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A system design for transforming an everyday object into an omnidirectional robot

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Abstract

Omnidirectional robotic platforms have greater mobility in congested environments compared to conventional vehicles, and a variety of omnidirectional wheeled robots have already been developed. The primary focus of conventional studies is to develop an improved mechanism for omnidirectional movement. This paper, on the other hand, proposes a system for transforming an everyday object, such as office furniture, into an omnidirectional robot by attaching several driving mechanisms. The driving mechanism arrangement for the proposed system depends upon its intended application. In order to achieve this objective, the control system must be easily redesigned based upon the changes in the driving mechanism arrangement. The system consists both a feedforward controller based on an inverse-kinematics model and a feedback controller to reduce the effects of eccentric loading and driving force imbalances. In order to illustrate the viability of the proposed system, experiments were conducted using a Horizontal Wheel Driving Mechanism as the driving mechanism. The system performance was verified experimentally. In addition, an operative example successfully transformed a steel office desk into an omnidirectional robot.

Keywords: omni-directional robot, flexible arrangement, inverse-kinematics, master-slave control system

1 Introduction

Omnidirectional robotic platforms have greater mobility in congested environments compared to conventional vehicles, and a variety of omnidirectional wheeled robots have already been developed. The Swedish Wheel [1] was the first system to accomplish omnidirectional motion without changing the direction of the wheels. This system has been applied to wheelchairs [2] as well as other applications. Pin and Killough developed a unique omnidirectional vehicle consisting of a pair of powered wheel units that alternately touch the floor [3]. West and Asada proposed a wheel design based on a concept that achieves traction in one direction while allowing passive motion in another [4] and the VUTON developed by Hirose and Amano consists of arrays of cylindrical tires combined with a unique crawler mechanism [5].

This paper considers omnidirectional robots from a different point of view. The primary focus of conventional studies is to develop an improved mechanism for omnidirectional movement. New mechanisms have been designed and a variety of omnidirectional robots have been developed. This paper, on the other hand, proposes a system for transforming an everyday object, such as office furniture, into an omnidirectional robot by attaching several driving mechanisms. The driving mechanism arrangement for the proposed system depends upon its intended application. In order to achieve this objective, the control system must be easily redesigned based upon the changes in the driving mechanism arrangement. For this purpose, three special features are included in this system. These features are detailed in Section 2. Section 3.1 describes an experiment intended to show that the proposed system can successfully transform a usual object into an omnidirectional robot. Finally, as an operative example, the system is applied to a steel office desk to create an omnidirectional robot. Note that the term "driving mechanism" will hereafter be referred to as an "actuator."

2 Proposed System

2.1 Main Features

The following three features are included in the proposed system:

1) A master-slave control system is employed to eliminate the variation in the high computational volume. If one controller is responsible for each actuator, the computational load depends upon the number of actuators. Hence, a control system containing master and slave controllers is necessary. The role of the master controller is to send commands to the slave controllers and the slave controller performs the task on its assigned actuator.

2) The system utilizes a feedforward controller using an inverse-kinematics model instead of an inverse-dynamics model. The actuator arrangement for this system is flexible and it is complicated to modify a feedforward controller with an inverse-dynamics model because a modification requires a drastic change in its dynamics model. On the other hand, a controller with only an inverse-kinematics model is unable to address the effects of disturbances due to eccentric loading or a driving force. For this reason, a feedback controller is incorporated in the control system to reduce these disturbances.

3) Any type of actuator can be included in this proposed omnidirectional system. The only requirement is that the driving mechanism must be able to produce driving forces in any direction.

These features are described in more detail in Sections 2.2, 2.3 and 2.4.

2.2 Master-Slave Control System with an Inverse Kinematics Model

A master-slave control system is employed to eliminate the variation in the high computational volume. The system consists of a master controller and several slave controllers. The number of slave controllers is equal to the number of actuators. The role of the master controller is to forward commands to the slave controllers and the slave controllers calculate the required movements for their assigned actuators by using the inverse-kinematics model.

