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REVIEW

A Review of Mobile Robots: Applications and Future Prospect

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Abstract

Approximately eight decades ago, during World War II, the concept of intelligent robots capable of independent arm movement began to emerge as computer science and electronics merged with advancements in mechanical engineering. This marked the starting point of a thriving industry focused on research and development in mobile robotics. In recent years, there has been a growing association between robotics and artificial intelligence, aiming to enable robots to make autonomous decisions akin to human cognition. To achieve this objective, researchers are actively exploring the integration of artificial neural networks with mechatronic robots. These intelligent and self-decision-making robots possess the potential to revolutionize human capabilities and elevate our intelligence to unprecedented levels. In various physical service sectors such as cleaning, security, and other tasks that don't require creative or analytical thinking, these robots can efficiently carry out the assigned responsibilities. Moreover, robots have the potential to play a significant role in military operations, eliminating the need for human lives to be sacrificed in warfare. This review article aims to explore the advancements in mobile robotics since their inception nearly 80 years ago. It will delve into the detailed applications of these robots across different sectors and discuss their profound effects on contemporary human lives and industrial landscapes.

Keywords Machine learning (ML) · Artificial intelligence (AI) · Deep learning (DL) · Artificial neural network (ANN)

1 Introduction

In the early twentieth century, Czech author Karel Capek wrote a theatrical play called “Rossum's Universal Robots”, which introduced the term “Robot” to the real world [1]. However, it wasn't until the 1960s that robots began to exhibit autonomy and some level of intelligence with the development of computer science and electronics [2]. An intelligent robot is defined as a machine capable of operating in uncharted and unpredictable environments, often referred to as an autonomous robotic machine [3]. These robots possess the intellectual capability to navigate freely without obstacles in their operating environment. Mobile robots, equipped with artificial neural network algorithms, can perform predefined tasks, and are controlled by software. They utilize sensor technologies to perceive their surroundings and execute their assigned tasks [4]. The working process of an autonomous robot involves three major steps: perception (sense), planning and interpretation (process), and movement (action). While mobile robots perform tasks like humans, they do not necessarily have to resemble or mimic human appearance to accomplish these tasks [4]. The versatility of mobile robots lies in their ability to solve a wide range of problems, ranging from complex mathematical calculations to logical argumentative problems [5]. This review article discusses these developments and their impact on real-world applications. In 1950, Tony Sale introduced the world to the first humanoid robot named “George”. Standing at approximately six feet tall, George was capable of walking and engaging in basic conversations with humans. It was constructed using salvaged metal from a scrapped aircraft called Wellington, at a cost of only fifteen euros [6]. Another notable robot, “Shakey”, was developed and presented to the world by Charles Rosen, who led Stanford Research Institute in the 1960s [7]. Figure 1 displays an image of Shakey the robot. Notable contributors to the field of robotics include Norbert

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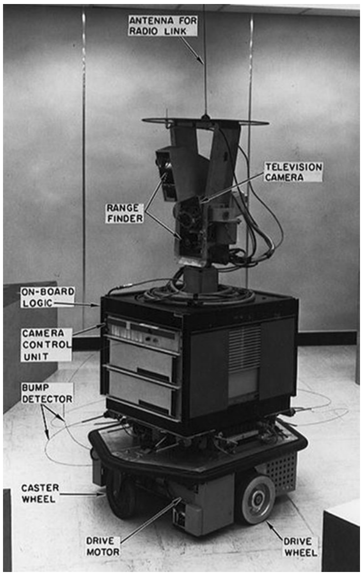


Fig. 1 ‘Shakey’ the Robot developed by Charles Rosen in late 1960s [8]

Wiener, who played a crucial role in the development of cybernetics, a science integral to the manufacturing of intelligent robots. Claude Elwood Shannon, an American engineering luminary, developed information theory and created a mechanical mouse called Shannon's Mouse. This mouse could navigate through a maze and was controlled by electromechanical relay circuits.

Modern industries are producing robotic machines that are much more advanced and these newly built robots are integration of electronics, mechanics, and artificial intelligence altogether. The most recently developed humanoid robot named ‘Ameca’ has been developed by Engineered Arts and showcased in public domain in January 2022 [9]. ‘Ameca’ is built with cameras in its eyes with face detection technology. It can fathom languages and participate in conversations with humans. The key feature of this robot is that it can imitate facial expressions of human beings can interact with humans easily. Figure 2 shows a picture of ‘Ameca’.

