A Large Payload Omni-Directional Platform

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Abstract

The design and development of the *OmniMaxbot*, an omni-directional platform with three degrees-of-freedom (DOF) capable of carrying large payloads, is presented. The OmniMaxbot is composed of a square aluminum platform driven by four omni-directional Mecanum wheels. A suspension system allows the OmniMaxbot to absorb any vibrations incurred while traveling. Currently, a 3-DOF joystick is used to control the system. Indoor localization is also implemented. This is achieved using a differential time-of-flight localization system based on a modified and expanded version of the Cricket system developed by the Massachusetts Institute of Technology (MIT).

Keywords: omni-directional, Mecanum wheel, Cricket localization, transport

1 INTRODUCTION

An omni-directional robot is a robotic platform that is able to move in any direction and rotate at the same time. It is holonomic in nature with all of its three degrees-of-freedom (DOF) being controllable. This gives it advantages over nonholonomic platforms in terms of mobility, maneuverability, and control.

Figure 1: Mecanum Wheel

Omni-directional wheels provide a vehicle with its omni-directional capability. A Mecanum wheel, shown in Figure 1, is a type of omni-directional wheel. It is a wheel lined with angled rollers along its perimeter. The rollers are at 45° to the wheel's axis of rotation. The integration of rollers into the main wheel gives these wheels 2-DOF. Figure 2 shows the directions in which the Mecanum wheel can roll. A vector in any direction along the 2D plane can be created by combining the shown vectors. This property enables the wheels to travel in any direction.

Figure 2: Motion of a Mecanum Wheel

Assuming that roller bearing friction is negligible, when a Mecanum wheel is driven, it only applies a force in the direction of the roller's axis (the roller that makes contact with the ground). The two possible forces are shown in Figure 3 as seen from the bottom. If the wheel spins forward, a reaction force of 45° to the top right is applied to the wheel by the ground. If the wheel spins backward, a reaction force of 45° to the bottom left is applied to the wheel by the ground.

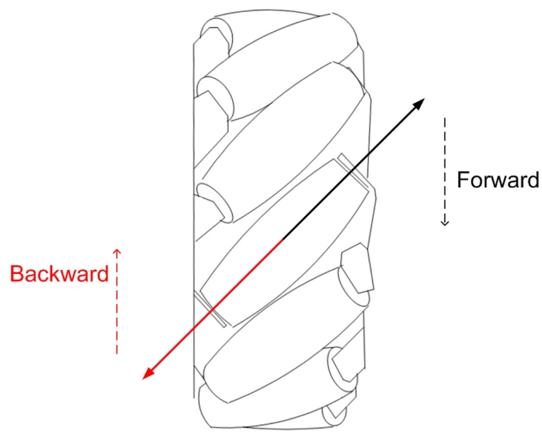

Figure 3: Forces on a Mecanum Wheel (Bottom View)

Bengt Ilon [1] designed the first Mecanum wheel in 1972. Since then much work has been done on omni-directional Mecanum wheeled robots. Muir and Neuman [2] studied the kinematics of robotic platforms with Mecanum wheels. They then implemented the kinematic model that they developed with feedback control onto an actual omni-directional robot in [3]. Dickerson and Lapin [4] showed that omni-directional robots achieved tasks much faster and using less space than their nonholonomic counterparts. As well, they showed that "excessive computation" is not necessary to compute the motion of an omni-directional robot powered by Mecanum wheels, even when wheel slip is considered. Tlale and de Villiers [5] developed and verified a mathematical model for an omni-directional platform built with Mecanum wheels that would be suitable for autonomous behaviour. Their work, like Muir and Neuman's, was based on the simplification that the Mecanum wheel's point of contact with the ground is always located directly under the geometric midpoint of the wheel. Viboonchaicheep et al. [6] also used this method. However, they proposed that vision sensor data be used to rectify the position. This was later implemented in [7]. Gfrerrer [8] later derived a much more accurate kinematic model of the Mecanum wheel by not using this simplification/assumption. Han et al. [9] studied the sources of position error in omni-directional robots that used Mecanum wheels. They found that most position errors occurred due to wheel slip. To fix this, they introduced a wheel parameter adjustment.