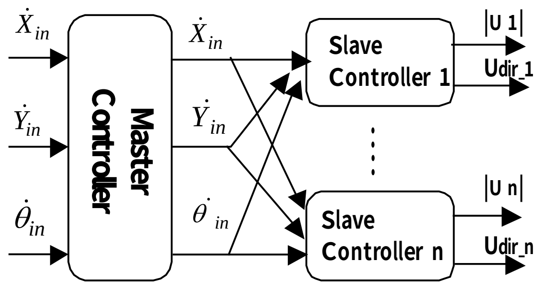


Figure 1: Master - Slave Control System

A schematic for the master-slave control system is shown in Figure 1. The command to the robot is given in terms of velocity $(\dot{X}_{in}, \dot{Y}_{in}, \dot{\theta}_{in})$. Suppose that actuator *i* is located at (R_i, θ_i), where the origin is the pivot point of the omnidirectional robot, R_i is the distance from the origin and θ_i is the angular coordinate. The movements of actuator *i*, $\dot{X}_i$ and $\dot{Y}_i$, needed to achieve the command velocity $(\dot{X}_{in}, \dot{Y}_{in}, \dot{\theta}_{in})$ can be calculated using

$$\dot{X}_i = \dot{X}_{in} - R_i \dot{\theta}_{in} \sin(\theta_i) \qquad (1)$$

$$\dot{Y}_i = \dot{Y}_{in} + R_i \dot{\theta}_{in} \cos(\theta_i) . \qquad (2)$$

The driving force for each actuator is given in terms of a vector with strength $|U_i|$ and direction U_{dir_i} . The total driving force needed to move the robot at a command velocity of $(\dot{X}_{in}, \dot{Y}_{in}, \dot{\theta}_{in})$ is given as

$$|U_i| = \sqrt{\dot{X}_i^2 + \dot{Y}_i^2} \qquad (3)$$

$$U_{dir\_i} = \tan^{-1}(\dot{Y}_i / \dot{X}_i) \qquad (4)$$

where $\dot{X}_i$ and $\dot{Y}_i$ are provided in Equations (1) and (2). Each slave controller computes its individual driving force using Equations (3) and (4). When the arrangement of the actuators is modified, their new positions (R_i, θ_i) must be sent to the slave controllers responsible for the modified actuators. This method is very flexible and the computational load does not change when the arrangement is modified.

2.3 Feedback Controller

A conventional control system using an inverse-dynamics model can handle dynamic element effects such imbalances in the driving force, eccentric loads, and tire slippage. The proposed feedforward control system with an inverse-kinematics model, though, cannot handle these dynamic effects. These effects, however, will significantly impact the robot's trajectory, especially during straight-line movement. An eccentric load will cause the robot's trajectory to curve. An eccentric load alters all three of the command velocities, but the angle velocity $\dot{\theta}_{in}$ is primarily affected while moving along a straight trajectory. Therefore, only the angle velocity is controlled by the feedback controller. Hereafter, the third command $\dot{\theta}_{in}$ is changed to θ_{ref} because it is easier for an operator to control an angle than an angular velocity. The angular velocity $\dot{\theta}$ measured by a gyro will be translated into the angle θ that is fed back. This angle is controlled by a PID compensator. As shown in Figure 2, the control system does not feed back velocities $\dot{X}_{in}$ or $\dot{Y}_{in}$.

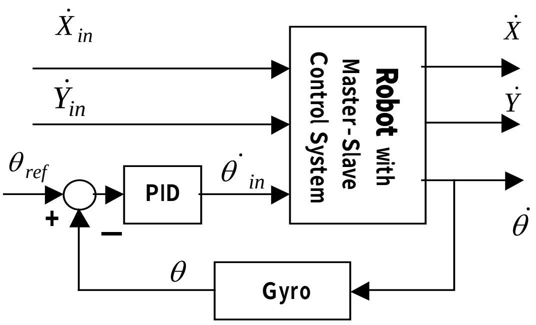


Figure 2: Control system with feedback loop

2.4 Driving Mechanism

The system must be flexible enough to accommodate any type of actuator. The only requirement is that the actuator must be able to produce driving vector forces in any direction. For example, a mechanism with three free-moving wheels located around its circumference can be used as an actuator. This paper conducted experiments using the horizontal wheel driving mechanism shown in Figures 3 and 4.

