobile Manipulators

Mobile manipulators merge locomotion with manipulation by placing a robotic arm on a mobile base. Such a setup is ideal for tasks that require both types of abilities, such as the automation of warehouses or assisting people in their homes (Siciliano & Khatib, 2016) in interaction with physical objects.

Kinematics for robots

Kinematics for robots is the movement of robots. It relates the actions of a robot joint and the end effector movements. It is used in programming, control, and design. Meanwhile, dynamics treats kinematics concerning the movement of bodies due to force. It is the study of form without respect to force; kinematics deals with the motion of systems.

Forward Kinematics (FK)

This method is concerned with the position and orientation of the robot’s end effectorabouto its joint parameters by applying transformation matrices to all joints such that their net effect determines the pose of the end effector. This technique is most valuable in applications requiring precision positioning, such as assembly operations.

Mathematical Representation

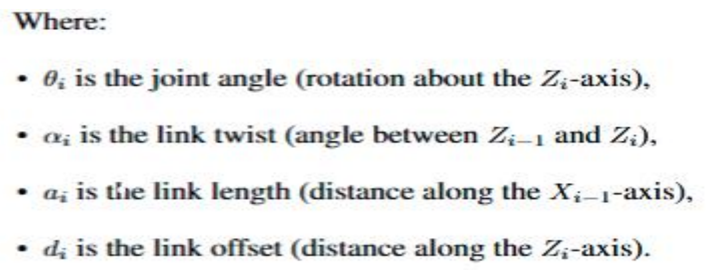
Forward kinematics refers to calculating the end-effector position and orientation from the joint parameters. For a robot with n joints, the overall transformation matrix T from the base to the end-effector is given by the product of the individual transformation matrices.

$$T = \prod_{i=1}^{n} T_i$$

Each individual transformation matrix T_i is a 4x4 homogeneous transformation matrix that combines rotation and translation. The matrix for the I -th joint is:

$$T_i = \begin{bmatrix} \cos\theta_i & -\sin\theta_i \cos\alpha_i & \sin\theta_i \sin\alpha_i & a_i \cos\theta_i \\ \sin\theta_i & \cos\theta_i \cos\alpha_i & -\cos\theta_i \sin\alpha_i & a_i \sin\theta_i \\ 0 & \sin\alpha_i & \cos\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\begin{vmatrix} 1 & 2 & 3 \\ a & b & c \end{vmatrix} \tag{1}$$



Where:

- θ_i is the joint angle (rotation about the Z_i-axis),
- α_i is the link twist (angle between Z_{i-1} and Z_i),
- a_i is the link length (distance along the X_{i-1}-axis),
- d_i is the link offset (distance along the Z_i-axis).

Inverse kinematics

the relevant joint parameters must be found to create a desired end-effector position and orientation. This aspect becomes inherently complex because it mainly involves non-linear equations that often lead to more than one or no solution. This is where most recent research has made strides. For example, Wu and Tron (2024) introduce IKSPARK. This state-of-the-art inverse kinematics solver utilizes semidefinite relaxation and rank minimization to find a more efficient and reliable solution to the IK problem.

Progress in Robot Kinematics

The 19th International Symposium on Advances in Robot Kinematics (ARK 2024) took place and show- cased excellent progress in this field. The symposium devoted itself to the latest theories and methods applied to various robotic mechanisms, such as serial, parallel, or cable-driven for industrial and service robotics. ARK 2024. The proceedings edited by (Lenarcˇicˇ and Husty, 2024) present a spectrum of the most current progress made in kinematic analysis, modeling, simulation, design, and control. They are, therefore, valuable documents for researchers and practitioners.

Applications of Humanoid Robots

Advances in kinematics have widely contributed to the overall improvement of humanoid robots. These robots are built to look like humans and mimic movements. They involve sophisticated kinematic models that enable more natural and efficient motion. Some recent humanoid robots involving Ameca and Optimus show excellent capabilities and attributes to improved kinematic modeling concerning mobility and dexterity.

Simulation Tools Simulation is pivotal for developing and testing robotic systems. Cop- peliaSim (formerly known as V-REP) is one of the versatile robot simulators used in industry, education, and research. It offers an integrated platform to simulate both the kinematic and dynamic behavior of robots, which involves modeling and controlling these robot systems.

AI Integration in Kinematics

AI Addition in Kinematics Nowadays, the application of AI to robotic kinematics continues toward complete adaptation and increase in efficiency. In this regard, Ma et al. (2024) proposed the Hierarchical Diffusion Policy (HDP), a hierarchical agent for multi-task robotic manipulation. An HDP consists of a high-level task-planning agent and a low-level goal-conditioned diffusion policy, which works for the two parts of a manipulation policy by addressing long-horizon task planning and fine-grained low-level actions within one framework. This will include a new kinematics-aware goal-conditioned control agent, Robot Kinematics Diffuser (RK Diffuser), which builds context-aware motion trajectories while the robot’s kinematics constraints are being met.

Adding Sensors

Adding sensors to a robot helps it understand its environment and react to commands. Sensors can help robots avoid obstacles, material management, and machine loading and unloading. Figure 4 shows all categories of the sensor domain

Tactile Sensors for Robotic Applications

Tactile sensing is a crucial technology enabling a robot to execute complicated tasks. Successful robotic grasping and manipulation rely on knowing almost entirely objects geometric and physical properties, especially deformable ones, which change shape with different environmental interactions. In this con- text, sensorized grippers are being increasingly implemented in robotic systems to use tactile sensors to assess objects' characteristics. In addition, high human-robot interaction (HRI) confidence is expected to be achieved considering interaction forces and contact point awareness to realize cooperation and co-manipulation tasks in safe conditions without significant risk of injury from unintentional collisions. This most crucial information can thus be gained through direct measurements allowed by an artificial sense of touch (Wu, Z., Zhao, W. 2023).

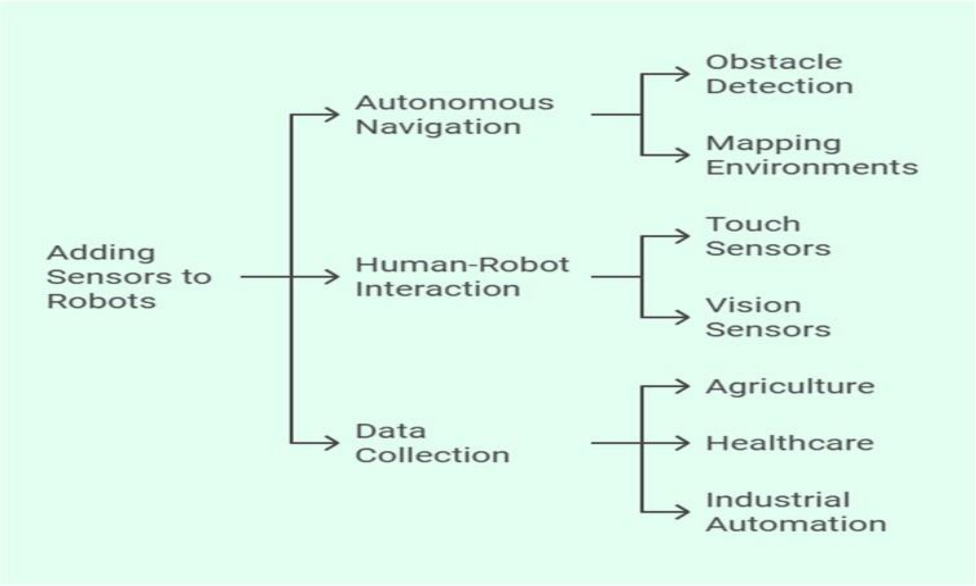


Figure 4: Adding Sensor

LiDAR and Visual Sensors for Environmental Perception in Robotics

Getting LiDAR and visual sensors for better environmental perception in autonomous robots. The authors have proposed a hybrid sensor to make depth perception possible for LiDAR capability analysis and high-resolution imaging through camera-as. This allows autonomous robots to perform accurate navigation and obstacle avoidance in unstructured environments, making them highly relevant for applications in agriculture, search and rescue, and autonomous vehicles (Zhang, Y., Liu, Y., Wang, S. 2022).

