Simultaneous Rotation and Translation Movement for Four Omnidirectional Wheels Holonomic Mobile Robot

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***Abstract*—Navigation and positioning is the main system for a mobile robot. Holonomicity in the field of robotic has becoming more and more important as it allow the mobile robot to do translation and rotation movements. Although many research had done to overcome the poor motion stability and trajectory motion using three omnidirectional wheels, they may have stability problems due to triangular contact area with the ground and the payload they carry. Thus, to increase the movement efficiency of the holonomic mobile robot, simultaneous translation and rotation movements for four omnidirectional wheels holonomic mobile robot was introduced. To create the system for the movement, a methodology is laid out in this paper. A kinematic analysis was done on the movement of the holonomic mobile robot. The algorithm of the kinematic movement of the mobile robot then was developed. A test grid was carry out to test the navigation algorithm of the system and the result is within the acceptable range. This algorithm would allow the holonomic mobile robot to do translation and rotation movements either simultaneously or independently.**

Keywords—Robot Navigation; Holonomic; Mobile Robot; Simultaneous movement;

I. INTRODUCTION

The majority of wheeled robots in manufacturing processes are not able to move in all directions from a given starting point while simultaneously rotating, this property is known as holonomy. The behavior of the system had made holonomic system become popular for mobile robots as they allow them to do translation or rotation movement easily [1].

Holonomicity in mobile robots provides an added advantage in which it has the ability to perform navigation without making many repetitively switching of its orientation along the travel path [2]. An omni-directional drive robot with omni-directional wheels attached around the circumference of the mobile robot allows the robot to move in any direction. The mobile robot would be able to perform two independent translational degree of freedom and one rotational degree of freedom, for the total of three degree of motion freedom on a flat surface.

Currently there are many design that exist for both research and commercial purpose. As shown in Figure 1, three wheeled omnidirectional drive system mobile robot were design in Faculty of Science and Engineering at Pontificia Universidad Catolca del Peru [3]. The drive system developed able to perform translational and rotational motion, the work was focusing on the speed and trajectory motion of the mobile robot.

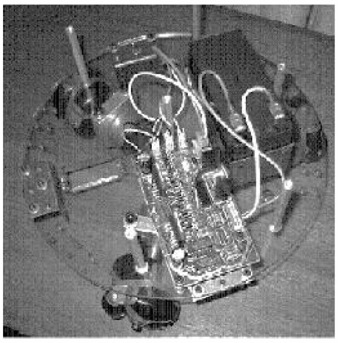

Fig 1. Three omnidirectional wheels mobile robot

Ball wheel drive mechanism for holonomic omnidirectional vehicle was then developed in Kyushu Institute of Technology, Japan [4]. The work was focusing on developing holonomic omnidirectional vehicle using ball wheel to solve the poor motion stability and poor step overcoming ability of the omnidirectional wheels.

Faculty of Engineering and Applied Science Oshawa, Canada had develop a decoupled teleoperation of a holonomic mobile–manipulator system using automatic switching [5]. The work presented using single joystick to control the entire mobile manipulator system.

Department of Computer Science, University of Freiburg, Germany had developed an online generation of Kinodynamic trajectories for non–circular omnidirectional robots [6]. Basically they had created a novel path representation for the non-circular omnidirectional robot using mecanum wheels. Figure 2 shows the omnidirectional robot with mecanum wheels. Basically they are able to create translation and rotation motion which can perform simultaneously.

Robotics and Intelligent Systems Research Group (myRIS) from Universiti Malaysia Sabah had develop a Medical Tele-diagnosis Robot (MTR). The work was focusing on a cost effective telemedicine mobile robot using four wheels holonomic system to provide a tele-presence capability for the specialist on a remote location to virtually meet the patient [7].

The same research team, myRIS also develop fuzzy logic based navigation safety system for a remote controlled orthopaedic robot (OTOROB). The work focused mainly on Danger Monitoring System (DMS) of the mobile robot [8].

Fig 2. Omnidirectional robot using mecanum wheels

The holonomic system can be created by using omnidirectional wheels. Three wheels holonomic system are capable to achieve 3 degree of freedom motions by driving three independent actuators. However, they may have stability problems due to triangular contact area with the ground and the payload they carry, especially when traveling on a ramp with high center of gravity [9]. Therefore, four wheeled holonomic system are preferred when stability is of great concern.

