Operation Direction to a Mobile Robot by Projection Lights

Takahiro Suzuki, Akihisa Ohya and Shin'ichi Yuta
Intelligent Robot Laboratory
University of Tsukuba
1-1-1 Tennodai, Tsukuba 305-8573, Japan
{ohya,yuta}@roboken.esys.tsukuba.ac.jp

***Abstract*— This paper describes the proposal of a novel concept for directing a mobile robot's motion by using human-operator lights. In addition, the construction of an experimental prototype, its operating system as well as results of some laboratory experiments are explained. Basically, the system architecture consists of a laser pointer and a flash light, whereby a target-object is brightened by a human-operator and an image is taken by an omni-directional camera. In such way that the position of the target object is showed to the mobile robot as for calculating its relative position by a vision system, and eventually the robot navigates towards the target-object direction.**

***Index Terms*— Mobile Robot, Omni-directional Camera, Stereo Camera, Projection Light**

I. Introduction

Until recently, research activities on mobile robots have became widely investigated. When a robot is operated to function in real human life spaces, there exist two main methodologies that can be chosen to instruct a robot's operation.

1) Humans instruct the robot about where the target-object position is.
2) Humans directly lead the robot towards the target-object.

In this research, the way for instructing the robot by using the latter modality (human-operator directly leads the robot to the object), as it is being showed in Fig.1. The usage of robots deploying lights and sound as integral parts of their operational system were proposed in reference [1]. In this research, only the usage of light as motion-action instruction is proposed as a means to operate in a simpler way. In the present methodology, information concerning the type of task and the place of execution is sent to the robot, even if the robot is unable to recognize the operable object. As a first approach in the development of this system, the authors aim to accomplish a simple operational task such as to push a switch-button on the wall.

II. Robot Instruction Methodology

The purpose of this research is the development of a lighting-based task instructing system for directing the motion-action of a mobile robot. The fact that the task instructing system could be commanded by human operators demands great significance. The authors decided to implement light-based directives specification (flash light and laser spot) as relevant means of information to perform

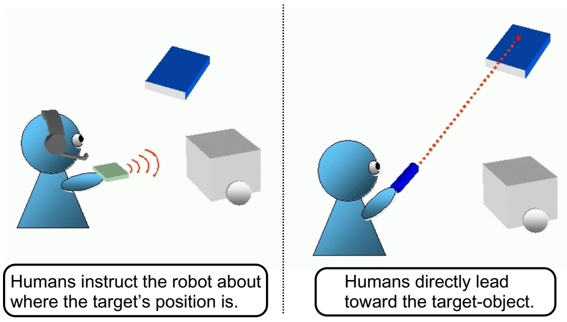

Fig. 1. Common frameworks for operation instructing.

operability over world's objects. The robot autonomously performs the type of operation at the place of the target object. A vision system processes an image of the brightened target-object. The robot has on-board an omni-directional camera and stereo cameras, whereby the image is captured. The concept of robot's task instructing system is depicted in Fig.2.

A. Flashing-based heading instruction estimation

Information on the direction to the target-object is sent to the robot. A sensor capturing an image of the surrounding is initialized timely, despite the mobile robot could be heading towards certain angle other than the target-object, the robot autonomously is able to determine an approxima-

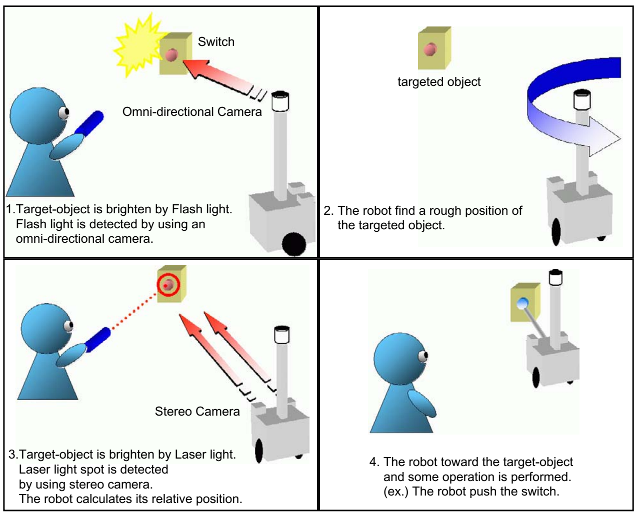

Fig. 2. Conceptualization of light projections for leading robot's navigation.

