IARJSET
ISSN (O) 2393-8021, ISSN (P) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
Impact Factor 8.066 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 11, Issue 4, April 2024
DOI: 10.17148/IARJSET.2024.11418

Macnum Wheel: An Emerging Trend for Material Handling Equipment in Industries

Prof. S. V. Tawade[1]

Sanket Tambe[2], Rutik Thakur[3], Ajay Duduskar[4], Mukund Gaikwad[5], Ganesh Ghogare[6]

Assistant. Professor. Navsahyadri Group of Institutes, College of Engineering, Pune, India[1]

B.E. Students. Navsahyadri Group of Institutes, College of Engineering, Pune, India[2-6]

Abstract: The present automobile industries need execution of industrial robots due to standard in mass and batch size production of the vehicles. Design of omnidirectional vehicles is now a traditional way in automobiles sectors. The operating advantage of this kind of vehicle is on any kind of surface such as a rough, smooth, flat, and curved surface. A vehicle has the potential to get omnidirectional, if it operated on mecum wheel. By providing the omnidirectional ability vehicle has moving flexibility that such type of vehicle can work in any internal and external application. In present paper design and different applications of mecnum wheel for omnidirectional vehicle has been presented. Different design and fabrication and manufacturing steps are discussed.

Keywords: Omni-Directional Mobile Robot, Mecanum Wheel & Autonomous System

I. INTRODUCTION

The mecanum wheel was originated by Bengt in 1975 from Sweden. It I based on the theory that canter wheel is placed in between the number of rollers around its periphery at an angle. A normal force is translated in the direction of the wheel by the peripheral roller. The resultant force is developed by the individual elements of the roller, which in turn move freely without changing the direction of the wheel. In the present automation world, the demand for industrial robots are increasing. Many processes service industries are using mobile or movable robots for transmitting of raw material of finished product from one place to another place. It is observed that uses of industrial robots are common due to the reason of saving in time and money in transportation. The advantage of the omnidirectional robot is that it can move independently as well as work in three degrees of freedom. An omnidirectional vehicle can increase its movability in an effective manner. Although, it is a challenging task to apply mobile robots in many industrial sectors like cement industry, automobile industry, aerospace industry and defence organization. This industry required high skills and high movability at the same time. Manufacturing of different parts in such type of industries requires high labour cost as well as complexibility in operation. They designed the mecanum wheel with the set of standard formulas. The wheels were designed for educational purposes and as a prototype for a possible larger model [1]. They developed an omnidirectional robot o which consists of nine rollers. The robot is operated using direct current motors and they are directly coupled to the chassis [2]. This paper proposed an improved design for a mecanum wheel for Omni-directional robots.

This design improved the efficiency of mobile robots by reducing frictional forces and thereby improving performance theoretically. Paper theorized that surface plays an important part in the creation of force vectors of individual wheels [3]. The paper shows results for four-wheeled Omni-drive transport systems and certain ranges for trajectories and starting conditions, a curved path can be traversed faster than a straight-line path [4]. This paper shows the results of an electrical design of a robot that uses mecanum wheels. It shows the different variations in its tests [5]. The paper was an overview of the design of Omni-directional mobile robot using mecanum wheel [6]. The main advantage of this type of wheel was represented by the omnidirectional property that it provided, allowing extreme maneuvrability and mobility in congested environments [7]. In this paper, they introduced the new design of the Omni-directional mobile robot with mecanum wheel to overcome the weak points of their previous robots [8].

II. THE MECANUM WHEEL

Mecanum wheel was first developed by1)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.

DOI: 10.17148/IARJSET.2024.11418

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. [6].

Mecanum Wheel was designed in 1975 in Sweden in collaboration with BengIlon, a Swedish design firm and Mecanum AB1). 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 hub22). 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.

