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Locomotion Systems for Land-based Mobile Robots

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Abstract

Land-based mobile robots (LBMR) are expected to be rabidly deployed worldwide with massive market sales owing to significant applications in modern and future life sectors such as industry, agriculture, security, health, and environment protection. However, this vital technology is critically affected by the locomotion over unstructured soft or rough terrain environments with different types of static and dynamic obstacles. This work investigates the existing wheeled, tracked, and leg-based locomotion techniques for LBMR applications and proposed solutions under unstructured environment conditions. These primary locomotion schemes are evaluated based on the achieved speed, ability to cross or mitigate obstacles, climb stairs/steps/slopes, move over soft, rough, or rocky terrain, energy efficiency, mechanical complexity, and technological readiness. Additionally, the hybrid categories that can be created by mixing the primary locomotion mechanisms are discussed with an insightful vision of future directions.

Keywords: *Mobile robot, Locomotion, Land-based locomotion, Navigation.*

1. Introduction

One of the research areas that is now expanding rapidly is mobile robots **[1] [2].** Given their capabilities, in many fields, mobile robots can take the place of humans **[1].** Robots are increasingly being created to aid or replace people in a variety of dangerous and hard tasks **[3].** In various difficult fields that humans cannot possibly operate in, like testing scientific experiments, detecting, and moving on Mars, mobile robots have been used [4]. Nowadays, mobile robots are commonly used in many fields and applications [**5].** They are used in the industry; robotics has considerably assisted humans in automating various industrial processes. Various industrial processes were employed to mass produce goods decades ago. Autonomous robots used in manufacturing do not typically have autonomous intelligence **[6].** In agriculture, over the last ten years, ground robots have been created for a variety of agricultural applications. Some agricultural jobs, like planting, monitoring, harvesting, pruning, and spraying, require automation technologies. The capability of the robot to navigate is crucial for all of these tasks **[7].** In-home service robots can do any task, including serving food, serving people properly, cleaning rooms, and controlling doors **[2].** Also, the applications of mobile robots in a restaurant are a robot waiter offering service **[4] [8],** education[9], medicine[10], military**[10][11],** and underwater robots that can sense their environment and move underwater. Such robots may help and even take the place of individuals in a variety of maritime tasks, such as resource exploration, leak detection, environmental monitoring, and undersea reconnaissance**[11],** also Unmanned Aerial Vehicles (UAVs) are one of the applications for mobile robots**[12][13].**

An autonomous mobile robot is a system that functions in a rapidly changing and largely unknown environment **[14].** The capability of autonomous robots to navigate their surroundings is one of their more desirable qualities **[15].** Accordingly. The robot should be able to freely navigate its surroundings and avoid any barriers that are put in its route. Whether indoors or outdoors, an autonomous mobile robot (AMR) is designed to navigate a specified path with minimal or no human help **[14].** Navigation of AMR is a fundamental but challenging task [16]. ARM now performs numerical tasks with incredible speed and accuracy while remaining safe **[17].** Mobile robots have the ability to move on their own in the area for which they are designed. They are capable of sensing their surroundings. They carefully adhere to their directives and take actions that enable them to execute their tasks successfully, effectively, and safely [2]. When a robot can choose the steps to take in order to complete a task, it is said to be autonomous. It has a helpful perception system. A cognition unit or control system is also required by the robot in order to coordinate all of its subsystems. The categories of locomotion, perception, cognition, and navigation together up the basis of mobile robotics. Understanding the mechanics, kinematics, dynamics, and control theory assists in solving locomotion problems. Signal analysis and specialist areas like computer vision and sensor technology are essential in perception. To fulfill the goals of the mobile robot, the responsibility for analyzing sensor input data and acting appropriately falls to cognition. Information theory, artificial intelligence, and planning algorithms are all necessary for navigation **[1].**

This paper's motivation is to provide an overview of mobile robot locomotion.

Not all of the information concerning the locomotion mechanism is covered in this paper. However, the literature undoubtedly captures the mainstream in this area. There are numerous studies on this subject in the literature. Similar work appeared by Rubio et al.[1] in 2019. M. B. Alatise, G. P. Hancke explain locomotion [14] in 2020. M. Rafeeq et al. [18] also M. A. K. Niloy et al.[2] in 2021.

