A Theoretical Review of Mobile Robot Locomotion based on Mecanum Wheels

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A Theoretical Review of Mobile Robot Locomotion based on Mecanum Wheels

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Abstract: The motivation behind this paper is to introduce a broad survey identified with pragmatic applications for portable robot stages dependent on specific wheels. In today's technology of mobile robots, Omni-directional wheels are trending in almost every field such as flying robot, swarm robotics and humanoid applications etc. Among them, Omni-Directional Mobile Robot (OMR) with mecanum wheels are mostly preferred due to their versatility, limited space, low cost and endurance. They can undoubtedly navigate in a jam-packed environment with dynamic imperatives, or parochial regions. This paper describes the highlights of the practical application of the mecanum wheel in different fields with their classifications, methodologies and comparison with the conventional wheels. Their merits and demerits and future utilities in the application of mobile robot navigation are also proposed in this paper.

Keywords: Omni-directional vehicle; Mecanum wheel; Mobile Robotics; Wheeled mobile robot (WMR); Locomotion.

1. Introduction

Omni-directional mobile robots with mecanum wheels were able to execute the holonomic motion in all directions without any effort in turn. This mechanism benefits the mecanum wheels to be unique and capable to navigate in narrow and complex path and the ability to accomplish reliable omni-directional drive. However the WMR can only able to execute the basic functions but failed to perform holonomic drive with rotational and translational movements. The mecanum wheels have been utilized in advanced mechanics, industry and manufacturing sector coordination for a long time. The literature survey associated with this form of wheel is mecanum, which describes structures that rely on wheels to suppress broad boundaries where the construction did not rely on display wheels by evaluating and separating existing ones. Exceptionally, these abilities make the vehicle an incredibly amazing manoeuvre, which can be extremely useful in various applications for indoor and outdoor locomotion. The different types of wheels such as, Omni-directional, universal, ball-driven, steerable and mecanum etc. have been taken from available literature and discussed their feasibility for different driving situations.

1.1 Background of work

The 1st Mecanum wheel was invented by B. E. Ilon in 1972[1)]. In history, there were many surveys on WMRs, some of which additionally cover OMRs. The first primary survey of WMRs was done in 1986[2)]. In which the authors summed up the kinematics of wheeled versatile robots and examined the current WMRs. From last three decades the study/research on mecanum wheels for mobile robot locomotion has been gaining increasing among the scientific community. Many aspects have been changed in today's mobile robotics wheels. Last two decades, further review of WMRs have concentrated on mecanum wheels[3)]. This exploration only restricted to OMRs dependent on mecanum wheels. Two years later, Kalman's work[4)] centered on particular forms of OMRs with configurable wheels about vibration characteristics and OMR modelling. Song and Byun[5)] were the first to implement steerable omni-directional wheels with a one-degree-of-freedom controlling framework. Steerable wheels were found to have decent instability. Hanzhen Xiao, Dengxiu Yu, C.L. and Philip Chen[6)] introduced the normal slippage issue that happened in mecanum wheels. They were able to execute their goal by using visual dead-retribution as a slip-versatile sensor. These techniques utilized an onboard camcorder to measure and compute the speed and heading angle of the vehicle. Gokhan Bayar and Salih Ozturk[7)] created two Omni-directional versatile wagons and restricted them by using omni-directional circulated mechatronics regulators. The vehicle was controlled using regulator region network modules. Zhe Sun, Shujie Hu, Defeng He, Wei Zhu, Hao Xie and Jinchuan Zheng[8)] suggested an inertial route structure for a mecanum-wheel programmed guided vehicle and investigated slippage phenomenon. Yoon, Park SB & Kim JS[9] devised a method to adjust the roller slippage-induced location inaccuracies by using sensor combination techniques. Kundu, Mazumder O & Lenka PK[10] provided a concept for a four-wheeled Omni-wheel chair and its detail design. These versions of mecanum wheels were designed to reduce wheel slippage and vibrations. Serrano, Kuzyk R & Solana G.[11] proposed curved and semi-round calculations for mecanum wheel layouts. The approach utilized in this study was created to reduce the tracking errors.