III. MANUFACTURING OF MECANUM WHEEL PARTS

Rollers are generally made of light materials. One can be used Teflon as it is light in weight and is one of the few polymers that can be manufactured on the CNC machines without unwanted deformation. Teflon, initially very smooth, tend to roughen over time, thus improving the grip of the wheel as it ages. The selection was based on two factors mainly the weight of the material and its ability to be machined. Teflon fulfilled both the criteria. For our wheels, one can required 8 feet length and 22 mm as diameter. Manufacturing of mecanum wheel consists of different parts like roller and rim. Following are the procedure for the fabrication of these parts. Machining of Teflon was done on CNC lathe machine. The final product goes various process, these are 1) Turning 2)Facing 3)Drilling 4)Radius Turning (Concave Profile) 5)Parting. It starts with the facing process which required reducing the length of the roller from 50 mm to 48 mm.Then turning tool was used to reduce the diameter of 22 mm to 20 mm. Then using radius turning operations one can achieve the required specifications of 20 mm diameter at the center and 15 mm diameter at its end. The drilling operation is used to drill a hole of 6 mm diameter for the attachment of studs. Lastly, parting process is used to remove the roller from the entire block of roller material. The figure shows the CNC code for manufacturing the roller. The final look of the roller was achieved. Studs and washers were attached to them to allow them to be attached to the rims. Threading was done at the end, while at the center it was allowed to remain the same. Studs are at a length of 74 mm, washers are of 1mm thickness. Nuts are M6 and threading is done in accordance to it. [3]

We present a design of an omni-directional mobile robot with Mecanum wheel and suggest a control method using the fuzzy technique. Our previous version of the mobile robot can be unstable due to the characteristics of the custom-designed Mecanum wheel or to the unexpected effect by suspension. To remedy these defects, we propose a new version of the custom-designed Mecanum wheel and a new structure design of mobile robot. To improve the performance of the robot we implemented a motor control algorithm using the fuzzy gain tuning scheme. The experimental results indicate that the developed holonomic mobile robot is better in performance than the previous robot. In this paper, we introduced the new design of the omni-directional mobile robot with Mecanum wheel to overcome the weak points of the previous robot. We implemented and tested the PID gain scheduling algorithm using the fuzzy system because it is hard to find the optimal values of the parameters, Kp, Kd, and Ki, in the conventional PID controller with the fixed gains. This al-

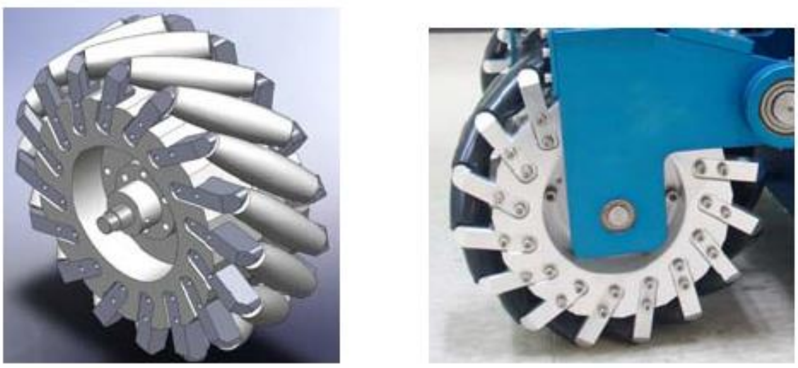

Fig. 1 New version of Mecanum wheel (left : CAD design, right : prototype)[11]

DOI: 10.17148/IARJSET.2024.11418

Motions of Omnidirectional platform

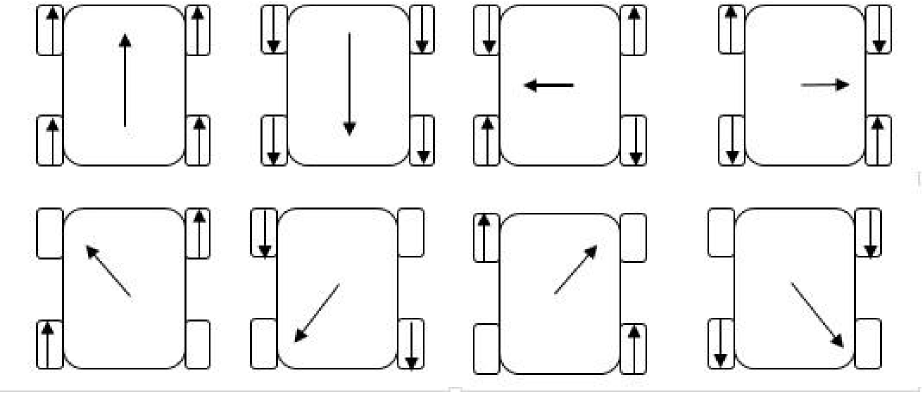

Fig2: Motions of Omnidirectional platform

A mobile platform with four omnidirectional wheels was introduced in this paper. The results were systematically obtained by using kinematic equations that were similar to those achieved from the experimental results. The results show that the platform performs full omnidirectional motions. This shows that by using Mecanum wheels in the platform the robot can achieve any direction between $0°$ to $360°$without changing its orientation Omni-differential locomotion is being using in current mobile robots in order to obtain the additional maneuverability and productivity. These features are expanded at the expense of improved mechanical complication and increased complexity in control mechanism.

