Operation of a Mobile Robot by Steering a Rope

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Abstract *– Our aim is development of an interface tool for operation a mobile robot by steering a rope. This paper describes some sensors which used to measure the direction of the pulling force, denied 3modes (*Guidance, Follow, and Waiting*), and algorithm for selecting of the robot behaviors. And finally, some experiments and its evaluations are shown.*

Keywords **–** robot interface, navigation, steering, rope.

1. Introduction

Ubiquitous robotics has brought on research attempting to automate or sometimes "robotize" various objects in the environment. For example, Tomokuni and colleagues developed an active caster module[1]; furniture and electric appliances installed with this device are able to move similar to a mobile robot. With further development, the use of automated objects and robots in homes or offices will just be in the near future. If mobile robot functions are added to objects, many useful applications can be developed. Some applications are:

- Teaching a home robot its environment with human guidance
- Movement of baggage cart
- Rearrangement of furniture
- Guidance of a visitor

It is often unsafe for people to push or carry some objects directly, especially large and heavy objects; the person may be injured or the object might be damaged. However, in the case of automated objects, movement can be easily achieved using its own mobile functions.

For people and mobile robots to move together, the interface between them is important. Moreover, the interface should be intuitive and intelligible for people. There are many methods to relay human commands to a robot: a robot which detects human hand movements to follow its direction [2], a robot which follows a small LED transmitter worn by a person [3], and a robot which follows a path by voice commands, are examples which have been developed.

In this research, a rope is used as an interface tool between a person and robot. The robot and user are connected by a constantly tense rope for control and interaction. Our purpose is to realize robot operation similar in sense to dog-walking and achieve natural behaviors to minimize consciousness that the "dog" is a robot.

2. System Structure

2.1 Mobile Robot

The mobile robot used in this research is the YAMABICO mobile robot series. developed in our laboratory [4]. The YAMABICO is a mobile robot equipped with two independent motor-driven wheels. Its body size is about 37cm (W) x 32cm (D) x 42cm (H) and body weight is 15kg. It has rotary encoders for speed control, accurate odometry, ultrasonic sensors and bump sensors for obstacles. Its maximum speed is about 1.4m/second, close to human walking speed.

2.2 Steering Rope

There are two required attributes for the rope to connect the robot to the user. First the user must be able to adjust the length of the rope to control the distance between the person and robot. To implement this, we adapted a retractable dog-leash for attachment to the robot (Figure 1). The leash has a range of length from 0.5m to 4.5m.

Another required attribute is elasticity. When sudden loads are encountered between the person and robot, a non-elastic rope can have the following problems: (1) robot position error due to wheel slippage, (2) damage to sensors, (3) turn over of robot. These problems are avoided by using an elastic rope. However, the same problems are also encountered when constant heavy load is placed on the rope. Thus, as an additional safety feature, when the load exceeds a threshold, the rope must be separated from the robot.

Results from experiments, show that more than 10N of tension is required to sense human pulling force via rope. Also, the robot will overturn if it is pulled by the tension above 40N. Based on these results, we designed the rope interface by connecting in series rubber bands, and a pair of magnets as shown in Figure 3. The rope is stretched with a 10N force, if tension exceeding 30N is applied the magnets will separate. Once the rope is disconnected, an emergency stop signal is sent to the robot.

2.3 Direction Sensors

For the interface, the robot must be able to sense presence and direction of the pulling force. To measure this information, three kinds of sensors were considered and experimented with: a 6-axis force sensor, a joy stick, and a rotary encoder.

Fig. 1. Rope (Retractable dog leash).

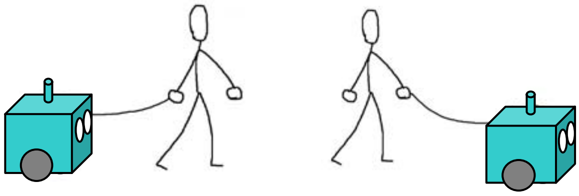


Fig. 3. Modes of operation: Follow Mode (Left);
Guidance Mode (Right);

3. Operation Algorithm

3.1 Process Flow

The robot runs by repeating the following two processes periodically:

1. The robot measures the direction of the pulling force (in the case of using a force sensor, not only direction but also the tension value), the robot's running speed, and also its angular velocity.
2. The next action is determined based on the obtained data.

3.2 Navigation Mode

In order to operate the robot, three operation modes, "Guidance Mode", "Follow Mode", and "Stop/Waiting Mode", are defined. These modes change depending on the relative position between the robot and user. The relative positions and their corresponding modes are shown in Figure 3. In "Guidance mode", the robot runs ahead of the user and controls the robot from behind. In "Follow mode", the user pulls the robot by the rope to lead the robot in the desired direction. Finally, in "Stop/ Waiting mode", the robot stays in position until it receives a start signal.

4. Sensors

We mounted three kinds of sensors to measure the direction of the pulling force.

