MATEC Web of Conferences **90**, 01077 (2017) DOI: 10.1051/matecconf/20179001077
AiGEV 2016

Omnidirectional configuration and control approach on mini heavy loaded forklift autonomous guided vehicle

Norsharimie Adam[1,*], *Mohd* Aiman[1], *Wan Mohd* Nafis[1], *Addie* Irawan[1], *Mohamad* Muaz[2], *Mohamad* Hafiz[2], *Akhtar Razul* Razali[2] and *Sheikh Norhasmadi* Sheikh Ali[3]

[1]Robotics and Unmanned Systems (RUS) research group, Faculty of Electrical and Electronics Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia.
[2]Manufacturing Focus Group (MFG), Faculty of Mechanical Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia.
[3]Vacuumschmelze (M) Sdn. Bhd, Lot 3465, Tanah Putih, 26600 Pekan, Pahang, Malaysia.

Abstract. This paper presents the omnidirectional configuration and control approach on Mini Heavy Loaded Forklift Autonomous Guided Vehicle (MHeLFAGV) for flexibility maneuverability in confine and narrow area. The issue in turning motion for nonholonomic vehicle in confine area becoming a motivation in MHeLFAGV design to provide holonomic vehicle with flexible movement. Therefore an omni-wheeled named Mecanum wheel has been configured in this vehicle design as well as omnidirectional control algorithm. MHeLFAGV system is developed with collaboration and inspired from Vacuumshmelze (M) Sdn. Bhd. Pekan, Pahang in order to have a customized mini forklift that able to work in a very confined warehouse (170cm x 270cm square) with heavy payload in a range of 20-200kg. In electronics control design, two stages of controller boards are developed namely as Board 1 and 2 that specifically for movement controller board and monitoring controller board respectively. In addition separate module of left, right, forward, backward, diagonal and zigzagging movement is developed as embedded modules for MHeLFAGV system's control architecture. A few experiments are done to verify the algorithm for each omnidirectional movement of MHeLFAGV system in the wide area. The waypoint of MHeLFAGV movement is plotted using Global Positioning System (GPS) as well as a digital compass by mapping the longitude and latitude of the vehicle. There are slightly different between the targeted movements with recorded data since Mecanum wheeled affected by the uneven surface of the landscape. The experiment is also further on moving in confine are on the actual targeted warehouse.

[*] Corresponding author: sharimie.adam@gmail.com

1 Introduction

Numerous research in nonholonomic systems has been widely studied especially on designing autonomous and guided vehicle. An autonomous vehicle can be in nonholonomic and holonomic mechanism depending on application requirement. However, most of the existed commercial industrial standard autonomous wheeled vehicles are nonholonomic with fixed driving wheels and focusing on wide area operations. There is an issue on dealing with confine area, especially for the heavy loaded task. Therefore omnidirectional configuration and control in the autonomous wheeled vehicle are essential. For the case of wheeled vehicle selection of omni-tyres are very important in order to realize omnidirectional movement. As for example mecanum wheel that consists of rollers around the surface body of the wheel depending on the size of mecanum, the bigger size the more roller is assembled[1]. As shown in Figure 1 (design is customized based on bought products from AndyMark, Inc.) the mecanum's roller assembled in 'axis-b' is slight skew to 'axis-a' wheel which usually 45 degrees of angle between 'a' and 'b' axis. In [2] an Omni-wheel is proposed by configuring three mecanum wheels with more controllable as well as steerable to use.

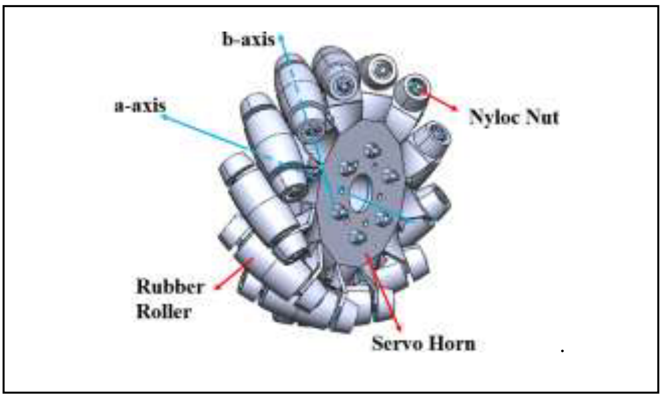


Fig. 1. Mecanum wheel design for MHeLFAGV.