The rest of this paper is organized as follows: Section 2 presents the definitions, design, and categories of locomotion for a mobile robot. The existing locomotion techniques for LBMR are presented in Section 3, while the possible hybrid schemes are given in Section 4. Finally, conclude the paper with future directions.

2. Locomotion for mobile robots

Any organism in nature has locomotion as its defining characteristic. A growing area of research focuses on comprehending its properties and using them as inspiration to create mechatronic systems that improve motion performance [18]. Mobile robots should be capable of working in a variety of environments, including dangerous, uneven terrain, places where there are many hurdles, and forbidden places. Therefore, a robot's ability to move around its working area depends so heavily on locomotion [2]. A critical characteristic of a mobile robot's design is its locomotion system, which depends not only on the terrain the robot moves on but also on other factors like maneuverability, controllability, topographical conditions, efficiency, stability, and so on. Depending on the service to be provided, the mobile robot's design should vary [14].

Robots can generally move by walking, rolling, jumping, sprinting, sliding, skating, swimming, and flying.

Land-based, air-based, water-based, and others are categories of mobile robots according to their locomotion systems.

Wheeled mobile robots (WMR), Walking (or legged) mobile robots, Tracked slip/skid locomotion, and Hybrid mobile robots are the four types of land-based robots [1]. Figure (1) explains the locomotion categories of mobile robots.

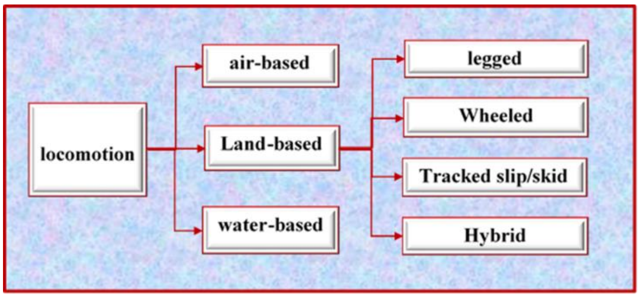

Figure (1) the locomotion categories of mobile robots

3. Land-based mobile robots

An important topic in robotics is ground mobile robots. Which is used in many applications. However, several problems in ground mobile robot applications still need to be resolved. For them, long-term stability and survival in unpredictable surroundings will be a major challenge, especially when the robots cannot avoid steep terrain or high obstacles. To overcome difficult obstacles and adapt to difficult terrain, robots need strong obstacle-negotiation skills and good flexibility more than humans do [19] [20] [21]. A mobile robot must be able to navigate in difficult, complicated, rough terrain and a variety of settings in order to support applications including monitoring, surveillance, reconnaissance, and military combat operations. More nimble and robust maneuvering in a variety of situations and terrain profiles is now possible because of recent technological developments and progress in mobile robotics [18]. Mobile robots can occasionally have legs or wheels since they are built to move, run, or walk in order to fulfill their assigned tasks (wheeled robots are proven to be the most efficient) [2]. These various multi-terrain robot locomotion have been discussed in this section.

3.1 *Walking (or legged) Mobile Robots*

The biomimetic (animal modeling) experiments provide the basis for the legged mobile land robots. The physiological and anatomical properties of land-based living organisms provide inspiration for their designs. The organisms' locomotion mechanisms are studied and modeled. Studying the natural development of the land's creatures helped as the framework for early studies in this field. In recent years, more research has been done on the development of legged robots [22] [23]. Stability is the main challenge for walking robots because gait and body balance is so vital [1]. The robots' high degree of mobility is made possible by their use of legs, which also allow them to maintain stably and dynamically stable gaits and navigate large obstacles like flights of stairs or multiple steps. Any robot's ability to coordinate its limbs depends on the number of legs it has. There are various ways to describe the leg arrangement [2]. Walking robots come in a variety of varieties depending on the number of legs (HOPPER), (BIPED ROBOT), (TRIPOD ROBOT), and (QUADRUPED ROBOTS) [1] [2].

Two-legged mobile robots are shown in Figure (2a) and four-legged mobile robots are shown in figure (2b).

