The 9th International Symposium on Automation and Robotics in Construction June 3-5, 1992 Tokyo, Japan

Development of a Desk/Chair Arrangement Robot

Yoshinori Kumita, Takashi Takimoto,
Akira Nozue, Kazuya Murakoshi,
Research Engineers

Presidential Research Laboratory "ICHIKEN,"
Fujita Corporation
2-17 Kanda Suda-cho,
Chiyoda-ku, Tokyo 101, Japan
c/o SAGAMI building

ABSTRACT

Unmanned transport technology for applications in ongoing construction sites would become prerequisite in order to carry out construction work with less labor as well as to promote the unmanned construction work which is anticipated to be established in the future. This paper will report on the position recognition technology employed for an unmanned transport system involving the proposed desk/chair arrangement robot. This robot was previously applied in "VENTE," an open space on the first and second floors of the Head Office building of Fujita Corporation.

1. AN OVERVIEW OF THE SYSTEM

The proposed robot system is designed to arrange the various types of desks and chairs in position according to the room's intended purpose, and then, after their use, to tidy them up. The system is mainly composed of an automatic warehousing system capable of handling incoming and outgoing desks, two unmanned, autonomously travelling robots capable of arranging and tidying up desks, an image processing system which monitors the travelling path of the robot, and a host computer which controls all of the above components (Fig. 1). Figs. 2 and 3 illustrate the system's configuration.

First, the host computer chooses the desk arrangement pattern involved, and gives a command on the arrangement or the removal of the desks. If "arrangement" is ordered, the automatic warehousing system moves out the desks from the warehouse, and the desks are then taken out one by one, and transported along the commanded path, to predetermined positions, by the two unmanned transport robots travelling simultaneously. Twelve overhead cameras mounted on the ceiling individually track the robots, so that the robots will not deviate from their programmed paths. For the removal of the desks, the cameras detect their positions, the host computer calculates any deviation between the positions in which they had been previously arranged and, the positions in which they are after use, and then changes the robots' programmed paths accordingly. As each robot must be guided as much closer to the individual desks as is practicable, with an accuracy of about plus or minus 10mm, calculating the correction in desk positions by means of the image processor is the most important job in the transport system.

As the robots are autonomously travelling type robots which utilize image processing, they need no guide cables, and are easily adapted to the changes in any desk arrangement pattern.

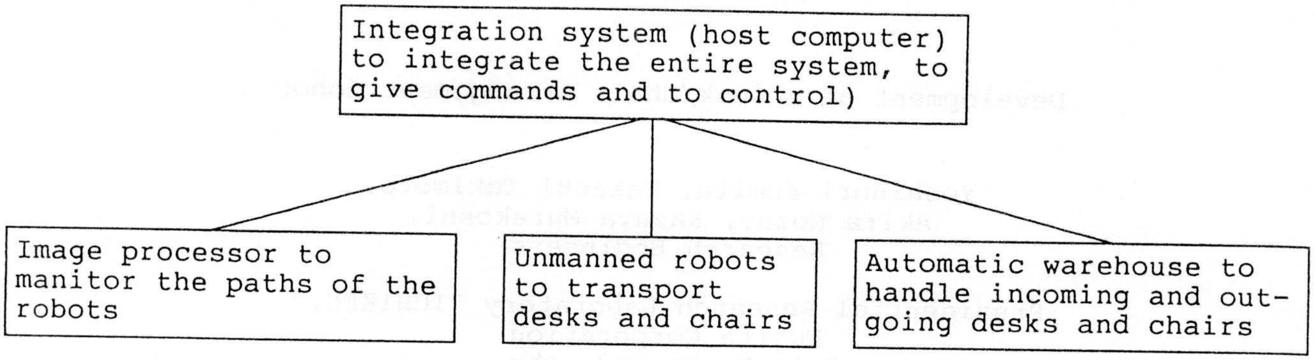

Fig. 1. System linkage.