Omni-differential systems work by applying rotating force of each individual wheel in one direction similar to regular wheels with a different in the fact that Omni-differential systems are able to slide freely in a different direction, in other word, they can slide frequently perpendicular to the torque vector. The main advantage of using Omni-drive systems is that translational and rotational motions are decoupled for simple motion although in making an allowance for the fastest possible motion this is not essentially the case [1].

Fig3: Omni wheel

IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.066 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 11, Issue 4, April 2024

DOI: 10.17148/IARJSET.2024.11418

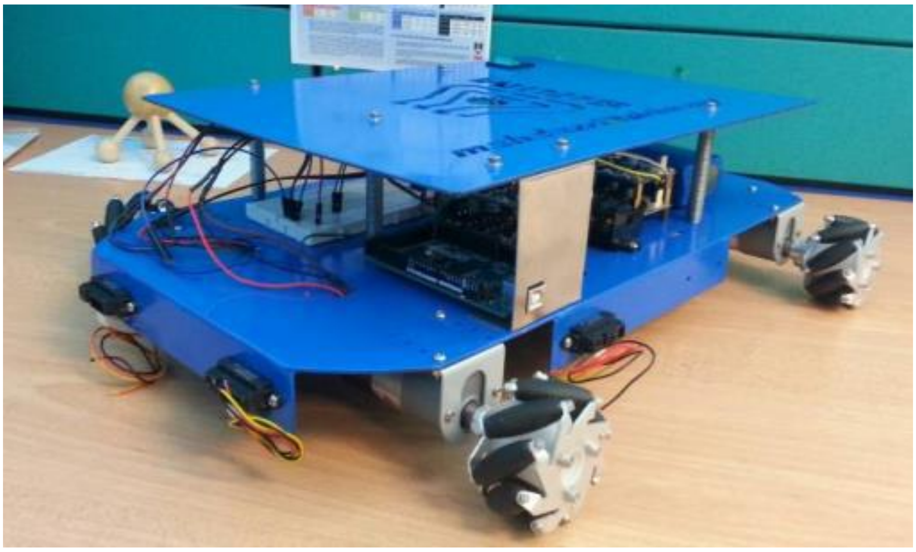

Fig 4: Mwar prototype [2]

