Object Posture Recognition for Remote Book Browsing Robot System

Tetsuo Tomizawa†, Akihisa Ohya†‡ and Shin'ichi Yuta†

† *Intelligent Robot Laboratory, University of Tsukuba,* ‡ *PRESTO, JST*

Tsukuba-city, 305-8573 Japan

{tomys,ohya,yuta}@roboken.esys.tsukuba.ac.jp

Abstract

Our purpose is the realization of a system able to access objects located at remote places, by integrating Internet technologies and robotic engineering developments such as mobile robots. As an example, in this research, we are developing a system for browsing books from remote places through the Internet with a robot. In order to do browsing operations, the robot has to recognize the alignment state of a bookshelf itself and to pick up a book correctly. This paper also describes the developed sensor for recognizing the posture of a book and the plan for extractional operation in the environment of a general library. In addition, we conducted experiments by the developed system, and summarize the consideration about this system.

1 Introduction

Researches on autonomous mobile robots have recently produced remarkable progress in indoor environment perception, navigation, as well as manipulative control of objects. However, concerning on mobile robots in real life and their applications, their number and variety have been very limited and those applications are focused essentially on cleaning tasks [1] and guidance [2]. For instance, we humans, often wish to interact physically with remote objects or other humans without displacing ourselves. The realization of such teleoperational applications by a mobile robot would enlarge greatly the range of mobile robot's usage in our everyday life scenes.

In addition, thanks to the fast and wide expansion of the Internet, a huge variety of information can be easily accessed and viewed from our homes. However, the storage of any kind of daily use information in databases and other digital media for remote access through the Internet, is impossible and unrealistic since informations from vivid objects are fading throughout time and space. Thus, real-world objects being remotely viewable by video technologies as well as telemanipulatable in real time, would open new frontiers as a result of the emerged information era. In order to realize such teleoperational system, the authors thought to apply a mobile robot as the agent whom will access and manipulate in real-time real-world objects. By this experimental prototype of a book browsing system using an autonomous mobile robot teleoperated via the Internet, we intent to expand mobile robot potentials and usage for human life benefits.

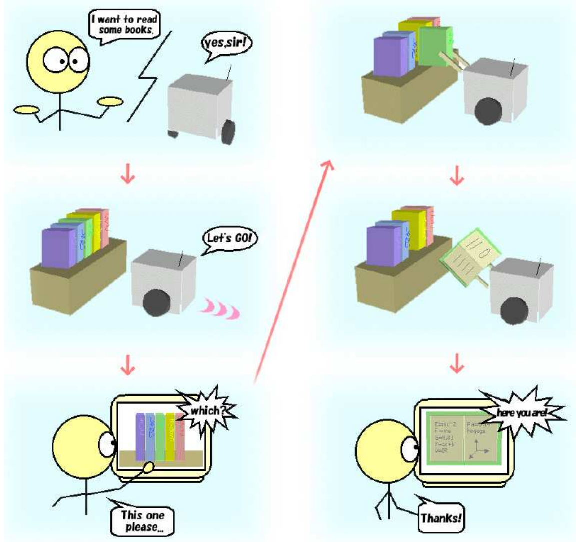


Figure 1: *Concept of remote book browsing system using a mobile robot.*

Similar works related with remote access of objects by using a mobile robot have been evolved by Maeyama et.al in [3]. Where, by means of a semi-autonomous mobile robot interacting in an art museum, humans can just observe objects, but can not manipulate them. In our research, we attempt not only to construct a system able to visualize objects, but also to integrate the mobile robot with capabilities for object manipulation.

In this study, the target task consists of browsing a book located in a remote place by controlling the mobile robot. Recently, various books are now processed electronically and Electronic Libraries have also being built. Processing books electronically focuses mainly on the information importance contained in books. Books can also be considered as the work of their author and as cultural objects, their physical existence has an important meaning. Since it is hard to imagine that it is possible to process all published books electronically, and that the existence of books may disappear in the near future, one can expect that the significance of the system being built in this research will not be lost immediately. Moreover, if such a system is realized, I think that it is applicable also to the automatic electronic processing of ancient documents.

