Performance Evaluation of Mecanum Wheeled Omni-directional Mobile Robot

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Abstract - Mobile robots with omni-directional wheels can generate instant omni-directional motion including lateral motion without any extra space for changing the direction 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.

Keywords - Mobile robot; Mecanum wheel; Omni-directionality; Ultrasonic sensor; Performance evaluation

1 Introduction

Conventional mobile platforms with differential-drive system such as automobiles can generate 3-DOF motion like translational or rotational motion on 2-dimentional plane. However they cannot control each DOF independently, which is called non-holonomic characteristics [1]. For example, a differential drive mobile platform with a steering system is able to make forward and backward motion, but it cannot generate instantaneous lateral motion without rotation of the body. So, in order to generate lateral motion, quite complicated motion plan and dexterous operation are required such as combination of several times of forward and backward motion and rotation of the body using the steering system. This property of conventional mobile platforms gives a bad effect on development of industrial mobile robots in aspect of easy control system realization as well as simple mechanical design.

To develop a mobile robot system for automation process, this research suggests a mobile platform based on omni-directional wheels [2]. This type of mobile platform is capable of overcome shortcomings of conventional mobile robots. In order to move sideways, conventional systems require some extra space to rotate the orientation of the body. The size of the space is usually much larger than that of the system itself. However, the omni-directional wheels enable immediate lateral motion without rotating the body platform. Moreover, since the mobile platform with omni-directional wheels doesn’t need any extra space to change the direction of the body, it can generate very flexible motion trajectory to approach its destinations even in narrow aisles or tight areas.

It is noteworthy that those working environments often occur in various industrial fields such as manufacturing facility, warehouse, hospital, exhibition space and so on [3]. This mobile platform wheel is commonly used in robotic applications requiring a high degree of maneuverability, such as those experienced by NASA for hazardous environment exploration [4]. The objective of the OmniBot project (Figure 1. (a)) 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. Airtrax ATX-3000 industrial forklifts (Figure 1. (b)) 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 [5]. Uranus (Figure 1. (c)) was the first mobile robot with Mecanum wheels, designed and constructed in Carnegie Melon University [6]. It was built to provide a general purpose mobile base to support research in to indoor robot navigation.

(a) NASA OmniBot mobile base (b) Airtrax Sidewinder lift truck (c) Uranus omnidirectional mobile robot

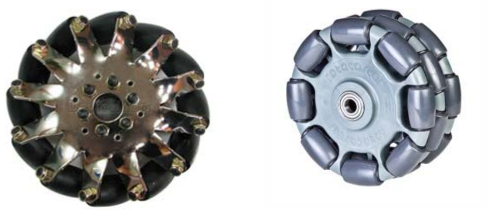
Figure 1. Applications of mobile platform based on Mecanum wheels

In this research, an omni-directional mobile robot based on Mecanum wheels was designed and manufactured. In this paper, the developed mobile robot prototype is briefly introduced and a few basic performances were evaluated by intensive experiments. Since it is a 'mobile' robot, the mobility was selected as the first performance index. After four-directional translation of forward, backward, left and right motion was generated, each directional velocity profile was obtained to observe it linear velocity and acceleration properties under a given distance. The second performance index is omni-directionality or omni-directional motion accuracy. It is measured by observing angular error between designated trajectory and measured trajectory for four-directional translation. The experimental results of the two performance indices are discussed in later sections.

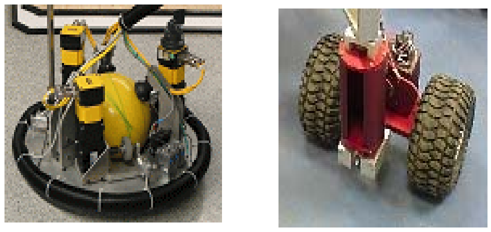
2 Basic Properties of the Omni-directional Mobile Robot

2.1 Properties of the Omni-directional Wheels

Figure 2. shows various types of omni-directional wheels. Especially the Mecanum wheel and orthogonal wheel designs are based on a concept that activates traction in one direction and allow passive motion in another, thus allowing greater flexibility in congested environments. In this research the Mecanum wheel, which is most frequently utilized in industrial fields, is selected to achieve omni-directionality of the mobile robot (Figure 2. (a)) [7]. Due to holonomic characteristics to generate instantaneous omni-directional motion, the mobile platform with omni-directional wheels can make flexible 3-DOF motion including instantaneous forward, backward, lateral and rotational movement in planar space and realize a simple control system through intuitive operating method. The Mecanum wheel is commonly composed of several sub-rollers which are mounted around the rim wheel circumference at a specific angle to the wheel axis (Figure 3.). Figure 3. (d) is the lateral view of the Mecanum wheel where sub-rollers are attached around the rim wheel with a specific angle, θ=45° in this study [8].