The locomotion mechanism is the main feature of robot navigation, which is a key aspect of mobile robotics. Throughout the paper, we've explored the key issues and approaches for each wheel mechanism. Because of its ease of installation and high manoeuvrability, Mecanum wheels have been used in the majority of navigation-based systems. The mecanum wheels are a preferable alternative for applications with a high payload, such as heavy-weight carriers as well as energy consumption are less important. Meanwhile, mecanum wheel are better suited to applications where accuracy and speed are more important. In this paper, we reviewed the state of the art in the omnidirectional WMR literature and provided the historical evolution of wheeled mobile robots in terms of omnidirectional navigation based on each category of wheels. We highlighted some of the most innovative ideas to yet, as well as a basic understanding of key terminologies in wheeled mobile robotics. Furthermore, we examined the many techniques and control features that have been used to achieve and improve mobile robot controllability.

In this paper, Holonomic and non-holonomic robots and along with their associated wheels i.e. conventional wheels, steering wheels, caster wheels, universal wheels and mecanum wheels are considered. This paper discusses mainly about different approaches of WMRs with different wheel based locomotive systems and advancement in methodology for holonomic drive systems based on mecanum wheels. The main objective of this paper is to present the state of art review of OMRs as well as classify the improvements and trends in holonomic approaches and their wheel mechanisms. This paper presents the methodology that will improve the research direction of mecanum wheels and provides the detail information in the broad field of omni-directional wheels. This study also helps the researchers to serve as platform for developing OMRs on different applications.

2. Mobile robot wheels

This section describes about the various types of wheels used in mobile robots locomotion. The mobile robot wheels are basically two types; i.e. Conventional wheels and special purpose wheels. The detail classification of mobile robot wheels are shown in Fig. 1.

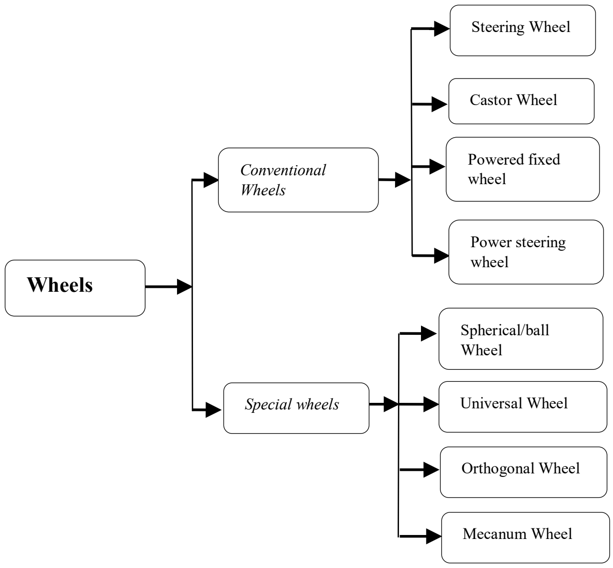


Fig. 1: Classification of mobile robot wheels

2.1 Steering Wheels

The steering wheel is similar to the conventional wheel but different in mechanical design. The term steering refers to a certain steering system that permits a conventional wheel to rotate along its vertical axis. The rotation of steering wheels is powered by a motor and they can be guided around an axis perpendicular to the axis of rotation as shown in Fig. 2 (a) & (b) in which the axes of rotation and steering does not intersect. Steerable wheels are utilised in a wide range of applications, including plane front wheels, clinic chairs, Television tables and self-contained portable robots etc.[12].

2.2 Caster wheels

The caster wheel is similar to the steering wheel but the working principle is different. Castor wheels are capable of carrying heavy payloads and their sensitivity to the conditions of the ground is smaller. These wheels are narrowly divided into two types by manufacturers: fixed wheels and pivot wheels. In a fixed wheel, the wheel can only move forward and backward. In other case, pivot wheels will rotate 360° passively as shown in Fig. 3[13].

2.3 Spherical/ball wheels

The spherical wheel also known as Omni-ball wheel is derived from a functioning turn hub that drives the controlling movement of the entire wheel in opposite way to the dynamic hub and two hemispherical wheels that revolves latently without creating pushing movement in the flat hub as show in Fig. 4[14].

