PRACTICAL APPLICATIONS FOR MOBILE ROBOTS BASED ON MECANUM WHEELS - A SYSTEMATIC SURVEY

Florentina Adăscăliței, Ioan Doroftei
"Gh. Asachi" Technical University of Iasi, Mechanical Engineering Faculty, Theory of Mechanisms and Robotics Department, B-dul D. Mangeron, 61-63, 700050, Iasi, Romania
E-mail: adascalitei_florentina@yahoo.com, ioan_doroftei@yahoo.com

Abstract: In this paper a literature review concerning practical applications for mobile robotic platforms based on special wheels (in this case, Mecanum wheel) is presented. Mobile robots equipped with four Mecanum wheels have the omnidirectional property, which means, they have the ability to move instantaneously in any direction, from any configuration. Therefore, compared to conventional platforms, these vehicles possess multiple advantages in terms of their mobility in narrow spaces or crowded environments. They have the ability to easily perform certain tasks in congested environments foreseen with static obstacles, dynamic obstacles or narrow areas. Usually, such environments are found in factory workshops, warehouses, hospitals, etc. Hence the resulting needs to create this kind of robotic platforms to satisfy the requirements of various fields, such as: industrial, military, naval, medical and last but not least, the educational field (as the basis for research). The characteristics of the Mecanum wheel, a short comparison between this type of wheel and a conventional wheel, as well as the constructive and design solutions previously developed are described in the first part of this paper. Then, some application fields and the related systems based on Mecanum wheel are presented.

Keywords: Mecanum wheel, omnidirectional mobile robot, AGV

1. Introduction

Omnidirectional wheels have been used in robotics, in industry, and in logistics for many years. By reviewing and analyzing systematically the existing literature concerning this type of wheels, it was revealed that systems based on Mecanum wheels detain omnidirectional capabilities, whereas systems based on conventional wheels do not. Specifically, these capabilities make the vehicle extremely maneuverable, which could be very helpful in different indoor and outdoor applications. Therefore, compared to conventional vehicles, omnidirectional robotic vehicles possess multiple advantages in terms of their mobility in narrow spaces and crowded environments. They have the ability to easily perform certain tasks in congested environments foreseen with static obstacles, dynamic obstacles or narrow areas. Usually, such environments are found in factory workshops, warehouses, hospitals, etc. Hence the resulting needs to create this kind of robotic platforms to satisfy the requirements of various fields, such as: industrial, military, naval, medical and last but not least, the educational field. Furthermore, to prevent the shortcomings presented by Mecanum wheel, researchers have focused on its optimization, developing new constructive solutions, thus allowing their implementation in new applications, such as planetary explorations, mine operations.

2. Mecanum wheel

2.1. Mecanum wheel characteristics

Mecanum wheel was designed and invented in Sweden, in 1975, by Bengt Ilon, an engineer with the Swedish company Mecanum AB [1]. Mecanum wheel is based on the principle of a central wheel with a number of rollers placed at an angle around the periphery of the wheel. The angle between rollers axis and central wheel axis could have any value, but in the case of conventional Mecanum wheel it is 45° (Figure 1). The rollers are shaped such that the silhouette of the omnidirectional wheel is circular. The angled peripheral rollers translate a portion of the force in the rotational direction of the wheel to a force normal to the wheel direction. Depending on each individual wheel direction and speed, the resulting combination of all these forces produces a total force vector in any desired direction, thus allowing the platform to move freely in direction of the resulting force vector, without changing the direction of the wheel.

A Swedish omnidirectional wheel has 3 DOF's composed of wheel rotation, roller rotation and rotational slip about the vertical axis passing through the point of contact (Figure 2). In the omnidirectional wheel, the wheel velocity can be divided into the components in the active direction and in the passive direction. The active component is directed along the axis of the roller in contact with the ground, while the passive one is perpendicular to the roller axis [2]. When the wheel rotates, a force vector along the wheel and a force vector perpendicular to the wheel are created. By a simple control of each wheel rotation, the vehicle moving direction can be changed instantaneously.

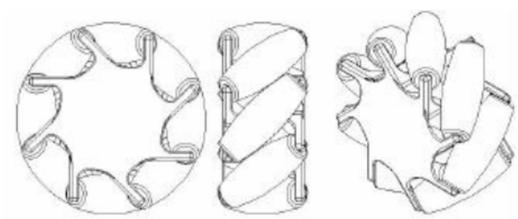


Figure 1: Mecanum wheel

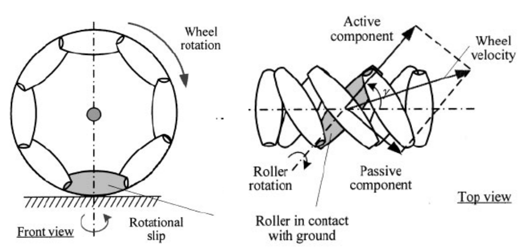


Figure 2: DOF's in a Mecanum wheel [2]

When a Mecanum wheel is rotating, at least one roller (maximum two rollers) is (are) in contact with the ground. Only a small surface (theoretical, one point) of the roller is in contact with the ground. The area of this surface traverses the roller from one side to another, depending on the sense of wheel rotation. The direction of the traction force will be done by the traversing sense of contact surface. It means, if we look to the wheel from the top side, the traction force will be perpendicular to the roller axis [3].

