

Paper:

Book Extraction for Remote Book Browsing Robot

Tetsuo Tomizawa, Akihisa Ohya, and Shin'ichi Yuta

Intelligent Robot Laboratory, University of Tsukuba
1-1-1 Tennoudai, Tsukuba, Ibaraki 305-8573, Japan
E-mail: {tomys, ohya, yuta}@roboken.esys.tsukuba.ac.jp
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Our purpose is the realization of a system able to access objects at remote sites by integrating Internet technologies and robotic engineering developments such as mobile robots. Concretely, we are developing a system that uses a robot for browsing remote books via the Internet. To extract books, the robot must recognize the book's pose-feature (position, angle, and thickness). This paper describes the sensor developed for recognizing the position of books and planning book extraction in a general library environment, and reviews experimental results.

Keywords: remote book browsing, book extraction, object location recognition, mobile manipulator

1. Introduction

The ability of robots to conduct activities in the place of humans in a real-world environment is becoming increasingly important, making it necessary to consider mobile robot applications aiding human operators in daily tasks [1-3].

The originality of our research consists in the proposal of concepts such as remote object access. Realization of such teleoperations by mobile robots would greatly broaden their application in daily life [4-6]. An important feature of this research is that actually is a practical implementation of our proposed idea which, after experiments, we considered an optimal system integration.

Concretely, we developed a remote book browsing robot.

Remote book browsing robot (**Fig.1**):

1. A mobile manipulator for extracting books turns pages, and capture book contents is stationed in a library.
2. The robot's computer, linked to the Internet, sends captured images to the remote site.
3. The user visually selects a book on the screen from the previously received image.

The user doesn't need to know how library books are arranged. The robot has a map of the library (in advance for self-localization). When an operator gives the title of a book or its category, the robot acts by autonomously generating an obstacle-free route. Route generation and

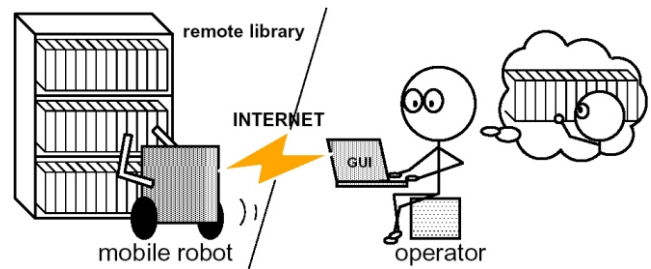


Fig. 1. Remote book browsing system using an autonomous mobile manipulator teleoperated via the internet.

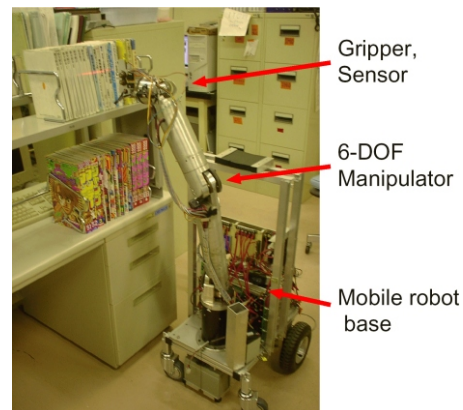


Fig. 2. Mobile manipulator used as a platform of the book browsing system.

path-following algorithms developed in our laboratory [7] enable mobile robots providing services in general libraries people at remote sites, e.g., homes and offices, to access book information.

Remote book browsing involves autonomous navigation, book pose-feature recognition by an active visual sensor, manipulation for extraction and return of the book by an actuator, page turning, viewing of a book's contents, and communication to/from the remote site.

To develop this system, we designed and built a prototype (**Fig.2**) that selects books using a manipulator. This paper focuses on book pickup motion process,



Fig. 3. An example of the alignment state of books.