On the other hand, model to control four wheel mecanum vehicle is proposed by [3-9] to develop the control model for the system to move more accurate and efficient by defining the velocity and the center of the wheel on the ground. The performance shows that the velocity of each wheel effect the smoothness of vehicle movement. Several wheel maneuver planning has been developed that incorporate kinodynamic constraint. Kinodynamic planning is aimed at solving kinematic constraints and dynamic constraints simultaneously, for designing the control input from the initial state and can be designed from the control input in one step[10]. Therefore, it has given the advantage that able to decide the control input simply, compared to existing planning [11, 12].

A survey of controllers' structure movements has been developed for vehicle systems that have an impact collision. For example, Zavala *et. al.* [13] introduced a family deadbeat feedback control laws to control a class of juggling-like systems. The contribution in their paper is a study of the intermediate control ability properties of the objects impact Poincare mapping [13, 14]. In previous work [15], the idea to collision free is by using the equations of motion. The difficulties with this two-stage planning approach are that the results of the kinematic planner may not be executable by the mobile robot due to limitations of the forces and torques available from the actuators. Other than that, the global optimality also cannot be guaranteed since only the optimal solution following the original kinematic path computed. Pan *et. al.*[16] in their research used a dynamic control planning method for a

DOI: 10.1051/matecconf/20179001077

vehicle steered without Global Positioning Systems(GPS) and unmanned operation in unidentified circumstances. The proposed technique displayed effective in results, however, the vehicle is not stable when the velocity in a high state.

Therefore, this research and development have taken the initiative to involve on design and develop flexible heavy loaded vehicle named Mini Heavy Loaded Forklift Autonomous Guided Vehicle (MHeLFAGV) (patent applied) specifically for maneuvering in a confine area. The problems involve in the MHeLFAGV system are to transfer the items and work in confine space with 170cm x 270cm square with the range of 20-200kg payload. A holonomic mechanism is applied in MHeLFAGV design as well as Mecanum wheels for flexibility moves. Moreover, the wireless remotely control module is developed in this phase of development with two ways communication with Board 1 as well as Global Positioning System (GPS) and Digital Compass for monitoring in Board 2. On the other hand, embedded omnidirectional module is developed to realize the designed motion vectors of omnidirectional movement of MHeLFAGV regarding each Mecanum wheel. Several experiments are done for waypoint and longitude/altitude verification as well as moving in the targeted warehouse.

2 Overview on holonomic MHeLFAGV forklift system and configuration

2.1 MHeLFAGV system configuration

The unavailability of a commercial AGV system for the targeted confine area and for heavy loading used became the motivation of MHeLFAGV development. The system is currently developed with wireless remote control and sufficient enough to be used in targeted warehouse. As shown in Figure 2, mecanum wheels with overall size 996mm x 700mm is used for this vehicle and the forklift unit placed on the left side of its structure in order to balance the whole vehicle. Moreover, the system is expected to be able to loading and unloading as well as transferring from point to point a heavy copper spool with flexible movement. The systems consist of three main components; Direct Current (DC) motor controller, Radio Frequency (RF) remote controller, and four industrial grade DC motor.

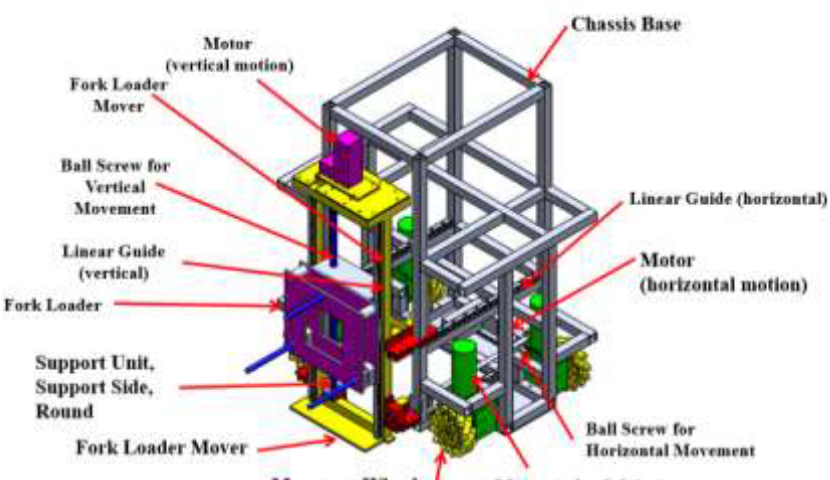


Fig. 2. Overview of design structure of MHeLFAGV system.