2.2. Mecanum wheel vehicle vs. Conventional wheel vehicle

The benefits of a vehicle with Mecanum wheels relative to one with steered wheels have been presented by [4]. Usually, robotic vehicles are designed to perform planar motion. In a two dimensional space, a body has three degrees of freedom, being capable of translating in both directions and rotating about its centre of gravity. However, most conventional vehicles do not have the ability to control every degree of freedom independently, because conventional wheels are not capable of moving in a direction parallel to their axis. These so called non-holonomic constraints of the wheel prevent vehicles using skid-steering from moving perpendicular to its drive direction. To reach every location and orientation in a two dimensional space it can require complicated maneuvers and complex path-planning. Non-holonomic vehicles can move in some directions (forward and backward) and can describe some curved trajectories, but cannot crab sideways. For example, to realize a parallel parking, a differential drive vehicle should make a number of maneuvers (Figure 3).

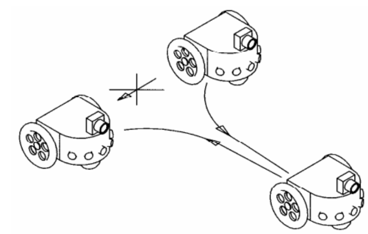


Figure 3: Lateral parking of a differential drive mobile robot [6]

A vehicle without non-holonomic constraints it can travel in any direction under any orientation. This capability is widely known as omnidirectional mobility. Omnidirectional vehicles have great advantages over conventional platforms, with car-like Ackerman steering or differential drive system in terms of moving in tight areas [5]. They can crab sideways, turn on the spot and follow complex trajectories. These vehicles are capable of easily performing tasks in environments with static and dynamic obstacles and narrow spaces.

Usually, vehicles based on Mecanum wheel have a square or a rectangular configuration, with two wheels on each side of the chassis. Using four of these wheels provides omnidirectional movement for a vehicle without needing a conventional steering system. When Mecanum wheels are actuated, the angled peripheral rollers translate a portion of the force in the rotational direction of the wheel to a force normal to the wheel direction.

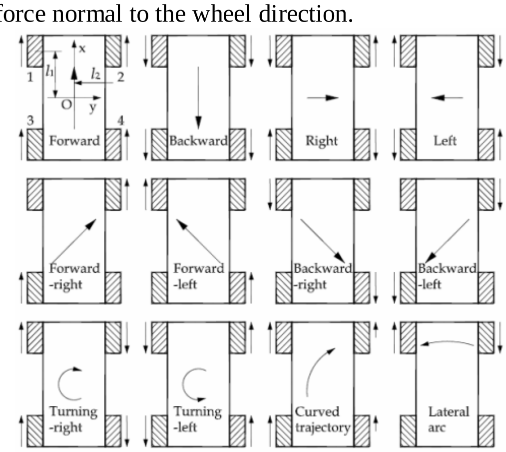
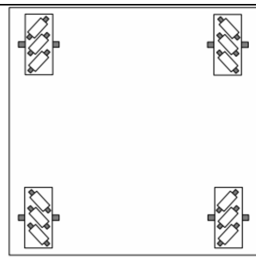
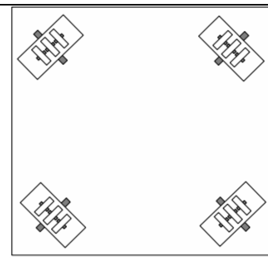
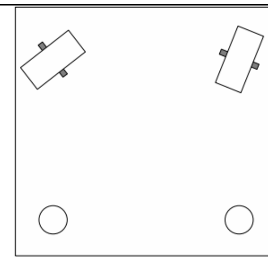


Figure 4: Vehicle motion according to the direction and angular speed of the wheels [6]

Table 1: Comparison between different types of drives

	Mecanum drive	**Holonomic drive**	**Swerve drive**
Description	 Wheels with angled rollers	 Wheels with “straight” rollers (omniwheels)	 Independently steered drive modules
Advantages	- compact design - high load capacity - simple to control - less speed and pushing force when moving diagonally	- low weight - compact design - simple to control - less speed and pushing force when moving diagonally	- simple conceptually - simple wheels - continuous wheel contact - high load capacity - robust to floor conditions
Disadvantages	- very complex conceptually - discontinuous wheel contact - high sensitivity to floor irregularities - complex wheel design	- more complex conceptually - discontinuous wheel contact or variable drive-radius - sensitive to floor irregularities - lower traction	- complex mechanical design - heavy and massive design - complex to program and control - high friction and scrubbing while steering