2 Self-governing Pilotage of Mobile Robots

Self-governing or autonomous mobile robots are provided with cameras and various kind of sensors. If a mobile robot notices an uncharted hinderance in its ambient navigation pathway, like a crew of people or pole, or a fallen tree, robot utilizes a skill of navigation like debar the collision with an obstacle by stopping, slowing down or deviate its path around the hindering object and resume with the already defined objective [11, 12]. Integrating Artificial Intelligence with mobile robotics can make mobile robots much more advanced and efficient in all sorts of applications. A crucial

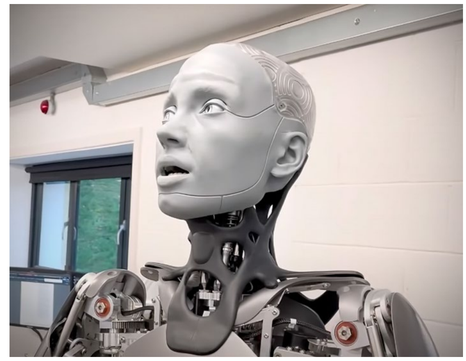


Fig. 2 ‘Ameca’ the humanoid robot developed by Engineered Arts in 2022 [10]

role is played by computer vision and image processing in the navigation of mobile robots. There are different visual techniques that are considered likeable in computer vision. Among all different visual techniques, most desirable one is being able to determine the range of obstacles in the predefined ambience [13]. If the robot is expected to perform the predefined task with greater accuracy, a path planning with no expected collisions is necessarily to be done before assigning a task to the robot [14]. The primarily important task for researchers when investigated real life implementation of robots is the map-reading of robots. Figure 3 depicts the system of control of mobile robots. The complete system is sectioned in to three major portions. First is reasoning, second is process and the third one is context. The reasoning section is responsible for decision making of robots. The section of process is responsible for motion control of robots by making use of various sensors. In the end, context section of control system is to represent the state and motive commands are engineered to prolong the context of the motion.

Recently, researchers and engineers have been putting their brains in control strategies on the based upon artificial intelligence like fuzzy logic-based control systems, sliding mode control systems, ANN based control systems, etc. for the map-reading of mobile robots. In the area of mobile robots, one major employment of artificial

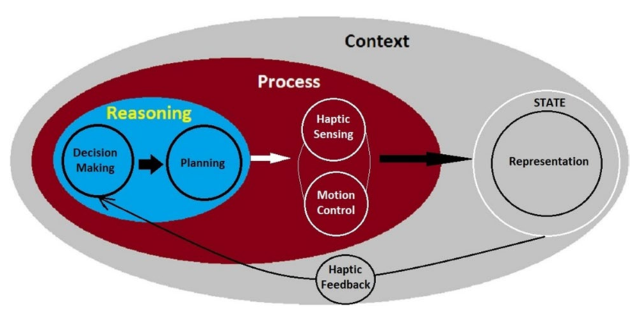


Fig. 3 Loop diagram of mobile robot control system

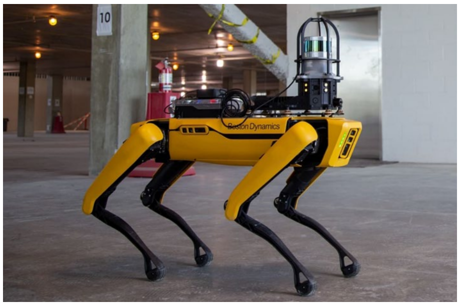


Fig. 4 "Spot Dog" a modern day mobile robot developed by Boston dynamics [16]

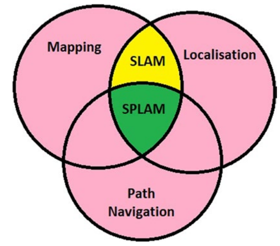
intelligence is to fabricate a cut-above control system for the self-governing map-reading of mobile robots. The basic and primarily important problem with mobile robots is their navigation. This problem can be solved using artificial intelligence techniques. Artificial neural network plays a significant role in improving the navigation of mobile robots due to its deep reinforced learning technique. It is because of its great learning through experience abilities. It can be utilized for navigation in indoor spaces, navigation in social circles, avoidance of local hinderances etc. The mobile robot can be commanded to navigate with the help of a robotic operating system which is directed by a complex neural network [15]. The best real-world example of a mobile robot in modern times is called "Spot Dog" developed by Boston dynamics in association with MIT, shown in Fig. 4.

The primarily crucial requisite for any intelligent ambulant robotic system is self-governing navigation. A mobile robot is supposed to perform planning, localisation, and mapping simultaneously (SPLAM) to navigate freely in an ambience. If any one-off above-mentioned activities is failed to perform by the robot, then a robot will not be able to ambulate through real-world deployments. Figure 5 shows the complete process of self-governing navigation of a mobile robot and explains all the gradations functions used by a robot to perform its predefined task without any hinderance. A mobile robot is expected to perform its defined task with higher rate of accuracy if it follows all the mentioned gradations.

