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Paper:

Development of an Infrared Sensory System with Local Communication Facility for Collision Avoidance of Multiple Mobile Robots

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In this paper, we propose a method for detecting both robots and obstacles using a local infrared communication system. If every robot in the environment has its own ID number and transmits it, then a robot can detect another robot by receiving the ID number. The robot can also detect an obstacle by receiving its own ID number which is reflected by the obstacle. We also propose a method of detecting interference during transmission when several robots are transmitting to one robot. Finally, we describe the development of a sensor system named LOCISS (locally communicable infrared sensory system) and basic experiments are carried out in order to evaluate its performance.

Keywords: Robot, Mobile robot, Sensor, Collision detection, Infrared communication, Local communication, Obstacle detection, Interference detection

1. Introduction

Various types of work that are carried out by mobile robots, including cleaning, freight transportation, etc., in buildings. Many of these tasks can be done more efficiently if more than one robot each bears a share of the work. In a multiple mobile robot environment, where more than one robot is used, it is essential to achieving a higher work efficiency that collisions between robots, and collisions between robots and obstacles are avoided .[1]

In order to avoid collisions between robots, proper measures must be taken so that two robots in the same vicinity can detect each other. To determine the optimum movement for avoidance, robots should be provided with mobile information regarding the other robot's direction, speed, motion, etc. In the past, sensors and communication systems have been used to detect one another's position of correlating robots or to acquire necessary information.

When sensors are used, it is possible to detect the position of the correlating Robot, but is difficult to acquire mobile information. Active-type ultrasonic sensors have the disadvantage that they interfere with one another. For example, Ishikawa et al.[2] have clearly established a method for avoiding mobile obstacles using sonar sets, but this method is not practical when more than one robot, equipped with ultrasonic sensors, is used at the same time. Arai et al.[3] have proposed a method for detecting interference-free robots with signs and a visual system that are used for acquiring mobile information, but calibration of the visual system and the image processing for this method cost a great deal. The use of communication systems makes it easier to acquire information concerning the position and movement of robots than the use of sensors. Premvuti et al.[6] and Ozaki et al.[4,5] have proposed a method for avoiding collisions between robots through a radio communication system for information interchange with regard to the predetermined courses and positions of the robots. This method, however, involves a problem in which the communication load becomes heavier with an increase in the number of robots, since the radio communication system is a large-area communication system that covers a wide range of communication. Robot collisions generally occur between robots in the same vicinity in a certain environment. To avoid robot collisions, therefore, a local communication system is more advantageous for information interchange.

To overcome the problems described above, the author et al. have proposed a method for detecting the presence of robots using an infrared communication system.[7] The communicable range using infrared rays can be set within fixed limits by adjusting the intensity of the emissions, so localized communication can easily be established using an infrared communication system. When infrared rays interfere with each other, however, information interchange cannot occur using the proposed method.

Consequently, the author et al. have made arrangements to encode the transmitting information and to detect interference, if produced. In the past, studies and proposals have been made by Fukuda et al.,[9] Ichikawa et al.,[10] and Koyama et al.[8] in relation to infrared communication systems for mobile robots. These studies refer to local communication systems used for discovering a cell having special functions and for effecting information interchange,[9] and also used for actualizing information transmission based on propagation between robots.[8,10] In these studies on local communication systems, however, infrared interference, which occurs when robots with infrared communication systems are close together, is not investigated.

In this paper, we propose and describe the principle of robot and obstacle detection and the principle of interference detection using an infrared communication system. On the basis of the principles proposed, we develop LOCISS (LOcally Communicable Infrared Sensory System) and examine its basic performance and efficiency.

2. Detection of Robots and Obstacles with Infrared Communication

2.1. Detection Principles

The basic unit for transmission and reception (hereafter, transmitter-receiver unit) is formed using an infrared transmitter and receiver set, and keeping the infrared light emitted at a certain height and parallel to the floor (**Fig.1**). The optical axis of the transmitter element is made to coincide with that of the receiver element. Then the communicable range of the transmitter-receiver unit is determined by the emission intensity of the infrared light and the directivity of the transmitter and receiver.

