Development of a Haptic Interface with Proximity Sensors and Vibration Motors

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Abstract: As described in this paper, we propose a new haptic interface for a service robot. For safety with service robots working in a space where people live, some notification before collision with an obstacle is desirable. To achieve such a function, we developed a master-slave manipulator system in which the slave manipulator surface is covered with many proximity sensors. Additionally, we developed a haptic device that feeds back proximity sense information to the operator using small vibration motors. We attached the haptic device to the arm of the operator and vibrated the vibration motor corresponding to the sensor. Thereby, the operator was able to ascertain the position of an object near the manipulator, and to make the robot maneuver to avoid it before collision. To confirm the system usefulness, we equipped subjects with the developed proximity sense presentation device and performed a detection-position-specific experiment and an obstacle avoidance experiment in a narrow space. As results of the detection position specific experiment on five subjects, four subjects reported the detection position correctly. The remaining one person failed because of his particular arm shape. Operation experiments conducted in a narrow space showed that all subjects' work was successful when given feedback of proximity sense information. Nobody was successful without proximity sense information. Results of these two experiments demonstrate that this proposed system is useful for obstacle avoidance of a master-slave manipulator system.

Key words: Master-slave manipulator, proximity sensor, vibration motor, Kinect, haptic device.

1. Introduction

When using a master-slave manipulator system, a bilateral controlling system that feeds back a sense of force received from the slave manipulator to the master manipulator is required. We have been developing a non-contact master-slave manipulator system using a Kinect™ (Microsoft Corp.) motion sensor for assisting elderly people who require nursing care living in a remote location. For this manipulator to be used safely in human living areas, it is necessary that proximity information be provided to a user before contact. Therefore, a haptic device from which the information is passed is needed. We examined ways to control a robot safely using a proximity sensor. Our proposed system provides a high level of safety because all slave manipulators we developed are covered

with numerous proximity sense sensors. Therefore, an operator can detect an object before collision.

This study was undertaken to measure control characteristics of the proposed feedback system and to acquire knowledge related to the operation of the proposed system.

2. Non-contact Master-Slave Manipulator System

Construction of the master-slave manipulator system developed by this research is portrayed in Fig. 1.

A proximity sensor mounted on the slave manipulator surface detects an object and makes an operator recognize the approach of an obstacle by small vibration motors. Because proximity sensors and vibration motors are installed with the same

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Fig. 1 Proposed system overview.

geometrical arrangement, an operator can sense the location of the object near the manipulator by a sense of touch because a vibration motor exists in the same location as the reacting sensor vibrates. Furthermore, the slave manipulator is controlled by the calculated angle of each joint of the operator's arm.

The motion of the operator's arm is acquired and calculated using the Kinect system (Microsoft Corp.). Using the Kinect motion sensor, the operator can control the slave manipulator easily merely by moving his own arm without operating a controller.

2.1 Acquisition of the Operator's Skeleton Model

Kinect is a noncontact three-dimensional depth sensor. Therefore, the operator can control the manipulator without special controller. Although the operating principle of Kinect is not exhibited officially, it is inferred to be a three-dimensional depth sensor based on the active-stereo method using a pattern projection from infrared ray projector and an image-processing algorithm [1]. One can capture human motion by assuming a human skeleton model based on this three-dimensional information.

To make a manipulator perform the same motion as an operator's arm, we obtained a skeleton model of the operator using the Kinect for Windows SDK (software development kit) (Microsoft Corp.) and calculated a joint angle from the coordinate of each joint of the operator's arm. Using the SDK, 20 points of three-dimensional coordinate are acquired. Then we reconstruct the operator's skeleton model by connecting these points. Fig. 2 presents an image of a skeleton model example.

Fig. 2 Human skeleton model by Kinect.

2.2 Slave Manipulator

To make the slave manipulator size the same as that of a human arm, the slave manipulator size was set to 350 mm. Each joint is bent two ways to ensure that the robot can conduct the same movements as a human. For this study, we use a servo-motor for a radio control model, and build a four DOF (degree-of-freedom) manipulator as a slave manipulator. For sufficient torque, we adopt four KRS4034HV servomotors made by KOPROPO. These servo motors are controlled via a serial communication interface of the ICS3.5 standard from PC (personal computer).

2.3 Proximity Sensor

To detect approaching obstacles, we also developed a device with many proximity sensors is covering the entire manipulator's surface. We designate this device as a sensor skin. A proximity sensor using infrared reflection was used by this device. This sensor detects an object by emitting infrared rays modulated at 38 kHz, and reflected on a surface of object, and received by Photo-IC. When strong infrared rays beyond some threshold value were incident, this photo IC sensor judges that an approaching object exists. The sensor emits a signal. A wide-angle infrared LED SFH421 can expand the detection area. Because the measured area can be adjusted by putting pre-set resistance in an anode circuit of this LED and adjusting an electric current, the measurement range of all sensors was adjusted to 60 mm in the vertical direction and to 38 mm in the crosswise direction. As depicted in Fig. 3, the sensor skin board size is 100 mm lengthwise, with 35 mm width, accommodating eight proximity sensors

Fig. 3 Sensor skin module.

in a 2×4 arrangement. All sensor data are gathered by a microcontroller and are attached to a data train that is sent from the previous module. The data train, which becomes long, is transmitted to a PC via serial communication line at 9,600 bps. Fig. 4 shows how the data train changes. The delay time of communication was about 60 ms when eight boards were connected in series.