In addition to research systems, due to their very practical nature, omni-directional platforms have made their way into industry. Kuka's youBot and Segway's RMP 50 Omni and RMP 400 Omni omni-directional platforms are three examples. The youBot consists of a small mobile manipulator driven by a platform with Mecanum wheels, while the RMP 50 Omni and RMP 400 Omni are solely platforms. Airtrax has integrated the Mecanum wheels into both forklifts and scissor lifts.

The OmniMaxbot presented here is a large payload omni-directional platform created at the Mechatronic and Robotic Systems Laboratory at the University of Ontario Institute of Technology (UOIT). The Omnibot, a much smaller omni-directional vehicle has previously been developed. The Omnibot's design and control is documented in [10, 11]. It is driven by double omni-wheels and is currently being used to test control algorithms for omni-directional mobile manipulators. The design goal of the OmniMaxbot was to scale up the capabilities of the Omnibot.

2 Physical Design

The OmniMaxbot is shown in Figure 4. It consists of a square frame driven by four Mecanum wheels. A suspension system composed of a spring and damper allows each wheel to travel over small obstacles.

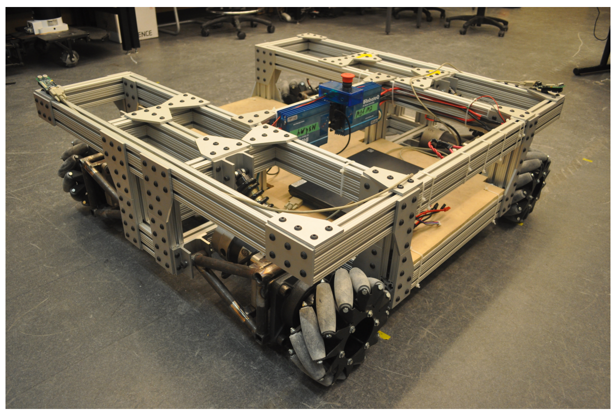

Figure 4: OmniMaxbot

The OmniMaxbot's square frame is made from 80/20® extruded aluminum. The use of 80/20® allows for easy and accurate construction of the frame and makes the frame very stable. The slotted nature of the aluminum allows for peripherals (such as sensors) to be easily added. The system is very modular, enabling easy design changes.

The large open area on the left side of the frame is designed to hold large vats/drums/boxes for transport. This area can also be used for mounting a large manipulator if one wishes to create a mobile-manipulator system.

Four Mecanum wheels drive the system. All four wheel axes are parallel to each other. However, their rollers are arranged in different orientations with respect to each other. This is shown in Figure 5. The force vectors of the Mecanum wheels are also shown. The combination of the four force vectors results in the motion of the OmniMaxbot. It should be noted in Figure 5 the top view of the OmniMaxbot is shown. Therefore, the rollers of the Mecanum wheel in contact with the ground are actually perpendicular to the rollers shown.

A suspension system has also been implemented on the OmniMaxbot. It is shown in Figure 6. It consists of a triangular linkage that is integrated with a spring-damper system. The suspension helps absorb some of the vibrations that the OmniMaxbot may encounter. This in turn allows for smoother motion and prevents the transported object from becoming damaged.

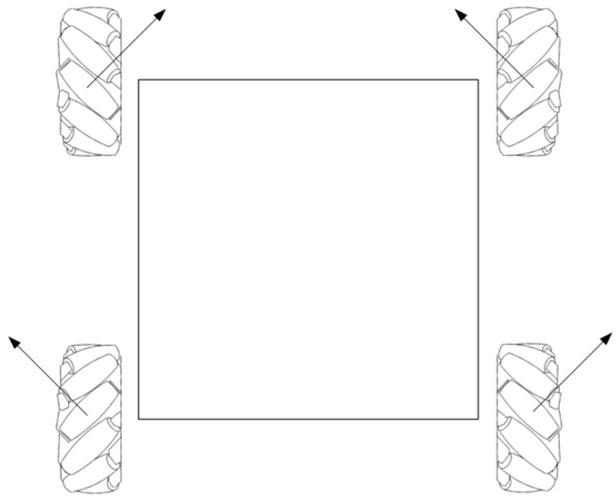

Figure 5: Mecanum Wheel Orientation on the OmniMaxbot (Top View)