It is assumed that all the robots in a given environment are equipped with LOCISS, and that each robot has its own identification number which is called the ID number of robot.

Each robot travels while continually transmitting its own ID number and checking the information received at the same time. The robots can detect the presence of another robot or an obstacle according to the ID number of robot received (**Fig.2**).

That is, robot No. 1 receives the ID number of a second robot or robot No. 2 when robot No. 2 is within communication range, so robot No.1 is able to detect the presence of robot No.2. When there is an obstacle within the communication range, robot No.1 receives its own ID number reflected off the obstacle, so robot No.1 can also detect the position of an obstacle. The range of the robot or obstacle detection depends on the communication range of the transmitter-receiver unit. Accordingly, an omnidirectional detection structure can be established by installing more than one transmitter-receiver unit.

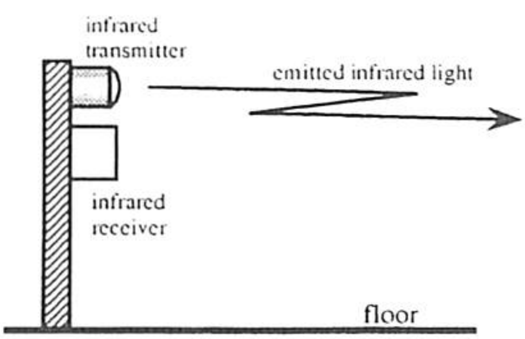


Fig. 1. The configuration of infrared devices.

Now, let us give an identification number to each transmitter-receiver unit. This number is determined according to an angle formed by the direction of the optical axis of the transmitter-receiver unit and the direction of the robot's motion (in LOCISS, which the author et al. have developed, the number is determined as shown in Fig.6 and is called the ID number of direction). When the ID number of direction, together with the ID number of the robot, are transmitted, the robots communicating with each other can recognize the direction of each other's motion. To be specific, a combination of the ID number of direction for the robot on the receiving side with the ID number of direction for the other robot corresponds to a combination of the direction of the former robot's motion with the direction of the latter robot's motion. The information, thus obtained, as to the direction of the robot's motion, enables the robots to judge whether they are getting closer to or getting further from each other and enables the robots to determine whether any action to avoid collision is to be taken..

2.2. Interference Detection Principles

It is considered that two robots in communication become unable to maintain communication when they are separated beyond a certain communication distance, i.e., beyond the range of the infrared rays, or when the infrared rays interfere with each other due to a third robot that has come near. The two robots must distinguish between the former and the latter. The author et al. consider it possible to provide the robots with a distinguishing function if the interference of infrared rays can be detected, and accordingly, have proposed encoding the transmission data which are supplemented with redundant signals for interference detection.

Let us assume the following: the transmission data is binary-coded and one bit is represented by an On/Off pulse in a certain width. Pulses in the same width as above are added before and after the above pulse with the result that one bit of data is expressed by three pulses (**Fig.3**). The first

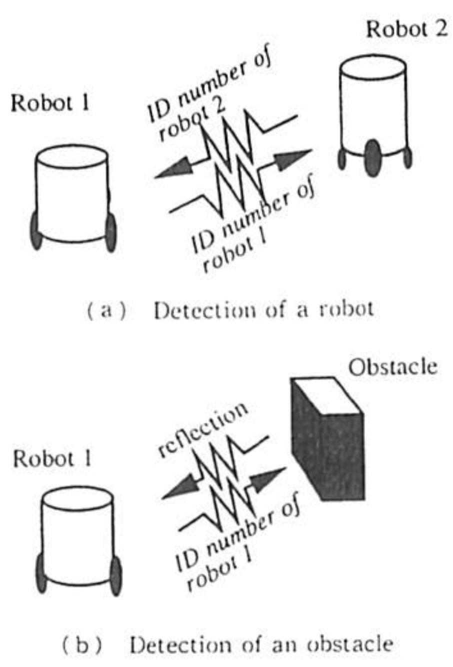


Fig. 2. Detection principles.

