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Mobile Robots: A Primer

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ABSTRACT
Mobility is the new frontier in flexible robotics. Mobile robots can move around in a physical environment. They combine software, sensors, artificial intelligence, and machine learning with physical robotics to navigate their surroundings. Mobile robots have garnered quite a bit of interest. They are the new era in automation. Autonomous mobile robots are machines that function on their own without a central control or human intervention. This paper presents an introduction to mobile robots.

KEYWORDS: *robots, robotics, mobile robots, autonomous mobile robots*

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INTRODUCTION
Robotics is an interdisciplinary discipline embracing mechanical engineering, electrical engineering, computer science, and others. The goal of robotics is to create intelligent machines (called robots) that behave and think like humans. Robots were originally intended for use in industrial environments to replace humans in tedious and repetitive tasks. They are used to drive efficiency, expedite processes, improve safety, enhance productivity, and enable greater flexibility in various industries. The most six common types of robots are autonomous mobile robots (AMRs), automated guided vehicles (AGVs), articulated robots, humanoids, cobots, and hybrids. Robots can also be broadly categorized in to two groups: those that move around their environment and those that do not [1].

Robotics is a growing field. It combines different areas such as mechanical, electrical and electronics engineering, computer science, and social sciences. Although robotics is automation, automation is not necessarily robotics. Robotics is taking automation to another level by using more adaptive robots. Mobile robots are the new era in automation. Rising automation across various industries such as automotive, manufacturing, defense and security, and others has led to increasing popularity of these robots among end users. Conventional robots lack mobility. A mobile robot is a robot that can move around and interact with its environment. Increasing number of robots use legs for mobility. Humanoid robots, unmanned rovers, entertainment pets, drones, and so on are typical examples of mobile robots. Today, there are mobile robots that can walk, run, jump, roll, walk, fly, or swim like their biological counterparts [2].

WHAT IS A ROBOT?
The word "robot" was coined by Czech writer Karel Čapek in his play in 1920. Isaac Asimov coined the term "robotics" in 1942 and came up with three rules to guide the behavior of robots [3]:

1. Robots must never harm human beings,
2. Robots must follow instructions from humans without violating rule 1,
3. Robots must protect themselves without violating the other rules.

Robotics has advanced and taken many forms including fixed robots, collaborative robots, mobile robots, industrial robots, medical robots, police robots, military robots, officer robots, service robots, space robots, social robots, personal robots, and rehabilitation robots [4,5]. Robots are becoming increasingly prevalent in almost every industry, from healthcare to manufacturing.

Although there are many types of robots designed for different environments and for different purposes/applications, they all share four basic similarities [6]: (1) All robots have some form of mechanical construction designed to achieve a particular task; (2) They have electrical components which power and control the machinery; (3) All robots must be able to sense its surroundings; a robot may have light sensors (eyes), touch and pressure sensors (hands), chemical sensors (nose), hearing and sonar sensors (ears), etc. (4) All robots contain some level of computer programming code. An autonomous robot must have a basic body structure (the chassis), sensors, a central control system (microprocessor), actuators (motors), a power supply and an overall program for its behavior. Programs are the core essence of a robot since they provide intelligence. There are three different types of robotic programs: remote control, artificial intelligence, and hybrid. Some robots are programmed to faithfully carry out specific actions over and over again (repetitive actions) without variation and with a high degree of accuracy.

The advantages of robotics include heavy-duty jobs with precision and repeatability. Despite these advantages, there are certain skills to which humans will be better suited than machines for some time to come. Humans have the advantages of creativity, decision-making, flexibility, and adaptability.

BACKGROUND ON MOBILE ROBOTICS

Robotics is an emerging field at the intersection of mechanical and electrical engineering with computer science. Mobile robotics is usually considered to be a subfield of robotics. Mobile robots are robots that can move from one place to another place by itself without any external human assistance. It may be regarded as a machine that uses a combination of software, array of sensors, artificial intelligence, machine learning, and physical robotic elements to identify its surroundings and move around its environment. Mobile robots need unique capabilities, such being able to navigate. They can beused to access areas, such as nuclear power plants, that are too dangerous for humans to inspect [7]. They offer several benefits such as working 24/7, being accurate and consistent, and working in harsh environments.