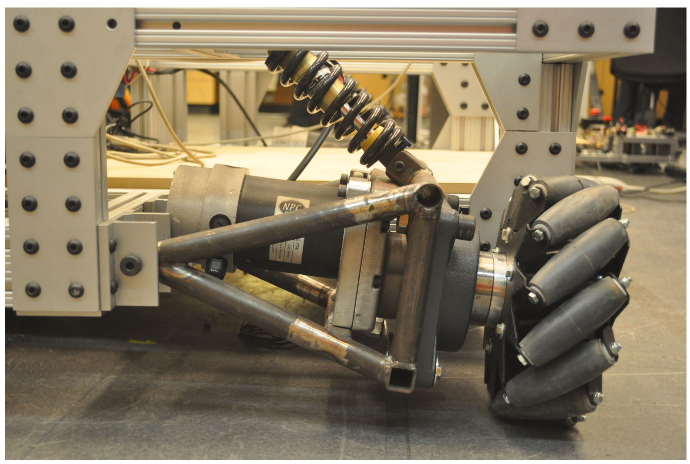

Figure 6: Suspension System

In terms of size, the OmniMaxbot is approximately $118\,\mathrm{cm}$ wide by $123\,\mathrm{cm}$ long by $47\,\mathrm{cm}$ high. It has been designed to support a payload of up to $500\,\mathrm{kg}$ and has a maximum translational speed of $2.2\,\mathrm{m/s}$ and a maximum rotational speed of $86\,\mathrm{rad/s}$.

3 ELECTRICAL SYSTEMS

Four NPC-T74 motors by NPC Robotics power the four Mecanum wheels. They have a maximum torque of $167\,\mathrm{Nm}$. The motors are equipped with encoders that have $1,250$ cycles per revolution.

Two Roboteq AX2550 motor controllers are used to control the motors. Each motor controller is capable of controlling two motors, both in terms of direction and speed. The motor controllers keep track of the encoder count. The encoder values are used in the PID motor speed controller. The motor controllers are capable of providing $4,800\,\mathrm{W}$ of power to each motor. Data logging is also permitted by the motor controllers. The system is being powered by five $11.1\,\mathrm{V}$ nominal three-cell lithium polymer batteries. Each battery is rated at $5\,\mathrm{amp-hours}$. Four of these batteries are used to supply power for the motors, two are wired in series and two are wired in parallel. The resulting battery is $22.2\,\mathrm{V}$ and $10\,\mathrm{amp-hours}$. The fifth battery is used to supply independent power to the control logic of the motor controllers.

4 CONTROL

Currently, the OmniMaxbot is controlled wirelessly via a joystick. Figure 7 shows the system layout in the context of the control scheme. Joystick data is read by an off-board desktop computer. This data is sent wirelessly to a laptop located onboard the OmniMaxbot. The joystick may also be attached directly to the laptop. In this way, the operator can control the OmniMaxbot while walking along with it. On the laptop, the joystick coordinates are then converted to the desired translational and rotational velocities. This involves a simple mapping of the three joystick coordinates to the three velocity components of the OmniMaxbot. The desired Mecanum wheel velocities are then calculated using the kinematic model Muir developed in [3]:

$$\left\{ \begin{array}{c} \dot{\theta}_1 \\ \dot{\theta}_2 \\ \dot{\theta}_3 \\ \dot{\theta}_4 \end{array} \right\} = \frac{1}{2\pi r} \begin{bmatrix} 1 & 1 & (l_a + l_b) \\ 1 & -1 & -(l_a + l_b) \\ 1 & -1 & (l_a + l_b) \\ 1 & 1 & -(l_a + l_b) \end{bmatrix} \left\{ \begin{array}{c} V_x \\ V_y \\ \dot{\rho} \end{array} \right\} \tag{1}$$

where r is the wheel radius and V_x, V_x, $\dot{\rho}$, $\dot{\theta}_1$, $\dot{\theta}_2$, $\dot{\theta}_3$, $\dot{\theta}_4$, l_a and l_b are defined as shown in Figure 8.

