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Mobile robot technologies: architectures, navigation, and applications in industrial and domestic environments

Tole Sutikno[1], Mohd Hatta Jopri[2]
[1]Faculty of Industrial Technology, Universitas Ahmad Dahlan, Yogyakarta, Indonesia
[2]Faculty of Electrical Technology and Engineering, Universiti Teknikal Malaysia Melaka, Melaka, Malaysia

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ABSTRACT

Mobile robots have become increasingly important in industrial automation and domestic services because they can perform transportation, inspection, cleaning, and assistance tasks with reduced human intervention. Their development involves several interconnected technologies, including mechanical platforms, sensors, embedded controllers, localization systems, path planning, and obstacle avoidance. However, the requirements of industrial and domestic environments differ considerably, particularly in terms of operational reliability, environmental complexity, human interaction, and cost. This review examines the principal architectures and navigation technologies used in mobile robots and compares their suitability for industrial and household applications. The reviewed literature indicates that reliable mobile robot operation depends on the integration of perception, localization, planning, and motion control rather than on a single navigation algorithm. The review concludes that application-specific system design is essential for achieving safe, efficient, and practical mobile robot deployment.

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1. INTRODUCTION

Mobile robots are robotic systems designed to move through their environments while performing assigned tasks. Their applications range from material transportation and equipment inspection in factories to floor cleaning, domestic assistance, and personal services in residential environments. Improvements in sensing technology, embedded computing, and control algorithms have increased the ability of mobile robots to operate with limited human supervision. These developments have also expanded the research focus from basic robot movement toward autonomous navigation and safe interaction with people.

Despite their growing capabilities, mobile robots still face important technical challenges. An industrial robot must navigate reliably around machines, production equipment, workers, and moving materials, while a domestic robot must cope with furniture, narrow passages, pets, and unpredictable human activities. Both environments require accurate localization, effective obstacle detection, and appropriate motion planning. However, the design priorities differ because industrial systems often emphasize productivity and reliability, whereas domestic systems place greater emphasis on affordability, usability, safety, and adaptability.

The central research problem addressed in this review is how mobile robot architecture and navigation technologies can be selected according to different operating environments. This question involves three related aspects, namely the integration of hardware and software, the selection of localization and navigation techniques, and the adaptation of robot capabilities to specific application requirements. Previous studies have investigated mobile robot navigation, visual perception, semantic mapping, and manufacturing applications from different perspectives [1]-[5]. This review connects these research areas to provide a comparative understanding of mobile robot technologies in industrial and domestic environments.

2. MOBILE ROBOT ARCHITECTURES

A mobile robot architecture defines how mechanical components, sensors, actuators, computing units, and software functions work together. A typical platform consists of a mobile chassis, drive motors, motor drivers, a power supply, sensors, and an embedded or onboard computer. The software architecture coordinates perception, localization, path planning, motion control, and communication between these components. The overall performance of a mobile robot therefore depends on the integration and reliability of its hardware and software architecture.

Mobile robot platforms can be classified according to their locomotion mechanisms. Differential-drive robots use independently controlled wheels to generate forward motion and rotation, making them relatively simple and suitable for indoor applications. Omnidirectional platforms provide greater maneuverability in confined spaces, while tracked platforms can operate on uneven surfaces where wheel-based movement may be limited. The choice of locomotion mechanism should reflect floor conditions, payload requirements, maneuverability, energy consumption, and maintenance needs.

From a software perspective, mobile robot architectures commonly use layered or modular structures. The perception layer processes sensor information, while the localization layer estimates the robot's position and orientation within its environment. The planning layer determines a suitable route, and the control layer converts the planned motion into actuator commands. This modular organization makes system development and troubleshooting more manageable because individual functions can be tested and improved independently.

Industrial mobile robot architectures generally require robust communication, safety monitoring, and integration with production systems. Shneier and Bostelman reviewed mobile robots for manufacturing and discussed robot types, localization, control, and safety in applications involving human collaboration [1]. Their review highlights that industrial deployment involves more than autonomous movement because operational safety, task coordination, and suitability for the production environment must also be considered. These requirements make industrial robot architecture more demanding than a basic autonomous mobile platform.