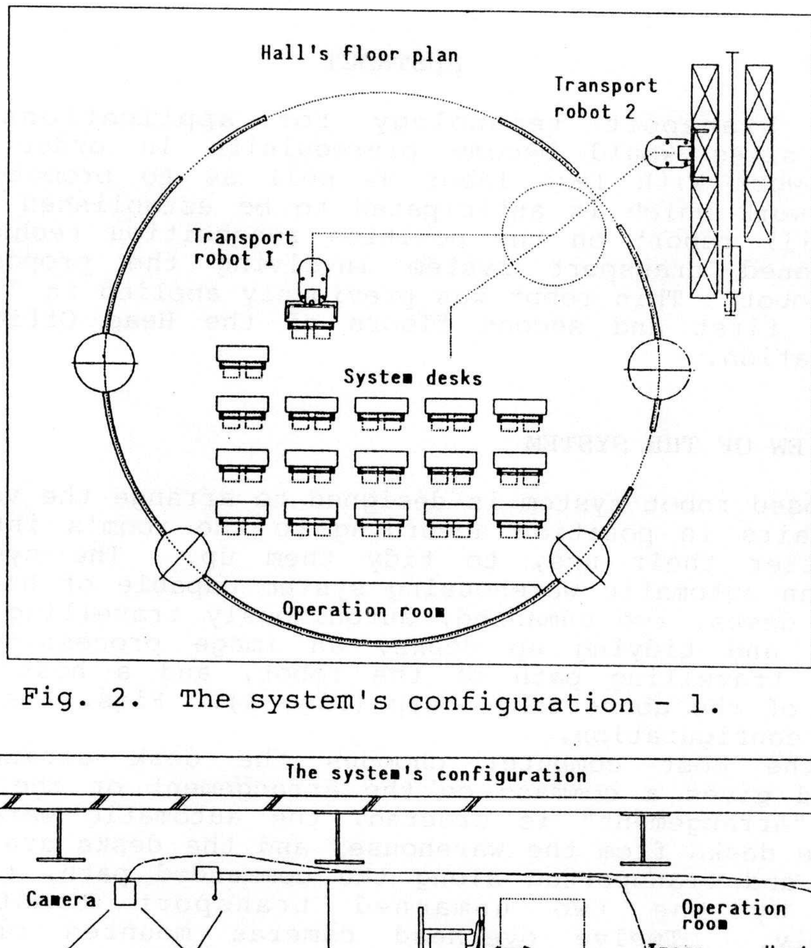

Fig. 2. The system's configuration - 1.

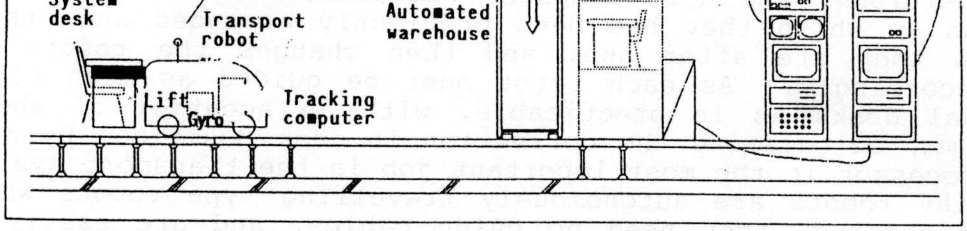

Fig. 3. The system's configuration - 2.

2. THE SYSTEM'S COMPONENTS

2.1 Unmanned Transport Robots

Each robot can be largely divided into a car and a lift. For its basic motions, the robot inserts its two arms underneath either side of a system desk, lifts it, transports it to the predetermined position, lowers it onto the floor, and arranges it in place (Photo 1).