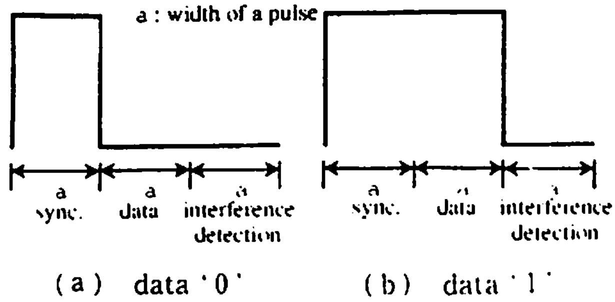


Fig. 3. Encoding of one bit of data.

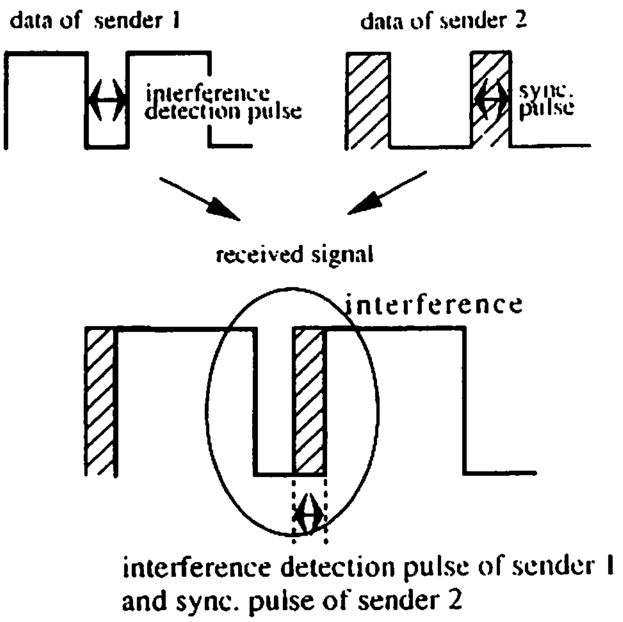


Fig. 4. The principle of interference detection.

is a sync On pulse for data reception. The second is a data pulse, and is an On pulse when bit is "one" or an Off pulse when bit is "zero." The third is an Off pulse, and is used as the interference detection pulse. Consequently, the transmission data is formed by a set: a sync pulse, a data pulse, and an interference detection pulse. Reception data consists of observing these pulses as they appear. If the transmitter is located at a considerable distance from the receiver, both the sync pulse and the data pulse cannot easily be received. It seems, therefore, that the Off pulses appear more frequently for the received signals.

When interference occurs, signals formed from the overlapping transmitted signals can be observed on the receiving side. In such a case, a sync pulse contained in one transmitted signal and an interference detection pulse in another transmitted signal overlap each other (Fig.4). Consequently, the Off period of the interference detection pulse becomes shorter in the received signal, so the interference can be detected by observing the Off period thus shortened.

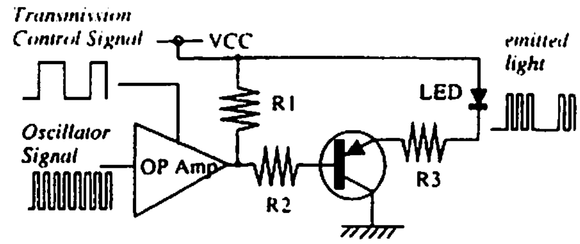


Fig. 5. The transmission circuit.

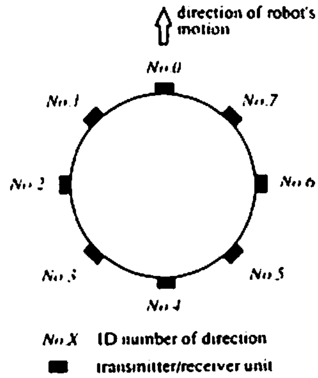


Fig. 6. The configuration of transmitter/receiver units.

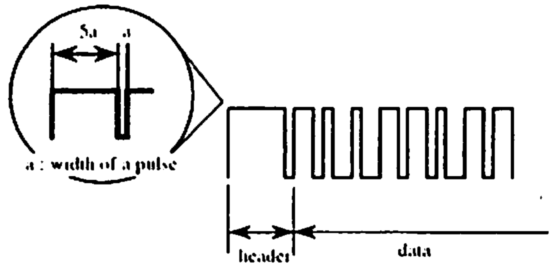


Fig. 7. Encoding of the header.