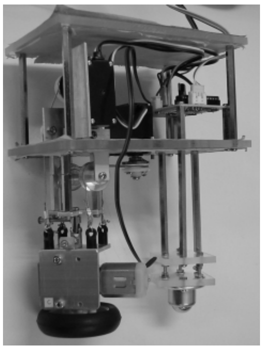


Figure 3: Photograph of the Horizontal Wheel Driving Mechanism

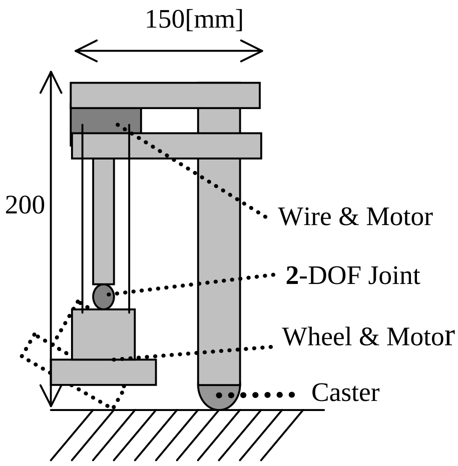


Figure 4: Schematic of the Horizontal Wheel Driving Mechanism (side view)

The driving mechanism consists of a wheel that can be rotated to any angle by a wire and a DC servomotor. A caster is employed as an auxiliary wheel. When the robot is standing still, the wheel rotates at a constant speed while it is suspended horizontally. Meanwhile, the caster supports the robot. When the robot is moving, the wheel rotates and contacts the floor to produce the driving forces. This horizontal wheel driving mechanism can generate a driving force with strength $|U_i|$ by adjusting the speed of rotating motor. The direction U_{dir_i} is modified by adjusting the contact direction. This driving mechanism can easily produce a desired driving force $|U_i|$ and U_{dir_i}, so it is selected to test the proposed omnidirectional system.

3 Experiments

3.1 Validation of the Feedback Controller

Experiments were carried out to verify the following two assertions. First, the proposed control system reduces the effects of dynamic elements, such as imbalances in the driving force and eccentric loads. Secondly, proper actuator arrangement improves the robot's motion performance.

For these experiments, a board with four "horizontal wheel driving mechanisms" is regarded as the omnidirectional robot. Figure 5(a) displays the arrangement of the four actuators. This arrangement causes an imbalance in the driving force. A 7-kg eccentric load is positioned on the board.

In order to ensure a straight trajectory, a constant command input $(\dot{X}_{in}, \dot{Y}_{in}, \theta_{in})$ is specified. The driving force imbalance and the eccentric load cause the robot to turn, as shown in Figure 6. When the feedback controller is employed, however, these effects are reduced and the robot moves in a straight line, as shown in Figure 7.

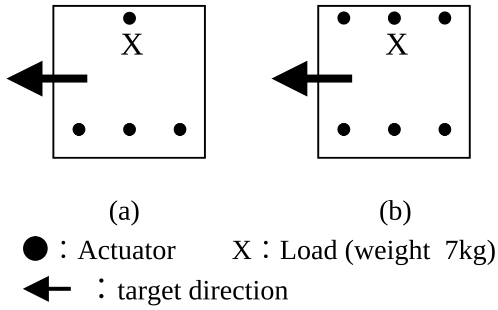


Figure 5: Configuration of the actuators and load

Figure 6: Robot trajectory without the feedback controller (configuration in Figure 5(a))

For the next experiment, the number of actuators is increased from 4 to 6. The new actuator arrangement is shown in Figure 5(b). The driving force imbalance for this arrangement is smaller than that for the arrangement shown in Figure 5(a). The trajectory of the robot is displayed in Figure 8. The figure reveals that the robot with six actuators is able to travel straight faster than the robot with four actuators. In this control system, only the angle θ was fed back while its velocity ($\dot{X}_{in}$, $\dot{Y}_{in}$) is not. Therefore, the speed of the robot depends upon the number of actuators.