Although many improvement had done in the aspect of the poor motion stability and the trajectory motion, the necessity to overcome the stability of the robot using omnidirectional wheels to drive the holonomic system is a challenging task. The flexibility and agility of the movement of the mobile robot will determine the efficiency of the navigation system.

To circumvent all these problems, an algorithm of simultaneous rotation and translation movement for four omnidirectional wheels holonomic mobile robot is developed. This design using four wheels to overcome the stability of the mobile robot. The mobile robot developed can be perform simultaneous translation and rotational movement. Basically it can move to any direction. Such an effort is laid out in this paper whereby the control and navigation of the holonomic mobile robot is introduced.

In section 2 of this paper, research methodology will be discussed. Section 3 elaborates on the hardware design encompassing the mobile robot platform and the controller board. Section 4 describes the navigation algorithm and the experimental and simulation results are laid out in the section 5. Section 6 brings out the conclusion.

II. Research Methodology

The system basically consists of software development such as motion algorithms development and hardware development such as mobile robot platform and circuit board development.

The system is first initialize for the controller and the omnidirectional mobile robot. The system will then continue to run until it received instruction from the controller. The controller will received the instruction from the user and the instruction will fetch to the system. After performing mathematically calculation, the robot position and orientation are determined. The mobile robot's position and orientation will then be converted to the wheel's angular velocity to perform translation or rotation movement whether independently or simultaneously. If the system does not receive any instruction from the controller, the system will not perform any action and the mobile robot will stay idle. The system end when the user manually stops the system. The system is illustrated in Figure 3.

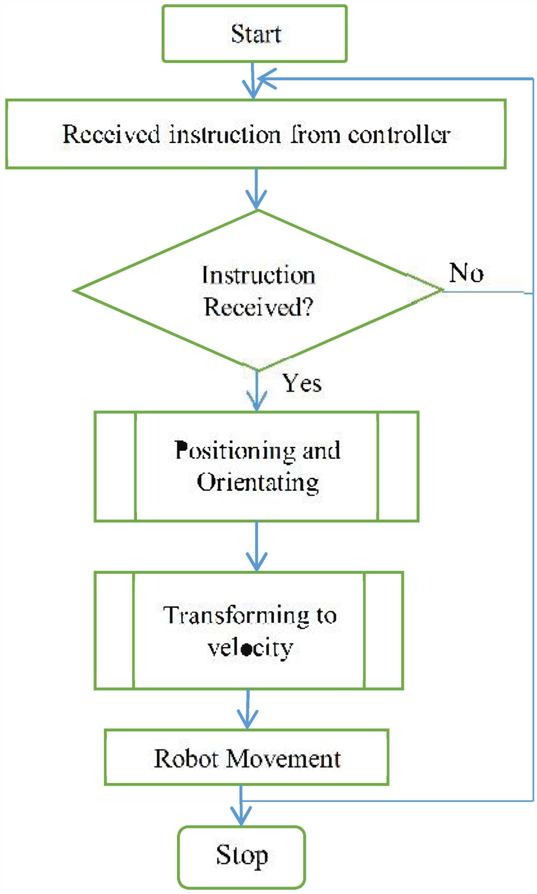

Fig 3. Overall System Flowchart

III. Hardware Design

The hardware design of the holonomic mobile robot is divided in to two main parts which are the holonomic platform and the controller board. Each of the hardware is discussed in this section.

A. *Holonomic Mobile Robot Pltatform*

The structure of the mobile robot platform was designed and developed. The platform of the mobile robot is designed in such that four holonomic wheels were attached perpendicular to each other to the circumference of the hexagon shape of the mobile robot platform. Each wheel was drive by each Vexta Brushless Motor (30W) with a gear ration of 10:1. Figure 4 shows the developed holonomic mobile robot with omnidirectional wheels and motors mounted. Based on the designed configuration, the holonomic robot is able to move in any direction.