Soft Sensors for Shape Sensing in Continuum Robots

A new approach for integrating soft e-textile sensors into continuum robots. These sensors provide real- time feedback about the shape and deformation of the robot for ergonomic soft robot control in compli- cated, restricted environments. These e-textile sensors are lightweight, flexible, and high-performance sensors that serve their purpose best in medical robotics and the human-robot interaction setting (Kong, J., Wang, F. (2024).).

Vision and AI Sensors for Real-time Adaptation in Robotic Work Cells

AI Power Vision Sensor: To propose establishing adaptive robot capability in a changing environment. The discussion concerns the development of general real-time visual feedback because of the vision sensor and the machine learning algorithms that require robots to adjust their workspace autonomously if any obstacle appears or object positions change. Incorporating this benefits the general efficiency of the robot in executing tasks in a shared environment(Li, B., Yang, G., Sun, L. 2024).

Advanced Skin-Like Sensors for Robotic Interaction

Soft, skin-like sensors have been developed for robots that enhance human interaction. This technology mimics the properties of skin: flexibility, sensitivity, and self-healing. Such properties allow the robot

to interact more naturally with humans and respond to external stimuli. The research results reveal how these sensors could be deployed in humanoid robots with the work on robotic faces using laboratory-grown living skin integrated with self-healing capacity; this stretches the limitations of the realism and functionalities of robots (Cheng, S., Zhang, H. 2024).

Environmental Perception with Multisensor Fusion in Autonomous Robotics

The fusions between such multiple sensors as LiDAR, ultrasonic, and vision-based systems for im- proving the environmental perception of autonomous robots. The authors explore how sensor fusion improves the accuracy and reliability of robot navigation, especially in cluttered or dynamic environments. They indicate that combining sensor modalities reduces the likelihood of sensor failures and provides a more stringent environmental mapping process (Cheng, Y., Liu, X., Zhao, L. 2023).

Vision

With the advancements in robot vision, autonomous systems employ more efficient navigation strategies for object manipulation and human-robot interaction today. Below is a review of some recent research contributions toward this subject. There are figure 5 shows the dimensions of robotic vision.

Robotic Vision for Human-Robot Interaction and Collaboration

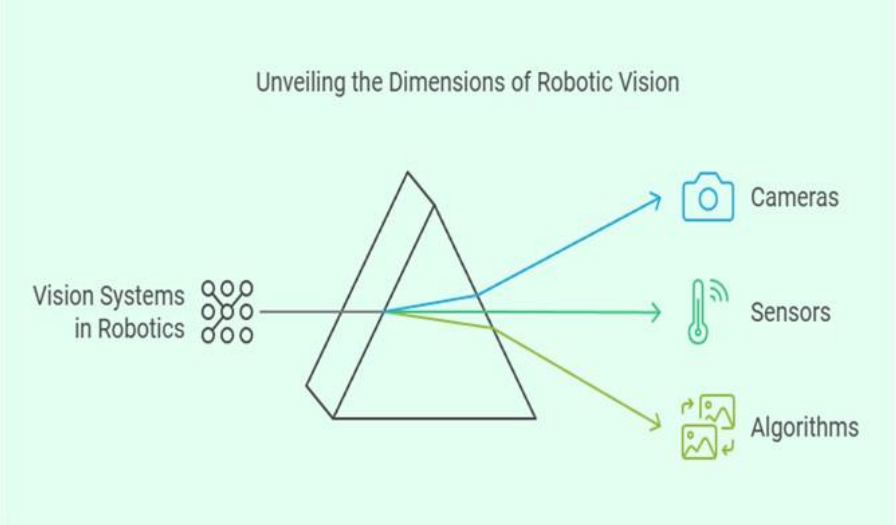


Figure 5: Vision Dimension

The role of robotic vision in facilitating human-robot interaction and collaboration. The authors analyze various methods through which robots may gain some insight into human actions, gestures, and intentions through visual perception to enhance their effectiveness during collaborative tasks. The current trends, challenges, and future directions in implementing more effective vision systems for im- proved human-robot synergy are highlighted (Robinson et al., 2023).

Real-time Vision-based Navigation in Indoor Environments

They offer an indoor vision-based navigation system for autonomous robots. Using real-time visual data, the system helps robots detect obstacles and avoid navigating to the intended destinations. It shows the effectiveness of combining vision techniques with path-planning algorithms to facilitate efficient and safe navigation in complex indoor environments (Manglani, S. 2023).

Vision-based Object Detection and Grasping in Lunar Conditions

The APT explores a vision-based framework for object detection and grasping designed specifically for lunar conditions. An articulated robotic manipulator will use this system to identify and handle objects at uneven lunar ground conditions and variable lighting. Therefore, this research will boost progress in autonomous robotic missions in space exploration (Boucher et al., 2023).

Stereo Vision-Based Robots for Remote Monitoring with VR Support

A robotic system that would be remotely operated and surveyed in the sense that it utilizes stereo vision. Then, it specifies further when it incorporates or supports virtual reality into the entire system, capturing 3D stereoscopic video, so it immerses the users in real-time visual feedback through any VR devices. It also tracks objects and faces, which are implemented through deep neural networks to ensure that everything will be autonomously monitored and interacted with within the place (Fazil et al., 2024).

Advancements in AI-Powered Robotic Vision Systems

The new robots are powered by advanced large language models, such as Gemini, developed by Google DeepMind, which can process input text and video together. Thus, the robots would navigate and assist more proficiently in office environments by understanding and executing complex commands with better commonsense reasoning. Indeed, it is a giant step towards human-robot interaction through AI and vision (systems. Zhang, Y., Li, X. 2023).

Feature extraction

At present, feature extraction is the most remarkable activity in robotics since it helps the system understand sensory data, such as recognizing objects, orienting itself, and even interacting with people. New approaches have been researched to improve feature extraction in various robotic applications. Some of them are given below, and Figure 6 shows the transfer of sensory data for robotics.

Automatic Feature Extraction and Optimal Path Planning for Robotic Drawing

A hybrid method to automatically extract features from user-specific 2D input patterns by local and global binarization grain method. It is employed to find the optimal path to robotically draw replicas on 3D objects with an accurate approach to duplicating intricate designs (Chandio et al.,2024).

A Neurosymbolic Approach to Adaptive Feature Extraction in SLAM

An adaptable SLAM pipeline via a neurosymbolic program synthesis approach. Using classical SLAM knowledge with data-driven approaches to improve feature extraction will improve pose and adaptability in dynamic environments (Garc´ıa, L. P., Garc´ıa, J. 2023).

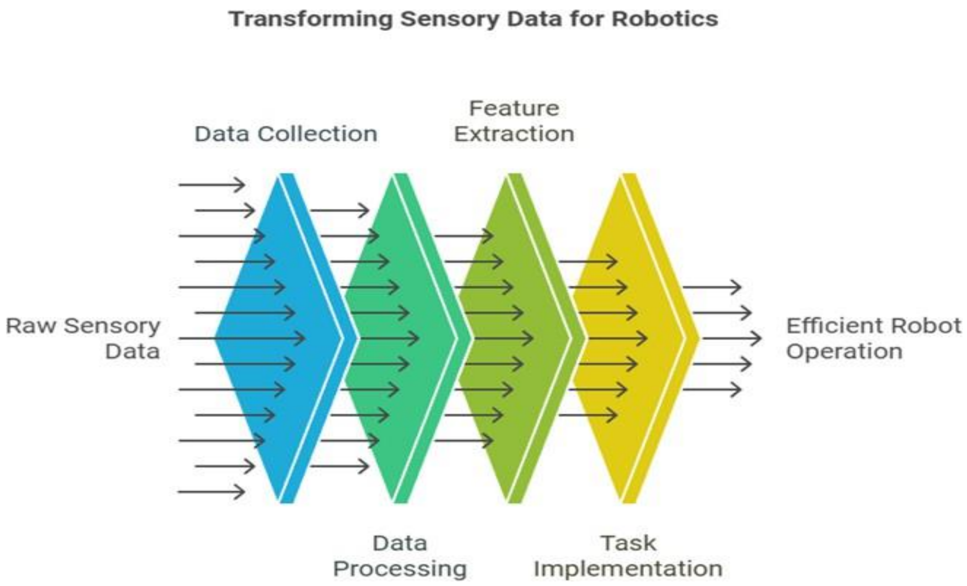


Figure 6: Feature Extraction

Machine Learning-Based Feature Extraction and Selection

Two phases are defined for the method: dimensionality reduction and feature selection. The method eliminates irrelevant features while the most significant ones remain. Efficiency and accuracy were improved in robotic perception systems (Han et al., 2017).