Figure 7: Robot trajectory with the feedback controller (configuration in Figure 5(a))

Figure 8: Robot trajectory with the feedback controller (configuration in Figure 5(b))

When position control is needed, a global position (X_{global} , Y_{global}) should be determined by a camera or other method and then be fed back. In addition, an image processing system or intelligent information handling system is required to achieve position control. Although position control is beyond the scope of this paper, the proposed system can be extended for this purpose.

Figure 9 displays the robot's attitude angle time response for the configurations in Figures 5(a) and 5(b). Decreasing the driving force imbalance stabilizes the variations in the attitude angle. This experimental result demonstrates that the number and arrangement of actuators affect the robot's motion performance.

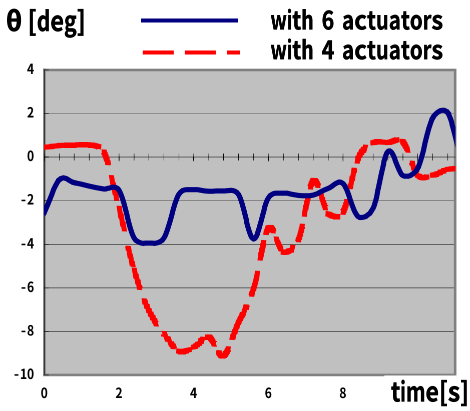


Figure 9: Attitude angle time response

3.2 Steel Desk Application

An operative example of the proposed system was conducted. For this experiment, a steel office desk is retrofitted for omnidirectional movement. Three actuators are attached to each side of the desk, as shown in Figure 10.

Figure 10: Steel desk with driving mechanisms

Figure 11 shows the schematic for the experiment. An operator stood at the point labeled ● and operated a joystick. The operator then observed the motion of the desk and sent commands through the joystick to move it from its starting position to its final position. The straight arrowhead line in Figure 11 represents the target trajectory for the robotic desk.

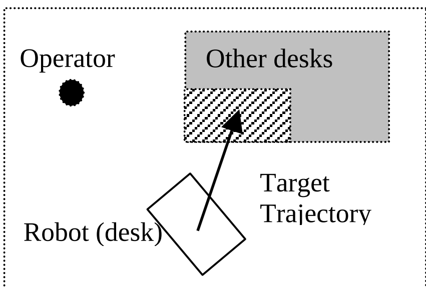
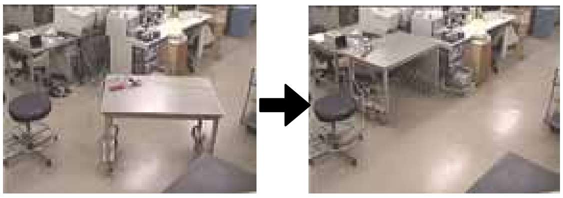


Figure 11: Schematic diagram for the experiment

The actual trajectory of the desk is shown in Figure 12. The desk successfully traveled from the starting position to the final position by modifying its attitude, however, a visual estimation error caused the actual trajectory to vary slightly from the target trajectory.



Starting Position   Final Position

Figure 12: Trajectory of the omnidirectional desk robot

The experimental results verify that the proposed system can successfully retrofit furniture, such as a steel office desk, into an omnidirectional robot. In the future, the proposed system will be extended to an automatic arranging system for office desks and office chairs by employing a navigation system specifically designed for moving robots.

4 Conclusions and Remarks

This paper proposed a system for transforming commonplace objects, such as office furniture, into omnidirectional robots by attaching several driving mechanisms. The system contains three key features.

A master-slave control system is employed to eliminate the variation in the computation load. The master controller forwards commands to each slave controller and the slave controllers perform the tasks using their assigned driving mechanisms.

The control system consists of both a feedforward and a feedback controller. The feedforward controller is based on an inverse-kinematics model instead of an inverse-dynamics model. The feedback controller is used to reduce the dynamic effects that cannot be managed by the kinematics model.

Finally, the proposed omnidirectional system can accommodate any type of driving mechanism. The only requirement is that the driving mechanisms must be able to produce driving forces in any direction.

Experimental results show satisfactory omnidirectional motion performance. An operative example successfully transformed a steel office desk into an omnidirectional robot. These results show that the proposed system is useful to transform an everyday object, such as office furniture, into an omnidirectional robot.

5 References

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