UNIVERSITY PARTNER

6CS014 – Complex System

Report
Locomotion and Mobility in Mobile Robot

University ID : 2330485

Submitted by : Renuka Dhakal

Module Leader : Mr. Deepson Shrestha

Tutor : Mr. Shiv Yadav

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Table of Contents

Table of Figure

1.Introduction:

When talking about robotics, we cannot overlook locomotion and mobility in robots. These concepts focus on the movements robots make and the patterns they follow while navigating, whether on land, in the air, or elsewhere. The movement and locomotion of robots are influenced by their intricate control systems, which act like a nervous system to regulate how they move. This also includes methods for enabling physical actions and gestures in all types of robots. Advancements in robotics and AI have significantly improved how robots move and adapt to real-world environments, even on natural, uneven terrains.

The term "mobile robot" is widely used in robotics when discussing locomotion and mobility. A mobile robot is essentially a machine that gathers information from its surroundings, processes it, and makes decisions based on what it perceives. For this, it requires a robust cognitive system that helps it sense changes in the environment and adapt accordingly. Thanks to developments in cognitive systems, mobile robots can now perform movements like walking, running, and even jumping. Various types of robotics have emerged due to these advancements in mobility and locomotion, such as wheeled robots, flying robots, legged robots, autonomous navigation robots, and more. Many of these technologies are already being applied in real-life scenarios.

The growth of mobile robots is linked to developments in areas like AI, automated vehicles, networks, nanotechnology, and human-robot interaction. These robots are now used in many fields, such as healthcare, sports, industry, distribution, and even everyday services. Mobile robots have become valuable helpers in numerous areas, performing tasks that range from simple chores to highly advanced operations. They are used in planetary exploration, factory automation, emergency rescue missions, amusement, logistics, healthcare, and much more. While robotics are commonly associated with industrial use, they are also becoming increasingly important in non-industrial applications, helping humans in countless ways.

2.Aim and Objective:

When discussing the aims and objectives of this project, I have explored the locomotion and mobility of mobile robots and how they can be used for various tasks. These robots offer great advantages, as their improved mobility makes them valuable in different industries, including manufacturing, agriculture, and healthcare. Advances in robotic locomotion and mobility also have the potential to significantly benefit areas like networking, collaborative work, the global food industry, and food processing.

To start my research, I read a journal report that explains the movement and mobility of robots in detail. Mobile robots generally fall into two main categories: legged locomotion and wheeled locomotion. These two types are often compared, and another study suggested that the challenges with both types could be addressed by creating hybrid locomotion. A hybrid system would allow robots to move efficiently on any surface while using less energy and achieving faster speeds.

This research shows that there is vast potential for mobile robots in many fields, and enhancing their capabilities could help us perform tasks more effectively. Mobile robots are becoming especially popular in industries like warehousing and distribution centers due to their advanced mobility. Additionally, they are highly beneficial in environments that are dangerous for humans, such as nuclear power plants or factories with high radiation levels.

One of the major advantages of mobile robots is their advanced computer vision and ability to use sophisticated sensors to detect objects in their surroundings quickly and accurately. These features make mobile robots suitable for a wide range of tasks and industries, offering innovative solutions to challenging problems.

3. Literature Review:

3.1 Tracked Locomotion Mechanisms for Ground-Based Robots:

In the article by Luca Bruzzone (2022), the author discusses the tracked locomotion mechanisms for ground mobile robots. The report focuses on describing locomotion and mobility and aims to address the challenges of two main types of locomotion: wheeled locomotion and legged locomotion. Legged locomotion allows robots to move across different types of terrain, but it operates at a slower speed. On the other hand, wheeled locomotion offers greater speed and energy efficiency but struggles with climbing over obstacles in uneven environments.

To tackle these issues, the report highlights industrial and academic research efforts to develop hybrid locomotion robots. These robots combine the strengths of both wheeled and legged systems, aiming to create a more versatile solution for navigating various terrains over the long term.