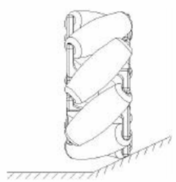
Depending on each individual wheel direction and velocity, the resulting combination of all these forces produce a total force vector in any desired direction thus allowing the platform to move freely in the direction of the resulting force vector, without changing of the wheels themselves. The vehicle is able to translate on any direction, forward/backward but also sideways left/right and turning on the spot, thanks to its special wheels (Figure 4). This is especially helpful when having to maneuver in tight environments [5]. A short comparison between Mecanum drive, holonomic drive and swerve drive is presented in Table 1.

2.3. Mecanum wheel constructive solutions

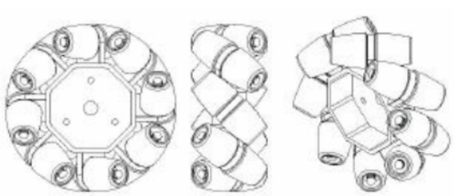
Omnidirectional wheeled vehicles with Mecanum wheels have some shortcomings. According to [7], a vehicle with Mecanum wheels is susceptible to slippage, and as a result, with the same amount of wheel rotation, lateral travelling distance is different from longitudinal travelling distance. In addition, the ratio of longitudinal travelling distance over lateral travelling distance with the same amount of wheel rotation, changes with ground condition. The second drawback is that the contact point between the wheel and the ground moves along a line parallel to the wheel axis, even though the wheel is always in contact with the ground. The lateral movement produces horizontal vibrations. The last drawback is that its ability to overcome obstacles is not independent of travel direction.

The slippage of the wheels prevents the most popular dead-reckoning method, using rotary shaft encoders [5], [8], from being performed well on a vehicle with Mecanum wheels. In order to solve the problem, visual dead-reckoning was used as a slip-resilient sensor [7], [9]. This technique, also used in optical mice, makes use of an on-board video-camera continuously capturing frames of the ground beneath and image processing hardware on the robot determining the speed and direction in which the current frame has moved relative to the previous frame thus allowing the speed and direction of that point of reference to be calculated.

A traditional Mecanum wheel with the peripheral rollers held in place from the outside is presented in Figure 1. This design, although having a good load carrying capacity, has the disadvantage that, when encountering an inclined or uneven surface, the rim of the wheel can make contact with the surface, instead of the roller, therefore preventing the wheel from operating correctly (Figure 5.a). A simple alternative design, also proposed by Ilon, which alleviates the problem, consists in having the rollers split in two (or in three) and centrally mounted as shown in Figure 5.b. This design ensures that the rollers are always in contact with the work surface, thus allowing a better performance on uneven surfaces [10].



(a)



(b)

Figure 5: a) Traditional Mecanum wheel on inclined surface; b) Mecanum wheel with centrally mounted rollers

One disadvantage of the Mecanum design is the inefficient use of the kinetic energy supplied to the wheels by the motors. Due to the rotation of the exterior rollers, only a component of the force at the perimeter of the wheel is applied to the ground and the resulting force only partially contributes to the motion of the vehicle. [11] proposed two designs to improve the Mecanum wheel efficiency. The first design is the Mecanum wheel with lockable rollers illustrated in Figure 6. This design was conceived to overcome the losses of efficiency due to energy lost in a direction normal to that of travel through the peripheral rollers (they bleed off energy as they rotate), when the vehicle is travelling in a straight line (forward/backward). Simple actuators are used to rotate the brake activation disc, therefore to lock and unlock the roller, when the vehicle is moving. When driving in longitudinal motion, the peripheral rollers will be locked and they will act as a heavy thread, but when driving in sideways motion the rollers will be unlocked. This design is effective in reducing any lost forces in the forward direction to zero, but does not improve the losses in any other directions.

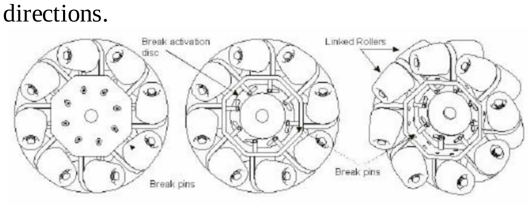


Figure 6: Mecanum wheel with lockable rollers [11]

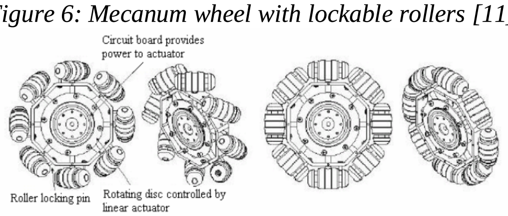
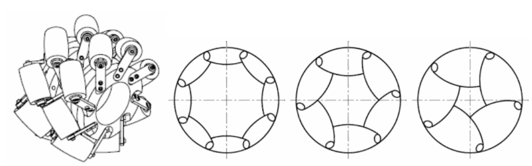