Simultaneous Feature and Body-Part Learning for Real-Time Robot Awareness of Human Behaviors

This is the newest technique a robot uses to learn the human act in real-time by learning the discriminative- tive parts of the body and, at the same time, discriminative features. The method beautifies human-robot interaction, as robots will be able to perceive human action much better (Liu, S., Sun, M., Wang, W., Wang, F. 2017).

Feature Fusion Using Extended Jaccard Graph and Stochastic Gradient Descent for Robot Vision

Using RGB depth information, a feature graph fusion method constructs fused features from Kinect sensors. Thus, improving the robot's vision strengthens the vision of a face and object recognition (Qiao, J., Guo, J., Li, Y. 2024).

Localization and Mapping

Localization and mapping are the central important performance for any autonomous robot, as they must navigate and understand their surroundings effectively. New promising research work has introduced novel improvements in these capabilities. Figure 7 shows principles, techniques, and technologies, and Figure 8 shows layers of Localization and mapping.

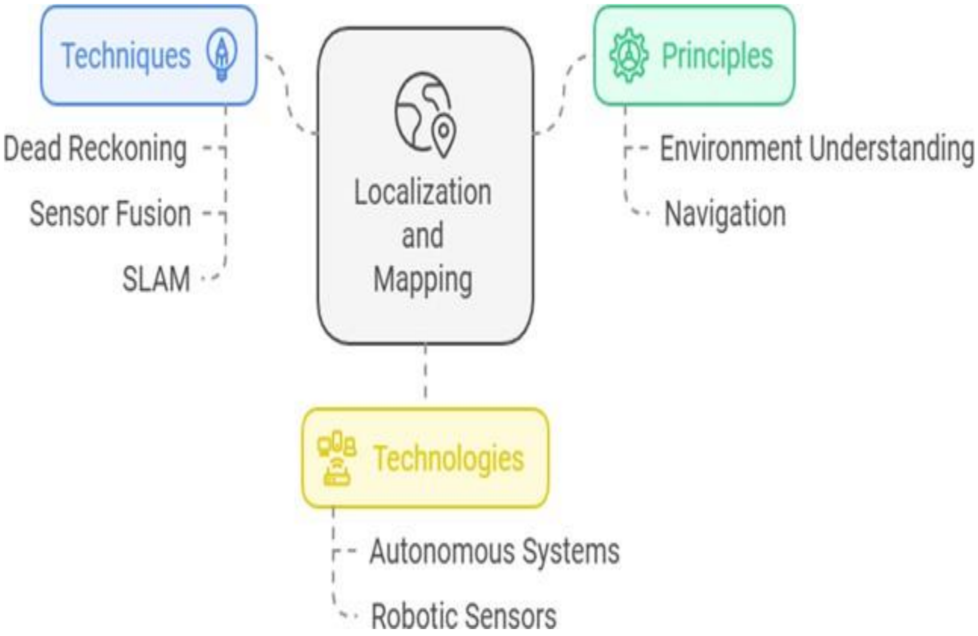


Figure 7: Localization and Mapping

SLAM-Based Robot Localization and Navigation

This is an extensive study of the SLAM algorithm for robot localization and navigation in unknown environments. The authors cover SLAM techniques that should be used for making maps and estimating the position of a robot at the same time, most useful in dynamic and unstructured environments (Nicky Zimmerman, Matteo Sodano,2024).

Long-Term Indoor Localization in Human-Oriented Environments

Employing geometric priors such as floor plans while combining textual and semantic information for long-term localization and mapping. The method was validated with open source on challenging consequences lasting months (Xiangyu S. Li1et.al.,2023).

Topological Localization and Mapping in Buried Pipe Networks

An algorithm for topological localization and mapping in buried pipe networks, allowing autonomous navigation of lightweight robots over extended periods. This method can relate well with human spatial intuition and thus promotes a more natural human-computer interaction (Ayman Hamdy Kassem et al.,2024).

Low-Cost Robotic System for SLAM in Indoor Environments

Describes a low-cost system for simultaneous localization and mapping (SLAM) in unknown indoor environments. Aim at making SLAM available for as wide an application as possible by reducing the cost and complexity of such systems' hardware and/or software components (Hadiseh Malakouti-Khah et al., 2023).

Decentralized Multi-Robot SLAM in Dynamic Environments

A novel decentralized approach to multi-robot SLAM problems in dynamic environments with unknown initial correspondences. This method improves scalability and robustness for multi-robot systems in complex, changing environments (Alvarado, D., Asif, S. 2024).

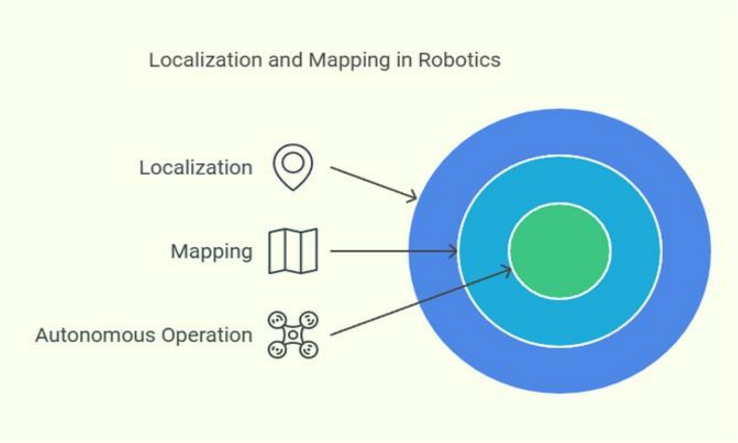


Figure 8: Localization and Mapping in Robot

Industrial robot

There is an area that is rapidly changing, and that of industrial robotics research at the moment has mainly concentrated on the further autonomy of robots, improved human-robot collaboration, and the integration of many other advanced technologies such as artificial intelligence (AI) and computer vision. Figure 9 shows the robot's workflow.

A Framework for Controlling Multiple Industrial Robots Using Mobile Applications

The mobile application framework is designed to operate multiple industrial robots across diverse operation modes. Its interface with users is through the smartphone. The framework is based on ROS and Arduino, tied with seamless controls and communication. The study has demonstrated how the framework could serve users in enhancing engagement and operational flexibility in industrial settings (Puljiz, D., Hein, B. 2022).

Updating Industrial Robots for Emerging Technologies

In this new development, they are modeling industrial robotic arms with new technologies, particularly virtual reality (AR) and the human-robot interface. The authors consider the integration of QR markers and RF-based ranging modules for improved safety, tracking, and intuitive programming. The study focuses on how industrial robots must adapt to future forms of technology to improve efficiency and collaboration. (Pazienza, A., Macchiarulo,et.al.,2024).

A Novel Integrated Industrial Approach with Cobots in the Age of Industry 4.0 through Conversational Interaction and Computer Vision

This is a new approach that merges collaborative robots with artificial intelligence. The intent is to increase collaboration between humans and robots in industry. The system combines conversation with computer vision to enable a co-robot to perform certain physical operations while assisting a human manager in decision-making. This study shows the possible future of such an integrated system in Industry 4.0 projects (Pietro Bilancia et al., 2023).