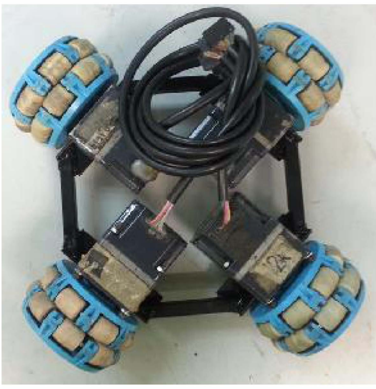

Fig 4. Structure of four omnidirectional wheels mobile robot

B. *Holonomic Mobile Robot Controller Board*

The holonomic mobile robot controller board is a dedicated board developed using dsPIC30F4011 microcontroller. The dsPIC microcontroller plays the role as the data processing unit. The location of the mobile robot will be input by user and the microcontroller will process the data and provide a PWM signal for the motor to allow the mobile robot run to the desired location. Figure 5 shows the data processing flowchart for the dsPIC microcontroller.

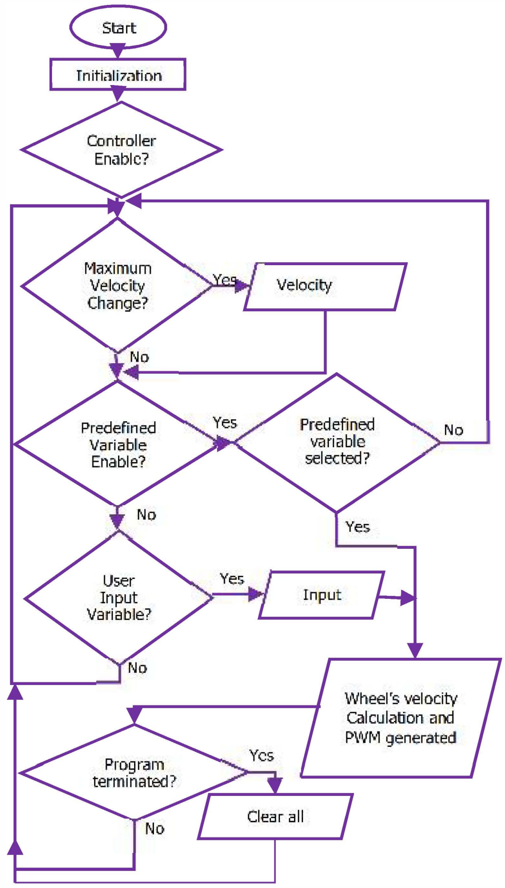

Fig 5. Data processing flowchart

IV. NAVIGATION ALGORITHM

The key elements of the holonomic mobile robot is its algorithm. The input data is processed by an algorithm developed using trigonometric, the microcontroller later output the correct command for the mobile robot to navigate to the correct destination.

When three or more of omnidirectional wheels are used on a platform, constrained and unconstrained motions can produce full holonomic motion. The wheels were installed at same distance from the center of the mobile robot platform with their driving direction vector aligned tangentially to the circle connecting them, and with a uniform separated angles between neighboring pair of wheels. The nature of the omnidirectional wheel allows it to obtain a velocity without applying any driving force itself. The force comes from the motion of other wheels. The velocity produced is called induced velocity, V_{in} [10]. Figure 6 shows the induce velocity of the holonomic mobile robot.

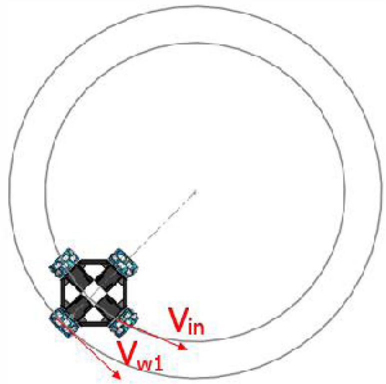

Fig 6. Induce velocity, Vin of holonomic mobile robot

The vectors acting at an omnidirectional wheel is shown in Figure 7. Where V_w is the velocity of wheel, V_{in} is the induced velocity of wheel, V is the velocity of the mobile robot frame, θ is the reference wheel angle, φ is the reference mobile robot frame angle, *L* is the radius of the mobile robot platform, and ψ is the angular velocity of the mobile robot frame.