Service robotics is becoming increasingly important in this era of AI and robotics, with significant potential to handle a wide range of tasks. This has led to extensive research from both corporate and scientific perspectives. While tracked locomotion provides solutions for surface-level challenges, adopting a hybrid approach to locomotion and mobility addresses these problems more comprehensively.

The primary goal of this article is to demonstrate the methods and principles for designing effective locomotion systems for tracked ground mobile robots (TGMRs). It provides a systematic approach based on key factors like body structure, track features, and track types to develop the most suitable and efficient designs for robotic applications in different environments. (Bruzzone, 2022)

3.2 Analysis of Service Robot Mobility:

This article by Hwan-Joo Kwak (2022) demonstrates the mobility and movements of robots for various applications, categorizing their features into aspects such as mobility and autonomy. The study primarily focuses on the utilization of service robots in industrial, commercial, and academic settings.

A significant challenge highlighted in the publication is the difficulty of managing the boundaries of operational areas for service robots, as these are not always clearly defined. To address this, the study compares three different types of robots in their respective work environments.

Robots with three to four wheels are demonstrated to be highly effective in large spaces such as offices or factories, where their mobility is well-suited. Bipedal robots, on the other hand, are better for smaller spaces like homes or compact workplaces. Quadrupedal robots excel in outdoor environments due to their stability and adaptability.

The article also demonstrates the importance of improving robot locomotion as a key factor in the long-term commercialization and industrialization of service robots. These advancements are crucial for increasing their efficiency and functionality across various fields. (Kwak, 2022)

3.3 Principles of Locomotion in Mobile Robotic Systems:

In the article by F.L. Chernousko (2022), the movement and mobility of robots across various surfaces are explored, focusing on the locomotion concepts for robotic systems. The study highlights how robots adapt their speed and energy depending on the surface they are navigating. Different forms of mobility utilize a variety of mechanisms, such as wheels, tracks, legs, and propellers.

The journal also discusses the multibody robotic system, which is central to understanding the movement of these robots. Additionally, research into locomotion and mobility is compared to the motion patterns of living organisms like fish, insects, and mammals. The study investigates and analyzes the different types of mobile robot locomotion, including those based on wheels, legs, and tracks, emphasizing periodic changes in movement. Further research is done to explore the dynamic and optimal modes of locomotion and mobility, aiming to improve efficiency and adaptability in various environments. (Chernousko, 2022)

3.4 An Overview of Mobile Robots: Concepts, Approaches, Theoretical Framework, and Applications:

In the article by Francisco Rubio (2022), the author explains the theories, practices, and real-world uses of mobile robots. The main goal of this journal is to give a clear overview of mobile robots by summarizing important information. It covers topics like robot movement, sensing, thinking, and navigation. The article also discusses the future of robots, focusing on changes and advancements that might happen.

With improvements in cognitive systems, AI, speech communication, and human-robot interaction, mobile robots are becoming more useful in various fields. These include security, military defense, dangerous work, and space exploration. Mobile robots will also be helpful in other industries, such as healthcare, manufacturing, and agriculture. As these robots become more advanced, they will have a big impact on areas like food production, processing, and global cooperation. One example of mobile robots' potential is autonomous vehicles, which show how robots can change many industries. (Rubio, 2021)

3.5 The mobility performances of the new wheeled and legged hybrid mechanisms system robot iSRo:

In the journal by Ardyansyah (2022), published by ICCAS-SICE in 2009, the use of robotics in modern engineering and natural science is explored, with a particular focus on the use of robots in field rescue operations. The article covers the concept of locomotion and mobility for the new hybrid wheeled and legged robot mechanism. These robots must tackle a variety of challenges due to the complex environments and obstacles they encounter. To address this, robots require strong mobility performance to overcome obstacles during movement.

To solve this issue, a hybrid robot combining both legged and wheeled designs was developed. The robot's design includes 10 basic movements that significantly enhance its mobility, making it more efficient in complex tasks.