Mecanum wheel Mechanism

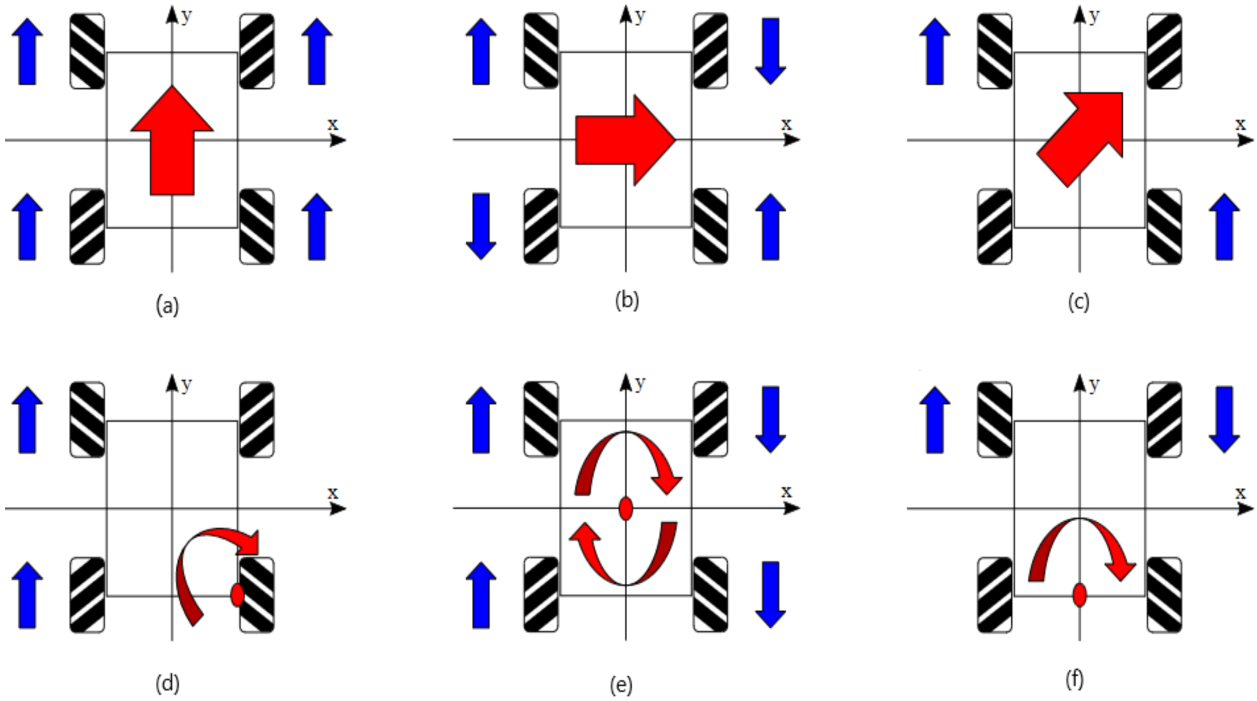

Fig5 : Mecanum wheel movement directions

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

IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.066 ⁘ Peer-reviewed & Refereed journal ⁘ Vol. 11, Issue 4, April 2024

DOI: 10.17148/IARJSET.2024.11418

(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 axle23). 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.

Macnum wheel applications

Fig. 6: NASA Mobile Platform OmniBot29)

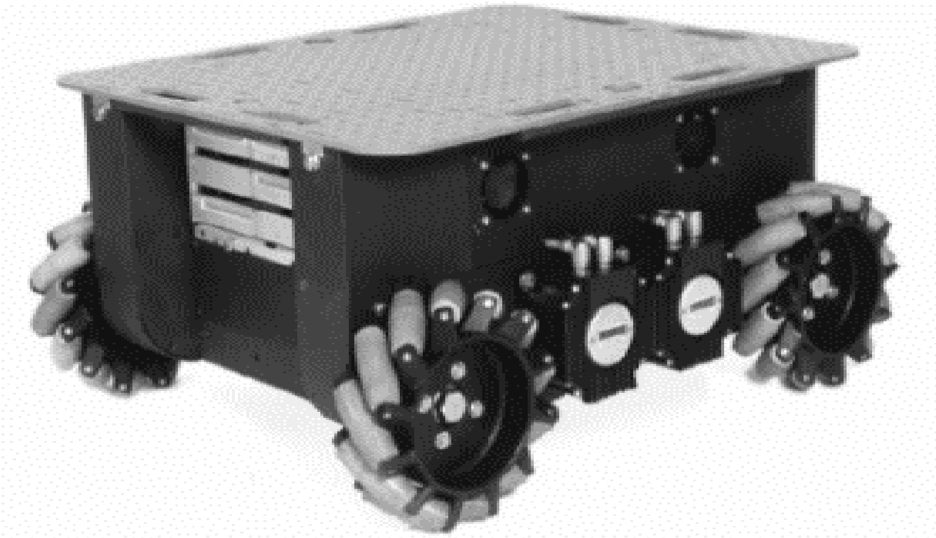

Fig. 7: Uranus omni-dire ctional mobile robot31)

IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.066 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 11, Issue 4, April 2024

DOI: 10.17148/IARJSET.2024.11418

Fig. 8: Omnidirectional wheel chairs

Fig. 9: Lift truck airtrax sidewinder28)

DOI: 10.17148/IARJSET.2024.11418

Fig. 10: The interactive trolley for shopping34)

Fig. 11: Airtrax Sidewinder lift truck

This paper presents a study of wheeled mobile robot WMR path tracking by presenting the kinematic modal of holonomic wheeled mobile robot with three mecanum controlled wheels. The advantage of mecanum wheels usage is to make the mobile robot movement in lateral and longitudinal directions smooth and to improve the tracking ability to travel in every direction under any orientation. This proposed type of WMR has three actuated input coordinates (angular velocities of the mecanum wheels) and three generalized output coordinates (robot linear translation along x, y axes and the robot orientation). The kinematic models of the WMR are based on a functional relation among configuration variables and their derivatives. It is a known fact that the WMR poses can be achieved in the configuration space but the path to reach these poses has complex step in the consideration. The mobility capability in the proposed design of WMR makes it suitable for different types of applications. The contribution in this work is the initiative to obtain the mathematical models of inverse and forward kinematics to analyse a new design of WMR with three mecanum wheels to simplify the task implementation of the robot by obtaining the suitable path to reach the mobile robot target. It has been taken in consideration that, the WMR motion is assumed as a pure rolling without any slipping.

IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.066 ⁒ Peer-reviewed & Refereed journal ⁒ Vol. 11, Issue 4, April 2024

DOI: 10.17148/IARJSET.2024.11418

Simulation example results presented in this work show the proposed control algorithm applied on two different cases of path tracking (circular path, infinity path) and the effect of WMR wheels angular velocities on the robot body velocities and robot position errors. The results show a good performance in minimizing the positioning errors during the implementation of its task.**[7]**

Mobile robots with omni-directional wheels can generate instant omni-directional motion including lateral motion without any extra space for changing thedirection of the body. So, they are capable of traveling in every direction under any orientation to approach their destinations even in narrow aisles or tight areas. Especially, if a construction tool is combined to the mobile robot, it can be a mobile construction robot to be able to move from one position to another. In this research the Mecanum wheel, which is most frequently utilized in industrial fields, is selected to achieve omni-directionality of the mobile robot. Through intensive experiments, performance evaluation of the developed omni-directional mobile robot was conducted to confirm the feasibility for industrial purposes. Velocity performance and straightness for each directional motion were selected as performance indices to assess the omni-directional mobile robot. Ultrasonic sensors in-stalled on the frontal and lateral sides were employed to measure the real-time distance between the mobile robot and the side wall of workspace. The linear position, angular position and velocity of the mobile robot were calculated with the distance information.

In this research, basic properties of the omnidirectional mobile robot based on Mecanum wheels, control system design, and experimental performance evaluation were treated. The suggested mobile robot has a squared mobile platform and four Mecanum wheels at each corner. By harmoniously coordinating the four Mecanum wheels, immediate forward/backward, lateral and rotational motion, in other words, omni-directional motion is guaranteed. In electrical design aspect, NI CompactRIO embedded real-time controller and C Series motion & I/O modules were employed. The operator can give driving signal of the mobile robot on the LabVIEW front panel. Ultrasonic sensors installed around the mobile robot can measure environmental situation such as distance between the mobile robot and the side walls. Based on this mechanical and electrical design, a real prototype was manufactured in this research project and performance evaluation for mobility and omni-directionality was conducted. After intensive experiments, it was confirmed that the developed mobile robot guarantees quite decent performances.[8]

The innovative method of modeling and kinematics simulation in RecurDyn are proposed, taking a Mecanum wheel platform(MWP) for omnidirectional wheelchair as research object. In order to study the motion characteristics and mobile performance of the MWP, the virtual prototype simulation model is established in SolidWorks, and virtual prototype simulation is carried out in RecurDyn.Theexperience of simulation for theMWPin RecurDyn is introduced, and the simulation steps and points for attention are described detailedly. The working states of the mobile system in real environment have been simulated through virtual simulation experiments. Four typical motion models including moving forward, moving laterally, moving laterally in the direction of 45∘, and rotation have been simulated in RecurDyn. The simulation results exactly reflect the motion of the MWP. By comparing the simulation results with the theoretical results, there are acceptable errors that are relatively less overall in the simulation results.The simulation results can be used to predict the performance of the platformand evaluate the design rationality, and design quality can be improved according to the exposed problem. This paper can provide reference for the simulation ofmobile platform by using RecurDyn. In order to study the motion characteristics and mobile performance of a Mecanum wheel platform for an omnidirectional wheelchair, the virtual prototype simulation model is established using SolidWorks, and virtual prototype simulation is carried out based on RecurDyn, before its physical prototype of MWP being manufactured. In this paper, the experience of simulation for the MWP by RecurDyn is introduced, and the simulation steps and points for attention are described detailedly. The working states of the mobile system in real environment have been simulated through a variety of virtual simulation experiments. Four typical motion modes including moving forward, moving laterally, moving laterally in the direction of 45∘ with horizontal line, and rotation have been simulated by RecurDyn. The trajectory of the related Marker that is set at the center of the mobile platform has been displayed using the Marker Trace command during simulation animation. The trajectories in the above four motion modes show the motion state of the platform clearly in the simulation process. The displacement-time curve of the Marker set on the MWP in vertical direction (Y-axis direction) in straight-line motion is drawn. Thevelocity-time curves of the platform in X-axis and Z-axis direction in oblique motion at 45∘ are drawn according to the simulation results. The trajectories and curves exactly reflect the motion of the MWP. By comparing the simulation results with the theoretical results, there are acceptable errors that are relatively less overall in the simulation results. The simulation results can be used to predict the performance of the platform and evaluate the design rationality, and design quality can be improved according to the exposed problem. On the basis of RecurDyn simulation, the design of Mecanumwheelmobileplatformhas been further optimized, and the physical prototype of omnidirectionalwheelchair was designed and manufactured, as shown in Figure 11. This paper shares the experience of modeling and simulation in RecurDyn.

IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.066 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 11, Issue 4, April 2024

DOI: 10.17148/IARJSET.2024.11418

The simulation example of the MWP further verifies the feasibility and scalability of the simulation method involved in this paper. This paper can provide reference for the simulation of mobile platform by using RecurDyn[9].

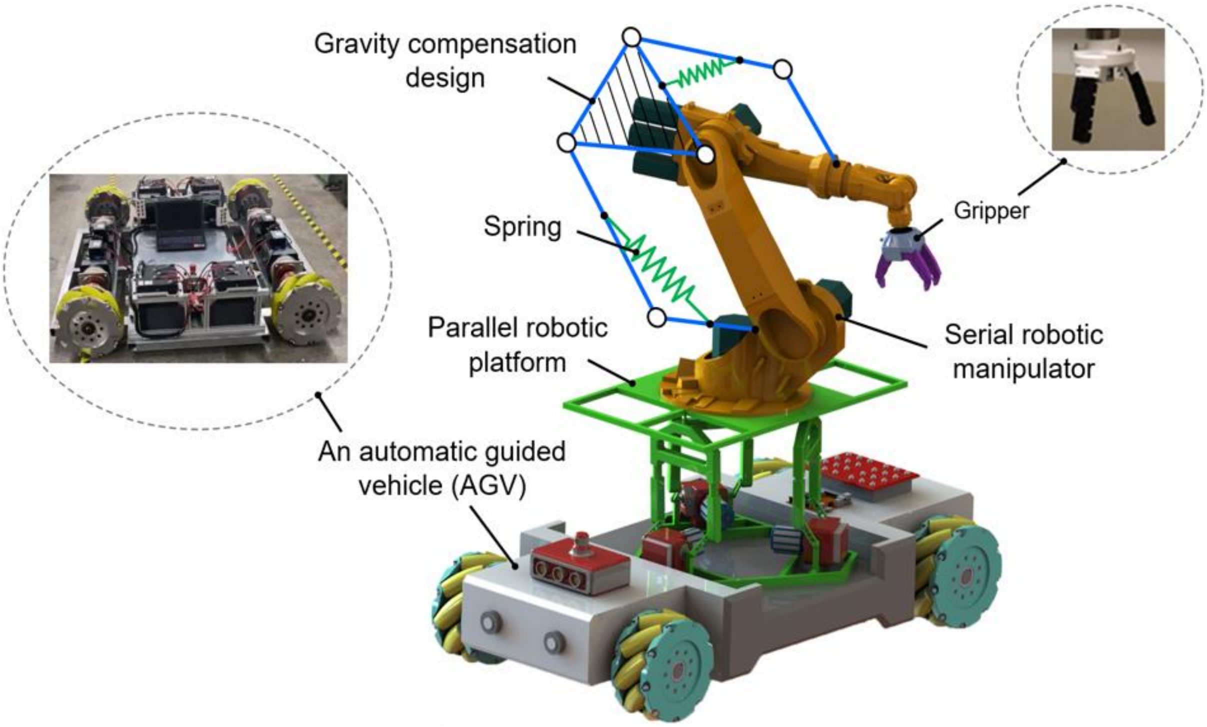

Fig. 12. Design of a high-payload ground vehicle with robot manipulation for industrial applications