3. Development of Sensor System

3.1. Configuration of Transmitter-Receiver Unit

In an infrared communication system, external light sources, such as solar rays and lighting apparatus, produce noise. To avoid this, infrared rays modulated by a frequency of 38KHz,[11] as in the case of TV remote controls, are used as the medium of transmission. The transmitter unit is provided with an infrared light-emitting diode to produce a transmission circuit, as shown in Fig.5, so that emitted light can be controlled. The range of the infrared rays is set to 1.2m after fully considering the mobile speed of the robot the author et al. have developed, i.e., 0.3m/s. It is possible to adjust the range of the above by adjusting the resistance in the circuit. The light receiving unit was provided with a commercially available remote control light-receiving element.

In order to realize an omnidirectional detection structure using as few transmitter-receiver units as possible, both the light-emitting and light-receiving elements are provided

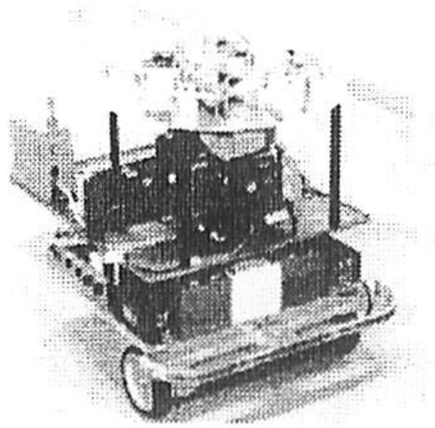


Fig. 8. The developed sensor system on a robot.

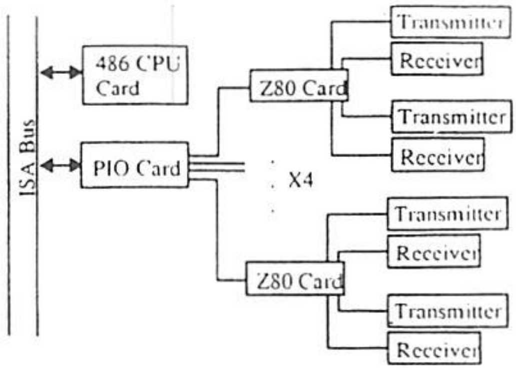


Fig. 9. The architecture of the sensor controller.

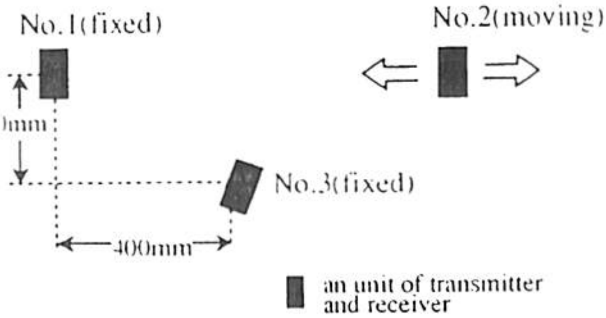


Fig. 10. Experiment in interference detection.

with 45 degrees of directivity (Sharp GL537 is used for the light-emitting elements, Sharp ISIU60 for the light-receiving elements). By eight pairs of transmitter-receiver units, the omnidirectional detection structure is realized.

Figure 6 shows the configuration of LOCISS, the locally communicable infrared sensory system, we have developed. The ID number of direction to be transmitted from each transmitter-receiver unit is set as shown in Fig.6.

3.2. Encoding of Transmission Data

The data to be transmitted consists of the ID number of robot assigned to each robot and the ID number of direction assigned to each transmitter-receiver unit in the sensory system. The transmission data is encoded in the way described in Section 2.2 after a frame with a header is formed **(Fig.7)**. The header makes it easier to detect a break-point on the receiving side. When interference occurs, it seems probable that the header of the transmission data on one side overlaps the interference detection pulse of the transmission data on the other side. Accordingly, the header is also useful in interference detection.