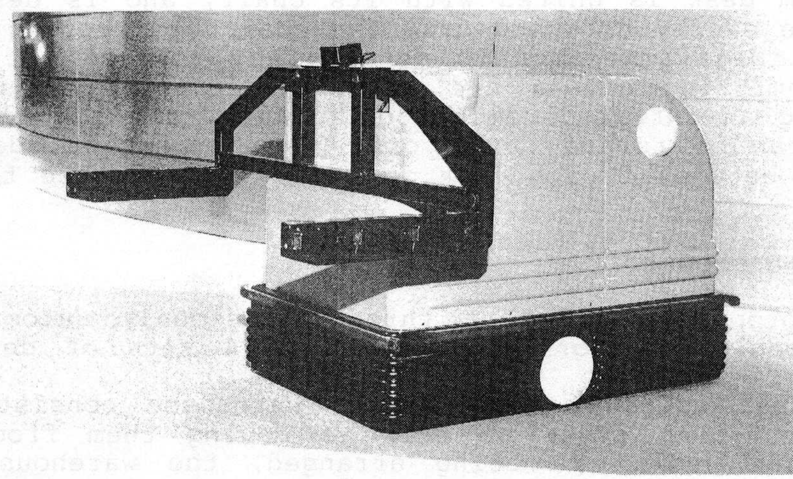

Photo 1. An overall view of the robot.

(1) Car

The motional modes of the car include moving itself forward and backward as well as spinning. With consideration given to the safety of the car, its travelling speed is set in a variable range of 50cm/sec at a maximum. It travels through a magnetic-tape guided-cum-autonomous travelling system. As the inside of the automatic warehouse is very narrow and has a fixed travel path, the magnetic-tape guided method was adopted to ensure safe and accurate travelling. The autonomous travelling method is used inside the hall in order to ensure the free layout of desks and chairs. A collision avoidance sensor is mounted on the front and rear of each car, and on the tip and left and right sides of the fork, so that, while travelling forward, backward, or spinning, the car can always be prevented from colliding with any other objects. These sensors are powered with chargeable batteries and can therefore be automatically recharged on standby each time the arrangement or removal of all desks has been completed.

(2) Fork

The fork on a car is provided with an X-Y table and a Z shaft, and is constructed in a way which enables fine adjustment; ±50mm to left and right, and 0 ~ 400mm up and down. Desks are stowed such that a beam sensor mounted on the tip and top of the fork enables it to detect one edge of a desk, and after fine adjustment, allows for the fork to move forward along the correct position, to lift the Z shaft, and then to stow desks one by one. The maximum carrying capacity of the fork is 100kg.

(3) Communication control

Communication between the system and the host computer is maintained using a wireless modem, so that the system travels, and stows desks as per the commands of the host computer.

2.2 System Desk

Each system desk is united with its chair, and is designed so that the desk can be easily detached from the chair by pressing a button. In order for the image processor to detect the position of a desk set in place, light emitting diodes are installed in the top surface of the desk. By using an infrared remote controller, the light emitting diodes of each desk can be turned on or off. A non-contact identity card is mounted on the bottom of each desk in order to recognize the identity of the desk.

2.3 Automatic Warehouse

With the proposed system, a three-dimensional, automatic warehouse with racks capable of storing a total of 26 sets of desks/chairs (52 seats), is provided.

The principal motional mode of the warehouse consists of handling incoming and outgoing desks as well as moving them from one rack to another. When desks are being arranged, the warehouse repeats the motion of moving out the next desks while the robots arrange the desks in the hall. When the desks are being removed from the hall, the warehouse repeats the motion of re-storing the desks which are being brought back to the warehouse by the robots.