In the process of realizing this system, we firstly designed and built a prototype of the mobile robot, equipped for the accomplishment of browsing books, which is mainly categorized by 3 goals: (1) picking the book by using the manipulator, (2) the book-opener and (3) page turner device. It has the slightest ability to extract books from a shelf, to browse them and subsequently, images of the page's contents are sent toward teleoperator humans [4],[5]. However, that prototype was constrained to extract books with vertical pose in the shelf. In this study we challenge to overcome these restrictions by improving the sensor for measuring the posture of the book, planning for manipulation in order to enable this robot system to act more robustly and independently in nearly real-world libraries.

In the following sections, the system concept of remote book browsing and robot structure is described (Section 2), the developed sensor for book manipulation (Section 3) is also presented. Finally, Section 4 describes the conducted experiments and shows some evaluation results of the integrated system.

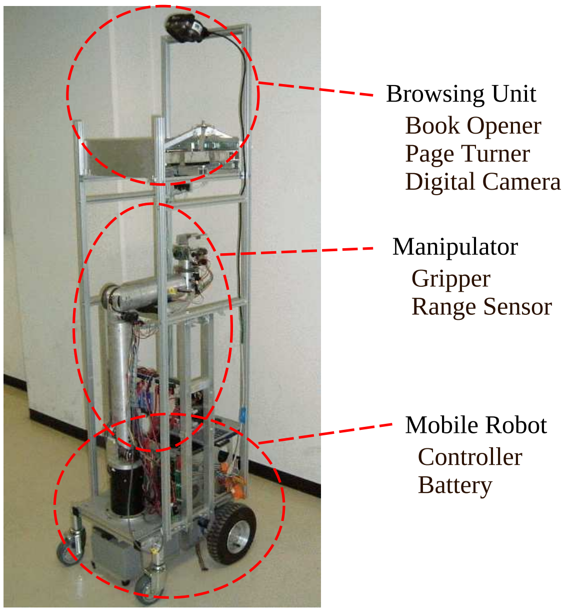


Figure 2: *Integrated book browsing robot.*

2 Remote book browsing system

2.1 System description

The motivation and general concept of this research is the consideration that, in everyday life, humans need constantly the access to any type of information, where in this modern times the Internet takes very important role for our benefits. Then taking advantages of a set of technologies, let us think about robotizaided book browsing system. Where mobile robots providing services in genelal libraries allow people localized at remote places (e.g. home, office, etc.) to access book's information. Basically, the general idea is that, a remote human request to a mobile robot in a library to consult a determined book by the Internet. Thus, human just commands what book and pages wish to consult, and robot will execute the necessary task in order to accomplish the human service. The following tasks are the general steps need for our system, and an overview of the remote book browsing is illustrated in Figure 1.

1. The user selects the target category.
2. The robot moves toward the target shelf, meanwhile is able to avoide obstacles.
3. The user selects visually a book from the previously sent image (by the robot).
4. The manipulator takes out the target book.
5. The robot opens the book and turns its pages.
6. Robot transmits images of current page to the user.

2.2 Robot system

In this system, our aim is to build a mobile robot able to carrying out the overall operation of book consulting, from the shelf extraction of a book, turning over pages and browsing the books in an all-in-one system. Moreover, the robot should have the size, which allow it to move freely inside of a library. Our robot is integrated by a 7 degree of freedom(DOF) manipulator of 1100mm of length, designed and built in our laboratory [6]. Likewise, in order to extract from and return books in a shelf, the height of the manipulator is added over 200mm due to is fixed on the body of the mobile robot. Then, our manipulator is technically able to locate its extremity between 400mm and 1100mm over the ground. Since the robot has only one arm, in order to open a book, and turning over a page, then extension of capabilities are aimed by adding another actuator if needed.

The locomotion platform of the autonomous mobile robot is equipped with a manipulator to grasp books and with a browsing unit for opening and viewing its content. The robotic hand designed in order to extract and insert books in a shelf has been attached at the extremity of the manipulator. Equipments and devices for an automatic turning over pages of a book have been developed, however are commercially available in the market [7], but expensive, big in size and inadequate for dynamical systems such as mobile robots. Therefore, in order to turn over efficiently the pages of an opened book by a simple mechanical structure built of low cost, we designed the opening/closing device and page turning over device in our laboratory and adapted it to the robot (Figure 2). Moreover, the control system and the set of commands which operate those actuators and the interface for establishing communication were built.

3 Object posture recognition

3.1 Basic strategy

In order to hold a book by using the manipulator, the robot has to measure correctly the shape, size, and relative position of the target book. The following conditions concerning books manipulation are established as:

- Book's size is considered from B5 to A4.
- Weight should be less than 400g.
- Thickness is restricted less than 50mm.
- The books should be hardcover.