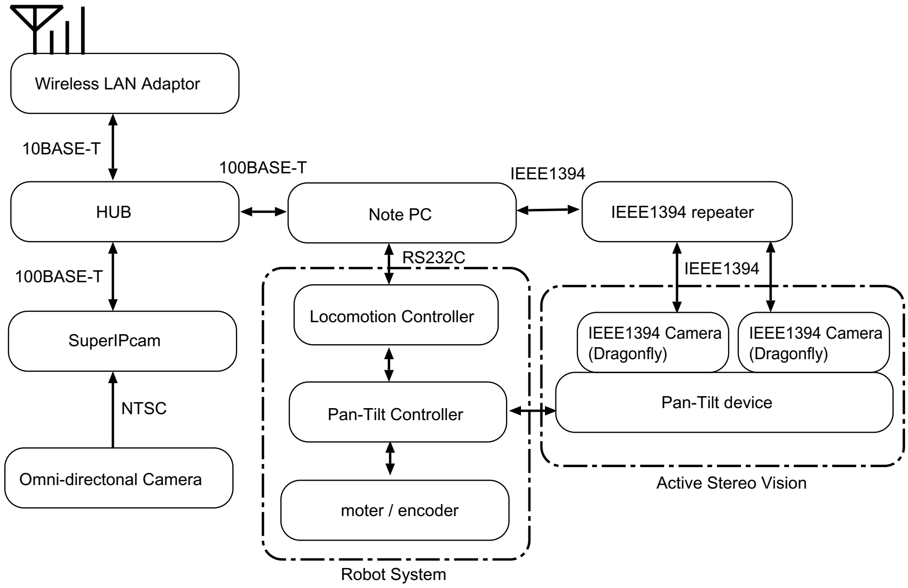

Fig. 3. Components of the system.

tion of target-position. Remarking that the omni-directional camera resolution is considered low, which means that when the target direction is estimated, the light projection size must be visible and bright enough for later processing, so that the camera flashing is squeezed by the system itself.

B. Accurate position instructing with a laser pointer

Once the target approximated heading direction has been taught, it is necessary to inform about the actual location. Thus, a laser pointer used to accurately irradiate a spot towards the operational object. Further, the distance between the robot and target-object is accurately calculated by taking a picture of the laser spot with the stereo camera. Therefore, the operation of the target-object became possible by transmitting its position to the locomotion unit (Fig.3).

III. System configuration

In this section, we describe the configuration of the robot system. The robotic platform which is being deployed is called "Yamabico", developed in our laboratory and was instrumented according to the need of the present research (Fig.4).

The robot was instrumented with vision, which is compounded by an omni-directional camera and the stereo cameras. Likewise, a SuperIPcam was also installed that is functioning as an image processor. Besides, the operator controller prototype was built up by the authors. The figure 3 is a depiction of the robot system implementation. Hereafter, we will describe the main component of the robot system.

A. Omni-directional camera

The figure 5 shows the omni-directional camera, which is compounded of a CCD camera and an omni-directional mirror. From the shape of the omni-directional mirror, the resolution in the outside part of the mirror is lower than the central part. And, the main feature is that it can take a picture of the surrounding in real-time.

Fig. 4. The mobile robot used in this study.