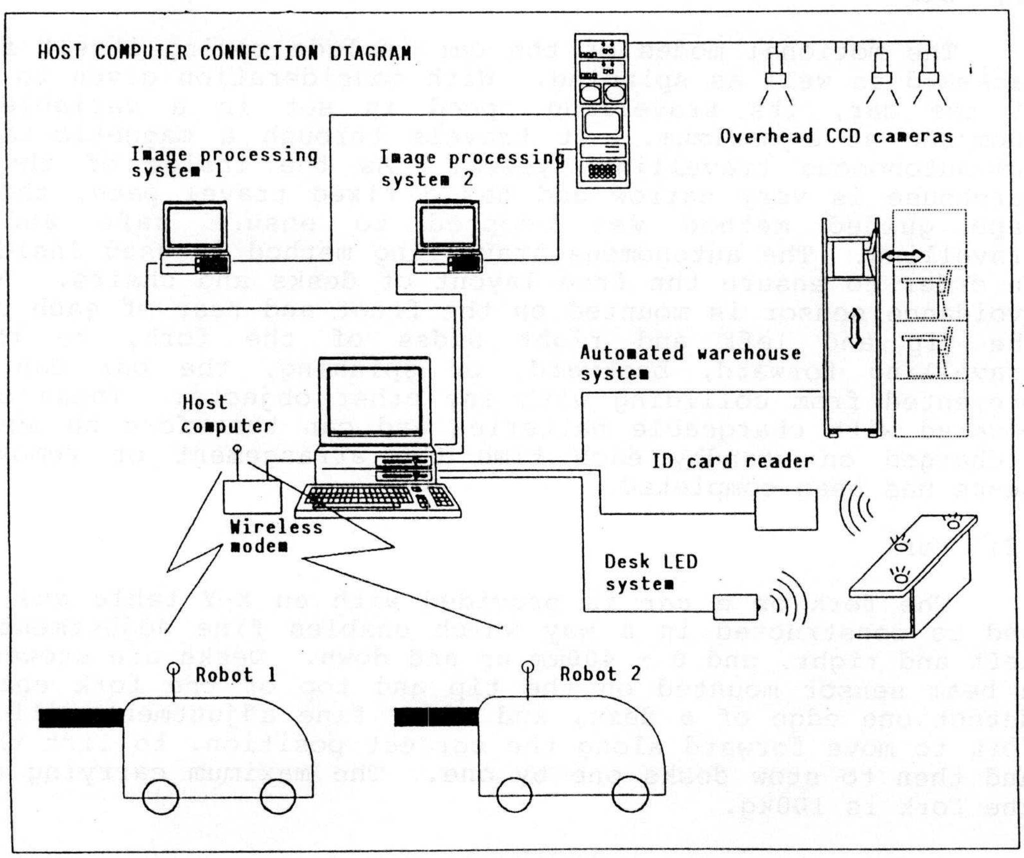

Fig. 4. Host computer connection diagram.

2.4 Image Processing System

Each robot is provided with a gyro to enable its autonomous travelling. Depending on the travelling distance, it is unable to avoid cumulative error. More precisely, an accuracy of ±10m is required for the removal of desks, therefore an image processing system composed of cameras mounted on the ceiling of the hall is provided to monitor the robots and the desks, as well as to measure the absolute coordinates and their degrees of angles. The details of this system will be touched on later in this paper.

2.5 Integrated Control Software

In order to perfect the entire system, it was necessary to organically relate each of the abovementioned separate systems, and to control them in a timely and accurate manner. A multi-task operation system is incorporated to simultaneously control not only plural systems but also the two robots. Fig. 4 illustrates how external connections with the host computer are accomplished.

3. A METHOD TO TRAVEL A ROBOT, AND ONE TO RECOGNIZE ITS POSITION

3.1 Magnetic Tape Travelling

As is illustrated in Fig. 2, the inside of the automatic warehouse is an extremely narrow area in which a robot must move, one example being the clearance of only 50mm between one side of the warehouse's door and the hall. Furthermore, a fixed, travelling path is provided in the warehouse, and to ensure that a robot is able to travel inside the warehouse safely and accurately, a guiding system using a magnetic tape has been adopted.

3.2 Autonomous Travelling

In order for the system desks to be freely arranged in the hall, a robot uses an autonomous travelling system, based on which the robot integrates the degrees of an angle determined by the gyro sensor with the travelling distance determined by the range finder (an encoder), so that it will always be able to recognize its own position. However, correcting a robot's self position by using only the gyro and the range finder may entail a risk which allows for cumulative error, and therefore initiating the travelling of a robot relying solely on the above instruments results in difficulties in arranging the desks with an accuracy of ±10mm, and more importantly, makes it impossible for the robots to remove the desks. Thus, to eliminate these negative possibilities, the proposed system utilizes image processing systems so that the robots' travelling paths can be monitored, and the absolute coordinates can be reset, in order to ensure the robots' accuracy.