(a) Two-legged [24]

(b) Four-legged [25]
Figure (2) two and four legged mobile robots

3.2 Wheeled Mobile Robots (WMRs)

WMRs are the most frequently used robot among the numerous highly developed, mature robots [26]. The wheel has by far been the most well-known locomotion system in mobile robotics and vehicles in general. Simplicity and Efficiency are two main advantages of the wheel. Building, designing, and programming wheels are simpler and less costly than doing it with other alternatives [14]. The main drawback of wheels is their poor ability to maneuver over obstacles like rough ground, sharp edges, or low friction areas [1]. A robotic system may be constructed into a holonomic or non-holonomic system, depending on the design of its wheels [27]. Wheeled locomotion can be divided into four different categories; fixed standard wheel it has one degree of freedom (DOF), Castor wheel with two DOF, Swedish wheel with three DOF, and Ball or spherical wheel[1][2]. Figure (3) shows the four types of wheeled locomotion. Depending on the drive system as shown in figure (4), can classify the WMRS into Differential drive WMRs, Car-type WMRs, Omnidirectional WMRs, and Synchro drive WMRs [1].

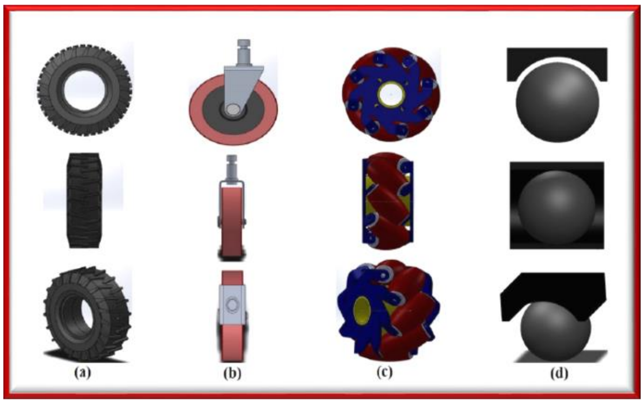

Figure (3) types of wheels (a) Standard wheel, (b) Castor wheel, (c) Swedish wheel and (d) Spherical wheel [2]

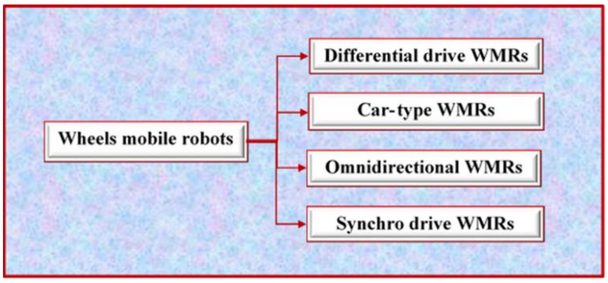

Figure (4) classification of wheel mobile robots

3.3 Tracked (slip/ skid) mobile robots

Due to the wide surface area in touch with the ground, as shown in figure (5), particularly effective for navigating soft, yielding, and uneven terrains is tracked locomotion. However, it is slower and less energy efficient than wheeled locomotion, and it has less capability to climb obstacles than legged locomotion [20]. Tracked mobile robots and vehicles have the advantage over wheeled unmanned ground vehicles in that they can operate effectively in challenging terrain and complete off-road missions. Tracked mobile robots can be used for a variety of tasks in mining and construction, When patrol and rescue missions require access to difficult terrain, tracked tractors are widely used in agriculture [28], military, and defense [28][29]. For military purposes, tracked mobile robots are typically utilized for bomb disposal or urban search and rescue (USAR). In addition, tracked mobile robots are used in many search and rescue efforts during natural disasters or difficult circumstances to locate trapped people. This enables the provision of emergency assistance, including food, water, and first aid supplies [29].

Figure (5) Tracked mobile robots [20]

In comparison to wheeled robot systems, the handling techniques for tracked mobile robots are slightly different. The use of curved-track steering, skid-steering, and articulated steering are a few of the suggested techniques for constructing the model. For tracked mobile, the skid-steering mechanism used as an effective steering system. A tracked mobile robot's vehicle speed and turning radius must be managed using the principles of this steering technique [29].