2.2 Control system architecture of MHeLFAGV system

The movement of the MHeLFAGV system with mecanum wheel is possible by controlling the four wheel independently that include speed and rotational. The direction of is navigated by rollers in mecanum wheel as depicted in Figure 3. These rollers are having a unique shape with an axis of rotation at 45° to the plane of the wheel and 45° to a line through the center of the roller parallel to the axis of rotation of the wheel[6] as discussed and labeled in Figure 1.

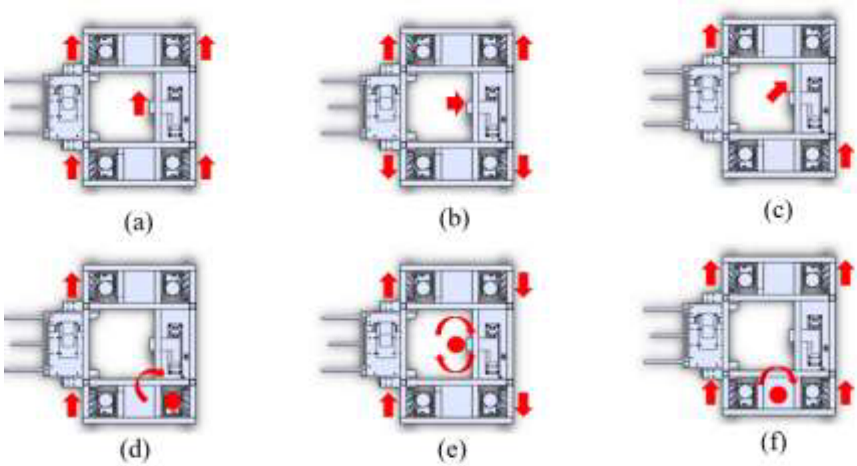
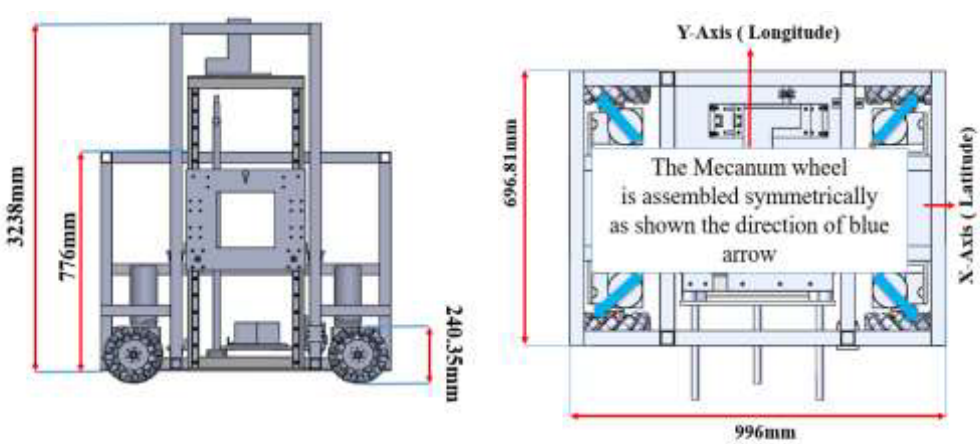


Fig. 3. Omnidirectional vector mapping for MHeLFAGV system; (a)Straight ahead, (b) Side Way, (c) Diagonal, (d)Turn Around, (e) Concerning, (f) Turn of Rear Axis.

Fig. 4. shows the dimension of MHeLFAGV base, from a top view the mecanum wheel is placed symmetrically. The roller of wheel acts as a reference point to place all four wheel performed in multidirectional movement system. The material used is a heavy duty which made from mild steel that can load over 150kg and the DC motor has the very high torque that could move the MHeLFAGV that weight about 200 kg.