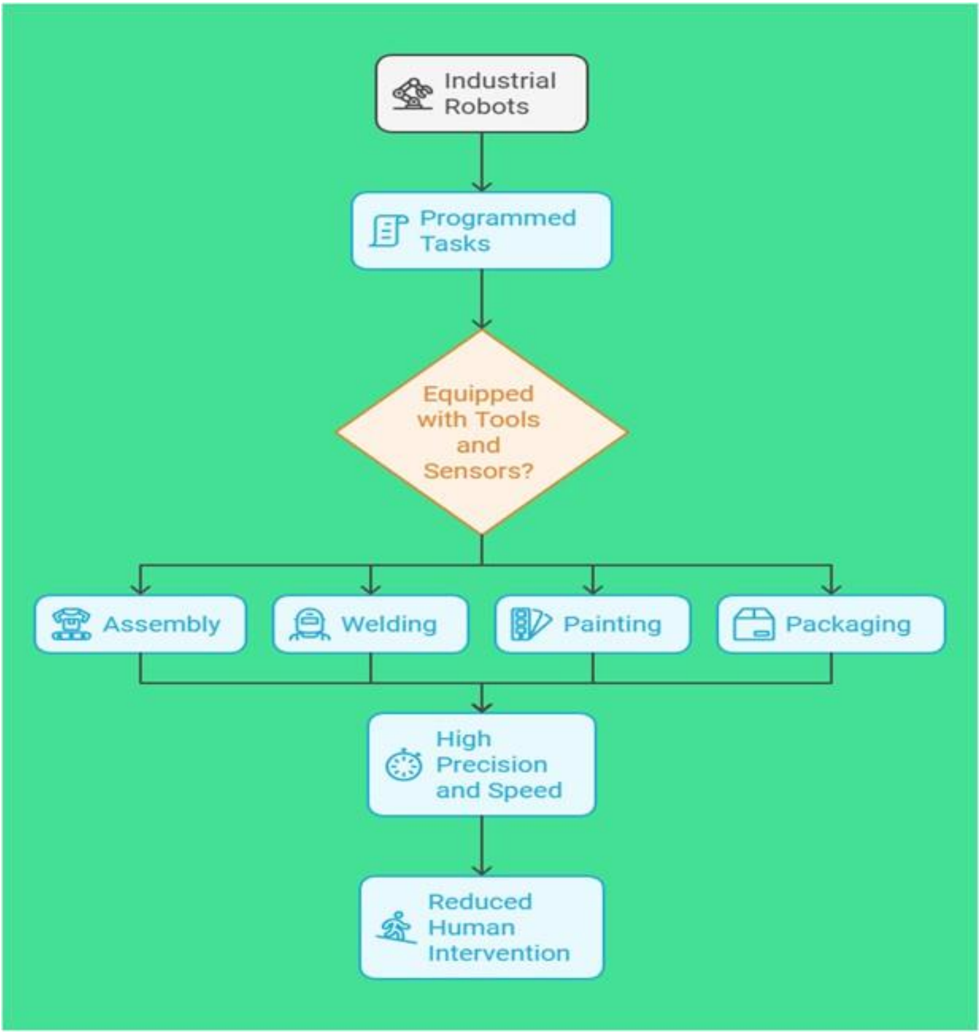


Figure 9: Robot workflow

An Overview of Industrial Robots Control and Programming Approaches

This overall picture or scenario will cover diverse control and programming methods and assorted tech- niques for industrial robots within the framework of scientific literature and the robotics industry, as discussed over the last decades. The paper also deals with the historical development in robot program- ming from traditional teach-pendant modes to offline programming and simulation techniques, finally shedding light on the current state and future directions of this area: industrial robots' control (Herron, D. M. et al. 2023)

Robot in Health

The transformation of the medical sphere by robotics enhances precision, increases efficiency, and im- proves patient care. Robots are currently used in several areas of healthcare, from surgical procedures to rehabilitation, diagnostics, and patient care. There are figure 10 shows the multifactored role of robots in healthcare.

Surgical Robots

Revolutionizing accuracy in medicine through robotic-assisted surgeries. For example, the da Vinci Surgical System increases precision in surgery, decreases recovery time, and minimizes complications. Robotic systems improve patient outcomes in complex laparoscopic procedures with dexterity and visualization (Meng, W. et al. 2024).

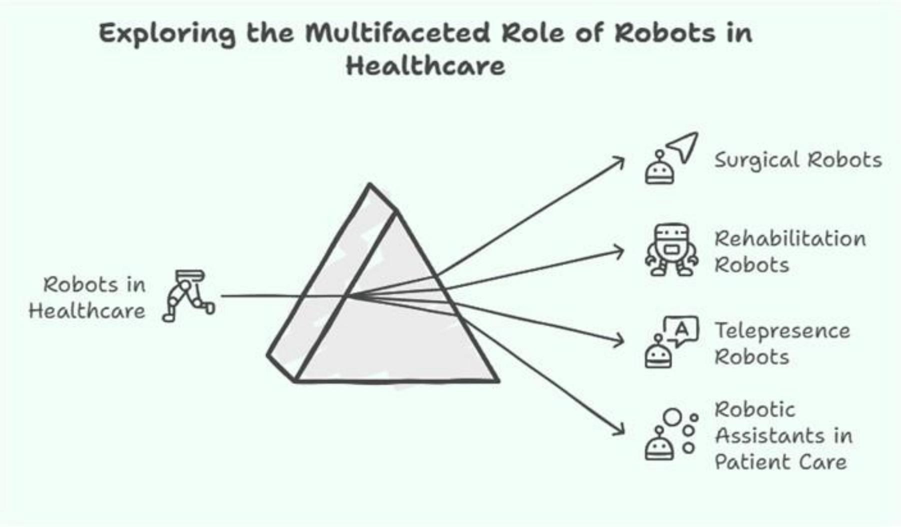


Figure 10: Robot in Health

Rehabilitation Robots

Rehabilitation robots are designed to restore mobility and strength after stroke or surgery and to provide- provide individualized and high-repetition therapeutic exercises. Exoskeletons, as rehab equipment, have considerably affected recovery conditions regarding motor skills (Kim, J. et al. 2023)

Diagnostics and Imaging Robots There has been much improvement in the early diagnosis and treatment provided by AI-empowered robots in cancer and cardiology. Robots enabled with AI have helped improve the detection accuracy of tumors as opposed to conventional techniques (Shibata, T. et al. 2023).

Patient Assistance and Elderly Care

Assisting robots helps most elderly and disabled persons improve their quality of living through activities and provide companionship. At the same time, PARO is an excellent example of a therapeutic robot that reduces stress and emotional problems in elderly patients (Ahn S. et al., 2022).

Hospital Automation

Disinfection and Logistics Autonomous robots optimize hospital processes regarding disinfection, trans- porting materials, and managing inventory. Ultraviolet disinfection robots that improve patient safety significantly reduce hospital pathogen distributions (Zhang, Y. et al. 2024).

Recent Innovations and Developments

Robotics for AI-Oriented Healthcare Hence, robots were made adaptable by incorporating AI that develops complex decision-making capacities (Gonzalez, J. et al. 2023).

Robotics in Wearable and Portable Versions Exoskeletons and portable robotic devices enable patient independence (Brown, L. 2023).

Telepresence Robots for Health Remote consultation will be offering services by robots, especially to such areas that have less cover age (Kumar, R. 2024).

Challenges and Ethical Considerations

High-Cost Factors: The high-cost barrier prevents the majority use of healthcare robots; hence, researchers are looking at more cost-effective designs (Green, P. (2023).

Ethical and Privacy Problems: These questions are where patient data security and robot decision- making will stand in AI-driven systems.