There are also two types of mobile robots: autonomous and non-autonomous, or guided. Mobile robots is autonomous when they are capable of navigating an uncontrolled environment without the need for physical guidance devices. A fully autonomous robot has the following features [8]:

- Track information from the environment
- Navigate from one point to another without human help
- Avoid obstacles and hazardous situations
- Repair itself to some extent without outside assistance

Guided mobile robots require some form of instruction or guidance system in order to move around. Autonomous mobile robots (AMRs) are commonly regarded to be the successor to older automated guided vehicles (AGVs). The two types of mobile robots are further explained as follows [9,10]:

- **Autonomous Mobile Robots (AMR):** The fastest-growing segment of mobile robots is the autonomous mobile robot (AMR). They can carry out a variety of tasks with a minimum of human interaction. They can help improve the efficiency of logistics and supply chain operations of all sizes. AMR is far more affordable than traditional automation, and easy to scale once in place. It offers huge advantages for efficiency, growth, scalability, and speed. Some of the tasks involved are material picking, handling, and sorting. AMRs address the challenges in today's supply chain. AMRs differ from their predecessors, autonomous guided vehicles (AGVs), which rely on tracks or predefined paths and often require operator oversight. Warehouses, logistical companies, agriculture, and healthcare institutions are all looking speed, ensure precision, and increase safety are turning to autonomous mobile robots for new and innovative ways to improve operational efficiency and increase safety. Figure 1 shows a typical AMR [11]. Elmer and Elsie, the world's first electronic autonomous mobile robots, were created in 1948 by William Grey Walter in UK. In 1961, UNIMATE, the first industrial robot, was introduced at the General Motors factory is New Jersey.
- **Automated Guided Vehicles (AGVs):** These are an older technology than AMRs. An autonomously guided robot knows at least some information about where it is and how to reach various goals and or waypoints along the way. AMRs differ from AGVs because AMRs possess the ability to be more independent. Since they have little on-board intelligence, AGVs cannot change their route or navigate around obstacles.

They typically must be relegated to low-traffic or caged areas due to safety concerns. AGVs typically require external guidance, such as magnet strips, wires or sensors installed in the environment's floor, making it an inflexible system that is both expensive and difficult to change. Figure 2 shows an example of an automatic guided vehicles [12]. AMRs are far more complex, using sensors and onboard intelligence to understand its environment and navigate congestion, whether that is people, racks, work stations, other equipment, and debris. The differences between AGVs and AMRs are becoming blurred.

APPLICATIONS OF MOBLE ROBOTS

Mobile robots are being applied across all sectors. From manufacturing and healthcare to customer service, robots perform remarkable tasks. Figure 3 depicts autonomous mobile robots market share in 2019 [13]. The capabilities for mobile robotic technology are endless. The following applications are typical of what mobile robots can do [14,15]:

- **Industrial Mobile Robots:** Mobile robots have found their way into many industrial applications. Industrial mobile robots are perhaps the most commonly used today. Mobile robots, as an automated guided vehicle (AGV) or autonomous mobile robot (AMR), provide manufacturers the flexibility to transfer the robot to work in multiple workstations. Industrial mobile robot systems, possess several core features such wireless communication, integrated safety, fleet simulation software, and fleet management software. Industrial mobile robots are popular in warehouses and distribution centers, mobile machine tending, order fulfillment, pick assistance, and automated storage and retrieval. They are useful in medicine, surgery, personal assistance, and security. Autonomous forklifts are using AGV or AMR technologies in the factory and warehouse environment.
- **Production:** Mobile robots pay off in production. Static production lines are being replaced by intelligent, mobile robots. Mobile robots navigate autonomously and offer total flexibility for industrial manufacturing. Continuous-flow manufacturing does not pose a challenge in modern production environments. Collaborative robots can work alongside humans, performing human tasks and trying to blend into the daily routine on the warehouse or production floor. They can perform a multitude of industrial tasks such as packaging, palletizing, assembly and picking. Two mobile robots can operate safely next to human co-workers, helping to free up skilled human labor. Mobile automation solutions increase the flexibility of the production facility and enable a sustainable increase in cost-effectiveness. Figure 4 shows the use of mobile robots in warehouse automation [16].
- **Healthcare:** Robots could reduce the amount of tedious tasks of nurses, doctors, and other medical professionals. Mobile robots can accelerate healthcare operations. They can move patients, transport supplies, and assist with surgical procedures. Mobile robots are already being utilized in some hospitals since there are AMRs specially designed for hospitals. AMRs are used to deliver medication, disinfect surfaces, or provide mobile telepresence functionality. A mobile robot can act as a conduit for communication by allowing multiple medical specialists and caregivers to collaborate in real time at the patient's bed side. Mobile robots can be used for rehabilitation purposes. The can help wheelchair-bound individuals with advanced muscular disabilities perform daily tasks. They can also help individuals with lower extremity weakness to walk again. AMRs offer a very cost-effective way of deploying automated cleaning and disinfection equipment.
- **Business:** Mobile robots are getting popular across different business sectors. Businesses use robotics in a variety of ways. They are typically deployed to enhance outcomes and reduce the burden on employees so they can devote their effort on the most-valuable tasks. The remote-controlled telepresence mobile robot lets users interact despite their location. It is providing an effective tool for a growing remote workforce. For example, Amazon uses cost-effective mobile robots to offer order picking and enables parcel delivery in less than 24 hours. AMRs are being used in grocery stores. Having an AMR show up on your house to deliver packages is coming at the near future.
- **Agriculture:** Mobile robots are crucial to agriculture, a sector that is suffering from labor shortage and requiring boring, dangerous tasks that could be better performed by mobile robots. Farmers have started using mobile robots to maintain, measure, and harvest fresh produce. AMRs are helping farmers harvest their crops more efficiently and delicately avoid causing any harm to the product.
- **Military:** Advancements in military and defense operations involves development of highly specialized expertise and custom-built tools