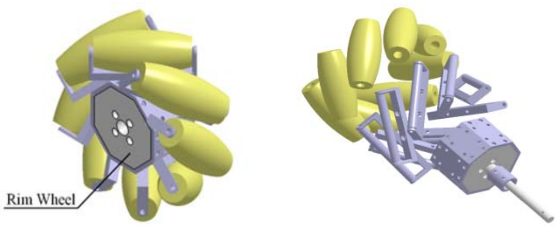


(a) Mecanum wheel (b) Orthogonal wheel

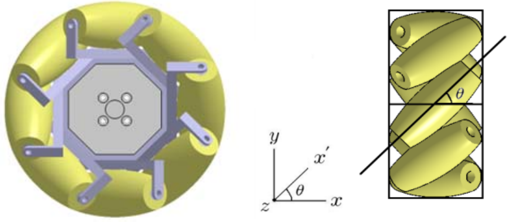


(c) Spherical wheel (d) Active castor wheel

Figure 2. Various types of omni-directional wheels



(a) Assembled view (b) Exploded view



(c) Axial view (d) Lateral view

Figure 3. 3-dimensional design of the Mecanum wheel

2.2 Mobile Robot Motion Mechanism Based on Mecanum Wheels

The suggested mobile robot has a squared platform with four Mecanum wheels at each edge in order to simplify the mathematical model and the motion control.

Using four of these wheels provides omni-directional movement for a vehicle without needing a conventional steering system. The sub-roller angled at 45^{o} about the rim wheel divides the force driven by the wheel rotation into one portion in the rotational direction of the sub-roller and the other portion in the axial direction of the sub-roller. The rotational force portion is dissipated by rolling of the sub-roller. Combination of the individual direction and velocity of each Mecanum wheel generates the total resultant force vector in any desired direction. Then, the mobile robot moves to the direction of the force vector without changing the direction of the mobile platform. Figure 4. shows the overview of the motion mechanism of the 4-wheeled omni-directional mobile robot.

3 Control System Design of the Omni-directional Mobile Robot

3.1 Electrical Circuit Design

In this research, CompactRIO (cRIO) and C Series motion & I/O modules of National Instrument Co. are utilized for the control system [9]. CompactRIO, which is a stand-alone embedded real-time processor, can equip various conditioning and I/O modules for sensors and actuators, so that it is often used as a control or data acquisition system. Table 1 presents the CompactRIO and C Series motion & I/O modules used in this research. NI cRIO-9082 is the embedded real-time controller, which has a chassis with 8 slots for inserting C Series motion & I/O modules. In order to coordinate four Mecanum wheels independently, four NI 9512 motion modules are employed. Analog and digital I/O signals are acquired or generated by NI 9205 and NI 9403 I/O modules. Four 800W servo motors and Sigma Series servo packs of Yaskawa Co. drive four Mecanum wheels. Figure 5. represents the control system hardware of the developed omni-directional mobile robot.

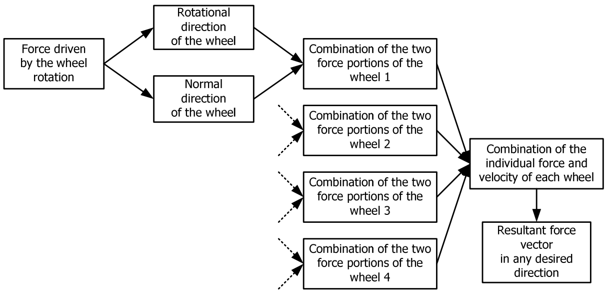


Figure 4. Overview of the motion mechanism of the 4-wheeled omni-directional mobile robot

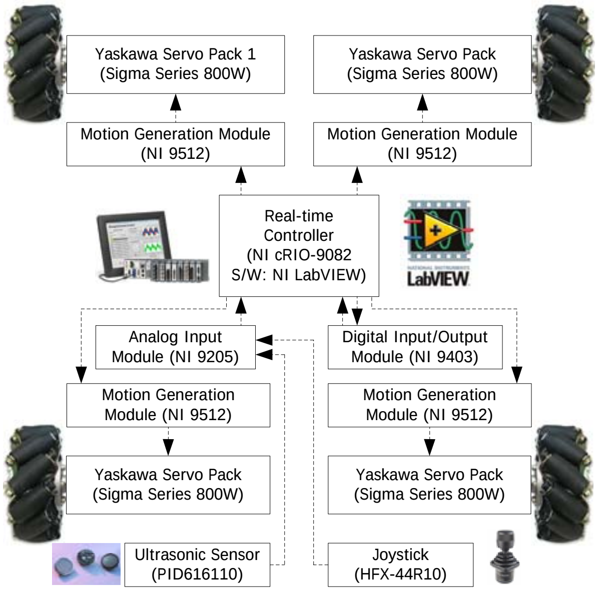


Figure 5. Control system hardware of the omni-directional mobile robot

Table 1 CompactRIO (cRIO) controller and C series I/O modules

Controller or Module name	Purpose	Note
NI cRIO-9082	Embedded real-time controller	8 slots for I/O modules
NI 9512	Motion generation	Stepper drive
NI 9205	Analog input	8 channels
NI 9403	Digital input/output	32 channels