3.2 Image Processing

(1) The System's Configuration

With the proposed system, image processing is utilized not only to reset the absolute coordinate while the robot is autonomously travelling but also to obtain the actual desk coordinates while the desks are being removed of by the robot. Since the positions of desks before and after a conference change, for example, the guide paths of the robots need to be corrected following a confirmation of the actual positions of the desks before they are to be removed.

Fig. 5 illustrates the configuration of the image processing system. The subsequent paragraphs highlight the principal function and performance of each of the components which constitute the system. In addition, as work is performed by two robots, these components are independently provided in two sets.

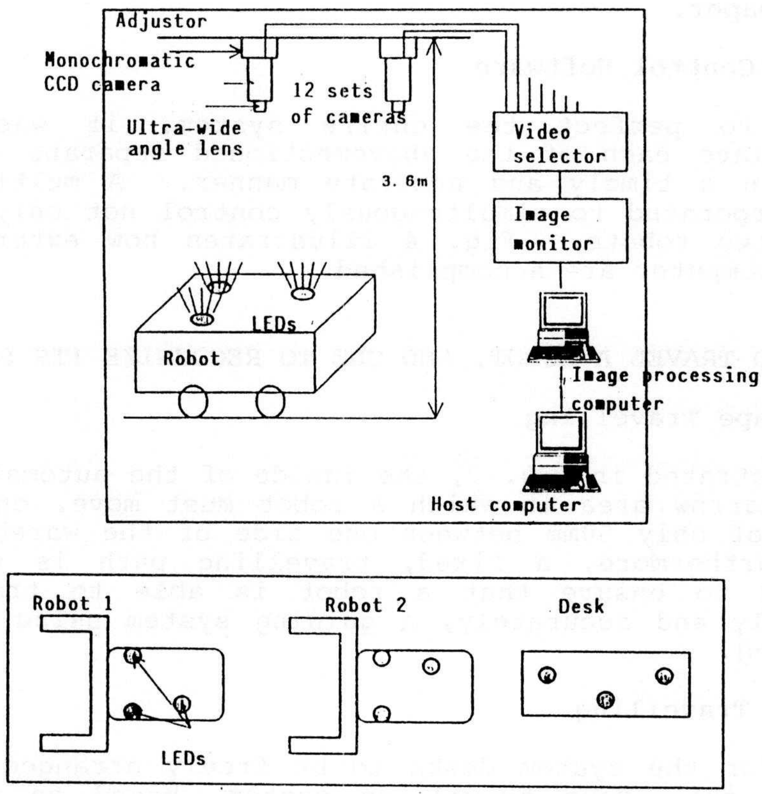

Fig. 5. Image processing system.

- Cameras

A total of twelve monochromatic cameras, each with high resolving power, and 360,000 picture elements, are mounted on the ceiling. Their lenses are ultra-wide angle types. Each camera covers an area of 4m × 5m, and the entire area is covered with these twelve cameras.

- Video selector

The video selector is designed to fetch images photographed with the twelve cameras, and from among these images, arbitrarily select, and transmit four images to the image processor.

- Image processor

The image processor is used for measuring two-dimensional movement. It is capable of calculating the image signals transmitted from the cameras by using an arbitrary level of brightness, thereby extracting the particular point which requires measurement, and then measuring the gravitational position and magnitude of the area. The processor is able to simultaneously process the images photographed with four cameras, catch three light emitting diodes at all times, and can also automatically pursue, in a cycle of 30 rounds per second, any one measuring point once it has been extracted.

o Image processing computer

The image processing computer controls both the image processor and the video selector, thereby positioning three absolute coordinates of each light emitting diode in the desk top and calculating each central coordinate and the degrees of an angle. In response to the command of the host computer, the image processing computer transmits, in a cycle of 4 to 5 rounds a second, the coordinates of the robots or the desks.