such as AMR. Unmanned aircraft is being used by the US military to deliver supplies to precise locations, thereby eliminating the risk to human lives. The unmanned aircraft can fly day or night, has autonomous or remote control capabilities.

- Other applications of mobile robotics include various uses at homes, personal assistance, e-commerce, government agencies, locomotive robot systems, construction, retailing, supply chain and logistics, education, package delivery, disaster recovery, security, warehouse and distribution, ocean and space exploration, hotels and hospitality, autonomous unmanned aerial vehicle, autonomous underwater vehicle, and mobile wireless sensor network.

BENEFITS

Mobile robots can offer virtually unlimited movement possibilities. They have become more commonplace in commercial, industrial, military, and security settings. They are being developed for and used in almost every industry in order to solve for a number of complex issues. The benefits of using AMRs are expanding their utility. Many of the most promising applications of mobile robots reduce or eliminate the need for humans to perform tasks in dangerous environments. Examples include space exploration, mining, and toxic waste cleanup.

Other benefits of mobile robotics include [17-19]:

- **Increased Safety:** Safe operation is mandatory for mobile robots since they interact with their environment. There is a special concern on human safety, work safety, routing accuracy. and collision avoidance. Mobile robots have built-in safety features that enable them to work alongside humans. In other words, mobile robots are programmed with safety in mind. Mobile robots understand their environment, eliminating the risk of human negligence and safety risks that could occur as a result of human error. They are getting more complex and handling heavier payloads creating new safety concerns. It is necessary to create safety standards that cover all areas of mobile robots. AMRs are designed to work dynamically with their surroundings. By using built-in sensors and intelligent algorithms, AMR can detect workers or obstacles and then adjust the route. This allows for a safe and collaborative environment of AMRs and warehouse workers. The Robotic Industries Association as well as the American National Standards Institute (ANSI) are working together to develop safety standards for industrial mobile robots.
- **Increased Productivity:** Mobile robotics applications have been the key automated tool for creating safer industrial spaces and achieving greater productivity. Productivity is higher with mobile robots because robot applications reduce errors, reduce defective products, and improve the quality of the finished product. Mobile robots must be designed, programmed, and tested to ensure that it offers a high and consistent level of performance. For example, mobile robot can increase picking productivity by 300% when compared to the manual operation.
- **Efficiency:** The main goal of robotization is optimizing the efficiency of a process. Mobile robots can boost output and efficiency, helping businesses handle unexpected spikes in demand. Unlike humans, robots do not get tired, bored, or distracted. They are not at risk of ergonomic injuries caused by lifting heavy loads and repetitive lifting activities.
- **Affordability:** AMRs cost significantly less than traditional automation systems. The robots have a modular construction which simplifies their maintenance and reduces the cost of ownership throughout their service life. Reduced costs enable deploying many robots in warehouse distribution and line-side logistics applications.
- **Greater Flexibility:** The inherent navigational flexibility is one of the major advantages of mobile robots. The flexibility also comes from its accessibility to workers with minimal robot training that can easily re-deploy the robot to a new task. Mobile robots are flexible and versatile and can perform multiple functions. They are designed to be programmed easy and fast. The robots can operate alone without human assistance. They adapt to different production environments and easy to maintain. Since AMRs rely largely on onboard sensors and cameras to operate, they exemplify flexible, agile automation.
- **Reducing Labor Costs:** One of the robot's profitability is the decrease in labor cost. When production becomes more efficient, fewer workers can achieve the same or much higher productivity than manual operation. This helps reducing labor costs.
- **Improving Quality:** Quality is always an important goal when implementing robotics and there are a few ways robots can address this need. In terms of quality-specific work, robots may be used to move parts to a quality inspection area if it is not next to the production line. There is the reduction in the number of rejects and the improvement in quality.