3.2 Electrical Components

To generate planar motion of the mobile robot, an operator adjusts a joystick. Figure 6. (a) shows the joystick (HFX-44R10, CH Products) adopted in this research. Forward/backward, lateral and rotational motion without changing the direction of the mobile platform or an additional space can be driven by tilting the joystick to forward/backward, lateral and rotational direction. An analog voltage signal from the joystick is given to the NI cRIO-9082 real-time controller via NI 9205 analog input module. Then an appropriate motor command signal made by the controller is sent to the motors, which are connected to the Mecanum wheels, via NI 9512 motion module. Three ultrasonic sensors are used to measure the distance between the mobile robot and the side wall. Figure. 6 (b) shows the ultrasonic sensor (PID616110, SensComp) used in this research. The specification of the sensor is given in Table 2. It makes an analog voltage signal proportional to the distance, which is transported to the NI cRIO-9082 real-time controller via NI 9205 analog input module. For designated linear motion, if the operator inputs a desired position on the user-interface screen, cRIO-9082 real-time controller generates motion command according to a designated maximum velocity and acceleration rate. Then the mobile platform follows the motion command automatically. The angular position feedback information is provided by Yaskawa servo packs including incremental encoders.

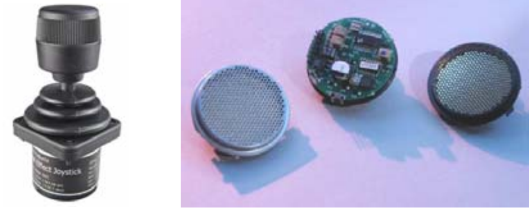

(a) Joystick (b) Ultrasonis sensor

Figure 6. Joystick (HFX-44R10, CH Products) and ultrasonic sensor (PID616110, SensComp)

Table 2 Specifications of the ultrasonic distance sensor

Model type	PID616110 (SensComp)
Distance range	0.15 ~ 5 m
Accuracy	+/- 0.1 %

4 Experimental Performance Evaluation

Ultrasonic sensors in-stalled on the frontal and lateral sides were employed to measure the real-time distance information 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. Figure 7. shows the laboratory view where artificial side walls were installed for reflecting the ultrasonic signals.

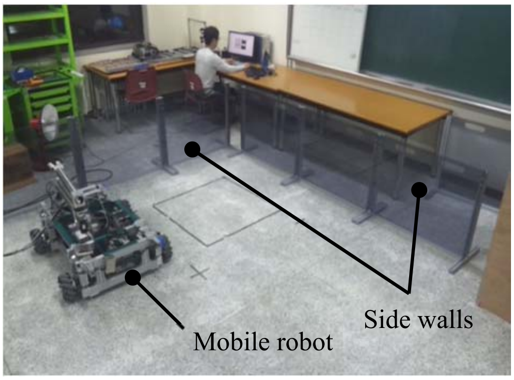
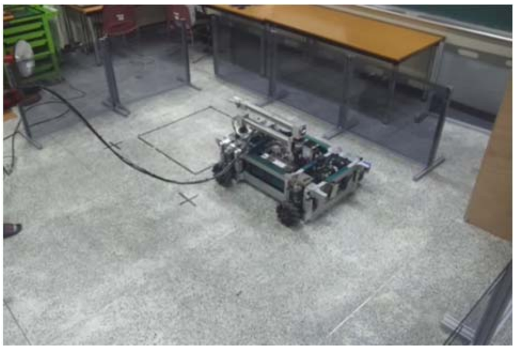


Figure 7. Laboratory view for experiments

4.1 Mobility

Since the developed system is a ‘mobile’ robot, the mobility was selected as the first performance index. After four-directional translation of forward, backward, left and right motion was generated, each directional velocity profile was obtained to observe its linear velocity and acceleration/deceleration properties under a given distance. Figure 8. and Figure 9. show the real experiment views for forward/backward and lateral translation.