(a) (b)

Fig. 4. The dimension of MHeLFAGV base. (a) Side view; (b) Top view.

In developing controller unit, two stages of controller boards are developed for this MHeLFAGV systems; movement controller board (Board 1) and monitoring controller board (Board 2). Moreover, several embedded modules are developed for each omnidirectional moving vectors including Zigzagging and Diagonal movement. A wireless remotely control modules are also prepared remotely controlled trajectory motion. On the other hand, Board 2 is developed as separated electronic system for MHeLFAGV motion vector mapping. As mentioned in the previous section Global Positioning System (GPS) unit is configured with Digital Compass is used and attached with MHeLFAGV system for longitude/latitude data acquisition.

The purpose of this separation approach is to guarantee a reliability of two ways real-time control and communication between user and MHeLFAGV system. As depicted in Figure 5, Board 1 is designed to consist of a microcontroller and dual channel motor controller that drive four wheels constantly. Three DC motor controllers connected to a microcontroller; Motor Controller 1 for front wheels, Motor Controller 3 for rear wheels and Motor Controller 2 for grasping/fork lifter. A potentiometer and Liquid Cristal Display (LCD) is configured for DC motor speed setup and calibration via its motor controller. SKPW-RX is an RF receiver that configured for the remote control connection between Board 1 and remote control as shown in Figure 6(a).

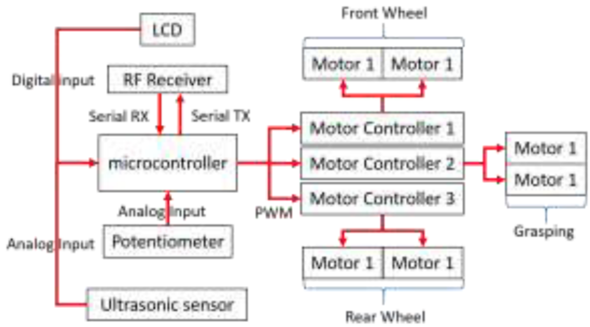


Fig. 5. Board 1 control schematic in MHeLFAGV system.

Each button on remote controller as shown in Figure 6(a) is programmed with reference to the omnidirectional vector as defined in Figure 3. The implementation The selected remote controller has function same as a potentiometer in terms of physical motion but producing pulses output as indication signal. Basically, this joystick can be slowly toggled to control the speed of movement of MHeLFAGV and producing a range of digital signals that useful for MHeLFAGV Cartesian inputs as shown in Figure 6(b). Separated board namely as Board 2 is developed with a combination of the GPS, Digital Compass sensor, and a microcontroller as shown in Figure 7. As mentioned earlier this second board is purposely developed to ensure a reliable real-time data logging for positioning and movement of MHeLFAGV. The GPS module transmitting the raw data of position and movement of MHeLFAGV to the microcontroller for longitude and latitude data encoding and saved into Micro Personal Computer (µPC).

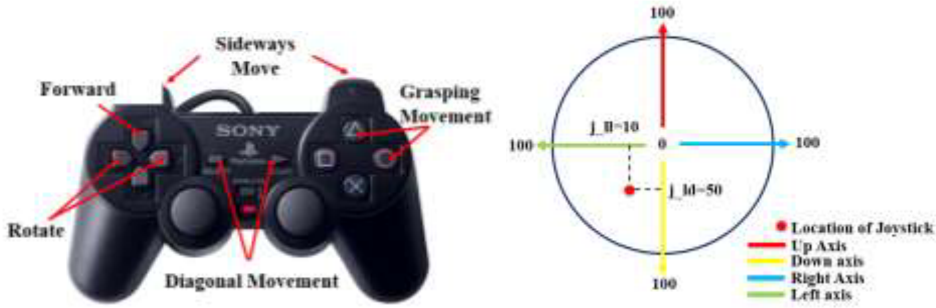


Fig. 6. MHeLFAGV Movement Controller (a) Physical feature of remote controller/joystick; (b) Remote controller/joystick button default mapping.