This study highlights new methods for improving mobility and locomotion by using hybrid robots for a range of activities. These robots are increasingly being used in demanding and dynamic industries. By combining their basic movements with those of other robots, they can adapt and learn to navigate difficult situations.

The article also discusses future developments in robot design, including mechanical optimizations for the robot's structure and the use of advanced control systems, such as algorithms based on recurrent neural networks, to improve robot behavior and learning capabilities. (Ardyansyah, 2022)

3.6 Soft Mobile Robots: A Review of Soft Robotic Locomotion Modes

In the article by M. Spenko (2021), the author explores the field of soft robotics and how these robots achieve movement through flexible, deformable structures. Unlike traditional rigid robots, soft robots can bend, stretch, and adapt to their surroundings, making them capable of navigating complex and unstructured environments. This adaptability allows them to excel in areas such as medical applications, search-and-rescue missions, and environmental exploration, where precision and flexibility are essential.

The article categorizes soft robotic locomotion into various modes, including crawling, swimming, flying, and jumping. These robots use unconventional actuation methods like pneumatic and hydraulic systems, allowing them to move smoothly and continuously without rigid joints. Researchers have drawn inspiration from biological organisms such as octopuses, worms, and snakes to develop robots capable of efficient movement across diverse terrains, from underwater to rocky surfaces and even within the human body for medical tasks.

However, soft robots face several challenges. One major limitation is their relatively low energy efficiency, as many soft robotic systems require external power sources or bulky air compressors. Another challenge is achieving precise movement control, as their flexible materials make it harder to direct motion accurately. Additionally, durability is a concern, as soft robots often experience wear and tear more quickly than their rigid counterparts.

The article discusses ongoing research to overcome these challenges, focusing on improving material strength, optimizing energy efficiency, and enhancing control systems. By advancing bioinspired designs and innovative materials, soft robotics is set to transform industries and unlock new capabilities for autonomous machines. (Spenko, 2021)

3.7 A Hybrid Tracked-Wheeled Multi-Directional Mobile Robot

Ben-Tzvi and Saab (2019) explore a hybrid approach to mobile robot design in their article, proposing a tracked-wheeled multi-directional robot that blends the benefits of both tracked and wheeled locomotion. Their goal was to overcome the traditional limitations of each system: tracked robots are great for rough terrains but tend to be slower, while wheeled robots excel on smooth surfaces but struggle with uneven ground. By combining both, the authors create a more adaptable robot capable of navigating a variety of environments. This hybrid design makes the robot suitable for challenging tasks such as search-and-rescue operations, industrial inspections, or exploration missions in dynamic settings.

What stands out in this design is its ability to move in multiple directions without having to rotate. Using omni-wheels alongside the traditional tracks, the robot can move side-to-side, diagonally, and even in tight spaces, offering much more agility compared to typical wheeled or tracked robots that can only move forward or backward. This multi-directional capability is a game-changer for environments where precise movements are necessary, like navigating through cluttered spaces or working in confined areas.

Despite the advantages, the article also highlights the challenges in developing such a hybrid system. The coordination between the wheeled and tracked components is complex, requiring careful management to balance speed, power consumption, and stability. Achieving the right balance of these factors is critical to ensure the robot performs efficiently on different terrains without compromising any of its capabilities.

In conclusion, Ben-Tzvi and Saab's work sheds light on the potential of hybrid robots, offering insights into how combining different locomotion systems can push the boundaries of robot mobility. Their research sets the stage for more versatile, high-performance mobile robots in a variety of applications. (Saab, 2019)

4. Analysis of Findings:

4.1 Motion Resistance Due to the Track-Terrain Interaction:

The Bekker Model describes the process of assessing the interaction between tracks and the ground. For a track with uniform contact pressure, the sinkage z0 is defined as:

$$z_0 = \left(\frac{p}{k_c/b + k_\phi}\right)^{1/n} = \left(\frac{W/bl}{k_c/b + k_\phi}\right)^{1/n}$$

p is the normal pressure; W is the normal load on the track & b and l are the width and length of the track; kc, kφ, and n are characteristic parameters o.