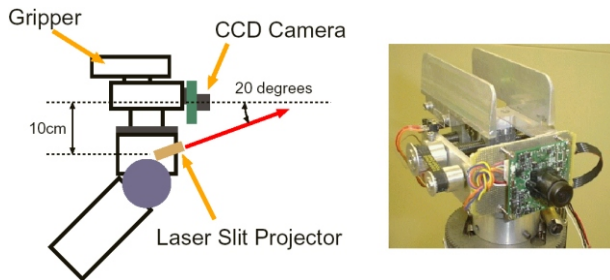


Fig. 4. Gripper and sensor for manipulation.

which requires book location recognition and book manipulation. Section 2 details book position recognition for book handling. Section 3 presents the developed robot and its motion and evaluates results. Section 4 summarizes conclusions.

2. Book Location Recognition

2.1. Basic Strategy

For a manipulator to hold a book, the robot must correctly determine its shape, size, and relative location. In this system, the user chooses the book from images sent by the robot, so book title recognition is not necessary.

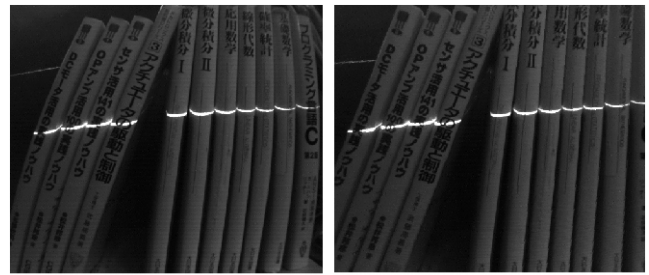
Conditions in book manipulation:

- Book sizes are considered from A5 to A4.
- Thickness is restricted to 50mm or less.
- Books are hard-cover.

An example of targeted books is shown in Fig.3. The following conditions were defined for book alignment:

- The location of a book is uncertain.
- Books are not set firmly, one beside the next.

Object recognition typically uses stereovision to detect the location and direction of an object over a wide area, but involves expensive computation. The target of our research is restricted to books, which invariably are box-shaped and have a rectangular spin, enabling their location and thickness to be determined from their boundary location and inclination.



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

Fig. 5. Distortion compensation processing.

We used a laser range sensor to determine a book's location. Information about shelf height is included in the robot's prerecorded environment map. The camera fixed on an extremity of the manipulator targets toward the bookshelf, then the sensor emits light through a slit, a camera captures the reflected light, and three-dimensional coordinates of reflection points are computed by triangulation [8]. When laser light is emitted at the bookshelf, light is then reflected on the sites of books, making it possible to determine book boundaries. To calculate the location of a book, the camera image is edge-extracted.

2.2. Range Sensor Configuration

The range sensor consists of a CCD camera (CIS, BCC-165A, view angle: 55 (h) 46 (v)), and a laser slit projector (Edmund 23367, wavelength: 670nm; rated output: 1mW) (Fig.4). The camera is attached at right angles to the mechanical hand. The laser slit projector is fixed at 10cm at an angle of 20° beneath the camera. The captured image is processed by IP7500 [9], an image processing module that uses an SH4 (166MHz) as the CPU and SH-Linux as its operating system (OS). It is lightweight and a compact 200mm(W) 150mm(D) 50mm(H), making it suitable for carrying on the robot. Sensed images are processed in 512 440 pixels. Since several image processing functions are performed by hardware, calculation is considerably fast. Subsequently, image processing results are then transferred to the notebook PC integrated on the robot and equipped with technology for connecting to a LAN.

2.3. Camera Calibration

The camera is lightweight, small and has an extensive view. Since raw images are distorted by its lens, to recognize objects, it is necessary to rectify distortion in pretreatment. The Camera Calibration Toolbox for Matlab [10] used to compensate for lens distortion was developed for camera calibrations and changes bent images into exact pinhole models (Figs.5(a) and (b)).

The IP7500 takes about 2 seconds to process an entire image.