2.1 Mapping

The process of drawing a blueprint of the map of predetermined ambience for the motion of robots so that robots can perform their predefined tasks with greater accuracy is called Mapping [17]. Mapping is the process that enables robots to be informed of the variations in the already calculated ambience through the navigation meantime.

Fig. 5 Venn diagram of activities of a mobile robot for most efficient performance



2.2 Localisation

The process of determining or finding the exact location of the robot in the environment is called localisation [18]. It is pivotal to know the exact location of the robots from where it can proceed its task. There are many methods that have been defined to achieve the process of localisation. One of the modern days easiest one is employment of "global positioning system" sensors.

2.3 SLAM

Slam stands for simultaneous localisation and mapping. Localisation and mapping have a directly proportional relationship with each other. If any one of these activities encounters an error, other will naturally show errors. Hence, both activities should be predicted in concomitance. Using SLAM technique, both activities are seen together [19]. SLAM provides the addressing of localisation and mapping at the same time.

2.4 Path Planning

A self-governing robot has requisite of algorithms that give calculative planning of the pathway for a decided map [20]. It is also supposed to have a capability to convey sensitive avoidance to hinderances that come across the process of achieving the defined mission. Calculative planning of path is global route planning and sensitive planning of path is called local planning [21]. The path planning map is usually developed online and is updated perpetually with the help of SLAM algorithm. Sampling-based methods and state-space search is efficient basis of path planning algorithms [22]. The vehicular kinematics of mobile robots is taken into consideration during the earlier stages of planning of pathway, so the execution of pre-planned path becomes easier for robotic systems. A path that is free from hinderances is preferred during the designing stages, so collisions can be easily avoided during performing the task [23].

2.5 SPLAM

SPLAM stands for simultaneous planning, localisation and mapping. It is an integrated approach of all three activities in

Table 1 A list of sensors used in robotics

S. no	Sensor type	Description
1	Temperature sensors	It is used to sense the temperature. Usually in tropical conditions. TMP 37 & LM34 are two examples
2	Navigation sensors	It is also known as position sensor. This type of sensor is primarily used to determine the exact location of the robot. Example: GPS, Compass etc
3	Current sensors	It is utilised to maintain the amount of current flow inside the robot
4	Acceleration sensors	It is used to measure and maintain acceleration and tilt. It works on the principle of static and dynamic forces
5	Sound sensors	It is used to recognize a sound and convert it into an electrical signal. Microphone is an example
6	Pressure sensors	It is primarily used for pressure quantifications. Tactile sensor is an example
7	Contact sensors	These sensors require physical contact of robot to work. It is widely used in avoidance of obstacles
8	Tilt sensors	An object's degree of tilt is measured and maintained using these sensors
9	Gyroscope	Angular orientation is measures and maintained using gyroscope
10	Light sensors	Photoresistors and Photovoltaic cells are used to identify the light in the ambience and convert it into electric signals
11	Distance sensors	It is also called range sensor. It is used to measure the distance. Ultrasonic and Infrared sensors are examples
12	Voltage sensors	It is used to sense the voltage levels inside the robotic machinery
13	Proximity sensors	It is used to detect an object in the predefined route without being in physical contact with the object

robotics. To achieve higher accuracy in navigation and map-reading of autonomous robotic systems, SPLAM is considered the best technique amongst all mentioned [24]. Sensors are considered one of the most crucial elements in mobile robotics. Table 1 demonstrates diverse types of sensors with their applications in robotic engineering and science.

3 Applications of Mobile Robots

Mobile robots are utilized in different areas in the world like personal servile, army superintendence and security, exploration of oceans and outer space, medical industry, warehouse distributions etc. Self-governing in Telligent robots are also used in manufacturing industries in a supremely controlled environment. Nonetheless, intellectual robotic systems cannot be programmed to perform the predefined task every time because the ambient conditions are not always favourable everywhere [25]. Table 2 describes the various applications of intellectual mobile robotic systems or self-governing mobile robots in various industries and real world and Table 3 explains various Effects on Mobile Robots with description.

Table 2 Various applications of mobile robots

Application	Brief description
Manufacturing	Material handling, assembly line operations, quality control, machine tending
Logistics and warehousing	Inventory management, order picking, sorting, item transportation
Healthcare	Medication delivery, medical supply transportation, patient care assistance, disinfection
Agriculture	Crop monitoring, planting, weeding, irrigation, harvesting
Exploration and space missions	Planetary exploration, sample collection, scientific data gathering in space environments
Security and surveillance	Security patrolling, surveillance, monitoring in various environments
Home assistance	Vacuuming, floor cleaning, lawn mowing, home monitoring
Hospitality and service industries	Room service, concierge assistance, guest information
Education and research	Teaching programming, robotics concepts, interactive learning experiences
Entertainment and events	Providing interactive experiences, performances, and information in entertainment venues