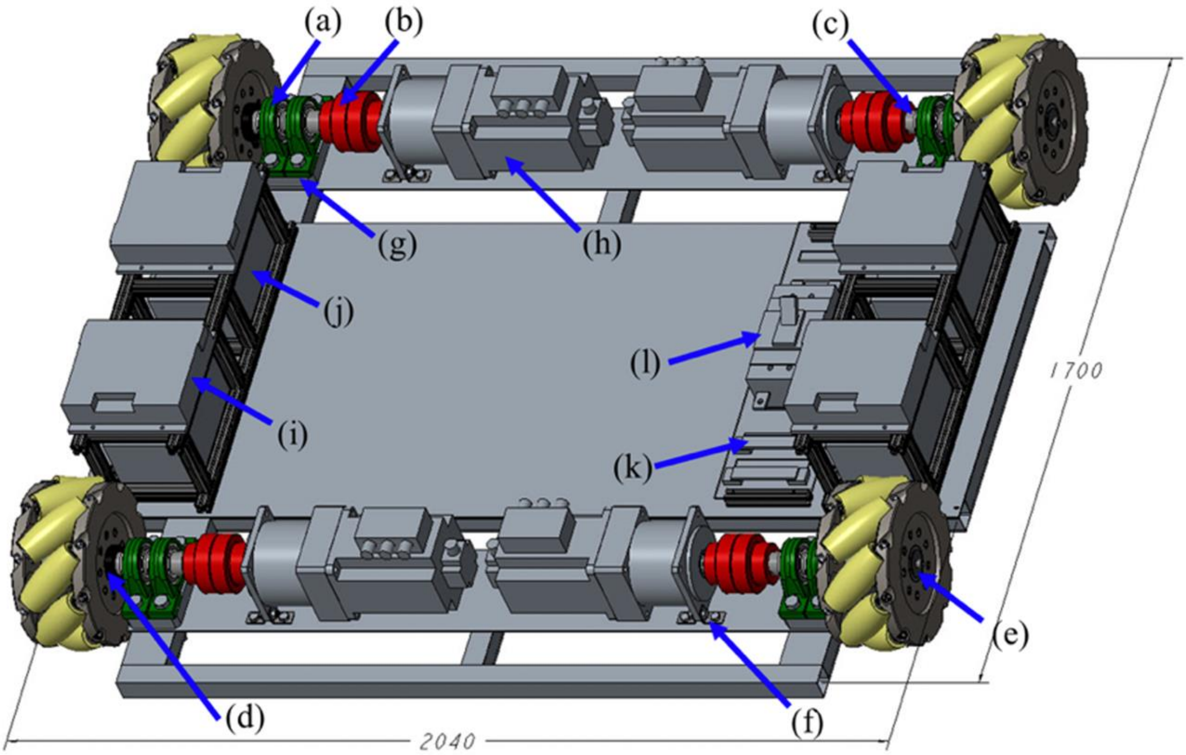

Fig. 13. The mechanical design of the MWGV: (a) ball bearing, (b) coupling rubber, (c) axle, (d) fixing ring, (e) washer, (f) L-shaped bracket, (g) metal plate, (h) motor and reducer, (i) driver, (j) battery, (k) copper ground bar, (l) fuseless breaker **[10]**

The omnidirectional mobility of the Mecanum wheel configuration is proposed and proved theoretically. Based on this approach, a sub-configuration judgment method is derived. Using these methods, on the basis of analysing the possible configurations of three and four Mecanum wheels and existing Mecanum wheel configurations of robots in practical applications, the law determining wheel configuration is elucidated. Then, the topological design methods of the Mecanum wheel configurations are summarized and refined, including the basic configuration array method, multiple wheels replacement method, and combination method. The first two methods can be used to create suitable multiple-Mecanum-wheel configurations for a single mobile robot based on the basic Mecanum wheel configuration. Multiple single robots can be arranged by combination methods including end-to-end connection, side-by-side connection, symmetrical rectangular connection, and distributed combination, and then, the abundant combination configurations of robots can be obtained. Examples of Mecanum wheel configurations design based on a symmetrical four-Mecanum-wheel configuration and three centripetal configurations using these topological design methods are presented. This work can provide methods and a reference for Mecanum wheel configurations design.

The condition that the Mecanum wheeled robot can achieve omnidirectional movement is that the inverse kinematics Jacobian matrix of any three Mecanum wheels on the robot is a column full-rank matrix. In this paper, the relationship between the intersections of bottom-rollers axles of any three Mecanum wheels on the robot and the column rank of the Jacobian matrix is established. A bottom-rollers axles intersections approach for judging the omnidirectional mobility of Mecanum wheel configurations is proposed and proved theoretically, which is a simple and e_cient geometric method. If the number of axles intersections is 2 or 3, the column rank is full and the robot can achieve omnidirectional motion in a plane; if the number of axles intersections is 0 or 1, this is not the case. A sub-configuration judgment method for judging whether a Mecanum wheel configuration has omnidirectional mobility is evolved based on the bottom-roller axle intersections approach. According to this method, if the multiple-Mecanum-wheel configuration has any individual sub-configuration with omnidirectional motion capacity, it can also achieve omnidirectional motion. The topological design methods of the Mecanum wheel configurations are summarized and refined, including basic configuration array method, multiple wheel replacement method, and combination method. The first two methods can be used to create suitable multiple-Mecanum-wheel configurations for a single mobile robot based on the basic Mecanum wheel configuration. Multiple single robots can be arranged by combination methods including end-to-end connection, side-by-side connection, symmetrical rectangular connection and distributed combination, and then, the abundant combination configurations of robots can be obtained.[12]

In this paper, we review researches on multi-directional automobile design with Mecanum wheel as component in the forklift vehicle. Multi-directional automobile has vast advantages over conventional design likes differential drive-in term of mobility in congested environments. Multi-directional automobile could perform important tasks in environments congested with static and/or dynamic obstacle and narrow aisles, such as those commonly found in manufacturing floor, warehouses, offices and hospitals.

