Optimal path planning with Holonomic mobile robot using localization vision sensors

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Abstract: Most of the present drive systems of the home service robots and the industrial robots use non-holonomic systems that function only when the robots are moving. For instance, the average vehicle can only be steered when driving so instant movement in all directions is not possible. And that is why the holonomic drive system is attracting attention. In this paper, we propose a holonomic system using three omni-direction wheels to enable instant movement in all directions. Also, IR-projector and vision sensors are proposed for autodrive robots to detect the robot's positioning. This system uses an infrared ray projector which processes the image reflected from the infrared reflector installed on the ceiling to detect the absolute position and direction angle of the robot in real time. Robot autodrive using vision sensors is also proposed.

Keyword - Holonomic, Non-holonomic, localization vision sensor, Optimal navigation, Omni-direction-wheel and Path-planning

I. INTRODUCTION

Industrial and technical applications of mobile robots are continuously gaining in importance. Mobile robots are already widely used for surveillance, inspection, and transportation tasks.

A further emerging market is that of mobile entertainment robots. The basic requirement for autonomous mobile robots is the ability to move through its operational area, avoiding hazards and obstacles, finding its way to the next location to perform its task.

These capabilities are known as localization and navigation. In order to know where to go, the robot must have an accurate knowledge of its current location. From here, the robot can navigate to the next position, using a great variety of sensors, external references, and algorithms.

The performance of a mobile robot is determined to a large extend by the tracking and localization algorithms, as well as its sensing capabilities. Research is continuously going on in this field, to improve the autonomous navigation capability of mobile robotic systems.

In order to test newly developed sensing, navigation and localization strategies, a universal mobile robotic base featuring omni-directional motion capability is designed, providing a flexible motion platform to test and improve developed algorithms and sensing systems.

In this paper, kinematics of omni-directional mobility will be derived. And then, navigation from the point on the reference path $P_p(i)$ to $P_p(i+1)$ via localization sensor will be shown.

II. Kinematics

The omniwheel powered base consists of three omniwheels, positioned at an angle α_i, relative to the local frame $[x_l, y_l]$. The center of this frame coincides with the center of gravity of the base and wheel 1 is located on the local axis (x_l), in other words: α_1 = 0, Fig. 1. The orientation of the base with respect to the global frame (x_g, y_g) is given by the global coordinates $[x, y, \theta]$. The relation between the global velocity of the platform $(\dot{x}, \dot{y}, \dot{\theta})$ and translational velocity v_i of wheel hub i can be obtained using the inverse kinematic equation of each wheel hub. The component of v_i in x_g direction, denoted as v_1x in Fig. 1, must be equal to $\dot{x}$, due to the fixed position of the hub relative to the center of the mass. For v_1y a similar relation can be derived. When the base rotates, the hub speed v_i needs to satisfy the condition $v_i = \theta \cdot R$, please note that r refers to the wheel radius, while R represents the distance from the center of the mass of the platform to the wheels along a radial path.

$$v_i = -\sin(\theta + \alpha_i)\dot{x} + \cos(\theta + \alpha_i)\dot{y} + R\dot{\theta} \qquad (1)$$

The translational velocity of the hub can be rewritten as a angular velocity $\dot{\phi}_i$ of the wheels using Eq. (2), resulting in Eq. (3)

$$v_i = r\dot{\phi}_i \qquad (2)$$

$$r\dot{\phi}_i = -\sin(\theta + \alpha_i)\dot{x} + \cos(\theta + \alpha_i)\dot{y} + R\dot{\theta} \qquad (3)$$

This can be transformed to matrix representation Eq. (4)

$$\underline{\dot{\phi}} = J_{inv}\underline{u} \qquad (4)$$

From Eq. (3) and Eq. (4) the inverse jacobian J_{inv} for the omniwheel powered base can be obtained, providing a direct relation between global velocities and angular velocities of the wheels.

$$\begin{bmatrix} \dot{\phi}_1 \\ \dot{\phi}_2 \\ \dot{\phi}_3 \end{bmatrix} = \frac{1}{r} \begin{bmatrix} -\sin(\theta) & \cos(\theta) & R \\ -\sin(\theta + \alpha_2) & \cos(\theta + \alpha_2) & R \\ -\sin(\theta + \alpha_3) & \cos(\theta + \alpha_3) & R \end{bmatrix} \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} \qquad (5)$$

In most cases, it is not convenient for users to steer a robot in global coordinates however. It is far more natural to think and steer in local coordinates. Fortunately, we can now simply convert global coordinates to local coordinates with the following equation.