3.3. Architecture of Sensor Controller

A commercially available Z80 microcomputer board (Akizuki Denshi Tsusho Ltd.; AKI-80 12M) has been chosen as the transmitter-receiver controller. A controller set is used for controlling two sets of transmitter-receiver units. That is, four sets of controllers are used for controlling eight sets of transmitter-receiver units in the sensory system. The programs for encoding the transmission data and for analyzing the reception data are described using an assembler language. Using the programs thus prepared, the width of a data-composing pulse is determined to be 630ms for the process of transmission, according to the processing capacity of the microcomputer board chosen, as described above. As a result, it takes 3.78ms to transmit the header, 1.8ms to transmit 1 bit of data, and approximately 18.18ms to transmit 1 byte of data with a header. Analysis of the reception signal takes half as much of an interval as one pulse at the time of transmission (i.e., 315ms).

As for reception, the status of communication can be classified into the following four categories, which correspond to four types of status of the relationships of the robot(s).

(1) No signal (the status in which no signal is being received). No robot is present within the communication range, and no signal is being received.

(2) Correct data & wrong data (the status in which data is received correctly). There is only one robot within the communication range.

This status can be classified into the following two categories: correct data (the original transmission data is received correctly), and wrong data (the data received differs from the transmitted data due to the influence of noise).

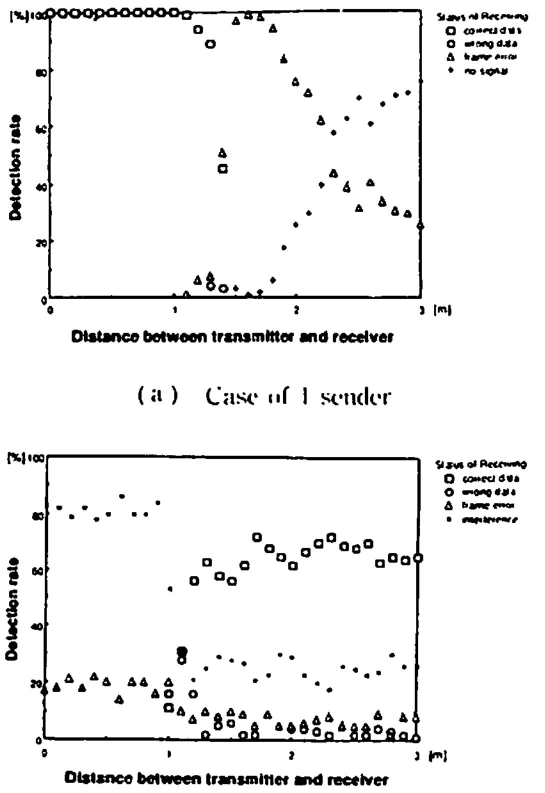
(3) Frame error (the status in which signals are being received but the data cannot be decoded). There is one robot located just beyond the communication range. In this case, the robot in question is separated beyond the communication distance from another robot and the infrared rays in use between the two robots are feebler than required. Consequently, it is impossible to distinguish the frame, although the signals are received.

(4) Interference (the status in which interference occurs).

More than one robot is present within the communication range. Interference detection is performed according to the principles described in Section 2.2.

Under the program prepared, the discriminations required are exercised.

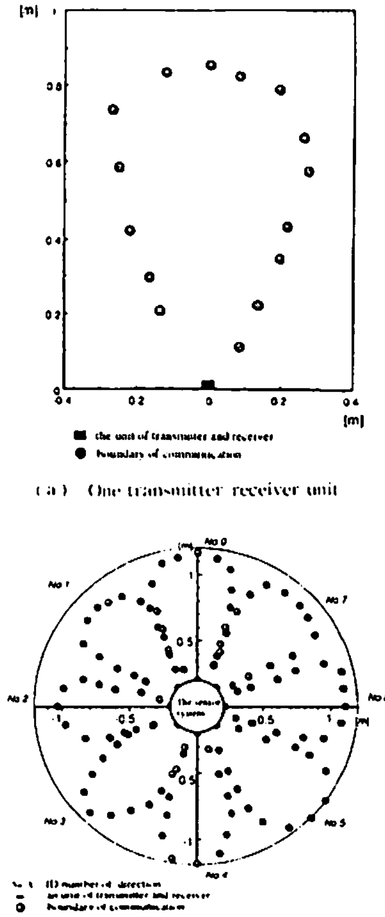
Figure 8 shows a photo of the trial sensor system. The controllers for a robot, on which the sensor system is installed, are equipped with a PC interchangeable system (CPU board with Intel 486 and real-time OS Vx Works). The controller for the robot is connected to the controller for the sensor system using a parallel I/O(PIO). **Figure 9** shows the architecture of the sensor controller, together with the connection to the robot system.