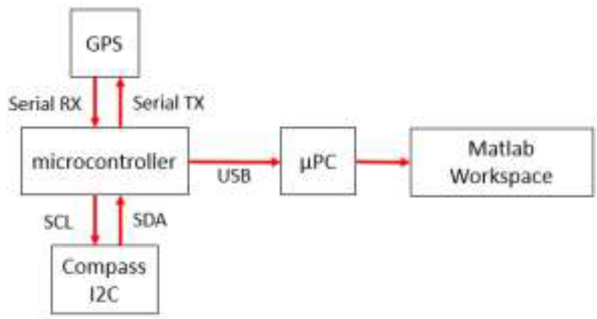


Fig. 7. Overall schematic diagram of Board 2.

3 Kinematic of MHeLFAGV system

For control planning, it is essential to model the kinematics of the system for desired input conversion to the driven elements. As shown in Figure 8, the MHeLFAGV system wheel consists of a fixed standard mecanum wheel with rollers attached to the wheel circumference. When viewing a MHeLFAGV from the top view, X_I and Y_I provide the final output coordinates of the system while *'a'* is the vehicle's width from wheel center to the MHeLFAGV center and '*b'* is likewise the MHeLFAGV length while '*l'* is the distance from the geometric center '*C'* to the wheel center '*D'*. Complete kinematics of an omnidirectional system with four wheels mecanum will be considered in this section.

Considering each of the mecanum wheels with mass (*mwi* = *mw*) and moment of inertia (*Iwi* = *Iw*) with the vehicle base has mass (*mb*) and moment of inertia (*Ib*). Figure 9 illustrated the system state variables $q=[x_I \quad y_I \quad \theta]^T$ in inertial laboratory frame *'I'* and input torques $\tau = [\tau_1 \quad \tau_2 \quad \tau_3 \quad \tau_4]^T$ acting on each wheel of the MHeLFAGV. In general, the vehicle base should be well balanced with the center of mass near the geometric center '*C'*. However, the model is generalized for bases where the center of mass '*C''* is offset from '*C*' by distances a_1 and a_2. As shown in Figure 9, the friction forces between each MHeLFAGV wheel are stated as $f = [f_1 \quad f_2 \quad f_3 \quad f_4]^T$.

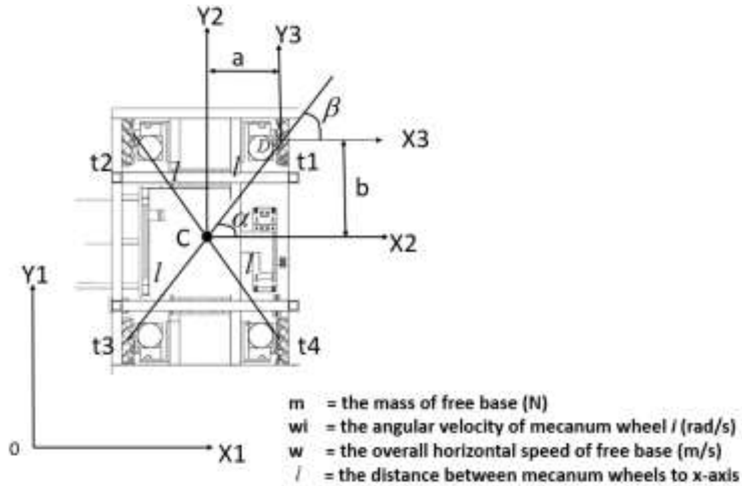


Fig. 8. Kinematic model of MHeLFAGV system.

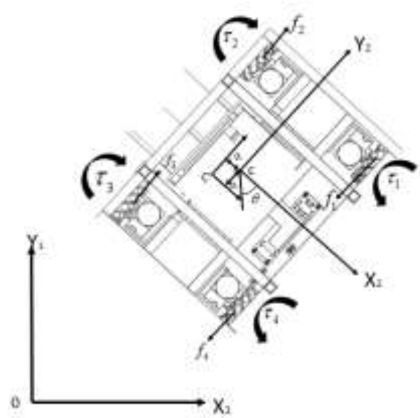


Fig. 9. System coordinates with input torques defined positively for Clockwise (CW) torques looking outward from the vehicle base.

The derivation of the system equations of this research shows that the kinematics of the MHeLFAGV wheel system rolling without slippage occurs. The components of inverse kinematic equations are tabulated in Table 1.

Table 1. Parameters of the each wheel.