B. Stereo camera system

The stereo camera is used to calculate the distance to the operable object to which the laser pointer is irradiated. This stereo camera consists of the two CCD cameras and the Pan-Tilt device (Fig.6). The CCD cameras are Dragonfly of Point Gray Research Inc. with IEEE1394 communication. The Dragonfly supports the DCAM 1.30 specification, whereby it is possible to use it with software available for Linux. The support frame rate is 15, 7.5, and 3.75fps and its resolution is XGA (1024 x 768 pixels) in color, and the frame rate is set to 7.5fps. Since it is necessary to capture the pair of images at the same time for producing a stereo image, an usual camera needs an external trigger, nevertheless our cameras support the DCAM 1.30 specifi-

Fig. 5. Omni-directional Camera.

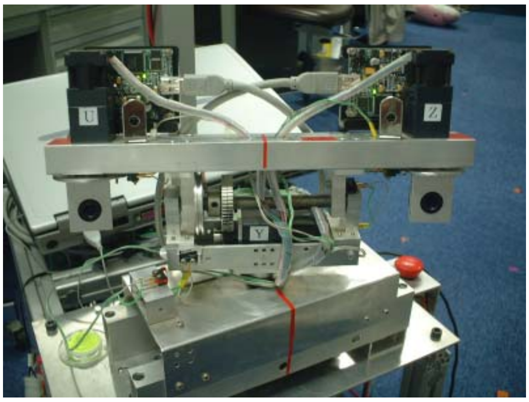

Fig. 6. Stereo camera mounted on the Pan-Tilt device.

cation, so they automatically synchronize their acquisition time within 20[μsec], without having need of any special device. The distance and direction to the target-object can be obtained by trigonometric operations of ranged data arose from the stereo camera. The baseline of the stereo camera at this time was 25cm.

C. SuperIPcam

The data sent from the omni-directional camera are analog signals. So, it was determined to use a SuperIPcam that was the image processing unit made by HITACHI, for data acquisition. The image processing unit can handle the analog input data in its own hardware. Therefore, various images can be processed at high speed and an image is captured in 256 x 220 pixels.

D. Controller device

The figure 7 is the controller device that projects light on the target object. The controller device is composed of a flash and a laser pointer. The cylinder was installed in the flash. We can get a round enlightened region of the flashing by using this cylinder (Fig.8). Though, time duration of the flash light is only for a moment, the robot can calculate an approximation of heading direction in case it needs to take a picture with the flashing light. Also, it is easy to recognize the laser spot light when the output of the laser is high. Nevertheless it was decided to use the product which its optical output is less than 1mW (CLASS2) as a consideration for safety.

Fig. 7. Prototype of the controller device.

IV. Entire system integration

This section describe the integration of each module described before and the system built in its totality.

A. Communication between SuperIPcam and note-PC

The SuperIPcam has a LAN port for I/O, used as means for communication between the notePC and the SuperIPcam. By TCP/IP communication, the information sent from SuperIPcam concerns a barycentric coordinate of the light yielded by the flashing. The notePC calculates an approximation of the direction heading to the target-object by using such barycentic coordinate.

B. NotePC programs inter-communication

The program for capturing the laser spot light and calculating its three dimensional position is executed within the notePC. Data were treated as a message, used for communication between programs. An ID identifies the mass of data, as a characteristic of the message, therefore the data can be selectively received by a specific ID.

C. NotePC and robot communication

Communication between the robot and its PC on-board was achieved by means of a set of sending and receiving data functions embedded in the OS (developed in our Lab.) in order to yield autonomous robot motions. Each control program is started with a specified process ID. After completion of the preparation for transmitting data, the note-PC selects a process ID and transmits data to the receiver program. Eventually, the robot receives the data and finishes certain actions, returning into the state of the standby again, waiting for more data reception.

D. Camera calibration

A process of cameras calibration is required in order to calculate an accurate distance up to the object, taking as means the pixels of the images (both cameras) performed by the image processor. The characteristics are the focal length of lens and pixel size, etc. and are called internal parameters. Similarly, position and posture of cameras are called external parameters. An accurate value for the internal parameters is calculated by using the "Camera Calibration Tool Box for Matlab". An external parameter can be calculated by firmly fixing the cameras.