Training Health Care Providers: Training medical staff sufficiently to use advanced robotics is crucial (Zhang, Z. et al. 2024)

Agricultural robots

Agricultural Efficiency and Robotics-agb or agrirobts are joining hands to make more fields productive and profitable and form the workforce of tomorrow. Figure 11 shows how robotics enhances farming, and Figure 12 explains the role and benefit of using robots in agriculture.

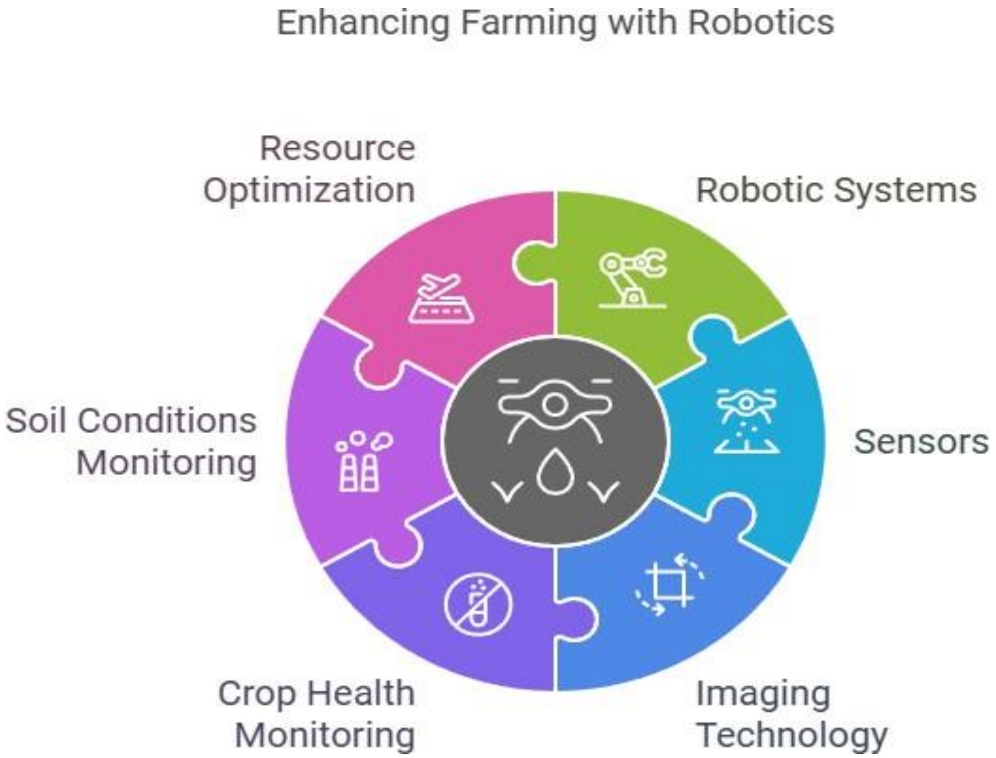


Figure 11: Robot in Agricultural

Crop Monitoring and Management

Agricultural robots monitor crop health, soil conditions, and pest and disease infestations, sensing and integrating AI with the improvement of computer vision and drones, as well as reality-refined precision crop monitoring (Bakker, T. et al. 2023).

Weeding and Pest Control

Weeding and Pest Control: Their specialty is targeting weeds and pests through robots such as Oz Weeding robots and autonomous sprayers, which apply chemicals minimally. The Intelligent Robotic Systems can also distinguish crops from weeds and apply pesticides accurately (Mahmud, M. S. et al. 2024).

Applications of Agricultural Robots

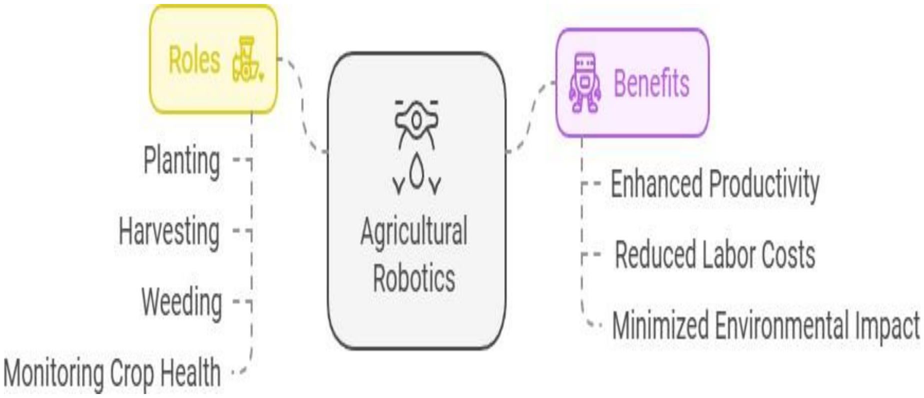


Figure 12: Robot in Agriculture

Planting and Harvesting

Robots automate various laborious tasks, such as sowing seeds and harvesting fruits—for instance, fruit- picking robots and automated tractors. The fruit-picking robots endowed with machine learning algorithms outperform in the speed of harvesting while at the same time minimizing wastage (Singh, V. et al. 2023).

Soil Analysis and Irrigation Management

robots with soil sensors analyze moisture, nutrients, and compactness in a soil medium for optimized fertilization and irrigation. Autonomous irrigation systems use water more effectively and enhance crop yield (Van der. Zande, D., et al. 2024).

Livestock Management

robots are used to feed, milk, and check livestock health, reducing manual operation. Robotic milking systems improve productivity and reduce animal stress (Oliveira M. et al., 2024).

Recent Advances in Agricultural Robotics

Breakthroughs in agricultural robotics enhance the industry significantly, with roboticists having brought to light in the last two or three years such issues as the use of robots for such agricultural chores as drones, robot laboring fields, and the demolition of barns for the activities which no farmer could perform using robots and perform within the last two years such activities as planting from the air through jets. There are figure 13 & 14 show advancing and efficient agriculture robotics

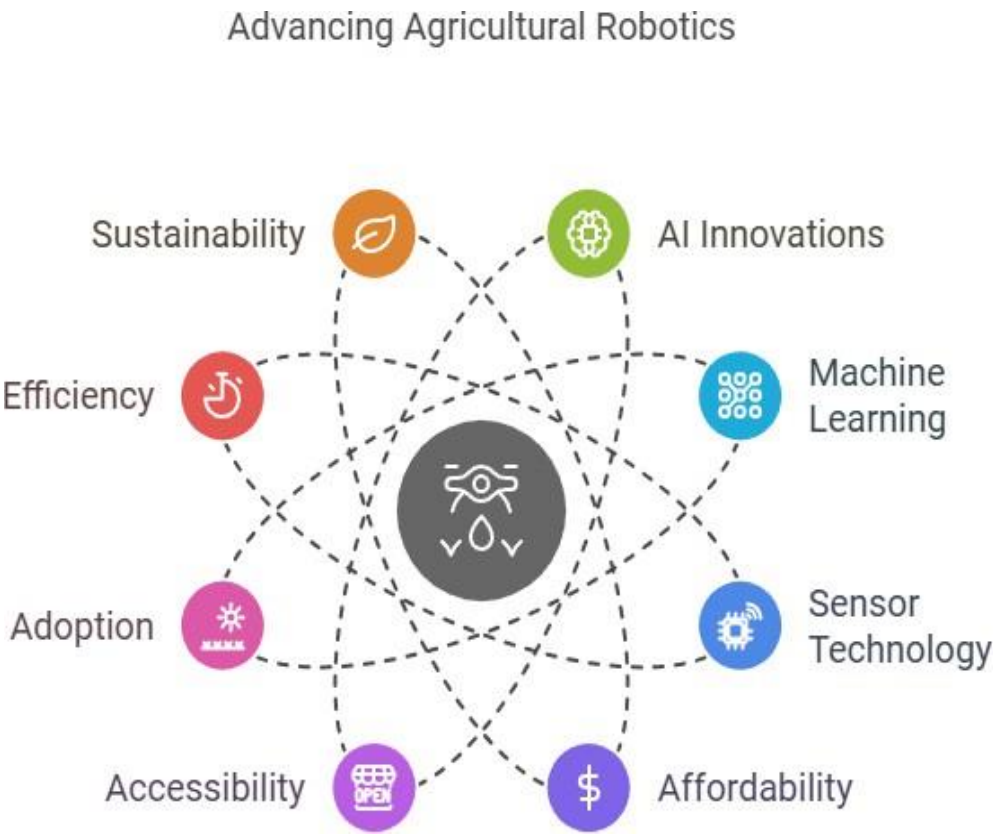


Figure 13: Advancing diagram of Agriculture Robo

Figure 14: Efficiency of Agriculture Robot

Swarm Robotics in Agriculture It involves numerous small robots working together for planting or weeding. Swarm robotics has the potential to improve task decentralization and scalability in big farms (hen H. et al. 2023).