Table 3 Various effects on mobile robots with description

Effects	Description
Increased efficiency and productivity	Mobile robots enhance efficiency and productivity in industries such as manufacturing, logistics, and healthcare by performing tasks faster and with greater accuracy
Improved safety and risk reduction	Mobile robots can work in hazardous or dangerous environments, reducing the risk of human injuries. They contribute to safer operations in industries like manufacturing, construction, and mining
Job displacement and workforce changes	The adoption of mobile robots in certain tasks may lead to job displacement and changes in the workforce. Certain industries, such as manufacturing and logistics, may require retraining and reskilling of employees for new roles
Enhanced accuracy and quality control	Mobile robots offer high precision and consistency in tasks, reducing errors and variability. They improve quality control in manufacturing, inspection, and testing processes
Socioeconomic impact and inclusion	The widespread adoption of mobile robots may impact socioeconomic dynamics, including job market shifts and income distribution. Ensuring inclusive growth and addressing potential inequalities become crucial considerations
Ethical considerations and accountability	Mobile robots with autonomous capabilities raise ethical questions regarding accountability, transparency, and decision-making. Ensuring responsible use, establishing ethical guidelines, and addressing potential biases are important considerations

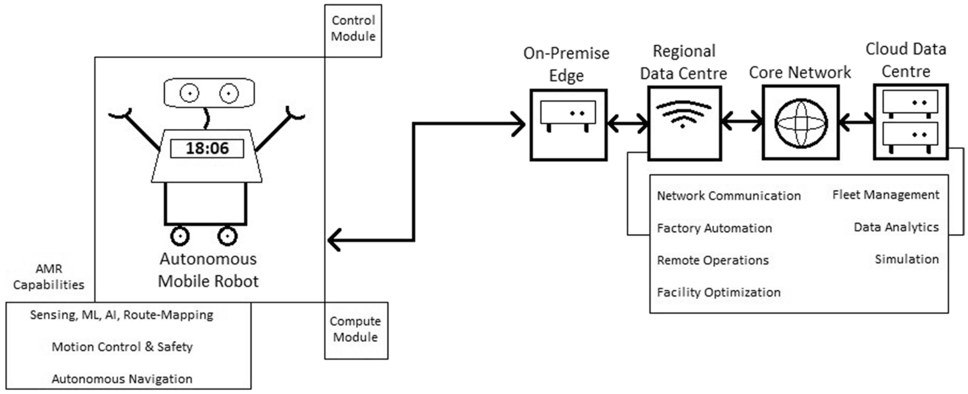


Fig. 6 Block representation of components and architecture of contemporary intelligent robotic systems

4 Architectonics and Constituents of a Modern Self-governing Mobile Robot

The thesis of self-governance of mobile robots is a path to IoT vision, satisfying improved amalgamation of intellectually sound systems and mitigating the intercedence of human beings in the process. Usually microprocessors, PCs and embedded processors are used as controllers [26]. Actuators are low voltage servo motors that are utilized for the movement of arm joints, legs, and wheels of the robot. To avoid the hinderances in the predefined ambient pathway, sensors are used to sense the ambience before occurrence of any hazardous situation [27]. Figure 6 shows through architecture and every component of modern day intellectually sound mobile robotic systems. Intelligent robotic systems work on their functionalities accordingly by taking utilization of their architecture. Overall, three continuous functions are performed by systems: perception of ambient property and nature, which means identification of dynamic state; taking actions to influence dynamic states in the preconceived environment; and issuing the cerebration to determine perceptions, solve problems, and look for suitable actions for the decided environment [28].

5 Mechanism of Movable Robotic Systems

Usually, a mobile robotic system uses wheels for movement on floor. An advanced artificial intelligence based movable robotic system is capable to recognize objects and voices, which could be applied for looking for an object specified by voice of the user. Recognition of voices and objects and motion control can be achieved by intelligent mobile robots [29]. Mobile robots can be classified into diverse types based on types of movement or locomotion. They can be wheeled, ball balancing or stepping robots [30]. Most frequently employed robots are wheeled robotic systems. Omnidirectional wheeled robots can compute internal condition of the ambience by using proprioceptive sensors and external conditions of the ambience can be determined using exteroceptive sensors [31]. Images taken by camera, voices recorded by microphone, directions through compasses etc. fall under exteroceptive speculations. Tracking of reference trajectory can be used for hinderance free movement and handling of a wheeled robot. Nevertheless, an ambience with hinderances can become inefficient for this type of motion control [32]. For computation of integral posture by using an accelerometer, gyroscope and a magnetometer, an inertial measurement unit is installed, and LiDAR is utilized for avoidance of hinderances and real-time navigation. Board of STM32 embedded system is a piece of control module that mat use Proportional Integral Derivative (PID) to control the gyration of motor using motor driver perceive error-free movement of the rotor and it also uses an industry level computer to maintain functioning of motor by the help of embedded system and a motor for wayfinding of the robotic system. Power sources like a battery are used by power module of a mobile robot for energy supplies [33]. Figure 7 illustrates the block representation of structure of hardware for wayfinding of wheeled movable robots.