2.4 Proximity Sense Presentation Device

To transmit the detected proximity sense information to an operator, we developed a proximity sense presentation device that is wound around an operator's arm and used. In the proximity sense presentation device we have developed as presented in Fig. 5, 22 vibration motors are installed.

These motors are arranged with the same geometry as a proximity sensor of the sensor skin module board mounted on the surface of the slave manipulator, as depicted in Fig. 6. Because each vibration motor moves when the proximity sensor that corresponds to the motor reacts to an object, the manipulator operator

can ascertain the existence of an object close to the manipulator by his own sense of touch. To choose the arrangement interval of the vibration motors, we have referred to the spatial resolution of the sense of touch based on the two-point discrimination threshold so that an operator can recognize the location of the obstacle sufficiently. The two-point discrimination threshold is the shortest distance at which it is distinguishable whether this is one or two points when two points are stimulated. Weinstein et al. [2] reported that the two-point discrimination threshold at the forearm part is 45 mm. Based on this report, vibration motors were mounted in an interval within 45 mm by our system.

3. Experiments

To confirm the system usefulness, a subject equipped with the developed proximity sense presentation device performed a detection-position experiment and an obstacle avoidance experiment in a narrow space.

3.1 Detection Position Specific Experiment

For the detection position specific experiment, we made an object approach a part of the slave manipulator. Then we performed an experiment that perceives the position of the subject, who is hidden. The subject indicates the position by moving a hand in the direction opposite to the direction from which the obstacle has approached. This experiment was conducted six times with each of five subjects. Results of the detection-position experiment are presented in Table 1.

Fig. 4 Module connection and delay time for data transfer.

Fig. 5 Proximity sense presentation device using a vibration motor.

Fig. 6 Correspondence of sensors and a motor.

Table 1 Detection position specific experiment.

Subject	Success/Trial
Subject A	6/6
Subject B	4/6
Subject C	6/6
Subject D	6/6
Subject E	6/6

Results of the experiment show that four subjects reported the detection position correctly. However, subject B could not do avoidance movement to the appropriate direction two out of six times. The reason for the failure is that the subject's articulation cubiti, unlike other persons, twisted when the subject hung his arm down in a natural form. For this reason, the vibrating motors touched a different position from other subjects. This fact indicates that calibration is necessary for a vibration motor to be parallel with the arm direction.

3.2 Operation Experimentation in Narrow Space

Next, operation experimentation in narrow space

was performed. In this experiment, work which inserts and returns a slave manipulator in a narrow space was conducted as portrayed in Fig. 7.

An interval in a space between obstacles is 250 mm. After putting an arm in from the bottom in a space and detecting the ceiling board first, a subject returns an arm to the original position. As in a previous experiment, we equip the subject with a proximity sense presentation device. Furthermore, subjective visual information was blocked off by blindfold. Without proximity sense information, the same work was performed to confirm that the operational success described above does not become familiar.

An experimentally obtained result is presented in Table 2. As a result of the same experiment conducted with five subjects, all the subject work was completed successfully with feedback of proximity sense information. However, when no proximity sense information was given, nobody was able to accomplish the task successfully. This result demonstrates that feedback of proximity sense information was effective for obstacle avoidance in a case where no visual information is given.

Moreover, the time taken by the end from the start of work was averaged: it was about 60 s. The opinion "vibration intensity is constant and so distance with an obstacle cannot be measured" was heard from an interview held after the end of work. Because outputs are binary values of ON-OFF, only the same detection signal can take out a proximity sense sensor to the obstacle within the detection range (60 mm). To

Fig. 7 Narrow space for the experiment.

Table 2 Operation experiment in narrow space.

Subject	with sensor information (time to an end)	without sensor information
Subject A	success(79(s))	fail
Subject B	success(148(s))	fail
Subject C	success(68(s))	fail
Subject D	success(60(s))	fail
Subject E	success(41(s))	fail

resolve this problem, a sensor that can acquire the distance to an obstacle as a continuation value must be developed.

4. Conclusions

For this study, we developed the inner force sense interface for remote presentation of a proximity sense. We used the Kinect motion sensor to acquire an operator's motion. Furthermore, we developed proximity sense information presentation device using many infrared proximity sensors and vibration motors.

Using the developed device, we made two experiments. In the detection-position specific

experiment, almost all subjects were able to guess the collision position correctly. Although subjects were few, one person was found to have a twisted arm. Therefore, when loading the device, some calibration is necessary. Manipulator operation in a narrow space was possible without visual information by an experiment in a narrow space of operation. However, distance information was not obtained. Some time was necessary before operation of the arm. For controlling the manipulator smoothly, we require a range sensor that can measure to about 5 cm distance continuously.

These results demonstrated that the system proposed herein is effective for use as a robot's remote control.

References

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