AI and Machine Learning Interface Using environmental features, an AI-based robot could rec- ognize crop disease types and schedule planting dates (Park, S. et al. 2024).

Robotic Technologies for Vertical Farm In high-revolution controlled environments like vertical farms, robots are introduced to perform planting, maintenance, and harvesting (Kumar A. et al., 2023).

Obstacles and Future Directions

Cost and Availability; It requires a high investment at the start and is not affordable by most small-scale farmers (Green, J., et al. 2024).

Environmental Consequence Developing energy-efficient robots is the way forward to minimize environmental footprints (Smith, R., et al. 2023)

Robots in Transportation

Applications and Advancements Robotics has revolutionized the transportation system with improved safety, efficiency, and operational effectiveness. From autonomous vehicles to delivery drones, robots are changing how goods and people move. Also, Figures 15 and 16 describe robots in transportation, with AI in transportation

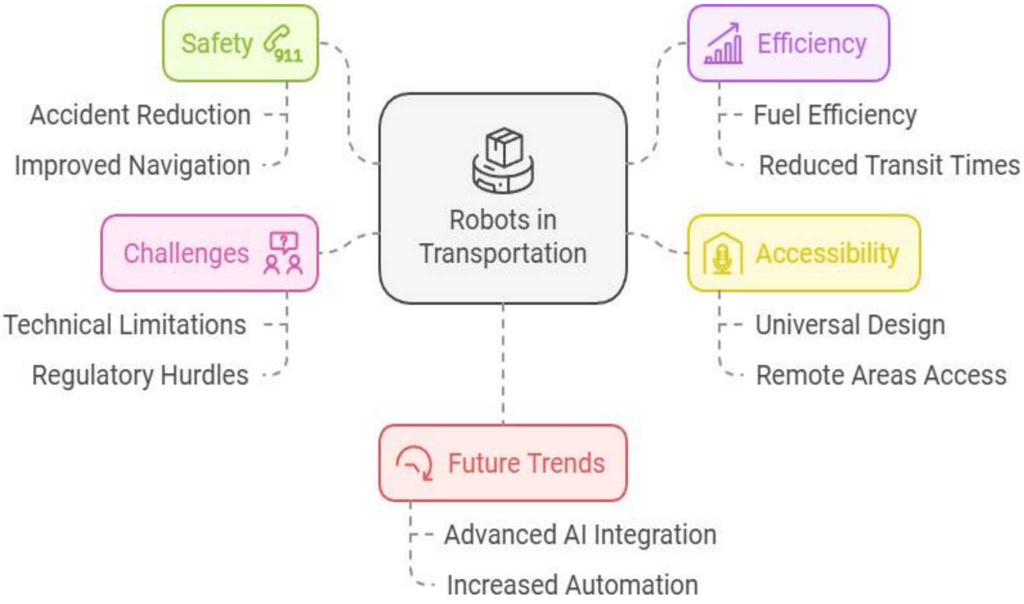


Figure 15: Robot in Transportation

Figure 16: Robot with AI in Transportation

Autonomous Vehicles

The robot is the core component of all autonomous vehicles. Using sensors and AI technology, it is accompanied by control mechanisms for navigating an environment. Such systems often include different types of sensors, such as LiDAR, cameras, and radar, allowing vehicles to make real-time decisions and navigate these terrains (Wang, H. et al. 2024).

Delivery Robots and Drones

Delivery robots and drones are being used for last-mile deliveries in urban areas. These delivery robots and drones help to improve efficiency and reduce costs. They are built to ensure speed and navigation in crowded urban places. Also, figure 17 describes the role of drones Delivery robots.

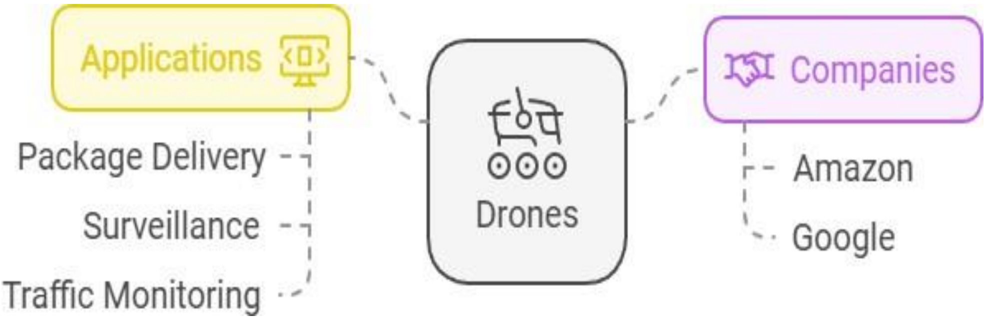


Figure 17: Drones Services

Warehouse and Logistics Automation

All warehouse robots are meant to transport goods from picking to packing and delivering goods, making the supply chain simple.

Public Transport Assistant

The robots can aid the public in finding their way into public transportation systems by providing nec- essary information or ticketing. (Chen, Y., et al. 2023).

Autonomous Mazarine and Aerial Systems

Uncrewed aerial vehicles (UAVs) and autonomous ships have changed cargo and logistics services. Advanced navigation systems are used on autonomous ships, as they reduce emissions and shipping costs (Tan, K. et al. 2024).

Research and Innovations of the Present Age

Artificial Intelligence in Autonomous Systems is enhancing the decision-making capabilities of autonomous transportation robots (Li, X. et al., 2023).

Electric and Sustainable Robots Development of energy-efficient robots powered by renewable energy to reduce the environmental footprint (Green, R., et al. 2024). Human-Robot Collaboration in Transportation Increased integration of co-bots into transport systems will enhance operational safety and efficiency shortly.(Jones, M., et al. 2023).

Robotic Systems for Traffic Management The robots and AI systems in these traffic monitoring systems will be able to monitor traffic flowing through the roads, predict congestion, and optimize traffic signals (Singh, P. et al. 2024).

Challenges and Future Directions

The Regulatory and Safety Aspects Compliance with regulation and furtherance of its safety issues in autonomous transport (Patel, S., et al.2023).

Infrastructure Development There is a need for infrastructure to support robotic transportation, including smart roads and dedicated lanes (Zhao, L. et al. 2024).

Social and Ethical Implications Job losses and the public acceptance of robots within transportation systems (Harris, E. et al. 2023).

Robots in Education

Transforming Learning Environments Recent advances in robotics education are revolutionizing the ways of learning by creating an entirely interactive and personalized experience beyond the reach of an individual. Classroom assistants and educational tools for STEM contended that robots would meet the learning needs entirely. Also, figure 18 describes Robots in education, and Figure 19 describes their subject-wise role in education.

Teaching Assistants

Educational Applications of Robots Teaching: Having a robot inside the classroom is helpful for the teacher in managing their class, giving lectures, and interacting with the students. For example, teaching assistance through an interactive lesson using robots such as NAO or Pepper has improved student engagement. Robots are used as teaching aids in classroom management, lectures, or student interactions. For example, robots like the NAO or Pepper improve the quality of student engagement during lectures in interactive lessons (Mubin, O., et al., 2023).