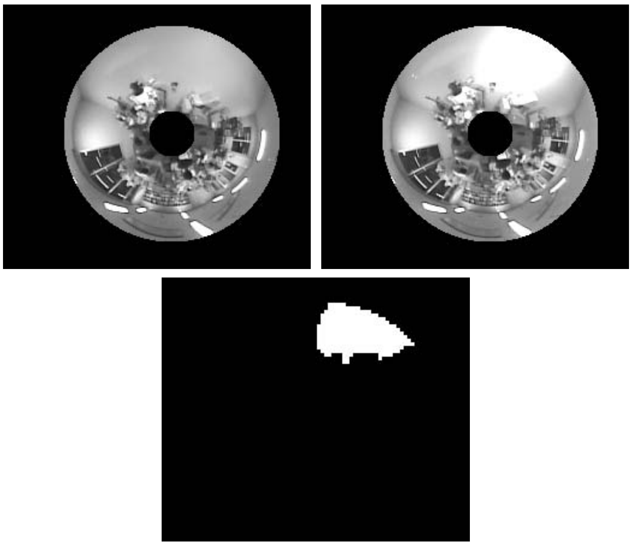

Fig. 8. The image sequence captured by the omni-directional camera.

V. Experiments on directing to the target-object

Experiments for target instruction were performed by deploying the controller previously described.

For detecting the light produced by the flash, we considered the method of image sequence difference. After taking a sequence of images by the sensor (camera), a mask-image was used to perform a spatial operation in order to extract the region mostly illuminated by the flash. In addition, it is worth mentioning that an operation for noise reduction was still applied to the resulted difference image. The final endeavor of this set of processes was to calculate the center of gravity of the flashed area resulted in the difference image, as a value exhibiting the angle towards the target-object place. The previous mentioned processing was carried out only by the execution of a command in the SuperIPcam hardware at considerable high speed. Fig.8 depicts the two continuous images where the pixel mask was applied, and a resulted binary image from such process.

A. Recognition of the laser spot light

From experimental results it was confirmed about the effectiveness on using fast speed shutter for easy detection of the laser spot. Since the "Dragonfly" cameras allow control over the shutter speed, several speed were tested in our experiments. Fig.9 depicts the results found by taking images at 110ms and 5ms shutter speeds. Actually, it can be said that Fig.9 right result was better than the obtained in Fig.9 left for our purpose.

The HSV that expresses hue(H), saturation(S) and value(V) was used as the color model palette information. Hue expresses where the color is along the spectrum. Saturation expresses how pure the color is, in other words how vivid. Value expressed the brightness, where the number 0 means complete black. Though the value of 100 is the brightest value, the maximum value doesn't yield white.

Fig. 9. The image of the laser spot light. Shutter speeds are 110ms (left) and 5ms (right).

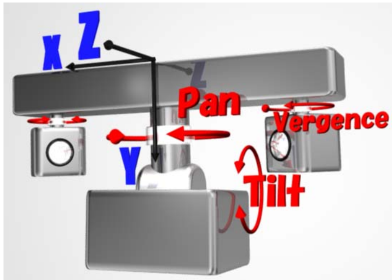

Fig. 10. Definition of a coordinate system.

The maximum value is just the brightest value with the color in a specific saturation.

In other experiments, laser ray was irradiated over various objects, where the results of hue produced circular red areas from the objects. As a consequence the threshold for laser spot segmentation was established based on the tests.

B. Experiments for detection of laser spot position

Experiments were performed for calculating the distance from the robot to the laser spot using the stereo camera. The configuration of the experiment is shown in Fig.11. We changed the robot's position and projected the laser spot light on the wall, and measured the distance.

Table I is a summary of the experimental results. Spot position in left camera and Spot position in right camera mean the laser spot (u, v) pixel positions. X, Y, Z are the coordinates in three dimensional space. The coordinate system base was set on the Pan-Tilt device as Fig.10. Also length measurement is given in millimeters.