2.4 Universal wheels

The universal wheel is identical to mecanum wheel and the only difference is in its design of passive rollers. In this, the axis of roller is perpendicular to the steering frame of wheel and the angle between the roller and hub is 90° as shown in Fig. 5[15].

2.5 Orthogonal wheels

The orthogonal wheel (shown in Fig. 6) is another type of holonomic wheel which is influenced by universal wheels. The orthogonal wheels can produce both restricted and unrestricted drive directions, and they can be configured using two different assemblies. These wheels can be used to change the direction of a movement without change in the platform or to power an omni-directional drive[16]. The orthogonal wheel is one in which the rollers are mounted at 90° angle to one another. Omni-Drives require exact points (60° for a Kiwi and 90° for a Holonomic) and in case you are not close to consummate your robot will have some weird driving attributes. However, the mecanum are likewise more effective in forward and turn around (like a typical wheel) with horizontal portability. Omni-Drives have a much lower proficiency (~50%) which results in genuine omni-directional movement. Additionally, omni-drives require considerably more expertise to drive than a mecanum drive.

2.6 Mecanum wheels

Mecanum wheel was first developed by[1]in 1972. Such wheels can rotate around an active wheel's axis. (i. e. the base wheel) and the rollers' axis at a 45° angle. The mecanum wheel has 3 DOFs consisting of a steering drive, roller motion and vertical axis turning slip at the point of interaction. The rollers on the mecanum wheel are positioned at an angle other than 90 degrees (typically ± 45 degrees) as shown in Fig. 7. The roller's contact point with the surface is discontinued, resulting in vibrations in the base frame of the robot specifically on uneven surfaces. In omni direction wheels, the problem of vibration arises due to the discontinuous contact with the floor. The vibration problem has been reduced by using extra rollers in the mecanum wheel. But usage of extra roller leads to complexity in design and suspension. J. Agullo, S. Cardona & J. Vivancos[17] proposed sliding motion control analysis with a design analysis of wheel. D. Kim, W.H. Kwon & S.P. Hong [18] have performed the geometric and kinematic study of a wheel and design the feedback system. L. Zhang, C.J. Zhou & Kukayou[19] developed a motion control analysis with fluctuation and oscillation. J. Wu, Lv, L. Zhao, R. Li & G. Wang[20] discussed about car-like OMR and investigate the influence of roller. A. Sofwan & A. Goni[21] designed proportional-integral-derivative controller for mecanum wheels.

(a) (b)

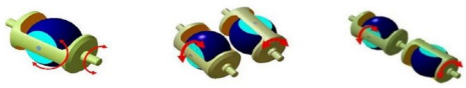
(a) Steering wheel without offset with axes of rotation (b) Steering wheel with offset with axes of rotation

Fig. 2: Steering Wheel

Fig. 3: Caster Wheel

Fig. 4: Spherical ball Wheel

Fig. 5: Different designs of the universal wheel



(a) (b) (c)

Fig. 6: (a) Single orthogonal wheel (b) Lateral configuration (c) Longitudinal configuration

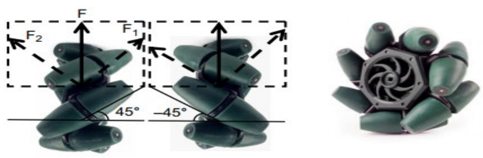


Fig. 7: (a) Mecanum wheel with α = 45 (left wheel) (b) mecanum wheel with α = - 45 (right wheel) (c) an actual mecanum wheel.

Source: (http://www.aceize.com/node/562.)

3. Mecanum wheel Mechanism

Many alternative techniques have been developed in many sectors of mobile robotics to achieve omnidirectional motion. Experts have been attracted to the Wheeled Mobile Robot because of its capacity to achieve maximum speed, ease of design and inexpensive implementation costs, the strength of inverse kinematic in algorithms and most importantly, their widespread use in human environments. This section describes the features of mecanum wheels (specifically for mobile robot) and its working principle.