Wheel	α_i	β_i	γ_i
$t1$	$\tan^{-1}(b/\alpha)$	$-\tan^{-1}(b/\alpha)$	$-(\pi/2+\pi/4)$
$t2$	$\pi-\tan^{-1}(b/\alpha)$	$\tan^{-1}(b/\alpha)$	$(\pi/2+\pi/4)$
$t3$	$\pi+\tan^{-1}(b/\alpha)$	$-\tan^{-1}(b/\alpha)$	$-(\pi/2+\pi/4)$
$t4$	$2\pi-\tan^{-1}(b/\alpha)$	$\tan^{-1}(b/\alpha)$	$(\pi/2+\pi/4)$

With reference to the equation (1) in order to find the direction of each wheel's rotation during the experiment, the equation of $\alpha = \tan^{-1}(b/\alpha)$ will be used. The equation is modified from the previous research works due to the positive or negative direction of γ_1.

$$\begin{bmatrix} t_1 \\ t_2 \\ t_3 \\ t_4 \end{bmatrix} = \left(\sqrt{2}/r\right) \begin{bmatrix} \sqrt{2/2} & \sqrt{2/2} & l\sin\left(\pi/4-\alpha\right) \\ \sqrt{2/2} & -\sqrt{2/2} & l\sin\left(\pi/4-\alpha\right) \\ -\sqrt{2/2} & -\sqrt{2/2} & l\sin\left(\pi/4-\alpha\right) \\ -\sqrt{2/2} & \sqrt{2/2} & l\sin\left(\pi/4-\alpha\right) \end{bmatrix} \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ y_1 \\ \theta \end{bmatrix} \quad (1)$$

4 Experimental results

Several experiments are done on MHeLFAGV completed system on both wide areas and targeted confine warehouse. The movement topology of the mecanum principle in Figure 10 depicts all moving vectors setup for MHeLFAGV system as discussed in the previous section. The test is done in remotely controlled mode. Moreover, each point longitude and latitude are recorded for every 2 seconds.

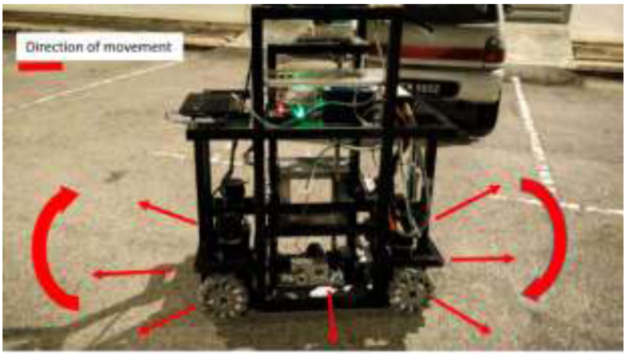


Fig. 10. Movement planning for MHeLFAGV.

The first test is done in wide as shown in Figure 11 where programmed omnidirectional moving vector is verified by using customize wireless remote control as trajectory input in a range of 100meters. According to the MHeLFAGV physical movement, RF communication performed very established connection even the system. With reference to the Figure 12, the coordination of latitude-longitude shows slightly fluctuated if compared to the desired signal as a factor of friction and uneven floor surfaces. However, the pattern of the desired movement is still followed by the vehicle in all omnidirectional movement vectors as shown from Figure 12(a) to 12(d). Moreover, this experiment shows that wireless remote controller with RF is successfully established and controlling the MHeLFAGV to move all vectors of omnidirectional movement. On the other hand, the GPS system with digital compass able to localize MHeLFAGV way point with an additional uFL connector to ensure GPS system having fast connection recovery with satellite.