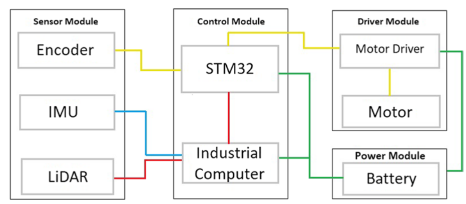


Fig. 7 Structure of hardware for wayfinding of wheeled movable robots

6 Perceptive Control System of Movable Robots

A perceptive and cognitive control system is a requisite to make an efficient strategy for communal action between robotic systems. An intelligent and cognitive control system is an arithmetically precise method of administering a convoluted system along with scant and partial portrayal of how to carry it in an uncharted ambience towards a predetermined task. Perceptive control, importantly, amalgamates planning with online reimbursement of error, which has a requisite of learning both the ambience and the system to become a section of process of control. Most importantly, perceptive control usually uses centralized attention, conception, and combinatorial analysis as the basic operators, which approaches to be a multiscale framework [34]. Algorithms like A*, RRT (Rapid Random Trees), path planning and probabilistic algorithm of localisation are utilized by self-driving cars, unmanned vehicle of areal arena to wander free from any collisions from origin to their defined destination. Selection of a relevant algorithm for planning of path of mobile self-governing robotic machines assists to confirm the safe and effective wayfinding. Selection of most efficient algorithm is dependent on geometry of and computational constraints of the robotic system [35].

- *The A* Algorithm* The A* algorithm is a computationally elementary algorithm in comparison with its counterparts of planning of path. This algorithm is very much satisfactory for employment in automobiles because it can be moulded with size, kinematics, and steering angles of the vehicle accordingly. It is a renowned marching algorithm for planning of path. It uses the cheapest path and shows it using the below mentioned function in Eq. 1 [35],

$$f(n) = g(n) + h(n) \tag{1}$$

  where the cost of most efficient path from the node target '**n**' is **h(n)** and **g(n)** is the actual cost from node '**n**' to primary node.
- *Probabilistic Algorithm* Collective localization and planning of motion are used for planning of path of robotic systems that are of multiple functionalities. One prominent algorithm that has been created for localization is called probabilistic algorithm for robotic localization. In this algorithm, the movable robot is required to speculate the dispensation as posterior over the zone over its postures tagged on the available set of data. If the postures of robot at time '**t**' is designated by '$\mathbf{S_t}$' map of the ambience is designated by '**m**' and '$\mathbf{d_{0\ldots\ldots t}}$' is a variable that denotes the enhancing of data until time '**t**' then writable equation for position '**(p)**' of the robot becomes as mentioned below [36].

$$p\left(\frac{St}{d0}\ldots t,\ m\right)$$

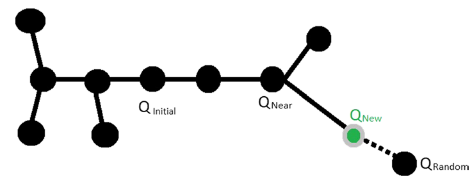


Fig. 8 RRT algorithm representation

  where $d_0\ldots\ \ldots_t = O_0,\ a_0,\ O_1,\ a_1,\ \ldots\ \ldots\ \ldots\ a_{t-1},\ O_t$. The representation of observation is done by '$\mathbf{O_t}$' and '$\mathbf{a_t}$' is a representation of action taken by movable robot at time '**t**.'
- *The RRT Algorithm* A tree is developed by this algorithm by creation of arbitrary nodes in unoccupied area. It begins at commencing node and terminates at targeted node. The tree expands at every repetition by generating a new arbitrary node. This one is a stochastic plan of action. The accuracy of this algorithm is highest for wayfinding of movable robots among all the above-mentioned algorithms [37]. Avoidance of hinderances in predefined path is an USP of this algorithm. Figure 8 shows the RRT algorithm for planning of path of movable robotic systems.

In figure above, $Q_{Initial}$, Q_{Near}, Q_{New}, and Q_{Random} are initial node, nearest node, new node, and random node, respectively.

7 Influence of Artificial Intelligence and Movable Robots

After the introduction of artificial intelligence into the science and engineering of robotics, human lives have been heavily affected in recent decades. Furthermore, the day to day domestic and industrial tasks of humans have been performed by robotic systems which is resulting in mitigation of errors made by humans and human energy is also saved in this process. Contemporary intelligent robotic systems are simple, primarily related to where to move or how to move but these systems have much more convolutions that they seem to have, this led engineers to associate artificial intelligence with robotics to develop intellectually sound robotic machines [38]. Currently in our lives, we are using self-governing robots in the form of vacuum cleaners, surgical tools, driving assistant etc. Figure 9 shows the usage of robotics in various areas in present times.