3.1 Features of the mecanum wheel

Mecanum Wheel was designed in 1975 in Sweden in collaboration with BengIlon, a Swedish design firm and Mecanum AB[1]. With several rollers arranged around the wheel's circumference, the mecanum wheel is based on the primary drive standard. The angle between the roller axis and the primary wheel axis of the mecanum wheel is 45°, as shown in Fig. 8. The rollers are shaped in such a way that the mecanum wheel has a round form. The circumferential shape of the roller corresponds to the wheel's rotational force direction, gives the wheel's normal trajectory. The cumulative convergence of all these forces provides a resultant force vector in any given direction, depending on the speed and direction of each wheel, allowing the platform to freely move in the direction of the resulting force vector without changing the direction of the wheels.

The mecanum wheel possesses 3 Degrees of Freedom (DOF) consisting of a steering drive, roller motion, and vertical axis turning slip at the point of interaction as shown in Fig. 9. The wheel speed can be classified into two parts in the primary and secondary directions. The primary segment is coordinated along with the hub of the roller in interaction with the surface, while the secondary one is opposite to the roller hub[22]. A force vector is formed around the rotation of a wheel. The vehicle moves by simply controlling every wheel rotation and the direction can be altered spontaneously.

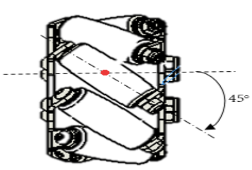


Fig. 8: Mecanum wheel

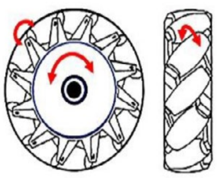


Fig. 9: Degrees of freedom In a Mecanum wheel[22]

3.1.1 Methodology of Mecanum wheel

The mecanum wheel's mechanism applies the wheel's force to the robot at a 45° angle rather than on one of the robot's axes. By applying the force at a 45° angle to the robot, it can change the magnitude of the resultant force vector to achieved motion of the mobile robot. Mecanum Wheels consist of axles and left and right-hand rollers. When the wheel contact with the ground, it is perpendicular and parallel to the vehicle frame's diagonal. In such a way, each wheel will produce a thrust that is almost parallel to the frame diagonal. By varying the rotational speed and direction of each wheel, the resultant force vectors from each wheel will provide both linear and rotational motions of the vehicle as shown in Fig. 10, enabling it to maneuvers about with narrow space. The sequences for motion for the mecanum wheels are (a-b-c-d-e-f) as shown in table 1.

Table 1. Motion of the mecanum wheels

The movement's direction	Wheel Actuation
(a) Forward motion	All four wheels move forward at the same time.
(b) Right motion	1,3 wheels forward; 2,4 wheels backward.
(c) Diagonal motion	1,3 wheels forward; 2,4 wheels standby.
(d) Turning motion	1,4 wheels forward; 2,3 standby.
(e) Rotatory motion	1,4 wheels forward; 2,3 wheels backward.
(f) Rotate about the centre point of one axle	1 wheel forward, 2 backward;3,4 standby.

The longitudinal force vectors have been added together, while the transverse force vectors have been cancelled, resulting in forward/backward motion when all four wheels are driving in the same direction at the same speed. When one wheel is pushed in one direction and the other is driven in the opposite way, the transverse vectors cancel each other out, but the longitudinal vectors pair to generate a torque around the vehicle's central vertical axis, resulting in a stationary rotation of the vehicle. When the diagonal wheels are pushed in one direction while the other diagonal wheels are driven in the opposite direction, the transverse vectors add up while the longitudinal vectors cancel out, resulting in a sideways movement.

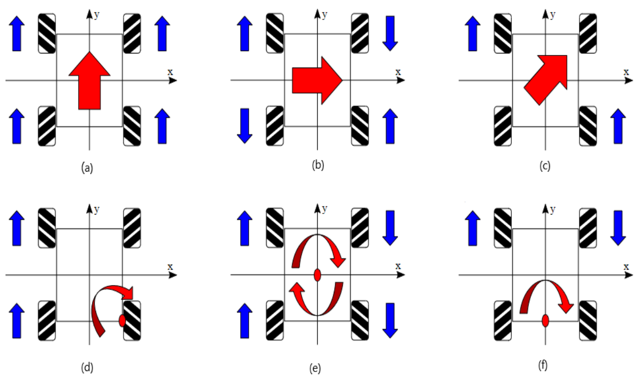


Fig. 10: (a) Forward direction motion (b) Right direction motion (c) Diagonal motion (d) Turning motion (e) Rotatory motion (f) Rotate about the centre point of one axle[23].