(a) Case of 1 sender

(b) Case of 2 senders

Fig. 11. Detection of communication status.



(a) One transmitter-receiver unit

(b) The developed sensor system

Fig. 12. Communication range.

4. Evaluation of the Basic Performance

Investigations have been conducted with regard to the basic performance of the infrared sensory system developed, such as interference detection, communication status discrimination, and robot and obstacle detection range. Both the ID number of the robot and the ID number of direction are expressed by 8-bits and encoded as the transmission

4.1. Discriminant Analysis of Communication Status, including Interference Detection

Two sets of transmitter-receiver units are installed face to face with each other; one side of each set is used for transmitting and the other side of each set is used for receiving. To adjust the distance between the transmitter and the receiver, the receiver is fixed while the transmitter is moved 0.1m at a time. Each time the transmitter is moved, the reception data is read on the robot controller on the receiver side, 100 times at intervals of 0.5s, so that a discriminant analysis of the communication status can be made.

Figure 11(a) shows the receiving communication status that is applied to a discriminant analysis at the distance between the transmitter and the receiver which is continually adjusted. It can be seen from this figure that the communication status applied to the discriminant analysis, according to the distance to the unit on the transmitter side, changes from the "correct data" status to the "wrong data," "frame error," and "no signal" statuses, and that the data receiving range is in approximate agreement with the range for infrared rays specified in Section 3.1.

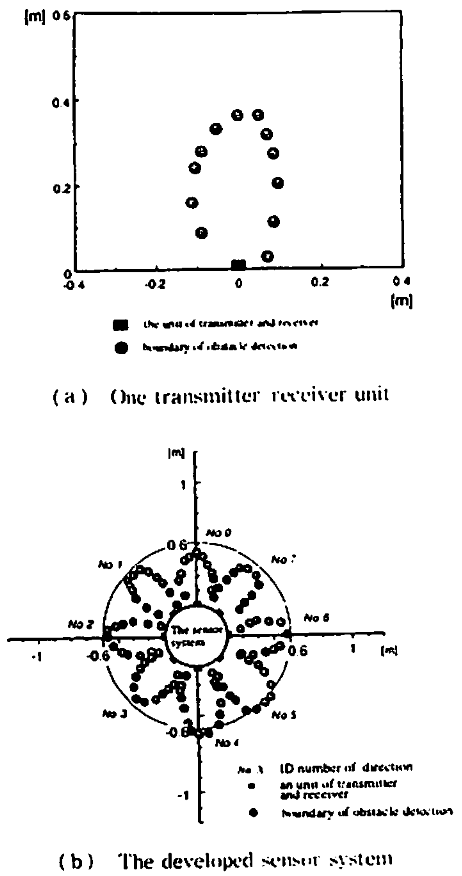
Figure 10 shows an experiment in interference detection using three sets of transmitter-receiver units (Fig.10).

Near the unit on the receiver side, as described above, an additional transmitter unit (unit No.3 in Fig.10) is installed. As in the case described above, the unit on the transmitter side (unit No.2 in Fig.10) is moved in 0.1m increments in order to observe the reception data. Each time the unit is moved, the reception data is read 100 times at intervals of 0.5s.

Figure 11(b) shows the detection rate of the discriminated communication status. It can be seen from this figure that the communication status, discriminated according to the distance to the moving transmitter unit, changes from the "interference" status to that of "correct data," and that the range in which the interference occurs is in approximate agreement with the range of the infrared rays specified in Section 3.1.