STEM Education

Programming through robotics and engineered robotics is widely learned, but there is a lack of interest in STEM disciplines. Thus, robotic learning involving students applies theoretical concepts to real-life situations and increases critical thinking ability in students (Kim, H. et al. 2024).

Special Education Such robots would help children who have autism spectrum disorder (ASD) and other kinds of learning disabilities by offering differentiated assistance and interactions with other children. They will be provided with some social interaction robots, and spending a small quantity of time with those robots will significantly enhance interaction skills in children with ASD (Huijnen, C. A., et al. 2023).

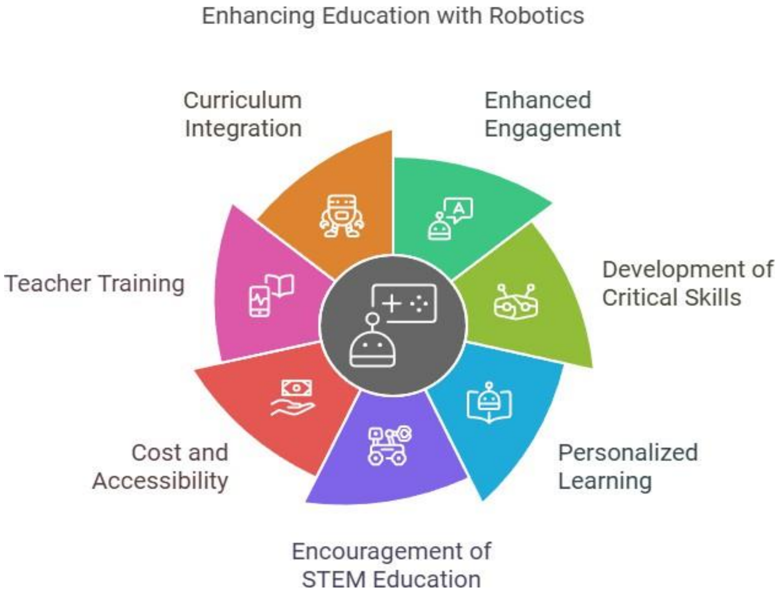


Figure 18: Robot in Education

Language Learning

It can teach new people new languages via conversations and various interactive exercises and uses typical NLP robots. Motivation and fluency during the informative process are increased with changes in language experience: robots encourage the experience with dynamic, fun, and exciting interactions (Zhang, Y. et al., 2023).

Remote and Virtual Learning

Telepresence robots allow students and teachers to connect with other students and participants from the attending classroom in a class in real time. The cross will close the gap between students, and teachers who have less access to some forms of education might be able to see a part of it (Brown, L. et al. 2024)

Latest Trends in Educational Robotics

Adaptive Learning through AI: AI-integrated robots offer individualized learning while assessing the performance of a particular student and adapting the content to that student's learning style (Kanda T. et al. (2023).

Collaborate Learning Environments: Robots create situations for working as teams, helping stu- dents develop teamwork and collaboration skills (Li, J. et al. 2024).

Cultural Awareness and Global Education: Teach cultural awareness and diversity to prepare stu- dents for a globalized world (Yamazaki, R. et al., 2023).

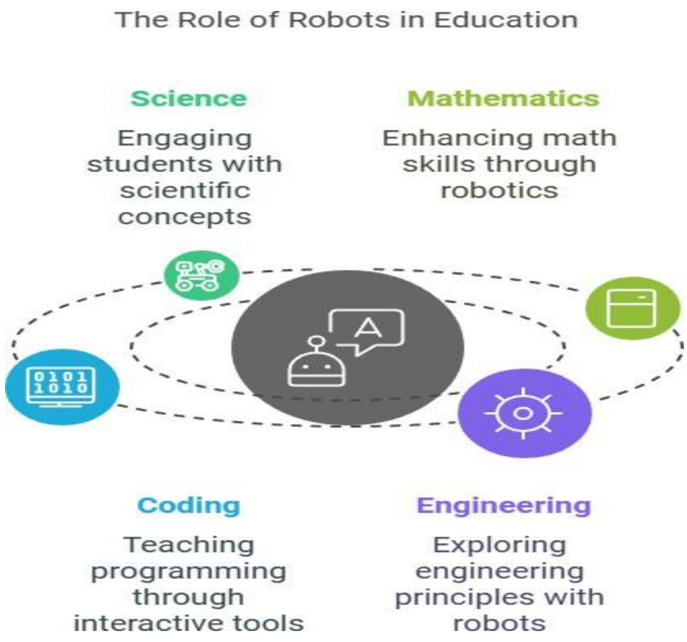


Figure 19: The Role of Robots in Eduction

Ethical Issues Regarding Robots

Robots in many sectors need attention to the ethical issues arising from the expanding capacity of health- care, military, education, and transportation. Accountability, data privacy, social impacts, and human rights are all topics of concern. Figure 20 also describes ethical issues in robotics and AI.

Accountability and Responsibility

The extent to which robots make decisions autonomously raises several issues regarding accountability regarding harm or failure. There is no legal framework for addressing the liability of robot actions. This poses numerous challenges and hurdles, especially in autonomous vehicles and surgical robots (Johnson D. et al., 2023)

Data Privacy and Security

Most importantly, robots, particularly those with artificial intelligence, rely heavily on the sheer volume of user data collected. This raises ethical concerns about privacy and misuse of information. Data privacy is usually compromised in educational and healthcare robots, which pose quite sensitive data and require a strict security arrangement (Li, S. et al. 2024).

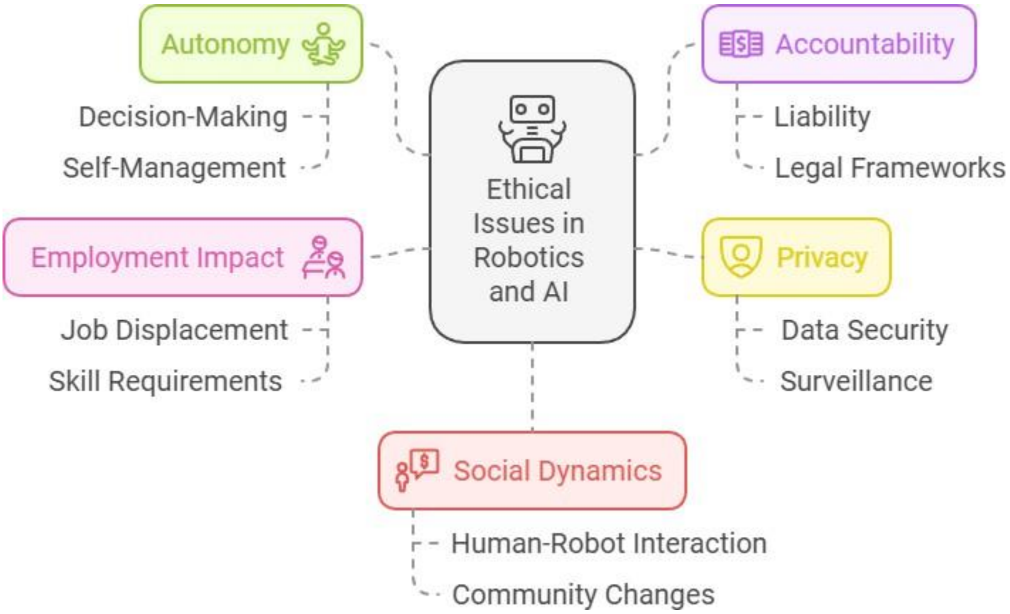


Figure 20: Robot in Ethical Issues

Job Displacement and Economic Inequality

Through automation with robotics, people can be thrown out of work, leading to economic inequality and disruption of industries. Though they may enhance productivity, the robots always end up disaffecting low-skilled jobs, causing income disparities (Acemoglu D. et al., 2023).

Bias and Discrimination in AI

Biased robot-trained data sets may produce or even exacerbate discrimination. All work toward reducing bias will be essential for any practical robot application used in hiring or policing to ensure fairness (Raji, I. et al. 2023).