- **No Single Point of Failure:** By implementing autonomous mobile robots (AMRs), warehouses can ensure continued operations and mitigate against issues associated with single-point-of-failure. When an AMR breaks down, it can be easily fixed and replaced without affecting the operation.
- **Fast Deployment:** AMRs can be flexibly implemented without the costs associated with fixed infrastructure. The mobility, autonomy, and size make them easy to implement into the existing warehouse. The infrastructures are required only as simple as five components.
- **Accurate Operations:** Avoiding errors is becoming increasingly important as people have higher demands for faster and accurate services. By deploying AMRs, you can avoid errors associated with manual operations like stress, new staff, and increasingly difficult logistics.
- **Scalability:** Unlike traditional automation systems, robotic solutions can be scaled up or down by adding or subtracting robots. The number of robots as well as hours of work per day can be easily adjusted to meet changes in demand. instead of purchasing a large amount of AMRs at once, you can start with one and add to more with time.

CHALLENGES

Robots operate under real-world, real-time constraints, where sensors and effectors with specific physical characteristics need to be controlled. They are not as fast as a human walking. Although robots can assist in experimental searches, their widespread adoption in materials research is challenging because of the diversity of sample types, operations, instruments, and measurements required. Other challenges include the following:

- **Poor Reliability:** Most current mobile robots have poor reliability, requiring frequent maintenance and repair. They are few, if any, other mobile robots that have operated for as long as a year without repair. Mobile robots are being designed to an appropriate level of unreliability. Reliability must be considered in the design of robots, robot teams, and robot missions [20].
- **Environmental Perception:** This is a complicated and complex task for mobile robots. A method used for environment perception is collision sensing. Robots sense collision points and direction to avoid collision again. Mobile robots controlled over the Internet pose several challenges such as Internet transmission delays and delay jitter [21].
- **Sensor Limitations:** These often prevent accurate state estimation of the robot. Often robots have to plan and execute tasks while being uncertain about their configuration and the environment in which they are operating. Planning with sensing uncertainty is common in robotics. The solutions for robotics tasks lie in the spaces of information states, which allows finding better plans for the robots. Each information state represents the current knowledge of the robot [22].

CONCLUSION

With advancements in technology, robotics solutions are being implemented in an increasing number of industries and applications. In view of the sheer number of the current applications of mobile robots, the future is bright. The technology offers near-limitless opportunities. Large companies such as Procter & Gamble have been leading the way in terms of mobile robot adoption. Walmart recently announced it will be bringing autonomous robotics technology to some of its regional distribution centers to improve throughput and boost warehouse capacity.

You should consider becoming a mobile robotics engineer if you like working on complex problems, making things, and working as a team. More information about mobile robotics can be found in the books in [23-33] and the following journals devoted to robot-related issues:

- Robotica
- Robitics and Autonomous Systems
- Advanced Robotics
- Journal of Robotics
- Journal of Robotic Systems
- Journal of Robotic Surgery
- Journal of Intelligent & Robotic Systems
- Journal of Mechanisms and Robotics-Transactions of the ASME
- Journal of Automation, Mobile Robotics and Intelligent Systems
- Intelligent Service Robotics
- IEEE Journal on Robotics and Automation
- IEEE Robotics & Automation Magazine
- IEEE Robotics and Automation Letters
- IEEE Transactions on Robotics
- International Journal of Medical Robotics and Computer Assisted Surgery
- International Journal of Robotics Research
- International Journal of Social Robotics
- International Journal of Humanoid Robotics
- International Journal of Advanced Robotic Systems.
- Recent Trends in Mobile Robots

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Figure 1 A typical autonomous mobile robot (AMR) [11].