The following conditions were defined as an alignment state of books.

- The posture of a book is uncertain.
- They are not stuffed strongly.

A method commonly used for object recognition is stereo vision. With stereo vision, position and direction of an object are detectable over a wide area. However, for our purpose is not enough suitable due to there is a high cost computation. In this research, the target object is restricted to the book, because of the form of a bookshelf do not change. So, the infomation of the shelf's height is beforehand included in the environment map. Moreover, the back cover of a book is invariable a rectangle shape. From its boundary position and inclination, the posture of a book and its thickness can be determined.

A laser range sensor was adopted as a system to measure the position of the books. This sensor uses a laser, which emit an infrared light slit, further a camera captures the reflecting light, and 3-dimensional coordinates of the reflecting points are then computed by using triangulation techniques [8]. When emitting a laser light in the direction of the bookshelf, the light is then reflected on the places were books are placed, therefore it makes possible to determine books posture and thickness. Finally, in order to calculate the posture of a book, we extracted the edge of a book from the camera image, as the main element in the performance of our method.

3.2 Sensor Structure

The range sensor consisted of a CCD camera (CIS, BCC-165A, view angle:55deg(h)$\times$46deg(v)) and a laser slit projector (Edmund 23367, Wavelength:670nm, Rated output:1mW), shown in Figure 3. The camera was attached at right angles of the mechanical hand. The laser slit projector was fixed at 10cm and with an angle of 20degrees under the camera. The captured image is processed

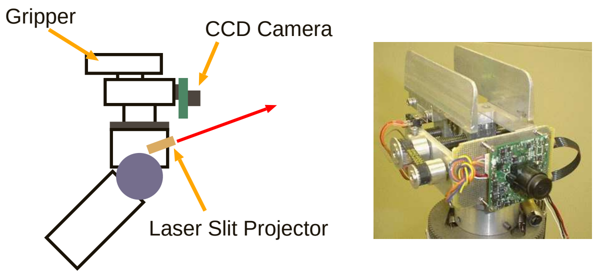


Figure 3: *Gripper and sensor for manipulation.*

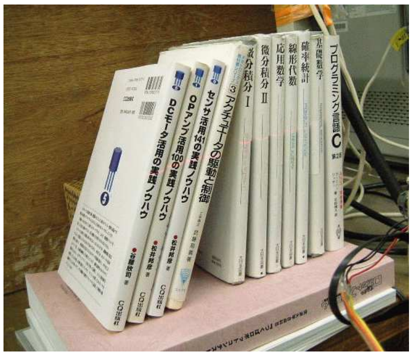
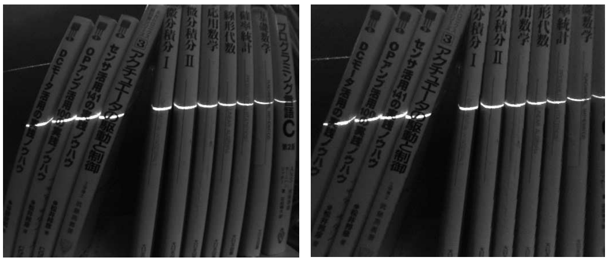


Figure 4: *The example of the alignment state of books*

by "IP7500 [9]". The IP7500 is an image processing module, which has a SH4 as CPU, and SH-linux was adopted as its OS. It is lightweight and compact size of 200mm(W)$\times$150mm(D)$\times$50mm(H). Hence it is suitable for carrying on the robot. Sensed images are processed in 512$\times$440 pixels since image processing functions are performed by the hardware itself, so calculation is quite fast. Likewise, image processing results are then transfered into the note-PC integrated on the robot, this last is equiped with technology for connection with a LAN. Evidently image calculation are transmitted through the LAN.

3.3 Camera calibration

The camera used by this system is lightweight, small and has an extensive view. However, raw images are distorted data arise from its lens. Then, in order to recognize objects, it is necessary to rectify distortion as a pretreatment. "Camera Calibration Toolbox for Matlab" [10] was used for compensation of lens distortion. This tool box was developed for camera calibrations, and can change the bent picture into an exact pinhole model. The input image of the camera is shown in Figure 5(a), and the image after distortion compensation is shown in Figure 5(b). IP7500 took about 2sec to process the whole image.