A variety of designs of Mecanum wheel installed forklift have been developed in recent years in order to improve their multi-directional maneuver and practical applications. These features are expanded at the expense of improved mechanical complication and increased complexity in control mechanism. Mecanum wheel systems work by applying rotating force of each individual wheel in one direction similar to regular wheels with a different in the fact that Mecanum wheel systems are able to slide freely in a different direction, in other word, they can slide frequently perpendicular to the torque vector. The main advantage of using Mecanum wheel systems is that translational and rotational motions are decoupled for simple motion although in making an allowance for the fastest possible motion this is not essentially the case.[13]

IV. CONCLUSIONS

The present paper presents a review of research papers of macnum wheel at one place to help the readers for the research work. The design and manufacturing aspects are presented in this paper. Also, the paper describes about the different motion directions of the macnum wheel with different varieties of applications of macnum wheel.

REFERENCES

[1] M. suvarna, S. Siddharth, and vidish shetty, "Design and fabrication of prototype model of Mecanum wheel forklift-A review," vol. 5, no. 2, p. 2019, 2019, [Online]. Available: www.ijariie.com
[2] Y. Li, S. Dai, L. Zhao, X. Yan, and Y. Shi, "Topological design methods for mecanum wheel configurations of an omnidirectional mobile robot," *Symmetry (Basel).*, vol. 11, no. 10, 2019, doi: 10.3390/sym11101268.

DOI: 10.17148/IARJSET.2024.11418

[3] K. L. Han, O. K. Choi, J. Kim, H. Kim, and J. S. Lee, "Design and control of mobile robot with mecanum wheel," *ICCAS-SICE 2009 - ICROS-SICE Int. Jt. Conf. 2009, Proc.*, pp. 2932–2937, 2009.

[4] Z.-Y. Chen, P.-R. Liaw, V. L. Nguyen, and P. T. Lin, "Design of a high-payload Mecanum-wheel ground vehicle (MWGV)," *Robot. Syst. Appl.*, vol. 1, no. 1, pp. 24–34, 2021, doi: 10.21595/rsa.2021.22133.

[5] Y. Li, S. Dai, Y. Zheng, F. Tian, and X. Yan, "Modeling and Kinematics Simulation of a Mecanum Wheel Platform in RecurDyn," *J. Robot.*, vol. 2018, 2018, doi: 10.1155/2018/9373580.

[6] B. Chu, "Performance evaluation of Mecanum wheeled omni-directional mobile robot," *31st Int. Symp. Autom. Robot. Constr. Mining, ISARC 2014 - Proc.*, no. Isarc, pp. 784–789, 2014, doi: 10.22260/isarc2014/0106.

[7] H. M. Alwan, "Path tracking simulation of a wheeled mobile robot with three mecanum wheels," *Int. Rev. Mech. Eng.*, vol. 14, no. 8, pp. 516–522, 2020, doi: 10.15866/ireme.v14i8.19647.

[8] P. S. Yadav, V. Agrawal, J. C. Mohanta, and M. D. F. Ahmed, "A Theoretical Review of Mobile Robot Locomotion based on Mecanum Wheels," *Evergreen*, vol. 9, no. 2, pp. 396–403, 2022, doi: 10.5109/4794163.

[9] O. Diegel, A. Badve, G. Bright, J. Potgieter, and S. Tlale, "Improved Mecanum Wheel Design for Omni-directional Robots," *Shinji Kamiuchi Shoichi Maeyama, "A Nov. Hum. Interface an Omni-directional Wheel. Int. Work. Robot Hum. Interact. Commun. 2004, pp. 101-106.*, no. November, pp. 27–29, 2002.

[10] N. Dhengre, A. Mogra, S. Verma, and A. Gupta, "Design and manufacturing of mecanum wheel for omnidirectional robot," *Int. J. Mech. Prod. Eng. Res. Dev.*, vol. 2018, no. August, pp. 14–19, 2018.

[11] S. F. Wani, A. Ashraf, and A. Sophian, "Applied Research and Smart Technology," *Appl. Res. Smart Technol.*, vol. 3, no. 1, pp. 38–48, 2022.

[12] H. Taheri, B. Qiao, and N. Ghaeminezhad, "Kinematic Model of a Four Mecanum Wheeled Mobile Robot," *Int. J. Comput. Appl.*, vol. 113, no. 3, pp. 6–9, 2015, doi: 10.5120/19804-1586.