$$R_c = b\left(\frac{k_c}{b} + k_\phi\right)\frac{z_0^{n+1}}{(n+1)}$$

Due to the presence of yielding terrain in front of the track; the bulldozing resistance Rb can be calculated employing the following expression

$$R_b = b\left(0.67 \cdot c \cdot z_0 \cdot (N'_c - \tan\phi')\cos^2\phi' + 0.5 \cdot z_0^2 \cdot \gamma_s \cdot \left(\frac{2N'_\gamma}{\tan\phi'} + 1\right)\cos^2\phi'\right)$$

4.2 Mobility of Service Robots with multiple Wheeled:

4.2.1 Different Robots Locomotion:

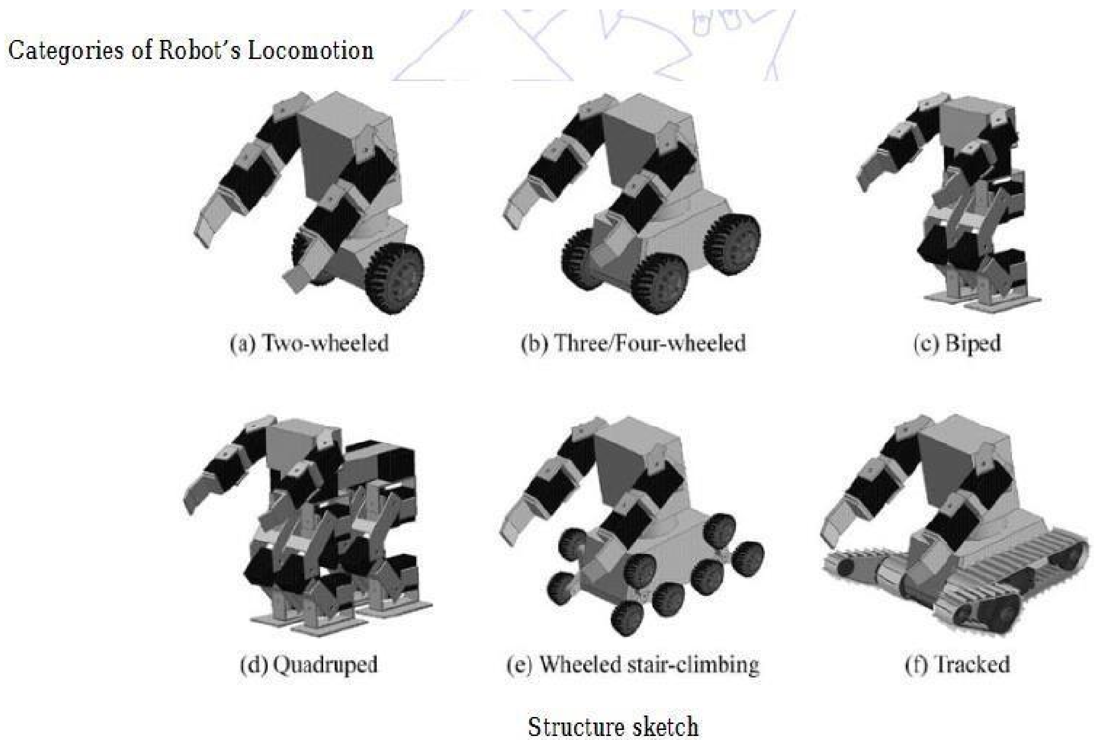
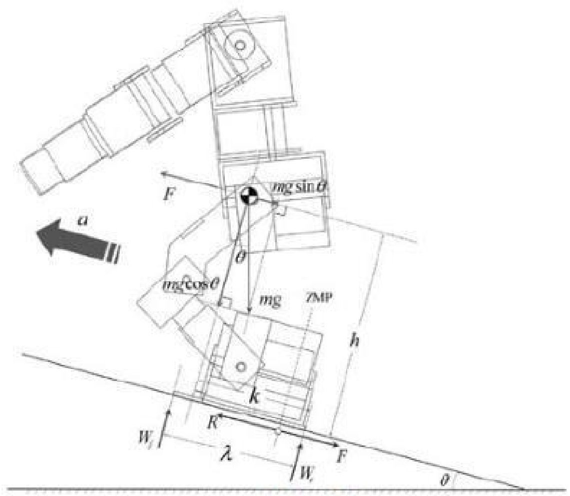