The data of the TableI between 200mm and 500mm were taken for the purpose of capturing the laser spot. The

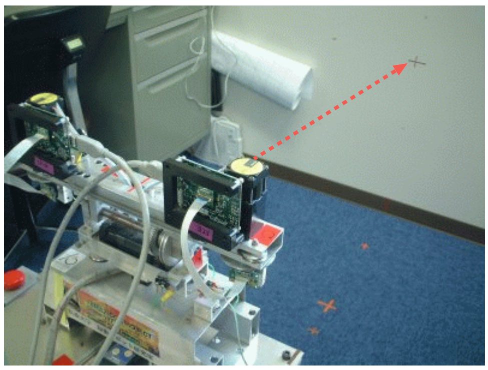

Fig. 11. The experimental configuration.

TABLE I

MEASUREMENT RESULTS.

distance [mm]	Spot position in left camera	Spot position in right camera	X [mm]	Y [mm]	Z [mm]
200	(113,537)	(999,558)	5.98	25.71	225.42
500	(485,537)	(612,555)	10.62	52.55	492.58
600	(240,732)	(772,755)	-4.89	139.70	571.72
700	(288,671)	(712,692)	-8.81	138.90	694.29
1000	(371,585)	(644,604)	-7.10	136.60	990.61
1500	(429,518)	(581,535)	-13.25	134.44	1505.34
2000	(457,486)	(553,503)	-17.24	131.20	1974.55
2500	(473,467)	(536,485)	-21.77	128.02	2405.07
3000	(486,453)	(523,470)	-26.40	125.51	2927.70
3500	(493,444)	(514,462)	-32.41	122.76	3336.14
4000	(500,436)	(508,453)	-35.64	117.23	3815.43

Fig. 12. The experimental environment.

Pan-Tilt device turned the cameras between inside about 10 degrees, also the tilt angle was set between 10 and 30 degrees. The cameras captured images in their front within a range of 600mm up to 4000mm. In general, we could obtain the data within small marginal errors when short distances. On the other hand, for the case of the long distances, the calculation results of 4000mm was 3815mm. This means that we obtained 185mm marginal errors in the direction of Z coordinates. We need to take into consideration this point, and include a program when the robot runs over these coordinates. Also we have the marginal errors of 88mm in the maximum value of Y axis. We considered that these problems are caused by the skew and the distortion and need to be corrected in the future.

VI. EXPERIMENT ON INSTRUCTING OPERATION

The experimental environment which has no obstacles is shown in Fig.12. We made the robot to operate (push) the target-object suspended from the ceiling.

Fig.13 shows the sequence of the experimental scenes. A first position of the robot is shown in 13-A. The robot captures the image of the flashing by the SuperIPcam, and the barycentric coordinate of light is transmitted into the notePC. The Pan-Tilt device is turned to the barycentric coordinate within the range of 180 degrees in front of the robot in the rear side. B is a state where the Pan-Tilt device is turned to that direction. Next, the robot captures images with the stereo camera, and the robot calculates the distance to the laser spot in the captured images. The angle of the Pan-Tilt device is adjusted based on the calculation result. In picture C, the user instructs the direction and the distance with accuracy by using the controller device. Next, the robot captured the image again after adjusting the amount of rotation of both cameras. In depiction D, the Tilt angle and the distance up to the final laser spot is then calculated. In illustrations E-G, the robot moves to the target-object position. At H, the robot pushed the target-object.

As a result of the experiment, we could confirm that the robot moved to the instructed position and pushed the target-object. But in several cases, the robot inaccurately stopped nearby or over passed just slightly the position of the target. The position should be estimated more accurately when the robot pushes a smaller object (e.g. a switch on the wall etc.).

VII. CONCLUSION

This paper described the proposal of a novel concept for directing a mobile robot by using lights. In addition, the construction of an experimental prototype, its operating system as well as results of some laboratory experiments were explained. Basically, the system architecture consisted of a laser pointer and a flash light, whereby a target-object is brightened while an image is taken by an omni-directional camera. In such way that the position of the target-object is showed to the mobile robot in order to calculate its relative position by using stereo vision, and eventually to navigate towards the target-object.