(a) Initial position



(b) Final position

Figure 8. Experiments for forward/backward translation

Figures 10. shows the velocity performance information for forward, backward, left and right translation. In these figures, while signal 1 is measured from the frontal side sensor, signal 2 and 3 are measured from the lateral side sensors. Therefore, signal 1 presents the forward and backward motion in Figure 10. (a) and (b), and signal 2 and 3 do the lateral motion in Figure 10. (c) and (d). Table 3 summarizes linear velocities of the four cases. In forward and backward motion, the linear velocities were 0.72m/s and 0.73m/s, and in the lateral motion, they were 0.64m/s when the desired travel distance and the angular velocity of the wheels were fixed.

(a) Initial position

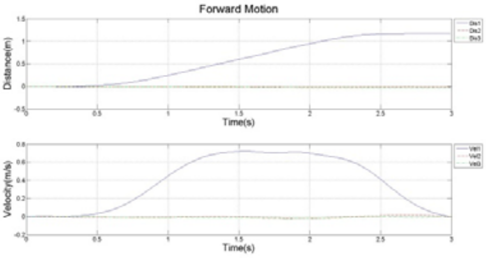
(b) Final position

Figure 9. Experiments for lateral translation

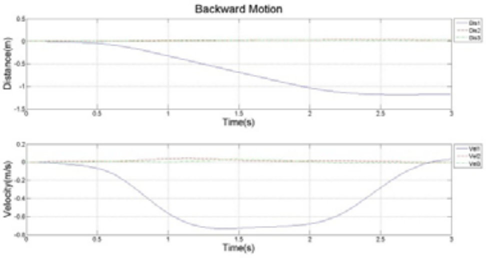
It is considered that the linear velocity difference between the forward/backward motion and lateral motion is caused by the structural characteristic of the Mecanum wheel. In the case of forward/backward motion, the Mecanum wheels act like conventional wheels without using passive rotation of the sub-rollers. However, in the case of lateral motion, passive rotation of the sub-rollers and frictional slip on the ground happen and the rotational velocity component of the driving rim-wheel is converted to the axial directional velocity component which makes the lateral motion of the mobile platform. In this converting process, the frictional slip on the ground gives rise to velocity loss.

Table 3 Linear velocities for four-directional motions

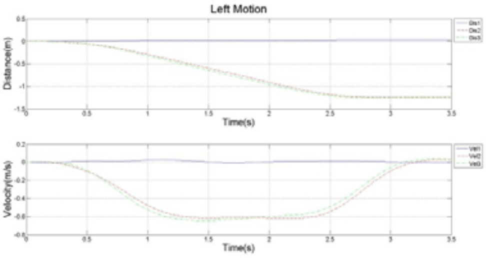
Direction	Linear velocity(m/s)
Forward	0.72
Backward	0.73
Left	0.64
Right	0.64



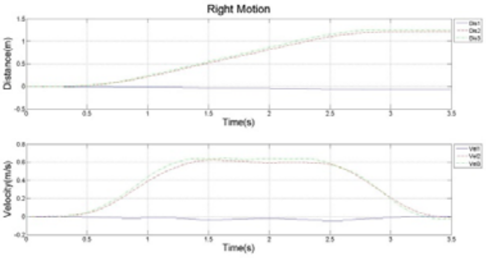
(a) Forward motion



(b) Backward motion



(c) Left motion



(a) Right motion

Figure 10. Velocity performance information for forward, backward, left and right translation

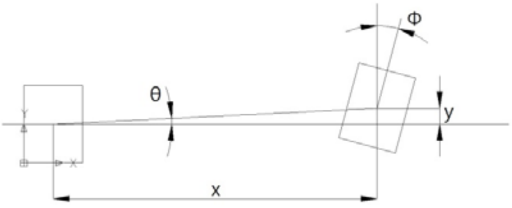


Figure 11. Angular error calculation for straightness

Table 4 Angular errors for four-directional translation

Direction	**Angular error(^{o})**
Forward	0.86
Backward	1.45
Left	1.32
Right	3.13

4.2 Omni-directionality

The second performance index of the developed mobile robot is the omni-directionality or omni-directional motion accuracy. It is measured by observing angular error between designated trajectory and measured trajectory for four translation cases, forward, backward, left, right motion. In order to find the angular error for translation, distance information from the frontal and lateral ultrasonic sensors is measured. With the distance information, the final position coordinate is calculated, then the relation between the initial and final position give the angular error. Figure 11. presents how to calculate the angular error for straightness where (x, y) is the final position coordinate and θ is the angular error. Table 4 shows the angular errors for four-directional translation. Since the accumulated angular errors are not compensated, there exist angular errors between reference and actual trajectory. For mobile application, some amount of slip between wheels and bottom always happens. Therefore, these kinds of mobile platforms are usually used in quite moderate situations where precise position accuracy is not required. Or an additional position control system should be employed.

5 Concluding Remarks

In this research, basic properties of the omni-directional 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.

Acknowledgement

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