3. NAVIGATION TECHNOLOGIES

3.1. Localization and mapping

Localization is the process of determining a robot's position and orientation within a known or partially known environment. Accurate localization is essential because a robot cannot follow a planned route reliably if its estimated position is incorrect. Common localization techniques include wheel odometry, inertial measurement, laser-based localization, visual localization, and combinations of several sensors. Each technique has different advantages and limitations depending on the environment and available hardware.

Simultaneous localization and mapping (SLAM) allows a mobile robot to estimate its position while constructing a map of an initially unknown environment. Durrant-Whyte and Bailey explained the fundamental SLAM problem and its importance in autonomous robotic systems [2]. SLAM is particularly useful when a robot must operate in environments where a reliable map is unavailable or where the environment changes over time. Nevertheless, localization errors, sensor noise, and dynamic obstacles can affect mapping accuracy and long-term navigation reliability.

Visual navigation provides another important approach by using cameras to recognize environmental features and estimate robot movement. DeSouza and Kak reviewed vision-based navigation methods and discussed their use in mobile robot perception and movement [3]. Camera-based systems can provide rich information about objects, surfaces, and environmental structures, making them attractive for domestic and service robots. However, their performance may deteriorate under poor lighting, motion blur, occlusion, and environments with insufficient visual features.

Semantic mapping extends conventional geometric mapping by associating environmental locations with meaningful objects or categories. Kostavelis and Gasteratos reviewed semantic mapping techniques and explained their relevance to mobile robot navigation and human-robot interaction [4]. A semantic representation can help a robot interpret locations such as corridors, rooms, workstations, or furniture rather than treating the environment only as geometric obstacles. This capability is particularly valuable for domestic robots and service applications where navigation tasks may be expressed through human-oriented descriptions.

3.2. Path planning and obstacle avoidance

Path planning determines how a mobile robot should move from its current position to a target location. Global path planning generally uses an environmental map to identify a route, whereas local planning adjusts movement according to nearby obstacles and changing conditions. Common approaches include graph-search algorithms, potential-field methods, and velocity-based obstacle avoidance. The selection of a planning method depends on map availability, environmental complexity, robot dynamics, and computational resources.

The dynamic window approach (DWA) is a local navigation method that evaluates feasible robot velocities while considering motion constraints and collision risk. Fox, Burgard, and Thrun demonstrated its use for collision avoidance in dynamic environments [5]. The method is useful because it considers the robot's movement capabilities rather than selecting a path based only on geometric distance. However, its performance depends on sensor information, velocity sampling, evaluation parameters, and the quality of the local environmental representation.

Obstacle avoidance is especially important when mobile robots share space with people or other moving objects. Industrial robots must avoid workers, vehicles, and moving materials, while domestic robots must navigate around people, pets, and household objects. Reactive methods can respond quickly to nearby obstacles, but they may not always produce globally efficient routes. Combining global planning with local obstacle avoidance provides a more practical architecture for environments containing both static and dynamic obstacles.

4. APPLICATIONS IN INDUSTRIAL AND DOMESTIC ENVIRONMENTS

Industrial mobile robots are commonly used for material transportation, production support, inspection, and logistics. Automated guided vehicles (AGVs) can transport components between production stations, reducing repetitive manual handling and improving material flow. More autonomous mobile platforms can use onboard sensors and mapping systems to navigate through changing factory layouts. Their effectiveness depends on localization accuracy, payload capacity, operating reliability, safety mechanisms, and integration with manufacturing processes [1].

Domestic mobile robots are designed to assist people with routine household activities and services. Common examples include robotic vacuum cleaners, floor-cleaning robots, and mobile platforms for monitoring or assistance. Unlike structured industrial facilities, homes contain irregular furniture arrangements, narrow spaces, carpets, thresholds, and frequently moving occupants. Domestic robots must therefore combine affordable sensing and navigation with simple user interaction and safe movement around people.