4 Hybrid mobile robots

Early in the 1980s, the idea of creating a hybrid locomotion robot by combining various forms of locomotion developed [30]. Two or more mechanisms of locomotion identify hybrid mobile robots. The combination of various technologies to develop robotic systems with complete mobility is described as the hybrid design of mobile robots. [23]. Moreover, the various types of locomotion can be used in the same environment or may allow the robot to move through two or more different areas, achieving efficiency and flexibility while working out a variety of tasks on the same mobile platform[31]. Due to their ability to integrate the advantages of many classes while avoiding their disadvantages, the most fascinating options for mobile robots' locomotion are likely hybrid systems. [21]. The primary trend in terrestrial hybrid robots is the employment of two motion modes: a primary one that is highly effective and performs well (often rotating), and a secondary one that is utilized to navigate obstacles and challenging terrain [23]. There really are four different types of hybrid mobile robots leg-wheel hybrid locomotion (LW), wheel-track hybrid locomotion (WT), leg-track hybrid locomotion (LT), and leg-wheel-track hybrid locomotion (LWT) [1] [21] [32]. Because they combine the benefits of various classes while avoiding their disadvantages, perhaps the most interesting solutions for mobile robots are hybrids' locomotion systems. For instance, wheel-track robots mix the operative flexibility of legs with the energy efficiency of wheels. Leg-track robots are particularly efficient when it comes to combining a smooth motion in a rocky and soft environment with energy efficiency on the smooth and compact artificial ground [21].

The easiest hybrid robots are those with wheels and legs since they are designed with both a wheel mechanism and a leg mechanism [22]. Wheel-driven robots of which are especially helpful in flat areas because of their numerous benefits in terms of movement speed, energy effectiveness, substantial movable loads, etc. The wheel's moving efficiency and stability, however, significantly decrease or even stop moving while traversing over rough surfaces or obstacles. Walking robots, on the other hand, although they travel slowly and use up a lot of energy, can move over uneven terrain where wheeled robots cannot. In order to combine the advantages of walking and wheel-driven robots, leg/wheel mobile robots with articulated legs and wheels at each tip were developed. [33] [34] [35].

Conclusions and future work

Mobile robots should be capable of working in any environment, including dangerous, unforgiving, loose, rough ground, surrounded by hurdles and forbidden locations. Therefore, for a robot to move across its working area, locomotion is vital. It is determined not just by the features of the area or the path taken by the robot, but also by important factors like the required controllability, mobility, efficiency, and stability in a variety of terrain conditions.

Locomotion systems for mobile robots are discussed in this paper to be beneficial in the early stages of design. Therefore, the locomotion mechanism must be chosen based on the operational requirements. The performance of a mobile robot and its ability to complete its tasks depend on the choice of its locomotion mechanism. Some system analysis is required to describe its purpose, capabilities, such as speed and stability, and the terrain it is intended to go across. Following that, the various possibilities should be studied because different types of locomotion systems have varied properties, levels of complexity, and costs

A significant amount of research has gone into developing cutting-edge robots with ground mobility and locomotion systems, depending on the particular application and irrespective of the robot payload. Wheels (W) easily and efficiently move objects at a high speed and with minimal energy use on flat, even terrain, the usage of tracks (T) and legs (L) in unstructured environments is also a wise choice. Considering that, they have a far greater contact surface with the ground than wheeled robots, tracks can move on rough and yielding terrain. However, they generally move more slowly and use less energy efficiency. Furthermore, compared to wheeled robots, they are more sensitive to vibrations. Unlike wheeled and tracked locomotion, which is biologically inspired, the leg is a form of locomotion. It is the best choice for navigating rough terrain and obstacles, but on level ground, it often moves more slowly and uses more energy. Legged robots' high cost and complexity provide the biggest barriers to their widespread adoption. Contrarily, hybrid locomotion systems are frequently the best option when a particular set of features is of primary importance in the mix of operating requirements (for instance, energy efficiency, speed, or mobility on sloping terrain), or when the application's economic feasibility requires that robot cost and complexity be kept to a minimum.

Quadruped-legged locomotion with a dynamic gait for high-end applications in completely unstructured outdoor environments (like military and homeland security jobs) and hybrid locomotion, particularly leg-wheel and leg-track, for compact and affordable mobile robotic systems, are two of the most promising areas of research in the future.

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