4.1 Six-axis force sensor

First, we describe the hardware and algorithm using a force sensor. The device is a six-axis force torque sensor

Fig. 4. 6-axis Force sensor.

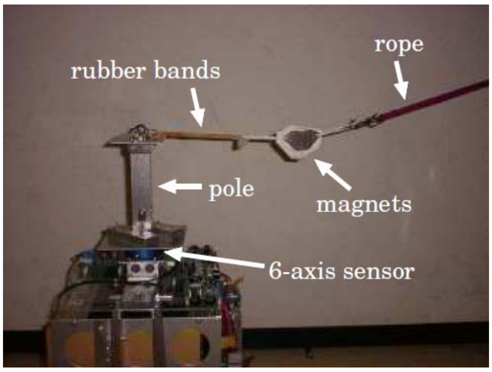


Fig. 5. Robot connected to the rope.

(IFS-67M25A25-I40, made by Nitta Co.) shown in Figure 4. This device can measure the force and torque along each axis. For this research, the value of force is measured; momentum is not considered. The pulling force and its direction are calculated by the following formulas.

$$F = \sqrt{f_x^2 + f_y^2 + f_z^2} \tag{1}$$

$$\theta = Tan^{-1}\left(\frac{f_y}{f_x}\right) \tag{2}$$

The behaviors of the robot for each mode are shown in Table 1. Since the sensor can detect the level of pulling force, various commands can be given to the robot based on this. Detected force from the user is divided into three levels S, M and L.

4.2 Joystick

The joystick used is shown in Figure 6. The joystick has four limit switches. When the lever is neutral, the state of all switches are “off”. When the joystick is moved the direction where the lever is pushed can be detected with eight levels of resolution. The hardware is simple, low-cost, and implementation is very straight-forward.

The behavior of the robot using the joystick is shown in Table 2. Unlike the force sensor, commands using the strength of force cannot be implemented. Instead with this sensor, a gesture system was introduced. Certain

Table 1 Behaviors of the robot (using force sensor)

Mode	Rope State	Behavior
Follow	Neutral	Deceleration
	Pull forward by S or M force	Acceleration & rotation to pulled side
	Pull backward by S or M force	Change to Guidance Mode
	Pull by L force	Change to Wait Mode
Guide	Neutral	Acceleration
	Pull forward by S or M force	Change to Following Mode
	Pull backward by S or M force	Deceleration & rotation to pulled side
	Pull by L force	Change to Wait Mode
Wait	Neutral	Keep position
	Pull by S or M force	Rotation to pulled side
	Pull forward by L force	Change to Following Mode
	Pull backward by L force	Change to Guidance Mode

Table 2 Behaviors of the robot (using joystick)

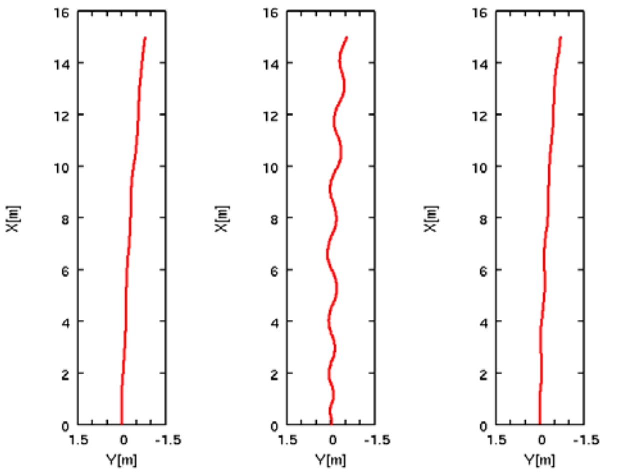
Mode	Rope State	Behavior
Follow	Neutral	Deceleration
	Pull forward	Acceleration & rotation to pulled side
	Pull backward	Change to Guidance Mode
	Double pull	Change to Wait Mode
Guide	Neutral	Acceleration
	Pull forward	Change to Following Mode
	Pull backward	Deceleration & rotation to pulled side
	Double pull	Change to Wait Mode
Wait	Neutral	Keep position
	Pull	Rotation to pulled side
	Double pull from front-side	Change to Following Mode
	Double pull from back-side	Change to Guidance Mode

pulling patterns are given unique command interpretations. Two quick pulls was defined as the gesture for “Change to Waiting Mode”.

4.3 Encoder

The third sensor was developed using an encoder (Omron E6A2-CWZ3C) to determine the pulled direction.

Fig. 6. Joystick.



(a) Force Sensor (b) Joystick (c) Encoder

Fig. 8. Path of robot running along a straight line.

The resolution of the encoder used is 800pulses/round. However, the encoder cannot detect whether the rope is being pulled, so a microswitch is used in order to detect the pulled state.

5. Experiments and Results

We conducted experiments in to evaluate whether a user can operate the robot accurately using the developed steering system. Particularly, ease of operation and if the user could get accustomed to the interface system were observed.