Figure 7: Mecanum wheel with rotatable rollers [11]

The second design is Mecanum wheel with rotatable rollers illustrated in Figure 7. Compared to the first design, this one is more effective, but mechanically more complex. The peripheral rollers are split and centrally mounted on an axle which can be pivoted through 135°. This allows the rollers to be adjusted from a straight position (in which they are locked so the rollers cannot rotate on their axles), thus effectively forming an almost normal treaded tire, to an angle of 45° in which case they act as a traditional Mecanum wheel, or to an angle of 135°, making diagonal travel easier as it overcomes the resistance given by the traditionally immobile wheels. The angle of the rollers on each wheel is controlled through all the roller shafts, which are connected through a bevel gear system in such a way that a rotary actuator on one of the shafts controls all the other simultaneously.

[3] proposed a new Mecanum wheel constructive solution in terms of its performance on various surfaces and concluded that the size of the peripheral rollers has a great effect upon this performance (Figure 8.a). The larger the rollers are, the greater the range of surface deviations can be overcome. Also, as the size of rollers increases, the slower they spin, resulting in lower friction losses in the driving of the wheel. In conclusion, when designing a new drive system for a vehicle, there exist a certain number of rollers that makes the ideal compromise between having a small number of large rollers per wheel, and having a large number of small rollers per wheel (Figure 8.b).



(a) (b)

Figure 8: a) New constructive wheel design; b) Rollers number according to their size.

Large size of rollers means a small number of them. This has as effect a very small radius to the rollers extremities and, in this case, it could be difficult to use ball bearings in order to decrease the friction between the roller and its axis. The new constructive solution not only facilitates the use of big bearings, but also makes possible the approximation of the roller shape with a circle, because the roller length becomes smaller than the one used in a traditional Mecanum wheel – it is half of the normal roller.

In order to overcome the Mecanum wheel difficulties when moving on rough terrain, [12] has developed two new concepts of this type of wheel, using the principle of “steeping on obstacles”. The first one is the concept of “elliptical Mecanum double wheel" (Figure 9). The wheel itself consists in two elliptically Mecanum wheels, *1* and *2*, coupled with a special mechanism in between *3*. The role of the mechanism *3* is to move (rotation and relative translation to each other) the components *1* and *2* in such a way that the resulting motion would provide the same movement (in terms of speed, direction, smoothness) to the vehicle as a traditional Mecanum wheel would. For practical purposes, components *1* and *2* are not truly elliptical, when viewed sideways, but rather an approximation of an ellipse is used. The designed wheel includes a total number of 12 rollers (8 of type 1 and 4 of type 2). The maximum obstacle height that this wheel can overcome is 75% of the wheel largest radius.

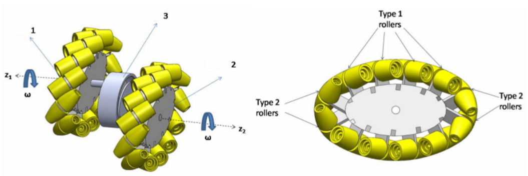


Figure 9: Assembled elliptical Mecanum double wheel [12]

The second concept is the "semicircular Mecanum double wheel". The idea was to modify the elliptically shaped wheel seen in Figure 9, and replace it with a wheel having half circular and half elliptical profiles as shown in Figure 10. In this case, as the double wheel rotates, the smooth motion of a regular Mecanum wheel is achieved, while the ability of overcoming small obstacles when travelling laterally is kept. In contrast to the elliptical wheel, the semicircular wheel includes three types of rollers (4 of type 1, 2 of type 2 and 7 of type 3) and the total number of rollers is 13. The flatter the elliptical part is the greater clearance can be achieved for overcoming higher obstacles. This type of wheel is capable of overcoming obstacles of height up to 37.5% of the wheel's radius. Also, both of these types of wheel have the ability of moving in soft dirt. The wheel would pile up a small amount of dirt and then step on it, thus avoiding being blocked by large amounts of dirt.

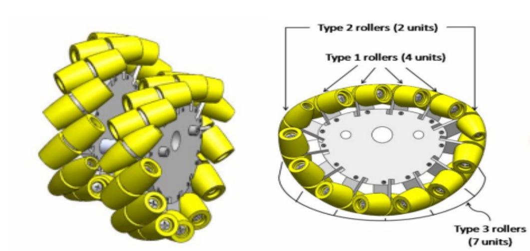


Figure 10: Assembled semicircular Mecanum double wheel [12]

3. Practical applications in various fields

3.1. Military field

The manoeuvrability provided by omnidirectional vehicles can be utilized and can be very important in numerous outdoors applications, such as search and rescue missions, military activities, planetary explorations and mine operations.