(a) raw image, distorted (b) rectified image

Figure 5: *Distortion compensation processing*

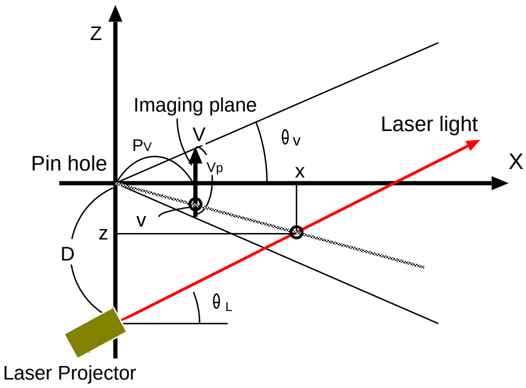


Figure 6: *Optical configuration of the sensor.*

3.4 Calculation of 3D coordinates

The images are compounded by 256 gray levels, and brightness values where books exist are approximately 100, likewise those values of laser reflecting points are over 200. So, we can distiguish reflecting points easily by filtering with a suitable threshold. We conjecture that the object's shape by calculating points on 3 dimentional coordinates, correspond to the all reflecting points(u,v) we computed before from the image. Our model for converting 2D points into 3D coordinates, was to use a pin-hole model described in Figure 6. The origin is the focul point of the lens, then in the real space coordinates, we considered the x-axis as the light axis of the camara, y-axis as right-left axis and z-axis as up-down axis. The definition of the geometric parameters is as follows.

D : The interval of camera and laser projector

P_V : The distance to a imaging plane (into the vertical pixel coordinate)

V_p : The number of vertical pixels of the image

P_U : The distance to a imaging plane (into the horizontal pixel coordinate)

U_p : The number of horizontal pixels of the camera

θ_V : The vertical view angle of the camera

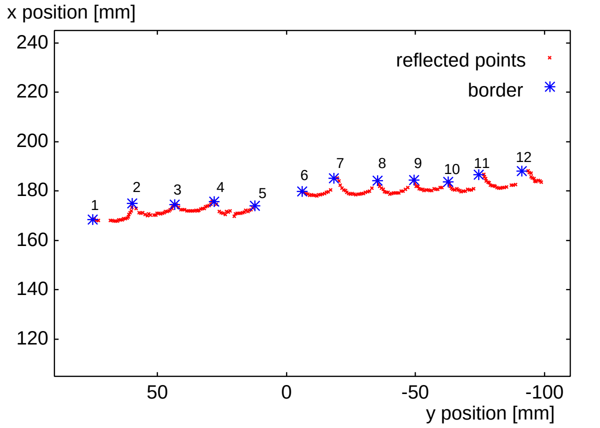


Figure 7: *Measured reflecting points and the recognition result of boundary positions.*

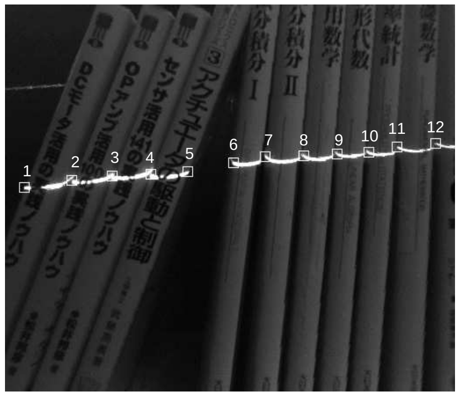


Figure 8: *The bookshelf picture with boundary positions.*

θ_U : The horizontal view angle of the camera

θ_L : The angle of camera axis respective to the laser plane.

The conversion of pixels (u,v) into 3D coordinates (x,y,z) is depicted as follows:

$$x = \frac{D}{\frac{v}{P_V} + \tan\theta_L} \tag{1}$$

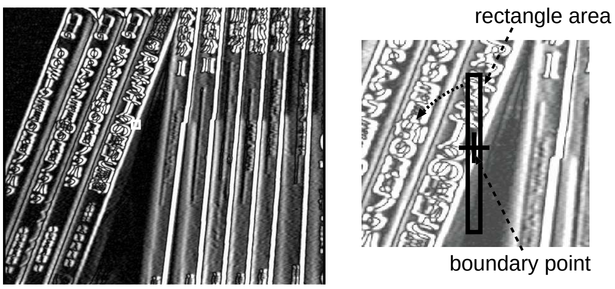
$$y = \frac{xu}{P_U} \tag{2}$$

$$z = \frac{xv}{P_V} \tag{3}$$

Here,

$$P_V = \frac{V_p}{2}\cot\theta_V \tag{4}$$

$$P_U = \frac{U_p}{2}\cot\theta_U \tag{5}$$



(a) filtered image (b) edge counting

Figure 9: *The method for book posture recognition.*

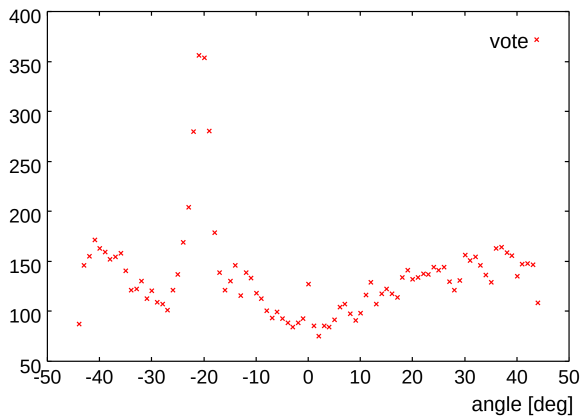


Figure 10: *The number of the white points included to a rectangle area.*

Figure 11: *The measurement of the degree of inclination of the books.*

3.5 Boundary recognition

Likewise, we determined the number of books which are visible by the sensor and thickness measure of each book as well. Projecting the group of points arising from laser sensor to the x-y coordinates, we check up ruggedness along to x-axis by selecting each gap of points on the y-axis. Thus, we classified the points up which have all conditions described below as candidates for boundary recognition of a book.

- Points, which gap within 2mm along y-axis, and there is a close maximum x-value.
- The mean value of two points when the gap along y-axis is between 2mm and 5mm.
- When the gap along the y-axis is over 5mm, the space between both points is considered as empty space.

In Figure 7, we describe the reflecting points projected on x-y coodinates and the result of boundary recognition. It takes about 100ms usually for one measurement. Moreover, it can calculate boundary within 1mm of error when measurment is performed about 250mm far away from the book shelf.

3.6 Book posture recognition

In order to measure the posture of a book, edge detection operation was performed on the original image, basically to extract the back cover of the books. Firstly, a differentiation filter is applied to the image for extraction of vertical edges. The extracted edges are shown in Figure 9(a). Thus, lines are matched from a differentiation image. In this example, the boundary position of a book is already known. Moreover, since the edge of a back cover passes along the boundary position, it can acquire the angle of a book by the following method.

It considers 100×5 pixel of rectangle area, focusing on the point of each boundary position as shown in Figure 9(b), and the number of white pixels contained in the domain is also determined. This rectanglar area was rotated from -45 degrees to +45 degrees, and when the rectangle overlaps with the edge of the back cover, then the total number of the white pixels becomes as the largest one. The relationship between an angle of rectangular area and the number of white pixels is shown in Figure 10. In this example, the rectangule of -21 degrees, had the highest number of points. This angle means the degree of inclination of the book. By means of this processing, the image in which the boundary line was computed from the original image is shown in Figure 11. The processing time of measurement of inclination by this method is about 1 second, and measurement accuracy is about 2 degrees. This accuracy is sufficient for manipulation.

4 Extraction of the book

We realize that this task implies some accurate considerations. For such reason we approached several implementations in order to evaluate the more suitable performance. For instance, the robot's hand has to displace in front of the target book, which this last is between left and right books.