5.1 Straight line

In the first experiment, the user operates the robot along a straight line with the rope interface. This experiment was conducted in a corridor about 3m wide. The path of the robot is shown in Figure 8. The maximun speed is set to 100cm/sec. Similar results were obtained even when speed was set to other values.

In the case where the force sensor or the encoder was used, the robot can be steered along a straight line path with minimal error. However, when the joystick was used, the robot moved in a zigzag movement, with sharp turns every ±20cm.

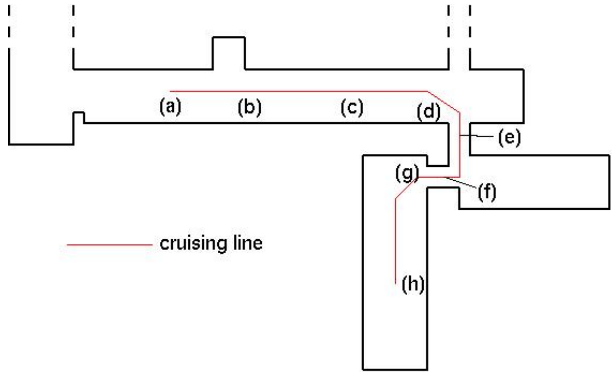


Fig. 9. Path used for experiments.

5.2 Long Distance Navigation

For the next experiment, long-distance navigation was conducted using the system. The route is shown in Figure 10 with a total length of about 180m. There are three corners and small steps in this route, with possible presence of some passersby.

The test users of this experiment have never operated the robot. The users were only instructed how to operate the robot before the experiment.

Scenes from the experiment are shown in Figure 10. The labels in this figure correspond to the labels on the map in Figure 9. Results of this experiment show, that for any of the three sensors the robot was able to reach the goal without colliding with obstacles and walls. Some problems were also identified.

The major problem in using the force sensor is that sensor data is affected by the robot's vibration. When the robot runs across a small ledge at high speed, sensor data is distorted. Another problem is the threshold of the different force levels; adjustment of this parameter is difficult for smooth operation.

The problem encountered using the joystick is its low resolution of angle. The zigazag movement when using this sensor was noted by some test users as a cause for concern for collissions.

For the developed sensor using an encoder, the response for direction was excellent. Since the level of force could not be detected, the change of speed was somewhat unnatural. Guidance of the robot in accordance with a path desired by the user was realized.

5.3 Evaluation

In order to guide a robot with rope steering, it is not necessary to sense the pulling force and the rope length. For smooth guidance detection of the direction of pull is most important. Rope gestures were effective to operate the robot.

6. Conclusions

We developed an interface tool for operation a mobile robot by steering a rope. In this research, three devices were inplimented and evaluated, and the experiments

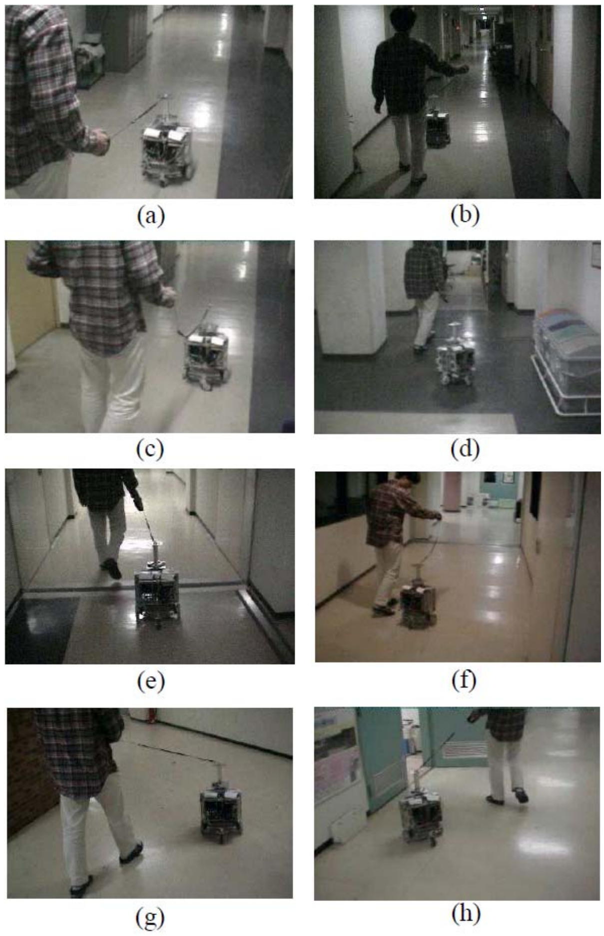


Fig. 10. Actual Experiment Scenes: (a) Signal for Departure (b) Signal for Direction (c) Robot Connection (d) Follow Mode (e) Passage across a ledge (f) Change from Follow to Guide Mode (g) Curve (h) Stop (Arrival at destination).

show long distance operation a mobile robot using the developed system.

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