This wheel is commonly used in robotic applications requiring a high degree of maneuverability, such as those experienced by NASA for hazardous environment exploration [13]. The objective of the OmniBot project (Figure 11) is to develop a hazardous duty mobile base as an advanced development test bed to research alternate technical approaches for remotely controlled operations in hazardous areas. In addition, this base will be used to test various automated umbilical technologies for autonomous mobile vehicles.

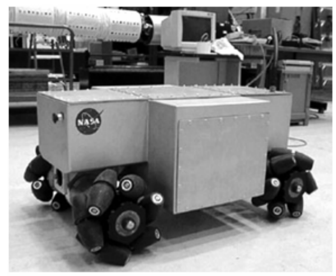


Figure 11: NASA OmniBot mobile base [14]

Figure 12: Mecanum wheel vehicle for USA Navy [15]

In hazardous environments where it is too dangerous to send in unprotected personnel, a mobile base could be used to perform remote inspections, site surveys, and operations. The OmniBot is driven with four brushless servomotors connected to omnidirectional wheels (Mechanum). This allows for complete 2-degree-of-freedom motion, which results in extremely high maneuverability. The benefit of this motion profile can truly be appreciated when the vehicle is operated in a teleoper-ational mode.The vehicle can be controlled with a radio frequency (RF) control box or with a hardwired joystick. With the video transmission gear installed, teleoperation is possible up to a distance of 1,800 feet [14].

Omnix Technology Systems, Inc. had developed Mecanum wheel vehicle for U.S Navy for inspection of areas inaccessible to humans and vehicles capable of transporting very heavy loads in military environments [15]. These vehicles can be seen in Figure 12 are especially adaptable for autonomous or teleported operations due to the unrestricted manoeuvrability and simplicity of control.

MarsCruiserOne is a pressurized, habitable rover, designed to allow exploration of the Moon and Mars during future space missions (Figure 13). Characterized by omnidirectional wheels especially suited to tackle rocky terrain, it travels at a speed of 5-10 km/h [16]. This design incorporates: hubless wheels (which allowed ingress/egress for the astronaut crew for extra-vehicular activities and access to other surface modules and rovers), Mecanum wheels, a linear motor drive and a single point rotary shock absorber/suspension system [17].

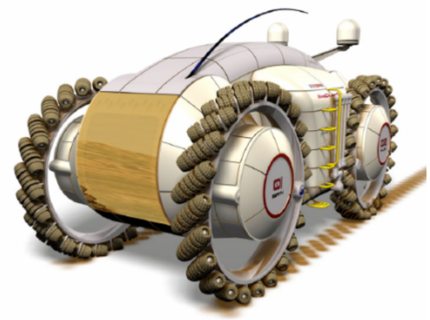


Figure 13: MarsCruiserOne [16]

3.2. Industrial field

Airtrax ATX-3000 industrial forklifts (Figure 14) excel in applications requiring tight manoeuvring or transporting long loads sideways through standard sized doors or narrow aisle ways. The ATX's unique, Omni-Directional movement allows it to travel in all directions thus making it an ideal vehicle to work in tight spaces where turns are not possible and finite control is a necessity. The truck features 48 volt transistor controls with state-of-the-art technology, infinitely variable travel, lift and lower speeds, excellent visibility, ergonomic controls and operator comfort [18].

The unique design of the four 21x12 independently driven Mecanum wheels enables the ATX's OmniDirectional capabilities. Each wheel is directly driven by individual transaxles. The wheels consist of a large, heavy-duty hub with 12 uniquely designed polyurethane rollers. The wheel and roller design provides the Omni-Directional movement of the vehicle based on the speed and direction of each wheel as determined by the operation of the traction joystick. Each roller incorporates bearings that do not require periodic greasing or maintenance under most conditions. Since each roller rotates freely, scrubbing against the floor is minimized while turning or moving sideways [18].

Figure 14: Airtrax Sidewinder lift truck [19]

[20] developed an Automated Guided Vehicle as a drive-under tractor in very compact dimensions. The development and realization of the vehicle are optimized for the transportation of small goods (Figure 15.a) [21]. The primary goal was a small vehicle at low cost [22]. Furthermore the vehicle has to be able to transport variable amounts of containers in an economic way. An innovative approach was to accomplish accumulated and single transports by towing a trolley (Figure 15.b) or by carrying one container with the same vehicle. For transport and providing of small goods, the following applications were found to be the most promising: Floor block storage, order picking, assembly and production. The vehicle has an omnidirectional drive, using four independently and electrically driven Mecanum wheels. The accomplished prototype is smaller than any vehicle that is available at the market in Europe. As a result the needed space for logistic operations, like the width of the track and stations, could be minimized compared to common solutions. Especially the height of the vehicle is very low so that an efficient use as a drive-under tractor is possible. The results showed an efficient approach for an automated transportation of trailers and small load carriers.