 DOI: 10.1051/matecconf/20179001077

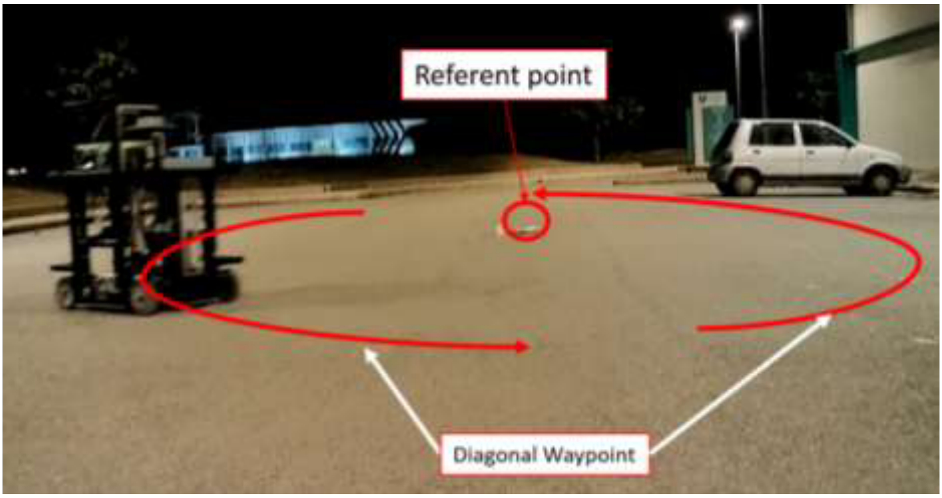


Fig. 11. Sample of MHeLFAGV experiment snap shot at wide area.

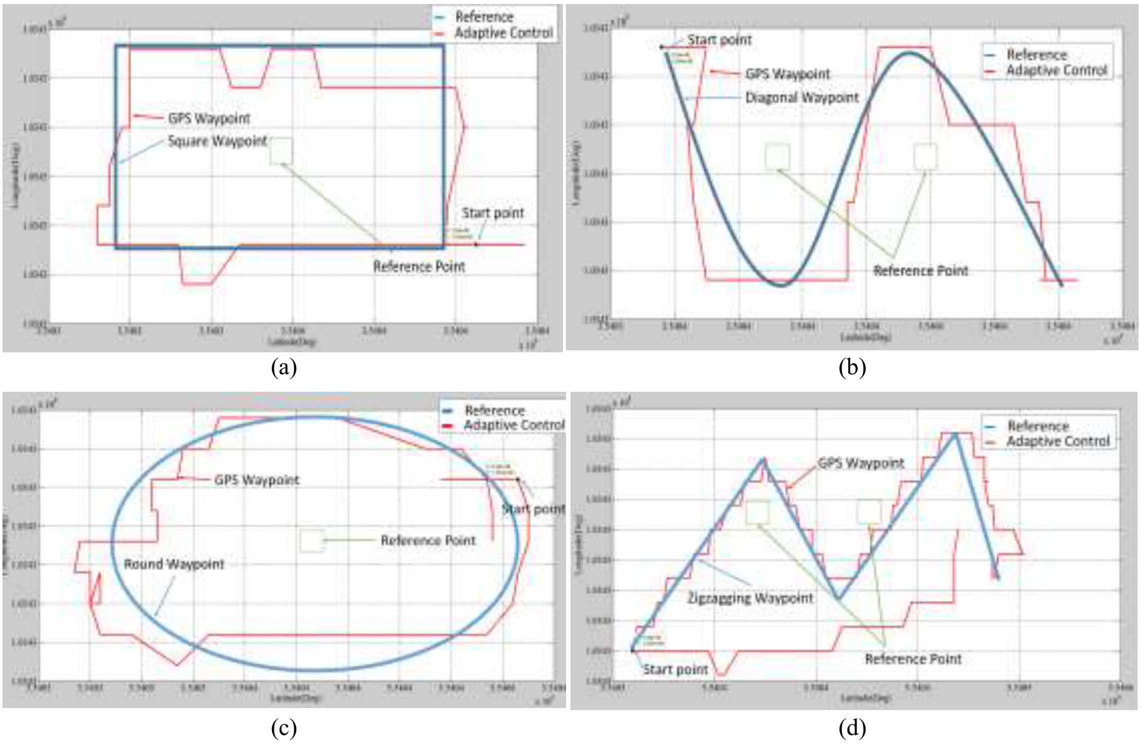


Fig. 12. The series testing of the movement of MHeLFAGV system.

The experiment is continued in the actual warehouse site at Vacuumshmelze (M) Sdn. Bhd. Pekan, Pahang, Malaysia. Through a series of movement tests, it shows that MHeLFAGV suitable to be deployed in the targeted line area as shown in Figure 13. The same omnidirectional movement was applied to move MHeLFAGV at this site as for the case of picking one of the heavy spools on the rack.

Fig. 13. Snapshot of MHeLFAGV on-site test.