Figure 2 An example of an automatic guided vehicle (AGV) [12].

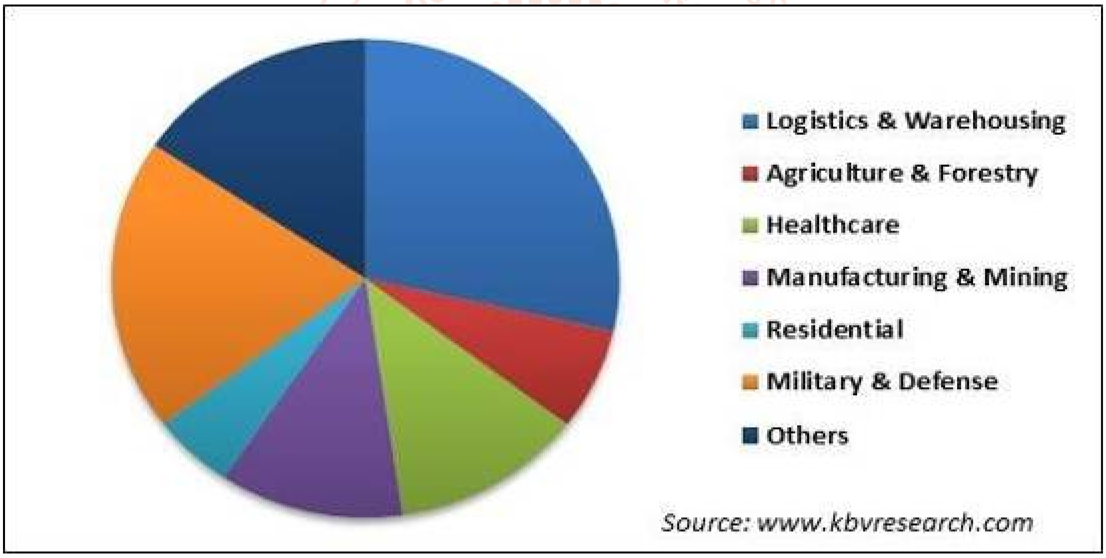

Figure 3 Autonomous mobile robots market share in 2019 [13].

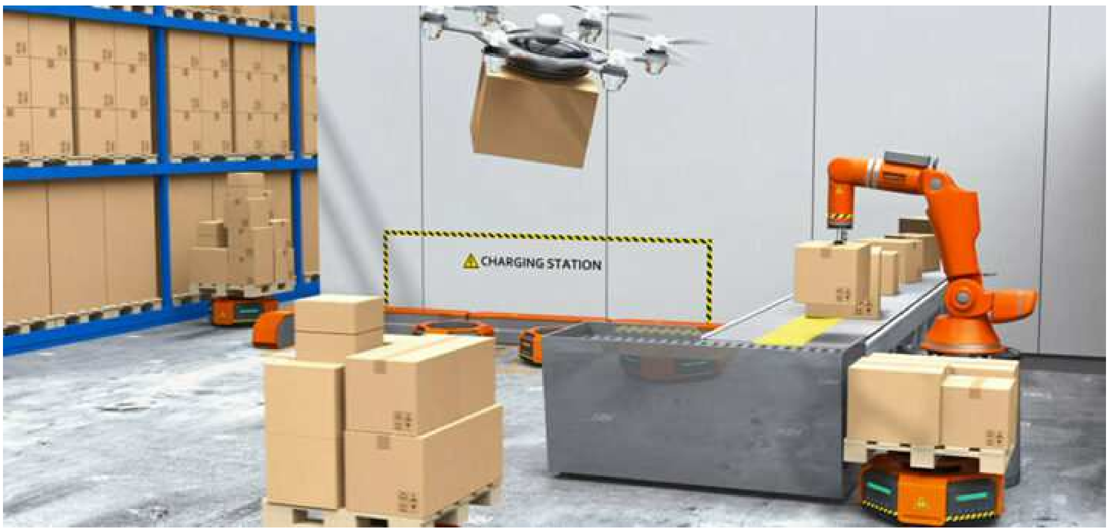

Figure 4 Use of mobile robots in warehouse automation [16].