The desired wheel velocities are then sent to the two motor controllers which in turn control the motors. Each of the motors has an encoder. The encoder values are read in by the motor controller and PID control is used to control the speed. In addition, the encoder data, motor current, battery voltage, and other information are sent to the laptop. Currently this data is not being used.

All the software is implemented within the Robot Operating System (ROS) (`www.ros.org`). ROS was developed by the Stanford Artificial Intelligence Laboratory and is now supported by Willow Garage. Implementing software within ROS has many advantages. First, it allows for ease of communication between the different computers and microprocessors in the system. Second, it allows the software to be distributed across a variety of processors, thereby allowing for more computing power. Third, ROS has a well supported database of tools that are already developed. Therefore, rework is avoided and much more complex systems can be designed.

5 LOCALIZATION

Indoor absolute localization is achieved using a modified version of the Cricket system developed by the Massachusetts Institute of Technology (MIT) [12]. The key benefit to an absolute localization system is that it does not carry the risk of error buildup due to successive measurements from previous positions. The majority of existing localization systems utilize information about previous positions, and therefore must deal with the problem of error buildup. The benefits of an absolute localization system come at the cost of requiring transceivers with known locations positioned in the environment.

The Cricket system is implemented in the same manner as was demonstrated on the Omnibot

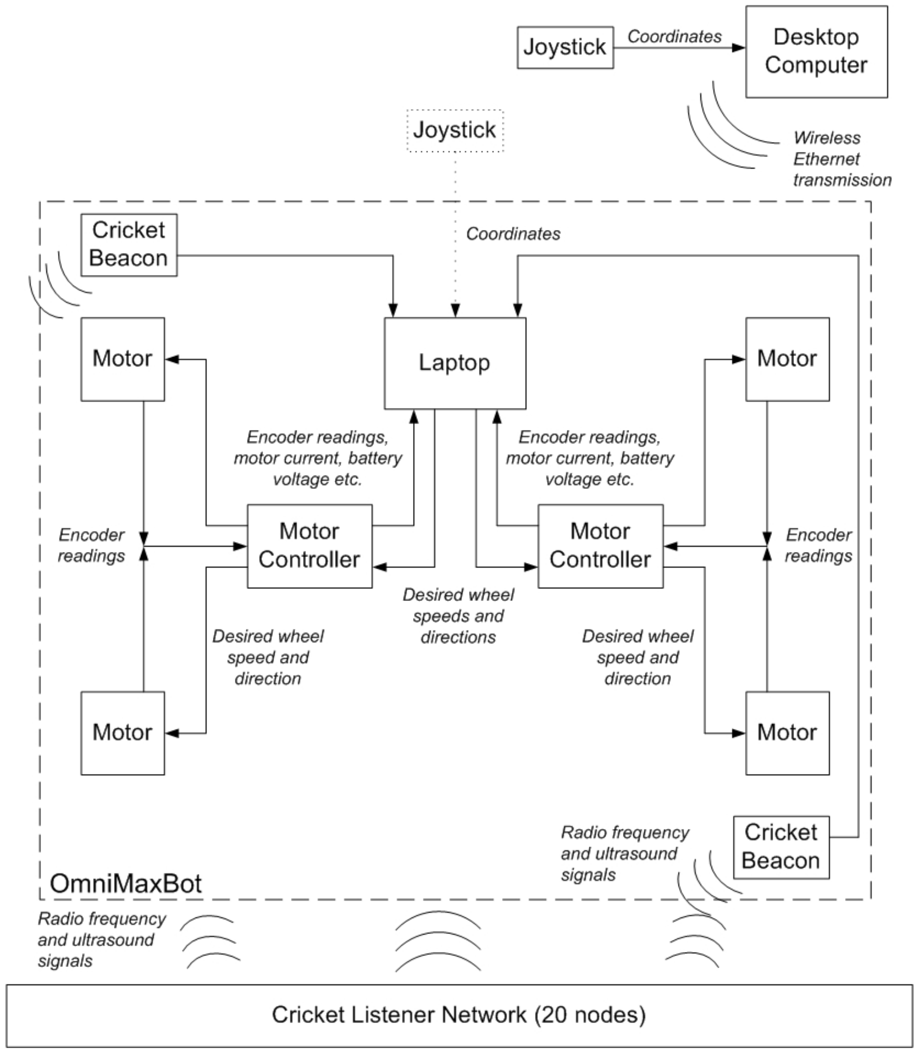

Figure 7: System Layout

[13, 14]. With this system, two beacons are placed on the OmniMaxbot at diagonal corners. These beacons continuously transmit radio frequency (RF) and ultrasonic (US) signals. Receivers are located on the ceiling of the OmniMaxbot's workspace. The time-of-flight of the RF and US signals from the beacons to the receivers is recorded. The time-of-flight is then converted to a distance measurement. Through the use of trilateration, the position of the beacons on the OmniMaxbot is calculated in an absolute manner. The positions of the two beacons are then used to find the pose of the OmniMaxbot.