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \cos(\theta) & 0 & 0 \\ 0 & \cos(\theta) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \dot{x}_l \\ \dot{y}_l \\ \dot{\theta} \end{bmatrix} \qquad (6)$$

Substituting Eq. (6) in Eq. (5) leads to:

$$\begin{bmatrix} \dot{\phi}_1 \\ \dot{\phi}_2 \\ \dot{\phi}_3 \end{bmatrix} = \frac{1}{r} \begin{bmatrix} -\sin(\theta) & \cos(\theta) & R \\ -\sin(\theta + \alpha_2) & \cos(\theta + \alpha_2) & R \\ -\sin(\theta + \alpha_3) & \cos(\theta + \alpha_3) & R \end{bmatrix} \begin{bmatrix} \cos(\theta) & 0 & 0 \\ 0 & \cos(\theta) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \dot{x}_l \\ \dot{y}_l \\ \dot{\theta} \end{bmatrix}$$

(7)

This matrix relation in the local frame can also be expanded to three separate equations for easy implementation in programming applications:

$$\begin{aligned} \dot{\phi}_1 &= \quad (-\sin(\theta)\cos(\theta)\dot{x}_l + \cos^2(\theta)\dot{y}_l + R\dot{\theta})/r \\ \dot{\phi}_2 &= (-\sin(\theta + a_2)\cos(\theta)\dot{x}_l + \cos^2(\theta + a_2)\dot{y}_l + R\dot{\theta})/r \\ \dot{\phi}_3 &= (-\sin(\theta + a_3)\cos(\theta)\dot{x}_l + \cos^2(\theta + a_3)\dot{y}_l + R\dot{\theta})/r \end{aligned} \qquad (8)$$

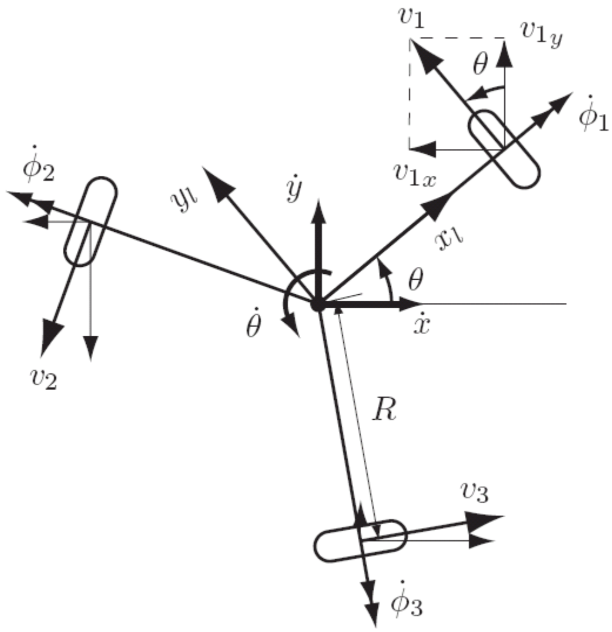

Fig 1. Kinematic diagram of the three wheel base

III. Localization Sensor

StarGazer is a localization sensor system for indoor localization of intelligent mobile robots. It analyzes infrared ray images which are reflected from a passive landmark with an independent ID. The output of position and heading angle of a robot is given with very precise resolution and high speed. It is seldomly affected by surroundings such as an infrared ray, a fluorescent light, and sunshine.

The sensor output data values are from the subsidiary's own protocol and communications used the RS232C output.

IV. CONTROLLER DESIGN

Design conditions of lateral controller of the omniwheel robot system are steady state error 2%, overshoot 5%, and rising time 1 second. The controller is designed by using system parameters.

The transfer function of PID controller is given by Eq. (9)

$$K(s) = K_P + \frac{K_I}{s} + K_D s \quad (9)$$

V. EXPERIMENT

1. Experimental system

Experiments were conducted in order to verify that the omniwheel robot moves accurately along the reference path using the StarGazer sensor.

In Fig. 2, StarGazer is mounted on the robot's C.G so it can obtain the position information and orientation. The information of the localization is sent to a PC via Bluetooth and the PC executes its trajectory tracking control. So the robot moves along the reference path in a counterclockwise direction.

In Fig. 3, Landsmarks are located on the ceiling and they reflect infrared to the robot.

2 Reference path for the experiment

As seen in Fig. 5, the reference path is situated on a twenty target point track[5].

3. Navigation algorithm

Fig. 4 represents the unmanned navigation algorithm. Navigation algorithm is PTP(Point To Point) method. The robot moves from the point on the reference path $P_p(i)$ to $P_p(i+1)$. If the robot arrives at a target point, the system continuously determines the next target point. And if the distance error between current position and $P_p(i)$ is smaller than d_e, the system corrects the next target point $P_p(1)$ to $P_p(i+1)$. d_e is selected by the velocity of the robot and the error of the position measurement.