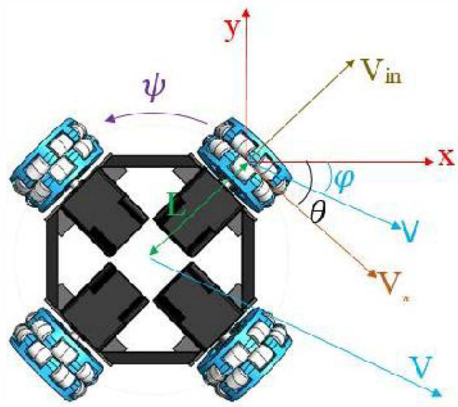

Fig 7. Components of omnidirectional wheel

Considering the x and y as the reference frame, knowing that the V_w and the V_{in} are always orthogonal,

$$V^2 = V_w^2 + V_{in}^2 \qquad (1)$$

$$beside,\ V_{in}^2 = V^2 + V_w^2 - 2V_w V\cos(\theta - \varphi) \qquad (2)$$

Substitute (2) into (1), we get

$$V_w = V\cos(\theta - \varphi) \qquad (3)$$

Assuming ψ is the angular velocity of the mobile robot frame, then each wheel of the robot must have,

$V_w = L\psi$

Then each of the wheel would have:

$$V_w = V\cos(\theta - \varphi) + L\psi \quad (4)$$

The angular velocity of the wheel is given by $\omega = \frac{V_w}{R}$, where R is the radius of the wheel. Combining with equation 4, we have:

$$\omega = \frac{V\cos(\theta-\varphi) + L\psi}{R} \quad (5)$$

The ψ, angular velocity can also be describe as

$$\int \psi \, dt = \int d\theta$$

$\theta = \psi t$, where t is orientating time (6)

Substituting (6) into (5),

$$\omega = \frac{V\cos(\psi t-\varphi) + L\psi}{R} \quad (7)$$

This is the general equation that is independent to the number of wheels. For four omnidirectional drive system, we would have wheels arranged at angles of $0°, 90°, 180°$ *and* $270°$. Thus:

At wheel 1, 0° $\omega_1 = \frac{V\cos(\psi t-\varphi) + L\psi}{R}$

At wheel 2, 90° $\omega_2 = \frac{V\cos(\psi t+90°-\varphi) + L\psi}{R}$

At wheel 3, 180° $\omega_3 = \frac{V\cos(\psi t+180°-\varphi) + L\psi}{R}$

At wheel 4, 270° $\omega_4 = \frac{V\cos(\psi t+270°-\varphi) + L\psi}{R}$

V. Experimental Result and Analysis

A. Algorithm Simulation

The simulation was created using Matlab to test the algorithms for the translation and rotation movements of the mobile robot platform in all direction either independently or simultaneously. Figure 8 shows the Matlab simulation results for an illustrated robot frame. From the simulation, the movement of the mobile robot was observed and it shows the algorithm work perfectly either independently or simultaneously. The simulation performed was a single point to point trajectory. To achieve a curvature trajectory, multiple point to point transformation can be performed.

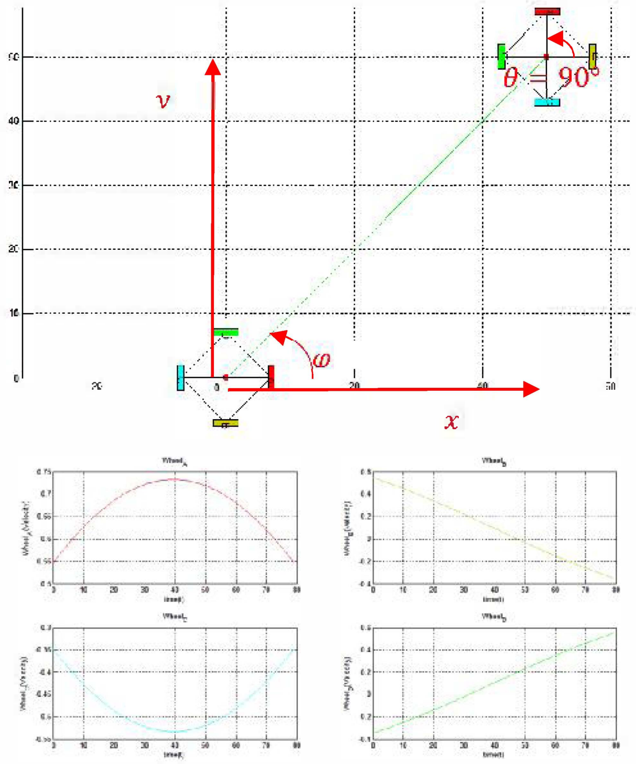

Fig 8. Matlab simulation for a robot frame that had move from origin to coordinate (50, 50) with orientation angle of 90°