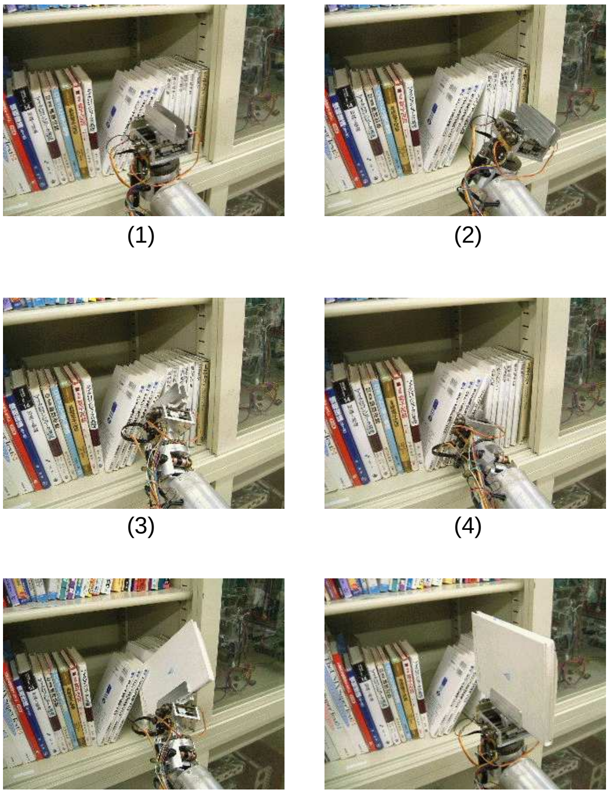

(1) (2) (3) (4) (5) (6)

Figure 12: *Scenes of extracting.*

Then, the hand is able to open adequately enough according to the book's thickness. In other word, the hand is able to penetrate horizontaly between boundaries of each book. However, this way frequently fails and hopefully 50% of the times success, because of robot-hand pushes both side books displacing the target book within them, in such a way that is not possible to control its desired position. Some methods were implemented for overcoming such problem, but among them the description of the following one was the best which had the highest fault tolerance rate.

1. The robot turns the manipulator to the direction of the bookshelf. If a user wishes to change the viewpoint, then the robotic hand's position will be moved vertically and horizontally (manipulator's movements).
2. The robot takes an image of the bookshelf, and looks for the posture of each book using the range sensor.
3. A hand is moved in front of the target book, and hand posture is leaned into the same angle (Figure 12(1)(2)).
4. Then, the gripper is widen proportionally to the width of the targeted book.
5. A wrist is rotated 90 degrees, and gripper is swung down and inserted in both sides of a book (Figure 12(3)(4)).
6. Finally, the hand pulls the gripper out (Figure 12(5)(6)).

The gripper should approach a given book within 2mm of accuracy in order to insert it by itself and grab smoothly the book. And, since the measurement accuracy of our sensor is 1mm and the developed actuator can operate accurately near to 1mm error range, then solving the issue of precise positioning of the mobile manipulator would enable the whole system to grab books from the shelf.

5 Conclusions

In this research, we aim to show the usefulness of a mobile robot system taking part actively in everyday living environment. In order to realize a remote book browsing robotic system which can be employed in a general library, we proposed the recognition method for the described allignment state of a book, and the integration of this technique in the robot. Moreover, the system experiment showed the usefulness of this system. Finally, we will test and evaluate our system in a real library environment.

Acknowledgments

The authors would like to thank Mr. Martinez Edgar and Mr. Soumare Seydou of the University of Tsukuba for their assistance for preparing this manuscript.

References

[1] E. Stroulia, M. Strobel : "Office Waste Cleanup : An Application for Service Robots", Proceedings of ICRA'97, pp.1863-1868

[2] J. M. Evans : "Help Mate : An autonomous mobile robot courier for hospital", Proceedings of IROS'98, pp.1695-1700

[3] S. Maeyama, S. Yuta, A. Harada : "Remote Viewing on the Web using Multiple Mobile Robotic Avatars", Proceedings of IROS'01, pp.637-642

[4] T. Tomizawa, A. Ohya, S. Yuta : "Book Browsing System using an Autonomous Mobile Robot Teleoperated via the Internet", Proceedings of IROS'02.

[5] T. Tomizawa, A. Ohya, S. Yuta : "Remote Book Browsing System using a Mobile Manipulator", Proceedings of ICRA'03 (to be appeared).

[6] http://www.roboken.esys.tsukuba.ac.jp

[7] DOUBLE Resaerch and Development Co,Ltd., http://www.j-d.co.jp/4_fks/readable/r_top_e.html

[8] S. Yuta, S. Suzuki, Y. Saito, S. Iida : "Implementation of an Active Optical Range Sensor Using Laser Slit for In-Door Intelligent Mobile Robot", Proceedings of IROS'91

[9] Hitachi Information and Control Systems, Inc., http://www.hicos.co.jp/seihin/gazou/ip7500eb/page1.html (in japanese)

[10] Camera Calibration Toolbox for Matlab, http://w3.impa.br/ pcezar/3dp/original/ CVL_html/appPage/calib_doc/index.html