5 Conclusions

This paper proposed a holonomic and omnidirectional design for a mini heavy loading AGV system named MHeLFAGV. Through a series of tests, it was shown that the programmed omnidirectional moving vectors were established and successfully deployed in various area including confine warehouses. It is remarked that experiment results show the durability of the designed AGV system to move almost accurately on the uneven surfaces with reference to the desired input. Improvement on the precision, dynamic motion, and autonomous movement are needed for MHeLFAGV system in order to comply with the industrial scale requirement and this will be the next step in this line of research.

This research and development are supported by Vacuumshmelze (M) Sdn. Bhd. Pekan, Pahang in collaboration with Universiti Malaysia Pahang (UMP) Research Grant (RDU150348).

References

1. Ramirez-Serrano, A. and R. Kuzyk. *Modified Mecanum Wheels for Traversing Rough Terrains*. in *2010 Sixth International Conference on Autonomic and Autonomous Systems*. 2010.
2. Jüttler, B., et al., *Classical Techniques for Applied Geometry and Kinematics of The Mecanum Wheel.* Computer Aided Geometric Design, 2008. **25**(9): p. 784-791.
3. Tlale, N. and M.d. Villiers. *Kinematics and Dynamics Modelling of a Mecanum Wheeled Mobile Platform*. in *Mechatronics and Machine Vision in Practice, 2008. M2VIP 2008. 15th International Conference on*. 2008.
4. Hoang, G., H.K. Kim, and S.B. Kim. *Control of Omini-Directional Mobile Vehicle for Obstacle Avoidance Using Potential Function Method*. in *Control Conference (ASCC), 2013 9th Asian*. 2013.
5. M. O, T., et al. *Design and Development of an Autonomous Omni-Directional Mobile Robot with Mecanum Wheels*. in *Automation, Quality and Testing, Robotics, 2014 IEEE International Conference on*. 2014.

 DOI: 10.1051/matecconf/20179001077

6. Vlantis, P., et al. *Fault tolerant control for omni-directional mobile platforms with 4 mecanum wheels*. in *2016 IEEE International Conference on Robotics and Automation (ICRA)*. 2016.
7. Chang Lin Lih and Y.S. Hao, *Modeling and Adaptive Control of an Omni-Mecanum-Wheeled Robot.* 2013. **4**: p. 166-179
8. Jia, Y., X. Song, and S.S.D. Xu. *Modeling and Motion Analysis of Four-Mecanum Wheel Omni-Directional Mobile Platform*. in *Automatic Control Conference (CACS), 2013 CACS International*. 2013.
9. Qi-Ye, Z., et al. *A TSK Fuzzy Model and Adaptive Sliding-Mode Controller Design for Four-Mecanum-Wheel Omni-Directional Mobile Free-Bases*. in *Chinese Automation Congress (CAC), 2015*. 2015.
10. Jiwung, C., *Kinodynamic Motion Planning for Vehicle* International Journal of Advanced Robotic Systems, 2015. **11**(90).
11. Haustein, J.A., et al. *Kinodynamic Randomized Rearrangement Planning Via Dynamic Transitions between Statically Stable States*. in *Robotics and Automation (ICRA), 2015 IEEE International Conference on*. 2015.
12. Hongchuan, W. and S. Ferrari, *A Geometric Transversals Approach to Sensor Motion Planning for Tracking Maneuvering Targets.* Automatic Control, IEEE Transactions on, 2015. **60**(10): p. 2773-2778.
13. A. ZAVALA, B.B., *On the Control of a One Degree of Freedom Juggling Robot.* 1999.
14. Dranga, O. and I. Nagy. *Stability Analysis of Feedback Controlled Resonant DC-DC Converter Using Poincare Map Function*. in *Industrial Electronics, 2001. Proceedings. ISIE 2001. IEEE International Symposium on*. 2001.
15. Shiller, Z. and H.H. Lu. *Robust Computation of Path Constrained Time Optimal Motions*. in *Robotics and Automation, 1990. Proceedings., 1990 IEEE International Conference on*. 1990.
16. Pan, Z., et al. *Dynamic Motion Planning For Autonomous Vehicle In Unknown Environments*. in *Intelligent Vehicles Symposium (IV), 2011 IEEE*. 2011.