4. Experimental results

In this experiment, the position information of StarGazer sensor is measured using the consisted experimental system. Figures 4 ~ 8 represent the experimental results for other velocities and other controller gain. The faster the velocity of the system, the bigger the position error.

Range of position error is from 10cm to 20cm.

Fig. 2 Configuration of omni-directional system

Fig. 3 Total composition of the experimental system

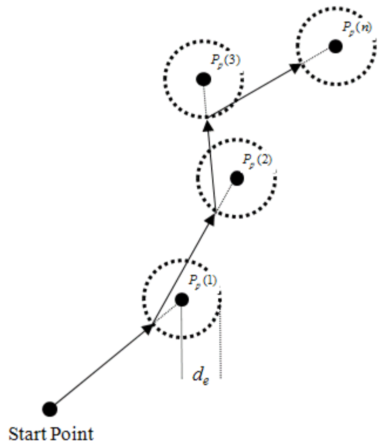

Fig. 4 Navigation algorithm

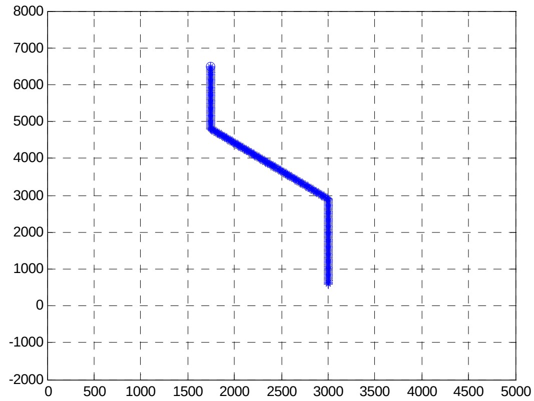

Fig. 5 Reference path

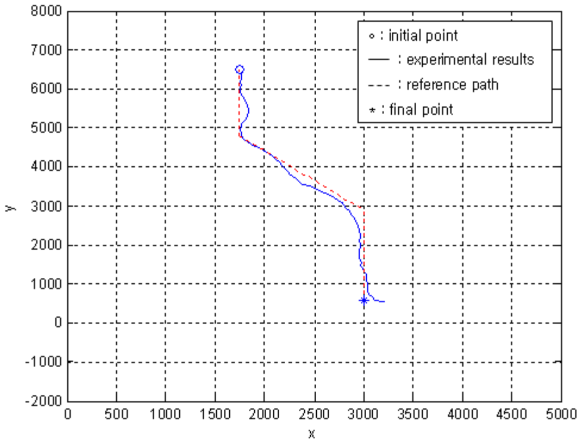

Fig. 6 Experimental result (0.25m/s)

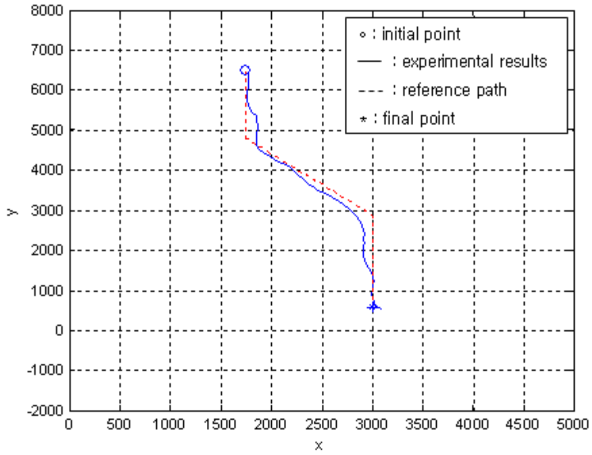

Fig. 7 Experimental result(0.3m/s)

VI. CONCLUSION

In this paper, the system model of an unmanned Holonomic-system robot is important to design parameter based controller in unmanned vehicle system. Using the subspace system identification method, we confirmed that the experimental model is very simple and accurate. It is important to design a controller that uses system parameters.

To minimize the modeling error, the system identification that uses system input-output data was used, and a PID controller was designed. To design the controller, the relation between the input and output is represented in state matrices.

The performance of the compensated system was satisfied based on the system identification.

Because modeling error of identification model is smaller than analytical model.

We will research the vehicle system identification with other dynamic and system conditions, for example, longitudinal control, nonlinear system, and MIMO system. And also, we will design a controller that is robust against system disturbance and parameter uncertainties.

VII. REFERENCES

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