(a) *(b)*

Figure 15: a) Vehicle with small goods container; b) Vehicle with trolley [20]

3.3. Medical field

Powered wheelchairs are known to provide benefits for older adults by enabling them to have a means of independent mobility. These benefits include: participation in self-care, productivity, and leisure occupations; as well as, socialization opportunities, and positive self worth [23] [24]. Overall powered wheelchairs are linked to an improved quality of life for older adults who have a reduced ability to walk and do not have the stamina, strength, or ability to propel themselves in a manual wheelchair [23]. Without a powered wheelchair these older adults would be dependent on others to complete life tasks [25], and unable to have independent mobility.

The OMNI (Office Wheelchair for High Manoeuvrability and Navigational Intelligence for People with Severe Handicap) is a standalone wheelchair developed with two goals in mind: 1) to allow high mobility in complex environments; and 2) to have modes of operation that will help the user have higher degrees of independence [26]. This wheelchair has been designed for individuals with severe mental and physical disabilities. It consists of Mecanum wheels that provide 3-DOF (degrees of freedom) for the wheelchair; a specialized joystick for 3-DOF movement; a sensor ring around the wheelchair that has IR (infrared) and ultrasound sensors to provide obstacle detection capabilities; a bumper sensor for fail-safe detection of collisions; wheel odometers for knowledge of the wheelchair's location; an elevating seat to raise the user; and a specialized display for the user select modes of operation (Figure 16).

The omnidirectional wheelchair being developed at the University of Western Australia's Centre for Intelligent Information Processing Systems (CIIPS) allows the user to easily manoeuvre in what would otherwise be an extremely complicated environment. This project made improvements to the Mecanum wheels, batteries, motor driver cards, human interface, control software, chassis and suspension system. These improvements transformed the partially working prototype into a fully usable wheelchair (see Figure 16). The result is much higher driving accuracy and a greatly improved overall experience for the user in both comfort and ease of use. On the whole, the project was extremely successful and will provide a very solid test bed for advanced driving and mapping projects in the future [19].

Figure 16: Omnidirectional wheelchairs: OMNI [26], CIIPS wheelchair [19], iRW [27] (from left to right)

Another example of an omnidirectional wheelchair is iRW [27], which provides a telehealth system with easy-to-wear, non-invasive devices for real time vital sign monitoring and long-term health care management for the senior users, their family and caregivers (Figure 16). A joystick controller is used to control the iRW to move forward/backward, sway right/left, and spin clockwise/counter clockwise. The maximum forward speed of the iRW is set at 3km/h, which is close to walking speed of human, and the maximum backward and sideways speed is set at 1.5km/h.

3.4. Educational field

Uranus (Figure 17) was the first mobile robot with Mecanum wheels, designed and constructed in Carnegie Melon University [28], [29]. It was built to provide a general purpose mobile base to support research in to indoor robot navigation. As a base, it provides full mobility, along with support for a variety of payloads, such as sensors and computers. It had not a suspension system, which is absolutely necessary if the ground is not completely flat.

Figure 17: Uranus omnidirectional mobile robot [28]

Other researchers, such as Braunl from University of South Australia have developed two different Mecanum wheel omnidirectional mobile robots, Omni-1 and Omni-2 [30], [31]. Figure 18 shows the structure of Omni-1 and Omni-2. The first design, Omni-1 used the Mecanum wheel design with rims that only leave a small gap/clearance for the roller. The motor and wheel assembly tightly attached to robot's chassis. The Omni-1 can drive very well on hard and flat surface but it loses the omnidirectional capability on soft surface.

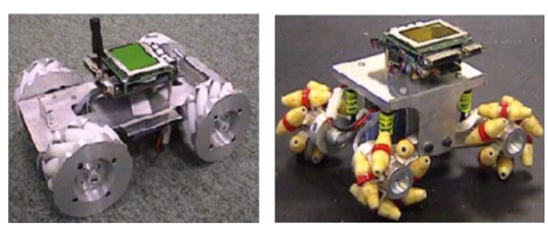


Figure 18: Mecanum Wheel Mobile robot Omni-1 and Omni-2 from University of Western Australia [31]

Omni-2 was develop using rimless and with centrally mounted roller. The motor and wheel assembly attach to cantilever wheel suspension with shock absorbers. The rimless Mecanum wheel and shocks absorbers encounter the sinking-in on softer surface and uneven work surface as a result allows omnidirectional driving for Omni-2.