4. Comparison of different wheels

In this section, comparative analysis of conventional wheels and special wheels (universal wheels, mecanum, and orthogonal wheel) are explained with their merits and de-merits.

The robot design of the mecanum wheel will perform planer motion with 3 DOF. It will be able to move in both directions as well as rotate around its own centre of gravity. However, conventional vehicles lack the capacity to individually control each DOF, because conventional wheels are unable to move in a direction parallel to their axis. In two-dimensional space, every position and orientation can require complex manoeuvres and path-planning[24]. In terms of maneuvering in tight spaces, mecanum wheel vehicles have significant benefits over conventional platforms, such as carlike Ackerman steering or differential drive systems. These vehicles can turn on the spot and accomplish jobs in surroundings with static and dynamic obstacles, as well as in tight areas.

Technical parameter of conventional & special wheels used in mobile robots are shown in Table 2.

Table 2. Different wheel types and their technical Parameters.

Type of wheel	Types and setups	Minimum required diameter	Maximum Payload
Caster Wheel (CW)	Standard CW, Decoupled CW	25.4 mm	15 kg
Steering Wheel (SW)	Standard SW, Decoupled SW	50.8 mm	45-58 kg
Universal Wheel	Single and Doubled arrangement of rollers	101 mm	3- 35 kg
Mecanum Wheel	45°rollers 135°rollers	100 mm	8- 16 kg

The mechanical properties of multiple wheels and their combinations are compared in Table 3.

Table 3. Design Parameters

Types of wheel	DOF	Wheels configuration	Minimum wheel
Caster wheel	3	1	1
Steering wheel	2	2,3, 4 wheels	2
Universal wheel	3	3 or 4 wheels	3
Mecanum wheel	3	4 or more wheels	4

5. Uses of Mecanum wheel in different fields

Mecanum wheel vehicles can be used essentially in different external applications for medical field, space missions, path planning etc.

5.1 Medical field

Wheel chairs are mainly used for elder people in order to have an independent manoeuvrability which includes socialization opportunities, self-work and leisure occupations etc[25]. These wheel chairs improves daily routine activities for elders who are unable to walk, have low stamina and strength or unable to propel and live dependently. The Centre for Intelligent Information Processing System (CIIPS) at the University of Western Australia developed omni-directional wheelchairs that

Fig. 14: NASA Mobile Platform OmniBot[29]

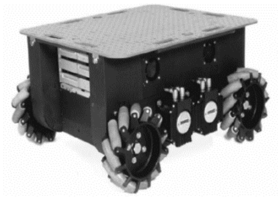


Fig. 15: Uranus omni-directional mobile robot[31]

allow the client to simply drive the vehicle in all directions, even on difficult terrain.

Fig. 11: Omnidirectional wheelchairs[26]

This project of mecanum wheels has improved battery life, human interface, suspension system, and chassis with motor drivers as shown in Fig. 11. These upgrades in mecanum wheels will transfer the partially driven wheel chair in to perfectly usable chair.

5.2 Space field

MarsCruiserOne[27] is a habitable rover mainly developed for future space missions like exploration on moon and mars etc as shown in Fig. 12. This vehicle is designed in such a way that it can navigate on hilly and rocky terrains with a speed of 5-10 km/h[27].

5.3 Industrial sector

Airtrax ATX-3000 is an industrial fork lift designed for applications such as transportation of loads to longer distance or sideways by means of narrow path or standard sized doors as shown in Fig. 13. This robot is unique as its omni-directional movement allows it to navigate in complex areas where turns are not easily possible and precise control is required. ATX is equipped with 48 volt transistor, altering speed, lift and state of art technology.