B. Practical Results

The holonomic mobile robot was developed as shown in the Figure 9. A predefined coordinate on a test grid (Figure 10) was created to test the movement or navigation of the holonomic robot. The value measured in the test grid was in cm. The holonomic mobile robot will navigate from the origin market with (0, 0) to the coordinate (100, 100) on the test grid.

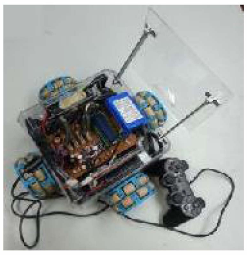

Fig 9. Holonomic mobile robot

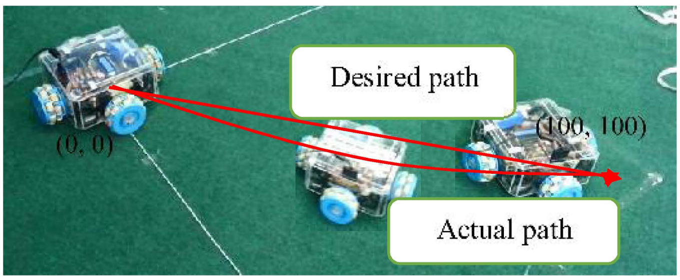

Fig 10. Robot simultaneous movement with translational coordinate (100cm, 100cm) and rotational degree of 45°

Table 1 shows the result of the robot moving from point (0, 0) to the coordinate (100, 100) as shown in Figure 10. The experiment was repeated for 10 times to determine the accuracy of the navigation of the holonomic mobile robot. From the results, statistical analysis shows that the standard deviation for the movement on the X and Y axis with angle are 0.83, 0.87, and 0.77 respectively. Since the standard deviations are below 1, it indicated that the values were not deviate too far away from the exact value. The maximum percentage error calculated for the X axis, Y axis, and angle are 4%, 4%, and 6.67% respectively.

TABLE 1. EXPERIMENTAL DATA OF HOLONOMIC MOBILE ROBOT NAVIGATION

Test Count	X coordinate, cm (Actual=100)	Y coordinate, cm (Actual=100)	Frame Angle 45°
1	97	98	43
2	98	97	42
3	96	97	44
4	98	98	43
5	97	99	42
6	99	97	43
7	97	96	44
8	98	98	42
9	96	96	43
10	97	97	44

The simultaneous movement shows in Figure 10 which the mobile robot slightly move out from the desired path indicates that the speed control of motors are important. The speed control of motor should be support by a feedback system to ensure the motors run in the correct speed, so that it achieve the correct pathway. The practical result is not ideal as the simulation result, this is due to the motors in the simulation are assumed to rotate at the perfect desired speed.

Besides that, the robot can only perform in certain type of floor only as the robot might slip in some of the surface. The dynamic analysis if perform will ensure that the slippage problem can be reduce.

Another contributing factor for the slight deviation is due to the acceleration and deceleration of the mobile robot, since the constant velocity of the mobile robot assumed in the simulation resulted in additional gain of unwanted inertia.

VI. CONCLUSION

The work presented in this paper describes the navigation methodology of a four omnidirectional wheels holonomic mobile robot. The research methodology of the mobile robot was discuss. The hardware design of the mobile robot comprising the holonomic platform, and dedicated holonomic robot controller are described. The navigation algorithm is explained, simulated and tested. A test grid is used to check for the validity of the measured value. Feedback system is suggested to encounter the minor curving of the pathway during the simultaneous movement. An algorithm to accelerate and decelerate was suggested to increase the performance of the system. A dynamic analysis should be done to avoid slippage issues. In spite of that, the analysis of the experimental data show that the accuracy is still within the acceptable range.

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