Human Rights Concerns in Military Robotics

The ethics of the use of robots in war are above lethal autonomy and protections for civilian lives. Autonomous weapons systems also interfere with the principles of accountability and proportionality of international humanitarian law (Sharkey, N.2023).

Human-Robot Relationships

As they become more humanlike, robots pose new ethical challenges regarding the connection between humans and robots and the relationships forged between people. Increased reliance on companion robots may result in social isolation, especially for particularly vulnerable groups (reazeal, C. et al. 2024).

New Ethical Frameworks

Transparency and Explainability

One of the most important ethical criteria for deploying robots is that their decision-making processes should be transparent toward users (Chen X. et al., 2023). These issues, including biases and ethical dilemmas, can be addressed by AI transparency, which means open public access to details about AI systems' designs, data, and operations. On the other hand, explainability makes the AI decisions under- standable at all levels of technical knowledge by the users.

Regulatory and Legal Issues

It remains a priority for lawmaking legislators to have laws that touch robot accountability and the ethical use of robots (Green, R. et al. 2024). Legal frameworks available now may not be enough to tackle the challenges of rapid developments in artificial intelligence and robotics. Clear regulations will govern data privacy, security, and liability issues.

Ethical Design Principles

Framing ethical principles during the development phase of robots is a possible way to prevent them from being misused (Florida L. et al., 2023). Formulating and deploying an AI system should not rely on addiction to the system itself or its services. 5. AI Applications should allow system operators and end-users to control, direct, and intervene in system operations.

Challenges and Future Directions

Global Standards

Establishing ethical standards common for robotics across different cultures and legal systems due to diverse interpretations (Smith, J. et al. 2024). ISO first posted the industrial robotic robotics safety Standard ISO 10218:1992, Manipulating Industrial Robots-safety. Over the years, the coverage of this standard has been further broadened to include part publication from 2006 onward, with the most recent part being ISO 10218-1:2011 Robots and Robotic Devices-Safety Requirements for Industrial Robots.

Innovation Versus Ethics

Balancing progress in robotics technology with ethical issues being raised (Patel, V. et al. 2023). Ethics and Innovation work symbiotically with each other. Ethics involves how actions affect people; innova- tion refers to doing things differently and overcoming barriers. Therefore, fusing ethics with innovation would yield even more transformational and inclusive technological advancements. Figure 21 shows the pros and cons of advancement in robotics.

Advanced Topics in Robotics

Frontiers and Emerging Trends The field of robotics is continually changing and maturing. Robotic systems are not only advanced technologically, but they also tend to focus on quite complex challenges and expanding capabilities. Most importantly, they make use of emerging technologies from artificial intelligence (AI), machine learning (ML), and bio-inspired design in the development of humanlike robotic systems (Rus, D., Tolley, M. T. 2023).

Soft Robotics

Soft robotics concerns the manufacture of robots using flexible, deformable materials reminiscent of biological structures. Soft robots are mainly used in sensitive operations and unison with unstructured environments. Usage of soft robots is on the rise in medical surgeries, underwater exploration, and disaster response (Brambilla, M. et al. 2024).

There are some challenges to given below.

Durability of the materials and complexity of control

Integration of sensors in soft materials.

Swarm Robotics

Swarm robotics studies the coordination of multiple robots so they can perform tasks collectively, in- inspired by social insects like ants and bees. Applications include search-and-rescue missions, environmental monitoring, and agriculture. There are challenges to robust communication and coordination under dynamic ecological conditions (Kim S. et al., 2023).

Bio-Inspired Robotics

Bio-inspired robotic design systems employ biological organisms to cultivate mobility, adaptability, and efficiency. Robots would compare a cheetah for speed, an octopus for agility in the water, or a gecko to climb walls. It has to face difficulties to replicating highly complex biological mechanisms and integrating them into functional systems (Zhao Y. et al. (2024).

Human-Robot Collaboration (HRC)

Now, robots are made to fit into a workspace where they are increasingly helping boost productivity within industries such as manufacturing, healthcare, and services. Advanced sensors used in collabora- tive robots ensure safety and improve human-robot interaction. To achieve the development of intuitive interfaces as well as safety in shared Robot Learning and Adaption, Machine learning enables robots to learn independently of new environments, tasks, and user preferences. Nowadays, robots may do complex tasks like manipulation, navigation, or assembly with less human intervention (Levine, S., et al. 2023).

Autonomous Navigation and Perception

Allowing robots to navigate through very complicated and dynamic environments using advanced al- algorithms and sensors. To navigate and perceive autonomous driving entities, they can move hither and yon by themselves and understand and see objects surrounding them without external forces, human or artificial. Robots and vehicles can move without external assistance, navigate around obstacles, and alter their behavior according to various situations and conditions. Using that information, the ability to sense surrounding stimuli and build a mental image of the environment (Thrun, S. et al. 2024).

Robotic Ethics and AI Alignment

Ethics in robotic systems must be applied mainly in AI-decision making. It shows how a robot can conduct itself. Essential to AI alignment is the practice of ensuring that the goals of an AI system coincide with those of its designers and users, or perhaps those goals generally match widely agreed standards, objective ethical principles, or the aims its designers would have if they were more informed and conscious (Floridi, L. et al. 2023).

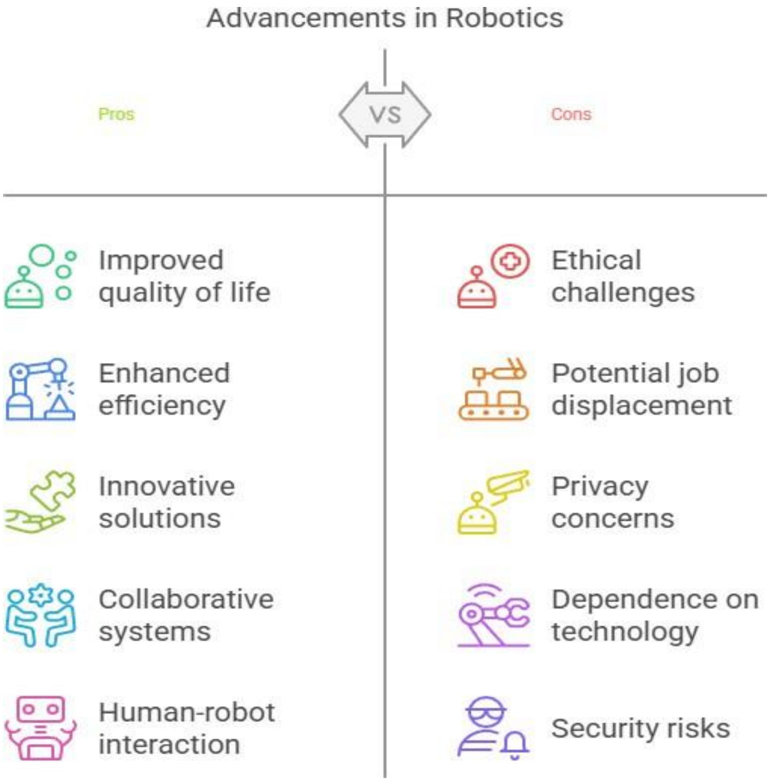


Figure 21: Advancements in Robotics Pros and Cons

Tactile and Haptic Robotics

Developing tactile sensors and haptic feedback makes robots more effective in manipulating their environment. Shaped like, but not limited to, surgery, it also applies to handling delicate objects in a high-precision climate. There are imputations to improve the sense of touch and the toughening of haptic sensors (Dahiya, R. S., et al. 2023).

Robotics in Space Exploration

Robots are essential for space exploration under extreme conditions preventing long-term isolation of humans from the planet. They include Rovers, landers, and robotic arms, which carry out explorations and resource collections. There are challenges facing to Design systems that can tolerate extreme radiation and temperature and withstand communication due to long distances (Dahiya R. S. et al., 2023).

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