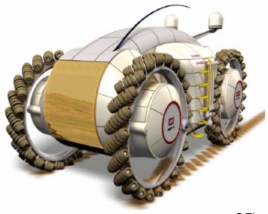


Fig. 12: MarsCruiserOne[27]

Fig. 13: Lift truck airtrax sidewinder[28]

5.4 Military field

The manoeuvrability of OMR is widely used in various outdoor applications such as mine operations, search & rescue, military activities and planetary explorations. These wheels are also used in hazardous explorations carried by NASA.

The goal of the Omnibot project as shown in Fig. 14 is to carry various tests with automated mobile robots and umbilical technologies. This Omnibot is equipped with four brushless motors connected to mecanum wheels. This robot can be operated with RF (Radio Frequency) enabled remote controller and has a range of 1800 feet[30].

5.5 Field of education

Uranus[31] as shown in Fig. 15 was the first OMR with mecanum wheels sensors and controllers, developed and fabricated in Carnegie Mellon University[32-33]. This robot was built to enhance the research in indoor robot navigation. It is widely used for carrying payloads.

5.6 Other applications

The main intention behind CommRob project was to progress in mobile robots with advanced technologies for human environments. The Interactive Behaviour Operated Trolley (InBOT)[34] as shown in Fig. 16 tackles with day to day multiple problems in human life such as find the required product in shopping malls by overcoming the use of cart as some times it may be heavily loaded and not possible to push for elderly people. InBOT has the abilty to execute multiple tasks and navigation.

Fig. 16: The interactive trolley for shopping[34]

6. Advantages & Challenges of Mecanum Wheel

The main benefit of this type of wheel is that it is omni-directional, allowing for outstanding mobility and portability in congested areas. The mecanum wheel is a concept for a steering wheel that can navigate in any direction. Mecanum wheels have no additional friction when turning as compared to skid steer. A swerve/crab drive system will be more sophisticated than Mecanum wheels, and probably less reliable. Contrasted with different drives, mecanum wheels have no extra rubbing when turning which is a benefit of the mecanum wheel.

Due to the complex nature, tight tolerances, engineering growth and other factors, costly tooling is necessary to manufacture the wheel. The wheel's intricate architecture contains far too many individual components. The key issue with the mecanum wheel is that when it is in motion, sliding occurs and vibration can be detected. These wheels are costly, difficult to process (90 percent are metal), heavy, sluggish and have a long life expectancy (relative to the traditional rubber wheel). It is not suitable for use in a standard car because it is designed for low-speed driving.

7. Conclusion

In this article, the practical implementations of the mecanum wheels are presented in an overview. The key benefit of the wheel is addressed by the omni-directional property that gives, permitting outrageous mobility and portability in congested areas. In future mobile robotics evolution will continue in experimental design, kinematic and dynamic upgrades, operating technology and full of human-robot connection will be progressively fused into robots which are planned for various applications such as military operations and security, surveillance, hazardous environment, exploring in risky places and space investigation etc. It gives that by the universal property allow outrageous versatility and portability in a packed climate. The most recent pattern affirms that commercialization of computerized vehicles because of innovative progression in portable mechanical technology is relied upon to drive the market over one year from now and that open-source stages along with a decrease costs are relied upon to help interest for home-grown versatile robots like vacuum cleaners and yard trimmers.

Based on the various literature reviews, this paper will discuss the many advantages of the mecanum wheel in terms of its application and manoeuvres. As previously discussed, we designed a mecanum wheel chair for elderly people that can easily navigate in a jam-packed environment.

7.1 Future scope

In recent years, some mecanum wheel-mounted forklift designs have been developed to enhance their multi-directional manoeuvrability and viable applications. These functionalities are extended to improve mechanical performance and expand the complexity of the control system. The control, mechanism controls the sliding motion of the mecanum wheel with the help of the Lyapunov-based method. Vibration is also a major cause of the mecanum wheel, it's due to discontinues contact of the roller with the ground, so the redesign of the mecanum wheel with the help of a fork (design of a fork with the help of spring) is proposed. In such a way, the vibration of the mecanum wheel is minimized.

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