In [14] it was demonstrated that the Cricket system is able to determine the position of the Omnibot platform with a mean error and standard deviation of $3.56\,\mathrm{cm}$ and $1.95\,\mathrm{cm}$ respectively at a translational speed of $0.5\,\mathrm{m/s}$, and a mean error and standard deviation of $1.11\,\mathrm{cm}$ and $1.05\,\mathrm{cm}$ respectively at $0.15\,\mathrm{m/s}$. The error of the orientation measurement is directly related to the distance between the two Cricket transceivers mounted on the vehicle and their position error.

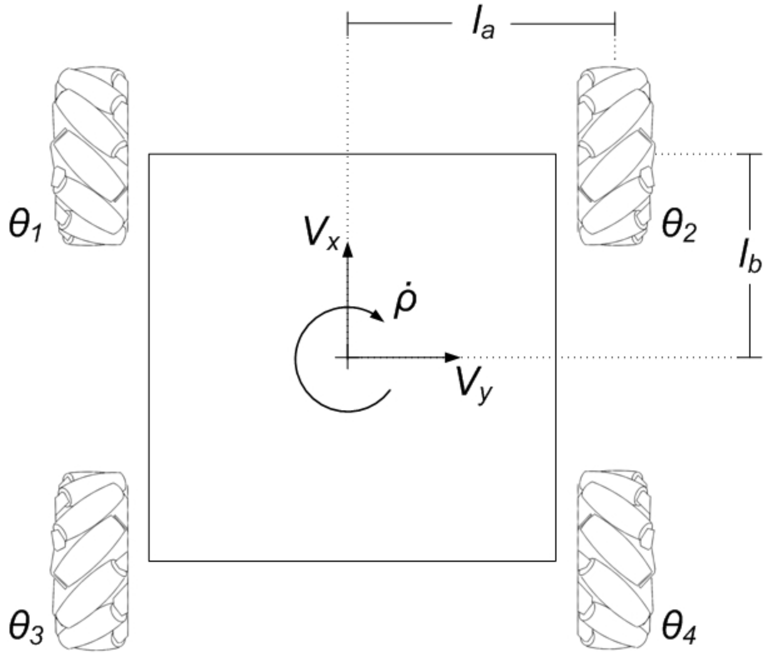

Figure 8: Variables

6 FUTURE WORK

Future work on the OmniMaxbot will focus on three primary goals. First, the localization system will be expanded and improved upon through the integration of a laser range finder and optical wheel encoders into the existing system utilizing a simultaneous localization and mapping (SLAM) framework. Second, a collision detection system based on infrared (IR) sensors will be implemented. The third goal will involve implementing an autonomous navigation routine based on the localization system. With the addition of these systems, the OmniMaxbot will be capable of working autonomously in a factory setting.

7 CONCLUSIONS

A large payload omni-directional robot has been designed. Dubbed the OmniMaxbot, it has 3-DOF as it can translate in the x and y axes of a plane and rotate about the vertical axis. The OmniMaxbot's square frame is built using extruded aluminum and is driven by four omni-directional Mecanum wheels located under the frame. A suspension system has been implemented to absorb any vibrations incurred during transport. The OmniMaxbot has been designed to transport a maximum payload of $500\,\mathrm{kg}$ and travels at a top speed of $2.2\,\mathrm{m/s}$. The OmniMaxbot is currently manually controlled using a 3-DOF joystick. Velocity control is used to control the wheel speeds. An indoor localization system has been implemented with a collision detection system and autonomous navigation routine currently being developed.

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