The Mechatronics and Robotics Research Group (MR2G) at Massey University have developed all terrain Automatic Guided Vehicle (AGV) using a set of Mecanum wheels combined with a set of conventional wheels [11]. Any terrain change is automatically detected and a set of pneumatics actuators used to change from Mecanum wheels for indoor and high mobility requirement to conventional wheel for outdoor and rough terrain. This new driving mechanism of AGV has been implemented on Mapped Environment Guided Autonomous Navigator (MEGAN). Figure 19 illustrates the structure of MEGAN.

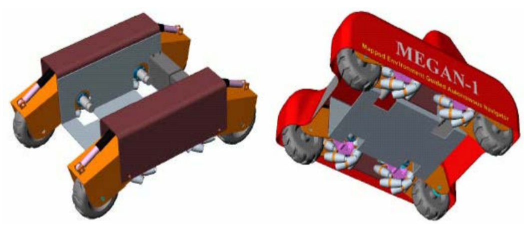


Figure 19: Mapped Environment Guided Autonomous Navigator (MEGAN) [11]

3.5. Other fields

The main goal of the CommRob project was to develop scientific methods or technologies to introduce robots in human environments. The Interactive Behavior Operated Trolley (Figure 20) InBOT addresses several everyday problems. Among other possibilities this means helping the customer to find the desired products without extensive search in big supermarkets, or relieving the customer from the burden of pushing the shopping cart using his own force all the time, especially if the cart is heavily loaded or the customer is elderly or handicapped. Especially for these groups of customers it could be very interesting that InBOT is able to avoid collisions on its own, even with objects that are moving themselves. InBOT has the ability to perform special local maneuvers and a flexible task-planner. It provides four different modes of operation to assist the user in the best way. First InBOT can be steered like an ordinary shopping cart by the haptic handle [32], including assistance functionalities like obstacle avoidance. Second and third it can follow or lead the user. Therefore the robot has to continuously track the user's position, to perform adaptive distance management and finally to estimate the user's intentions. And fourth the robot can be commanded to act independently until ordered otherwise [33].

Figure 20: The interactive shopping trolley [33]

4. Conclusions

In this paper, an overview over the Mecanum wheels and their practical applications is presented. The main advantage of this type of wheel is represented by the omnidirectional property that it provides, allowing extreme maneuverability and mobility in congested environments. Also, some research that was carried out in Mecanum wheel mobile robots in order to improve the wheel design is described. The manoeuvrability provided by omnidirectional vehicles can be utilized and can be very important in both outdoors applications, such as search and rescue missions, military activities, planetary explorations and mine operations, long loads transportation, and indoor applications, like small goods transportation, powered robotic wheelchairs or shopping carts.

5. Acknowledgement

This paper was realized with the support of POSDRU CUANTUMDOC "DOCTORAL STUDIES FOR EUROPEAN PERFORMANCES IN RESEARCH AND INOVATION" ID79407 project, funded by the European Social Found and Romanian Government.

6. Bibliography

[1] Ilon, B.E., 'Wheels for a course stable self propelling vehicle movable in any desired direction on the ground or some other base", US Patent and Trademarks office, Patent 3.876.255, 1975.

[2] Song, J.B., Byun, K.S., "Design and Control of a Four-Wheeled Omnidirectional Mobile Robot with Steerable Omnidirectional Wheels", Journal of Robotic Systems, 21(4), 2004, pp. 193-208.

[3] Doroftei, I., Stirbu, B., "Design, Modeling and Control of an Omni-directional Mobile Robot", Solid State Phenomena Vols. 166-167, 2010, pp 173-178, Trans Tech Publications, Switzerland. doi:10.4028/www.scientific.net/SSP.166-167.173.

[4] Dickerson, S.L., Lapin, B.D., „Control of an omni-directional robotic vehicle with Mecanum wheels", in National Teleystems Conference Proceedings, p. 323-328, March 26-27, Atlanta, USA, 1991.

[5] Borenstein, J., Everett, H.R., Feng, L., „Navigating Mobile Robots: Sensors and Techniques", A K Peters, Ltd, MA, USA, 1996.

[6] Doroftei, I., Grosu, V., Spinu, V., „Omnidirectional Mobile Robot – Design and Implementation", Bioinspiration and Robotics: Walking and climbing Robots, Book edited by: Maki K. Habib, ISBN 978-3-902613-15-8, pp. 544, I-Tech, Vienna, Austria, EU, September 2007.

[7] Nagatani, K., Tachibana, S., Sofne, M., Tanaka, Y., „Improvement of odometry for omnidirectional vehicle using optical flow information", IEEE/RSJ International Conference on Intelligent Robots and Systems, 2000.

[8] Everett, H.R., „Sensors for Mobile Robots: Theory and Application", A K Peters, Ltd, MA, USA, 1995.

[9] Giachetti, A., Campani, M., Torre, V., „The use of optical flow for road navigation", IEEE Transactions on Robotics and Automation, Vol.14, No.1, pp. 34-48, 1998.