- *Effects on Workplace* The primary motive for employment of intelligent robotic machines at workplaces is

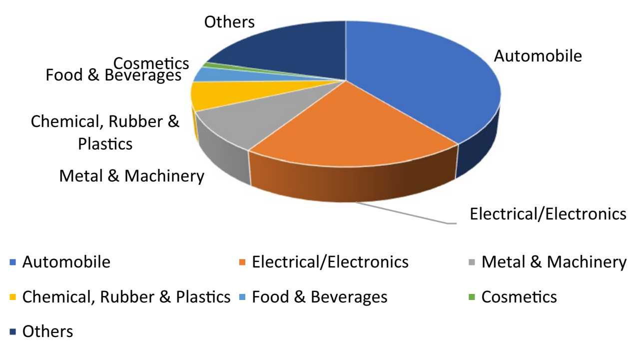


Fig. 9 Usage percentage of robotics in various industries

to diminish cost of labour, improve efficacy, enhance production etc. [39] Obviously, there can some drawbacks of employment of intelligent robots like elimination of jobs that can result in high rates of unemployment, but the optimistic side of this scenario is that we as humans can focus on more intelligent stuff that robots cannot.

- *Effect on Industries* The introduction of intelligent mobile robots can become a crucial factor in growth of productivity and can positively modify the world supply chains [40]. These robotic machines have an outstanding accuracy level of even hundred percent, while humans can result in errors. Hence, usage of these machines enhances satisfaction of customers and results in improvement of businesses.
- *Effects on Human Lives* In present times, we are using many electronic appliances that are based on artificial intelligence technology like smart phones, Amazon Alexa Assistant, Apple Siri, smart TVs, automatic washing machines, robotic vacuum cleaners etc. The amalgamation of artificial intelligence with robotic mechanics gives and improved way to engineers, scientists, medical professionals to perform their jobs with greater efficacy [41].

7.1 Case Studies of Mobile Robots in Action to Help Readers Better Understand Their Applications and Effects on Contemporary Human Lives and Industrial Scenarios:

7.1.1 Case Study: TUG Autonomous Mobile Robot in Hospitals [42]

One notable example of mobile robots in healthcare is the TUG Autonomous Mobile Robot developed by Aethon. The TUG robot is designed to assist healthcare professionals in hospitals and other medical facilities.

Description The TUG robot is a compact, self-driving robot that navigates hospital corridors and autonomously performs various tasks. It can carry and transport a range of items, including medications, laboratory samples, medical supplies, and linens. The robot is equipped with sensors, cameras, and mapping technology that allow it to safely navigate through busy hospital environments, avoiding obstacles and people.

Implementation The TUG robot has been deployed in several hospitals and healthcare facilities worldwide. It has been utilized for various tasks, such as:

1. Medication Delivery: The TUG robot is programmed to transport medications from the hospital pharmacy to patient care areas. It securely transports medication carts, reducing the time and effort required by nurses and other staff to retrieve medications manually. This enables healthcare professionals to spend more time on patient care activities.
2. Laboratory Sample Transport: The robot can transport laboratory samples from patient floors to the laboratory, ensuring quick and reliable delivery. It follows predetermined routes, avoiding congested areas and maintaining sample integrity. This improves the efficiency of lab operations and reduces the chances of errors or delays.
3. Supply Distribution: The TUG robot can carry medical supplies, equipment, and linens to different hospital departments. By automating supply distribution, it frees up staff time, reduces manual labor, and ensures that supplies are available where and when needed.

Benefits and Impact The implementation of the TUG robot in healthcare settings has brought several benefits and positive impacts:

1. Improved Efficiency: The TUG robot significantly reduces the time and effort required for manual transportation tasks, allowing healthcare professionals to focus more on direct patient care. It streamlines workflows and reduces the risk of human errors associated with manual handling.
2. Enhanced Safety: By autonomously navigating hospital corridors, the TUG robot avoids collisions with people and objects, minimizing the risk of accidents. This contributes to a safer environment for both patients and staff.
3. Cost Savings: Automating tasks traditionally performed by human workers using the TUG robot can lead to cost savings in labor and operational expenses. The robot operates continuously and can work 24/7, contributing to increased operational efficiency.
4. Workflow Optimization: The use of mobile robots like the TUG allows for better coordination and optimization of healthcare workflows. The robot can be integrated into existing systems, such as electronic medical record

(EMR) systems or pharmacy systems, to enhance the overall efficiency and accuracy of operations.
5. Staff Satisfaction: By offloading time-consuming and repetitive tasks, the TUG robot can help reduce staff burnout and improve job satisfaction. Healthcare professionals can focus on more critical and rewarding aspects of patient care, leading to improved work-life balance.