(2) Correction of the lens data

Technically, the most difficult job encountered during the accomplishment of the image processing system was the correction of the lens data. Determining the absolute coordinates requires converting the relative coordinate of any one measuring point obtained through image processing, into the absolute coordinates. With this development, an ultra-wide angle lens is used in order to broaden the area which can be covered with one camera. As a consequence, as illustrated in Fig. 5, the lens magnifies a distorted image, to a degree large enough to stay out of the center of the camera. It was also found that the error between the physical center of the camera and the center of an image was not small enough to realize an accuracy of 1cm (Fig. 6). Such a deviation, and the distortion of a lens, differs depending on the individual product.

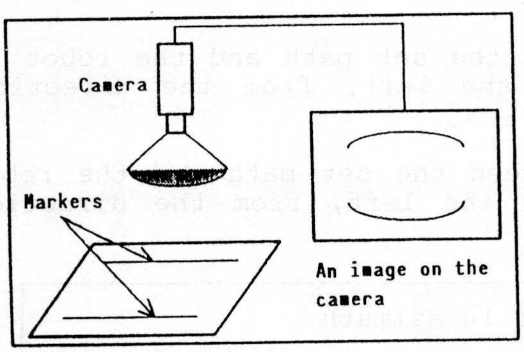

Fig. 6. Distortion of a lens.

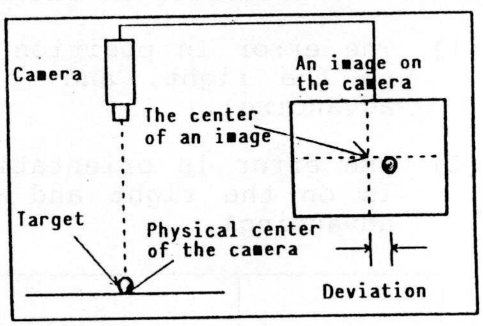

Fig. 7. Deviation of the center of an image on the camera, from the center of the camera.

Here, we calculated the absolute coordinates, by using a conversion formula consisting of a parameter peculiar to a camera + a lens, and a parameter which is determined according to the subject to be seen. In order to find a parameter peculiar to a camera, we measured 2,000 points per camera. The parameter involving the subject was determined through calibrations conducted in an actual hall. By using this conversion formula, we were able to measure the position of the robot, and follow this with image processing, for the accuracy of ±1cm.

4. GUIDING THE ROBOT AND MONITORING ITS TRAVELLING PATH

4.1 Selection of Travelling Paths, and Exclusive Control

The selection of the travelling paths for the two robots is conducted as per two types of restrictive items; one being safety, for which, as the two robots simultaneously move around, exclusive control is performed in front of the access to the automatic warehouse so that the guide path of one robot does not overlap that of another robot, and so that they do not bump against each other inside the warehouse; and the other being an optimal selection of travelling paths, for which the path optimal to allow for the arrangement of the desks in the shortest possible time within the scope of the conditions that satisfy the abovementioned safety requirements, is automatically calculated.

4.2 Path Monitoring Based on Fuzzy Inference

As previously described in 3.2, the robot is subject to a risk of cumulative error, and therefore is required to be compulsorily stopped before it deviates too far from its guide path, through the monitoring of its position coordinates. To realize this, based on the robot's positional information produced by image processing, we calculated the robot's degree of risk by using fuzzy inference, the details of which follow:

The following types of data were input:

(1) The coordinates of the starting and terminating points of the path on which the robot is now advancing.

(2) The coordinates of the robot's present position.

(3) The present azimuth of the robot.

From these types of data, the information to be input for fuzzy inference was processed as shown below:

(1) The error in position between the set path and the robot (+ is on the right, and - is on the left, from the direction of advancing).

(2) The error in orientation between the set path and the robot (+ is on the right and - is on the left, from the direction of advancing).