[10] Doroftei, I., Grosu, V., Spinu, V., "Design aspects of omnidirectional wheels and mobile platforms", Proceedings of he 4th International Conference on Robotics, Buletin of the Transivania University of Brasov, Vol. 15(50), Series A, Special Issue, ISSN 1223-9631, 2008.

[11] Diegel, O., Badve, A., Bright, G., Potgieter, J., Tlale, S., „Improved Mecanum Wheel Design for Omni-directional Robots", Proc. Australasian Conference on Robotics and Automation, Auckland, November 27-29, pp. 117-121, 2002.

[12] Ramirez-Serrano, A., Kuzyk, R., „Modified Mecanum Wheels for Traversing Rough Terrain", 6th International Conference on Autonomic and Autonomous Systems, IEEE Computer Society, 2010, doi: 10.1109/ICAS.2010.35

[13] Lippit, T.C., Jones, W.C., „OmniBot Mobile Base", KSC Re-search and Technology Report, NASA, USA, 1998.

[14]http://rtreport.ksc.nasa.gov/techreports/98report/09-ar/ar06.html

[15] http://www.robotics.com/robomenu/odv.html

[16] http://www.architectureandvision.com

[17] Ransom, S., Krömer, O., Lückemeier, M.., "Planetary rovers with Mecanum wheels", 16th ISTVS Intl Conf, Nov 25-28, 2008, Torino, Italy.

[18] http://www.lomag-man.org/nouveautes/20vehicules/airtrax_omnidirextional.pdf

[19] Tuck-Voon How, „Development of an Anti-Collision and Navigation System for Powered Wheelchairs", 2010

[20] Schulze, L., Behling, S., Buhrs, S., „Development of a Micro Drive-Under Tractor - Research and Application", Proceedings of the International MultiConference of Engineers and Computer Scientists, Vol. II, March 16-18, 2011, Hong-Kong.

[21] Furmans, K., Schleyer, M., Schönung, F., "A Case for Material Handling Systems, Specialized on Handling Small Quantities", in Proc. of 10th International Material Handling Research Colloquium, Dortmund, Germany, 2008, pp. 185-197.

[22] Schulze, L., Behling, S., Buhrs, S., "Automated Guided Vehicle Systems: a Driver for Increased Business Performance", in Proc. of International Multi Conference of Engineers and Computer Scientists 2008, Hong Kong, pp. 1275-1280.

[23] Brandt, A., Iwarsson, S., Stahle, A., "Older people's use of powered wheelchairs for activity and participation", J. Rehabil. Med., no. 36, pp. 70-77, 2004.

[24] Evans, R., "The effect of electrically powered indoor/outdoor wheelchairs on occupation: a study of users' views", British Journal of Occupational Therapy, vol. 63, no. 11, pp. 547-553, 2000.

[25] Hardy, P., "Powered wheelchair mobility: An occupational performance evaluation perspective", Australian Occupational Therapy Journal, no. 51, pp. 34-42, 2004.

[26] Hoyer, H., Borgolte, U., Jochheim, A., "The OMNI-Wheelchair - State of the art," in Center on Diabilities, Technology and Persons with Disabilities Conference, Northridge, CA, 1999.

[27] Po-Er Hsu, Yeh-Liang Hsu, Jun-Ming Lu, Jerry, J.-H. Tsai, Yi-Shin Chen, „iRW: An Intelligent Robotic Wheelchair Integrated with Advanced Robotic and Telehealth Solutions", in „1st Asia Pacific eCare and TeleCare Congress," June 16-19, 2011, Hong Kong, China.

[28] Muir, P. F., Neuman, C.P., „Kinematic Modeling for Feedback Control of an Omnidirectional Wheeled Mobile Robot", IEEE Intenational Conference on Robotics and Automation, 1987.

[29] Muir, P. F., Neuman, C. P., „Kinematic Modeling of Wheeled Mobile Robots", Journal of Robotic Systems, No. 4(2), pp. 281-340, 1987.

[30] Braunl, T., „Embedded Robotics: Mobile Robot Design and Applications with Embedded Systems", First Edition. Springer-Verlag, Berlin, 2003.

[31] http://robotics.ee.uwa.edu./eyebot/omni.html

[32] Goller, M., Kerscher, T., Ziegenmeyer, M., Ronnau, A., Zollner, J. M., Dillmann, R., „Haptic Control for the Interactive Behavior Operated shopping Trolley InBOT", in New Frontiers in Human-Robot Interaction symposium at the Artificial Intelligence and Simulation of Behaviour (AISB) 2009 Convention, 2009.

[33] Goller, M., Kerscher, T., Zollner, J.M., Dillmann, R., Devy, M., Germa, T., Lerasle, F., „Setup and Control Architecture for an Interactive Shopping Cart in Human All Day Environments", In Proceeding of the Int. Conf. on Advanced Robotics (ICAR'09), pp. 1-6, 2009.