A problem to be solved in the future is that we need to control the motion of the Pan-Tilt device accurately, achieving a distance measurement with higher accuracy by the stereo camera system.

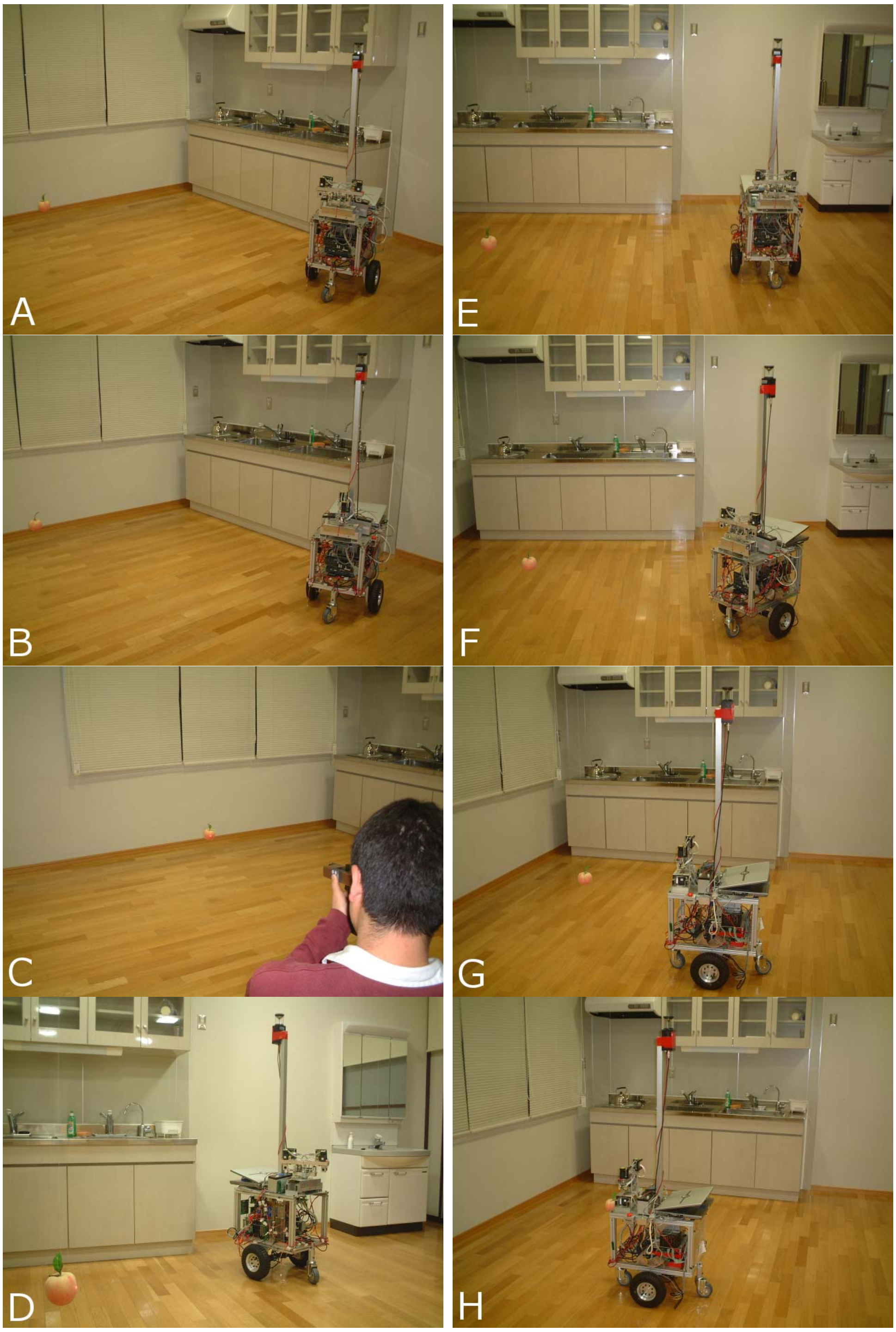

Fig. 13. The sequence of the experimental scenes.

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