Figure 1: Image of different robots locomotion

One wheeled Locomotion (Biped):



(c) Biped

Figure 2: Image of One wheeled Locomotion

Equation for One wheeled locomotion (Biped):

This type of locomotion is based on the pushing of leg, not on the rolling of wheel. Pushing the ground, the center of mass will be pushed to the front by reaction. The normal forces of the front and the rear of foot are given by

$$W_f = (kmg\cos\theta - hmg\sin\theta + mah)/\ell \qquad (A7)$$

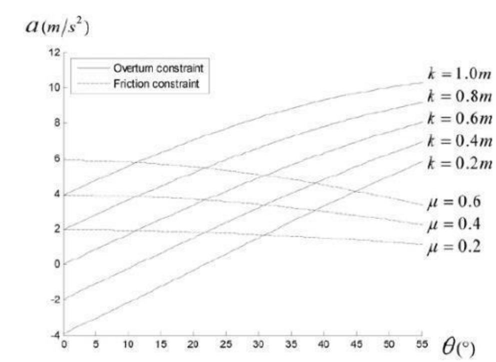
$$W_r = ((\ell - k)mg\cos\theta + hmg\sin\theta - mah)/\ell \qquad (A8)$$

and the friction force of foot is given by

$$R = \mu mg\cos\theta \qquad (A9)$$

Similar to the four-wheeled robot, the bipedal robot must satisfy $W_f, W_r \geq 0$.

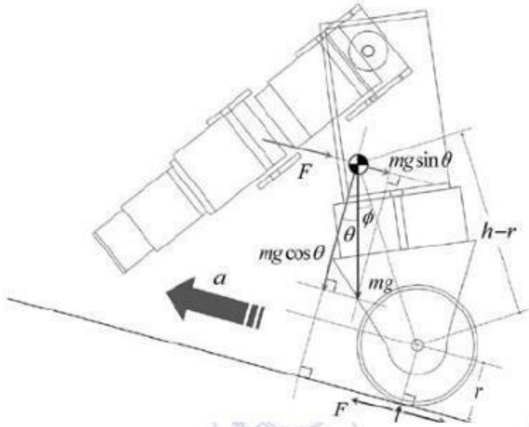
$$-g\left(\frac{k}{h}\cos\theta - \sin\theta\right) \leq a \leq g\left(\frac{\ell - k}{h}\cos\theta + \sin\theta\right) \qquad (A10)$$



(c) Biped

Figure 3: Image of one wheeled locomotion equation

Two wheeled Locomotion:



(b) Two-wheeled
Fig. A1 Schematics of robots on the slope

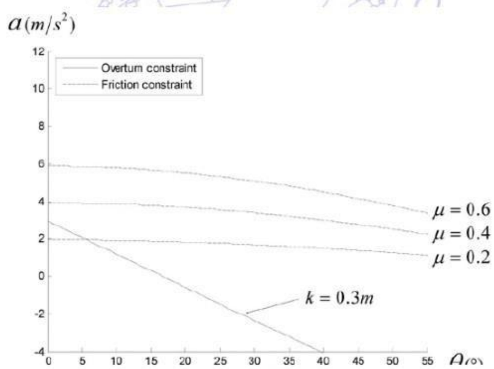
Figure 4: Image of two wheeled locomotion

Equation for Two wheeled locomotion:

TWO-WHEELED:

In contrast to the four-wheeled robot, the mobility of two-wheeled robot only dependent on the friction force of wheels. Adjusting the lean angle of body ø, the robot can accelerate to a(m/s^2) stably.

$$a = g\left(\frac{(h-r)\sin(\theta+\phi)\cos\theta}{(h-r)\cos(\theta+\phi)+r} - \sin\theta\right) \quad \text{(A6)}$$



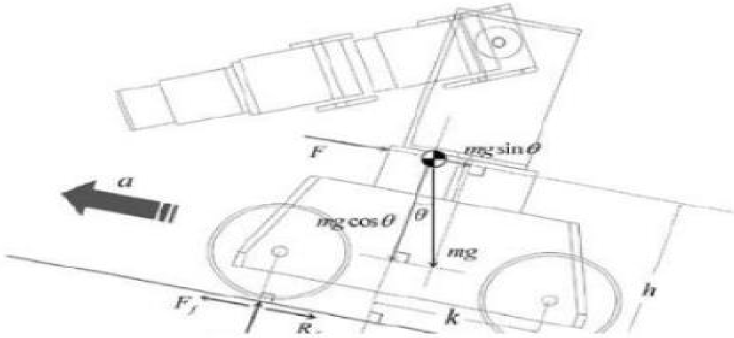
(a) Four-wheeled

Fig. A2 The maximum acceleration versus the angle of slope (*h=1m, g=9.8m/s2, λ=0.6m*)

Fig. A2(b) describes the acceleration values for the stable equilibrium condition, according to the lean angle of body ø. Leaning to the front, the two-wheeled robot can increase the acceleration within the constraint of friction constraint.

Figure 5: Image of equation of two wheeled locomotion

Four wheeled Locomotion:



(a) Four-wheeled

Figure 6: Image of Four Wheeled Locomotion

Equation for Four wheeled locomotion:

FOUR-WHEELED:

The normal forces of the front and the rear wheels are given by

$$W_f = \left(kmg\cos\theta - hmg\sin\theta - mah\right)/\ell \quad \text{(A1)}$$

$$W_r = \left((\ell - k)mg\cos\theta + hmg\sin\theta + mah\right)/\ell \quad \text{(A2)}$$

and if the robot is designed with four wheel drive, the friction force of wheels is given by

$$R = R_f + R_r = \mu mg\cos\theta \quad \text{(A3)}$$

The normal forces of wheels must be positive in order not to be overturned, and robot must not be slipped because of the low friction force: Wf, Wr $\geqslant$ 0 and R $\geqslant$ ma. Using this constrains in (3)-(5) gives:

$$-g\left(\frac{\ell - k}{h}\cos\theta + \sin\theta\right) \le a \le g\left(\frac{k}{h}\cos\theta - \sin\theta\right) \quad \text{(A4)}$$

$$a \le \mu g\cos\theta \quad \text{(A5)}$$

Fig. A2(a) shows the maximum acceleration according to (6) and (7). The lower acceleration is only available, as the slope steepens and the coefficient of friction decreases.

Figure 7: Image of equation of four wheeled locomotion

5. Conclusion:

After completing this report, I’ve learned that mobile robots can be used for many different tasks, which makes our daily lives easier. The report also highlights that improving robots will help us solve problems more efficiently. We can already see many robots performing tough jobs that would be very hard for people to do, such as in dangerous environments or during disaster recovery. As technology advances, the potential applications for mobile robots continue to expand, bringing new possibilities for various industries.

A lot of research is focused on improving how robots move. This is crucial because robots need to work in different and often unpredictable environments. One development in this area is combining legged and wheeled movement into one robot, allowing for greater versatility and adaptability. The two main types of movement in robots are legged and wheeled locomotion, each offering distinct advantages. By blending both, we can create robots that are capable of navigating challenging terrains while maintaining the speed and efficiency of wheeled systems.

This growing field of research is paving the way for the next generation of robots, which could have a significant impact on industries like healthcare, manufacturing, and even space exploration.

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