The implementation of the TUG Autonomous Mobile Robot in hospitals demonstrates how mobile robots can streamline healthcare operations, improve efficiency, and enhance patient care. These robots provide valuable support to healthcare professionals, allowing them to focus on their core responsibilities and deliver high-quality care to patients.

Here's a case study for *Mobile Robots in Environmental Monitoring and Exploration*.

7.1.2 Case Study: REMUS (Remote Environmental Monitoring UnitS) Underwater Robot [43]

Description REMUS (Remote Environmental Monitoring UnitS) is an autonomous underwater robot developed by the Woods Hole Oceanographic Institution (WHOI) in the United States. REMUS is designed for environmental monitoring and exploration of the ocean floor and has been used in various research and exploration missions.

Implementation REMUS is equipped with a suite of sensors, cameras, and scientific instruments, allowing it to collect valuable data on marine ecosystems, geology, and oceanographic phenomena. Some of the key features and applications of REMUS include:

1. Ocean Floor Mapping: REMUS can create high-resolution maps of the ocean floor, providing researchers with detailed information about the seafloor topography, geological features, and habitats.
2. Environmental Sampling: The robot can collect water samples and other environmental data, including temperature, salinity, and dissolved oxygen levels. These measurements are critical for studying oceanographic processes and understanding the health of marine ecosystems.
3. Marine Biology Research: REMUS can be used to study marine life and their habitats. It has been employed in studies of marine species distribution, behaviour, and migration patterns.
4. Pipeline and Cable Inspection: In addition to scientific research, REMUS has been utilized for practical applications such as inspecting underwater pipelines and cables. Its ability to autonomously navigate and capture data makes it valuable for infrastructure monitoring and maintenance.

Table 4 Current areas of agreement, controversies, and debates, gaps in current knowledge, and unanswered questions related to mobile robotics

Aspect	Description
Areas of agreement [44]	(1) Mobile robots have significant potential in various domains, including manufacturing, healthcare, and logistics (2) Mobile robots can enhance efficiency, productivity, and safety in industrial settings (3) Collaboration between humans and robots can lead to synergistic outcomes
Controversies and debates [45]	(1) Job displacement: There is ongoing debate about the impact of mobile robots on employment and the future of work (2) Ethical considerations: Discussions focus on issues such as robot rights, privacy, transparency, and the accountability of autonomous systems (3) Human–robot interaction: Controversies exist regarding the design of intuitive interfaces, social acceptance, and trust in mobile robots
Gaps in current knowledge [46]	(1) Human–robot collaboration: Further research is needed to understand how to effectively integrate mobile robots into human work environments (2) Ethical and legal frameworks: There is a need to develop comprehensive frameworks to address the ethical, legal, and social implications of mobile robotics (3) Long-term societal impact: more research is required to assess the long-term socioeconomic impact of widespread mobile robot adoption on employment, income distribution, and human well-being
Unanswered questions [47]	(1) Interdisciplinary collaboration: How can diverse fields like robotics, ethics, sociology, and economics work together to address the challenges of mobile robotics? (2) Explainability and transparency: How can mobile robots provide understandable explanations for their actions and decisions to improve human trust and acceptance? (3) Human-centred design: How can mobile robots be designed to better understand and adapt to human preferences, emotions, and social cues?

Current Areas of Agreement, Controversies, and Debates, Gaps in Current Knowledge, and Unanswered Questions Related to Mobile Robotics can be seen from Table 4.

Here are some concrete suggestions for *future research directions* in mobile robotics:

1. *Multi-sensor Fusion* Investigate advanced techniques for fusing data from multiple sensors (such as cameras, lidar, and inertial sensors) to improve perception, localization, and mapping capabilities of mobile robots [48, 49].

2. *Efficient Path Planning* Develop algorithms for efficient and optimal path planning in complex and dynamic environments, considering factors like obstacle avoidance, energy efficiency, and real-time adaptability [50, 51].
3. *Long-Term Autonomy* Explore strategies for enabling mobile robots to operate autonomously for extended periods by addressing challenges such as energy management, self-recharging, and robust decision-making in unpredictable environments [52].
4. *Human–Robot Interaction* Study methods to enhance the interaction between humans and mobile robots, including natural language understanding, gesture recognition, and intuitive interfaces, to improve collaboration and usability [53].
5. *Soft Robotics and Manipulation* Investigate soft robotic systems and flexible manipulation techniques that enable mobile robots to handle delicate objects, navigate complex terrains, and interact with unstructured environments more effectively [54].
6. *Swarm Robotics* Explore the coordination and cooperation of multiple mobile robots within a swarm, studying algorithms for decentralized decision-making, task allocation, and robust communication protocols for achieving collective goals [55].
7. *Safety and Ethics* Conduct research on developing safety standards, risk assessment methodologies, and ethical frameworks for the deployment of mobile robots in shared spaces, ensuring their safe and responsible integration into society [56].
8. *Learning from Demonstration* Investigate techniques for enabling mobile robots to learn from human demonstrations, allowing them to acquire new skills and adapt to different tasks and environments more efficiently [57].
9. *Real-World Adaptability* Focus on developing adaptive algorithms and learning approaches that enable mobile robots to quickly adapt and generalize to novel or changing environments, reducing the need for extensive retraining or manual programming [58].
10. *Robotic Swarms for Environmental Monitoring* Explore the use of mobile robot swarms for large-scale environmental monitoring, studying strategies for efficient data collection, collaborative sensing, and data fusion techniques [59].