Dayoub, Morris, and Corke discussed the practical challenges of deploying mobile service robots in environments shared with people [6]. Their work emphasizes that real-world operation requires attention to safety assessment and the risks associated with prolonged testing in populated environments. These considerations are relevant to both domestic and industrial applications because autonomous movement creates physical interaction between robots and their surroundings. A robot that performs well in a controlled laboratory may still require substantial adaptation before it can operate safely in everyday environments.

The differences between industrial and domestic applications are summarized in Table I. The comparison focuses on operating conditions, navigation requirements, system priorities, and representative tasks. Although both application categories use similar fundamental technologies, their implementation requirements are shaped by different environmental and user expectations. Table I therefore provides a practical basis for selecting mobile robot technologies according to their intended operating context.

Table 1. Comparison of mobile robot applications in industrial and domestic environments

Aspect	Industrial environment	Domestic environment
Main applications	Material handling, inspection, logistics, production support	Floor cleaning, household assistance, monitoring
Environment	Factories, warehouses, production areas	Homes, apartments, residential buildings
Navigation requirements	Accurate localization, route efficiency, fleet coordination	Flexible navigation, obstacle avoidance, room coverage
Common sensors	LiDAR, encoders, safety scanners, cameras	Cameras, infrared sensors, ultrasonic sensors, bump sensors
System priorities	Productivity, reliability, payload, safety	Affordability, compactness, usability, safety
Main challenges	Human-robot collaboration, changing production layouts, operational downtime	Furniture, narrow passages, pets, human activity, uneven floors

As indicated in Table I, industrial robots generally require stronger emphasis on payload, reliability, and integration with production systems. Domestic robots, in contrast, must operate in less structured environments while maintaining affordability and ease of use. Both categories require dependable localization and obstacle avoidance, but the sensor configuration and navigation strategy may differ considerably. These differences demonstrate why a single mobile robot architecture cannot be assumed to satisfy every application equally well.

5. TECHNICAL CHALLENGES AND FUTURE DEVELOPMENT

One of the major challenges in mobile robotics is achieving reliable navigation in dynamic and partially unknown environments. Sensor measurements may become inaccurate because of noise, lighting variation, surface characteristics, or moving obstacles. Localization errors can accumulate during long operating periods and may cause the robot to deviate from its intended route. Future systems should therefore emphasize robust sensor fusion, map updating, and recovery strategies when localization or navigation fails.

Another important challenge is safe human-robot interaction. Mobile robots operating in factories, hospitals, offices, and homes must detect people and respond appropriately to unexpected movement. Safety should be considered throughout the design process, including mechanical structure, speed limitation, emergency stopping, obstacle detection, and system validation. Dayoub *et al.* [6] and Shneier and Bostelman [1] highlight the importance of addressing safety as part of real-world deployment rather than treating it as an additional feature.

Future mobile robot development is likely to involve more intelligent perception, semantic understanding, and cooperative operation. Semantic maps can support task-oriented navigation, while communication between robots can improve coordination in warehouses and manufacturing facilities. Improvements in embedded processors and sensor technology may also make advanced navigation functions more accessible to compact domestic platforms. Nevertheless, the practical value of these developments must be evaluated through experiments that consider cost, reliability, energy consumption, and actual user requirements [7].

6. CONCLUSION

This review has examined mobile robot architectures, navigation technologies, and applications in industrial and domestic environments. The analysis shows that mobile robot performance depends on the integration of locomotion systems, sensors, localization, mapping, path planning, and motion control. SLAM and visual navigation provide important capabilities for localization and environmental understanding, while DWA and related methods support local obstacle avoidance. Semantic mapping further improves the ability of robots to interpret environments in ways that are relevant to human tasks.

The comparison also indicates that industrial and domestic applications require different design priorities. Industrial mobile robots emphasize productivity, payload, reliability, safety, and integration with manufacturing systems, whereas domestic robots prioritize affordability, compactness, usability, and adaptability to everyday environments. Both application categories benefit from robust localization and safe navigation, but their hardware and software configurations should be selected according to their operating conditions. Future research should focus on improving sensor fusion, semantic navigation, human-robot interaction, and system reliability to support wider adoption of mobile robots in practical environments.

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