From the facts described above, we may conclude the following.

The communication status changes with the distance to the transmitter unit, and the discriminant analysis results of the communication status serves as information on which a robot can effectively judge its surroundings. According to Fig.11(a), however, the "frame error" status is detected even when the distance between the transmitter and the receiver is more than 2m and the expected detection rate of the communication status does not reach the 100% level. According to Fig.11(b), interference is detected even when the



(a) One transmitter receiver unit

(b) The developed sensor system

Fig. 13. Range of obstacle detection.

distance is more than 1m. The reasons for this are probably that parts of the signals may work effectively at distances beyond the range of infrared rays, and that noise arises from other disturbances, such as fluorescent lamps. To reduce the influence of noise and to improve the detection rate, it is necessary that the performance of the sensor controller be improved, that the signal reading intervals during receiving (specified in Section 3.3) be shortened, and that the hysterisis, as a discriminant analysis of the communicating conditions, be used for circumstantial judgements by the robots.

4.2. Measurement of Robot Detection Range

The sensory system developed is fixed. Separately, another transmitter-receiver unit is prepared. While the transmitter unit is moved, the reception data is observed in order to measure the communication range. The communication range is equivalent to the robot detection range.

Figure 12(a) shows the results of the measurement using a set of transmitter-receiver units of a fixed sensory system. The dots in the figure show that all ten pieces of data, received continually, and the transmission data are in the same boundary.

Figure 12(b) shows the communication ranges of the sensory system developed. Slight differences in the communication ranges exist among the transmitter-receiver units, probably due to scatter in the light-emitting and light-receiving elements.

Results of an experiment have proved that the sensory system can receive signals omnidirectionally in a 360 degree range, provided that the detection distance is approximately from 1.0m to 1.2m (including the size of the system itself). Accordingly, a robot with the sensory system can detect the presence of another robot with the same system as above when the latter robot moves into the range where the former robot is located, since the former robot can recognize the ID number of the latter.

4.3. Obstacle Detection

As in the case of measurement of the communication range, the sensory system is fixed. Instead of the transmitter unit, an obstacle or a sheet of A4 size paper is moved face-to-face with the sensory system in order to measure the detection range of an obstacle. As with the previous case, described above, ten pieces of data received continually are compared with the transmission data in order to observe the range in which 100% of the same data can be obtained.

Figure 13(a) shows the obstacle detection range for a set of transmitter-receiver units of the sensory system. The dots in the figure indicate the boundary of obstacle detection.

Figure 13(b) shows the range of obstacle detection for the sensory system developed. As in the previous case, there are some differences in the range of obstacle detection due to scatter in the elements. The results of an experiment have proved that the sensory system can recognize obstacles omnidirectionally provided that the detection distance is approximately from 0.4m to 0.6m (including the size of the system itself), and that the sensory system is valid as a proximity sensor. In the sensory system, the range of obstacle detection is rather narrow compared to the communication range. This is probably because reflected light is rather feeble compared with direct light.

5. Conclusion

In this paper, we have proposed a method for detecting both robots and obstacles using a local infrared communication system. According to the proposed method, we developed LOCISS (Locally Communicable Infrared Sensory System) and have examined its basic performance. The results of a series of experiments have proved that the sensory system developed can be used as a proximity sensor for obstacle detection or it can be used for detection of a robot by another robot using LOCISS. We also proposed a method of interference detection in order to cope with cases in which signals transmitted from more than one robot interfere with each other. We then confirmed that this method can detect interference. In order to avoid collisions in environments where multiple mobile robots exist, it is necessary to detect (1) obstacles at rest, (2) moving obstacles, and (3) a robots by other robots. The sensory system that the author et al. developed satisfies conditions (1) and (3) above. In other words, this system is as an effective sensor for improving the collision avoidance capacity of robots. In this paper, it has been proved that the LOCISS developed is a highly effective sensory system in a multiple mobile robot environment and may have wide application. It is expected in the future that robots will be provided with a circumstantial judgement capacity capable of uniting the hysteresis of information from the sensors with that of other information, that new controllers will be developed for the improvement of efficiency, and that a wider application of the system will be observed.

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