These suggestions provide specific areas where future research can contribute to addressing the existing limitations and challenges in mobile robotics, advancing the field towards more capable and versatile robotic systems.

8 Future Scope

Agrarian industries, storehouses, army mission, healthcare establishments, and manufacturing plants are looking for unique and temporal methods to increase efficacy of various operations, enhancement of safety, precision assurance, and increment in speed of production. Therefore, all of them will feel a supportive need for autonomous robotic vehicles in future. If we consider the long-term scenario, to achieve self-governance of higher level in robotic machines, loads of analytical and computational research is to be done yet. Amalgamation of machine learning and deep learning methods with science of movable robots can result in enhancement of spectrum of applications of robotics and their rates of accuracy. Technological advancements in engineered innovations like self-driving vehicles, delivery drones, and smart factories equipped with robots as assistant work force

Table 5 Limitation and challenges of mobile robots

Limitations/challenges	Description
Navigation and localization	Mobile robots face challenges in accurately perceiving their environment, localizing themselves, and planning optimal paths
Obstacle detection and avoidance	Recognizing and avoiding obstacles in real-time can be challenging, especially in dynamic or cluttered environments
Battery life	Mobile robots often rely on batteries, and limited battery life restricts their operation time before requiring recharging
Payload capacity	Mobile robots may have limited carrying capacity, which can restrict their ability to transport heavy or large objects
Manipulation and dexterity	Achieving fine-grained manipulation tasks or handling delicate objects can be challenging for mobile robotic systems
Communication and connectivity	Maintaining reliable and robust communication in various environments, including areas with poor signal strength, can be difficult
Adaptability to unknown environments	Mobile robots may struggle to adapt to novel or unstructured environments that they have not been trained or programmed for
Cost	Building and maintaining mobile robotic systems can be expensive, making them less accessible for certain applications
Safety	Ensuring the safety of humans and the environment in the presence of mobile robots remains a significant concern
Social acceptance	Widespread acceptance and integration of mobile robots into society may face challenges due to ethical and social considerations

have a remarkable influence on the way factories operate. The employment of movable smart robots in mining can facilitate the mapping process of mine, assist mining labour, generate virtual paradigms, and ameliorate safety standards. There are various gaps, limitation and challenges are there in mobile robotics that are open for potential researchers to be filled by them. Some of them are avoidance of hindrance, planning of smooth movement of a robot, multi tasked collaborative robotic actions and path planning etc. The limitation and challenges of Mobile robots has been shown in a tabular form below as Table 5.

8.1 Ethical or Societal Implications of Mobile Robotics

Mobile robotics has several ethical and societal implications that arise from the increasing integration of robots into various aspects of our lives. Here are some key considerations:

- Job displacement.
- Privacy and data security.
- Ethical decision-making.
- Safety and liability.
- Social acceptance and trust.
- Equity and accessibility.
- Cultural and ethical sensitivity.
- Environmental impact.

These ethical and societal implications highlight the need for interdisciplinary collaboration involving robotics engineers, ethicists, policymakers, and the public to ensure that mobile robotics technologies are developed and deployed in a responsible and beneficial manner for individuals and society.

9 Conclusion

To meet the skyrocketing demand of movable robotic machines in various areas like factory outlets, medical industry, army missions and many more, intelligent self-governing movable robotic vehicles can become a reliable option. Uniquely advanced technologies have been developed by researchers and engineers to human life easier than ever by minimizing detrimental behaviour of machines. It is observed that robotics has emerged as a great area of interest for researchers in recent times. This document summarizes the developments and advancements of mobile robots in last seven decades. Developments in self-governing robotic vehicles, their working and applications have been discussed in this paper in detail. From 1920's when the term 'robot' was firstly introduced to current times of twenty-first century when robots have become more dependable, efficient, and intelligent, every aspect of development in robotics has been discussed in this document in detail. Thus, we expect more detailed studies on this topic to be conducted in future by potential researchers.

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