		Error in azimuth		
		Nagative	0	Positive
Positional error	Nagative	Bad	Moderate	Good
	0	Moderate	Good	Moderate
	Positive	Good	Moderate	Bad

Fig. 8. Input rule.

Based on the data above, the information to be output will be represented as the degrees of a risk, in figures 1 through 100. By changing the input rule, the input scale, and the membership function, a simulation of the data was achieved. And, in order to (1) input the degree of a risk, to a greater level, and (2) shorten the time required for calculation, it was determined that the input rule shown in Fig. 8, and the membership functions shown in Fig. 9, should be used, and that actions to automatically stop the robot at a point beyond 90% of the degree of the risk, should be adopted.

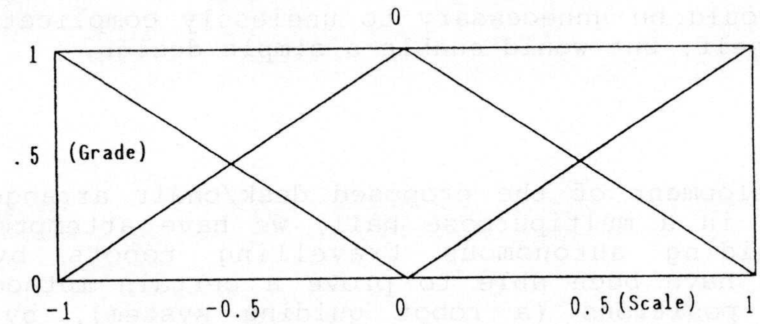

Fig. 9. Membership functions.

5. FUTURE TASKS

5.1 Methods to Recognize the Robot's Self Position and the Environment

For the proposed system, we used two methods in combination; one for the robot to recognize its position as it travels autonomously, by using a gyro, and the other for the robot to recognize its absolute position coordinates by utilizing image processing. A gyro has been extensively applied in various areas such as in controlling the posture of a shield machine engaged in the excavation of underground areas, and in the inertial navigation systems of aircraft. Thus, it is certain that a gyro continues to be the leading instrument for the technology of position recognition. The proposed system, however, must still overcome the problem of how best to reset the absolute coordinates when necessary. If the travelling range is limited, a method of resetting the absolute coordinates by image processing through overhead cameras, similar to the one mentioned in this paper, would be effective. But at an actual job site, this method would be unrealistic due to the magnitude of the travelling range as well as to the difficulties encountered during the gyro's installation. If image processing is used, attaching a camera to a robot proper and allowing the robot to travel while recognizing the surrounding environment, would be the optimal method. However, there are still many problems and tasks, such as a three-dimensional measurement of positions by using two cameras, a recognition of obstacles and human figures, and a change in outdoor brightness, that we must solve and overcome in the future.

5.2 Remote Control by Using Tele-existence Technology

In a robot, the role of communications is very important, in that when plural robots are being controlled, a host computer is required to intensively manage information, or else these robots are required to exchange information among themselves so as to capture the surrounding situation. Another important role of communication is in its utilization in the technology of remote control. Although it would be ideal for a robot to be able to make its own judgements accurately, and make advances on its job, there would be numerous incidents in which human assistance would be required; when some minor trouble occurs, when the robot encounters an unexpected situation, or when the situation requires a high level of judgment. In the event of such incidents, a high-speed image communication system capable of transmitting the in-situ condition to a remote place, and a remote control system capable of controlling the robot while watching its image, would be a very effective communication device. Also, if remote control is assumed to be employed from the beginning, it would be unnecessary to uselessly complicate the algorithm of the robot itself, but would enable a simple design.

6. CONCLUSION

In the development of the proposed desk/chair arrangement robot for its application in a multipurpose hall, we have attempted to realize a system for guiding autonomous travelling robots by using image processing, and have been able to prove a certain method involving the recognition of positions (a robot guiding system), by achieving the intended purpose. This method was also proved in regard to accuracy. Hence, we will continue further efforts to apply the various types of element technologies which we have accomplished up until now, for the robotization of future construction work.