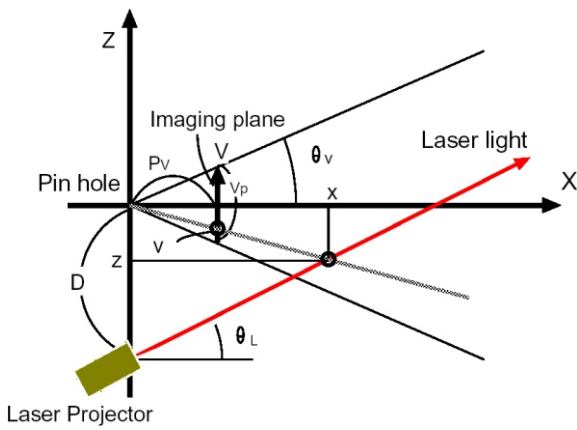


Fig. 6. Optical configuration of the sensor.

2.4. Calculation of Three-Dimensional (3D) Coordinates

Images are compounded by 256 gray levels, and brightness where books exist are approximately 100 and values of laser reflection points exceed 200, so reflection points are easily distinguished by filtering with a suitable threshold. We assume that an object's shape determined by calculating points on 3D corresponds to all reflection points (u,v) computed before from the image. Our model for converting two-dimensional (2D) points to 3D coordinates used the pin-hole model described in Fig.6. The origin is the focal point of the lens, so, in real space coordinates, we consider the x-axis as the optical axis of the camera, the y-axis as the right-left axis, and the z-axis as the vertical axis. Geometric parameters are defined as follows:

- D: interval of camera and laser projector
- P_v: distance to imaging plane (on the vertical pixel coordinate)
- V_p: number of vertical pixels of image
- P_u: distance to imaging plane (on the horizontal pixel coordinate)
- U_p: number of horizontal pixels of camera
- v: vertical view angle of camera
- u: horizontal view angle of camera
- L: angle of camera axis for laser plane

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

$$x = \frac{D}{\frac{v}{P_v} \tan L} \dots \dots \dots (1)$$

$$y = \frac{xu}{P_u} \dots \dots \dots (2)$$

$$z = \frac{xv}{P_v} \dots \dots \dots (3)$$

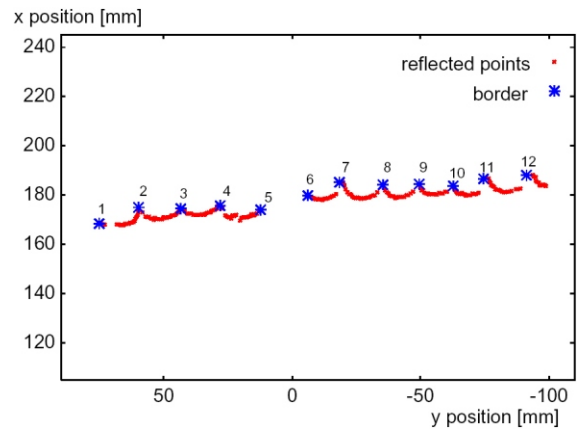


Fig. 7. Measured reflecting points and the recognition result of boundary positions.

Here,

$$P_v = \frac{V_p}{2} \cot v \dots \dots \dots (4)$$

$$P_u = \frac{U_p}{2} \cot u \dots \dots \dots (5)$$

2.5. Boundary Recognition

To determine the location of each book, book boundaries must be recognized. Projecting the group of points from the laser sensor to x-y coordinates, we checked ruggedness along the x-axis by selecting each gap of points on the y-axis, and classify points that meet the conditions below as candidates for boundary recognition of a book.

Points, spaced within 2mm along the y-axis, with a close maximum x-value.

Mean value of two points when the gap along the y-axis is between 2mm and 5mm.

When the gap along the y-axis exceeds 5mm, the space between both points is considered empty.

In Fig.7, we describe reflection points projected on x-y coordinates and the result of boundary recognition. It takes about 100ms for one measurement, which calculates a boundary within 1mm of error in measurement about 250mm away from books. An image of a bookshelf with recognized boundary locations is shown in Fig.8.

2.6. Book Location Recognition

To determine the location of a book, edge detection process was performed for the original image, basically to extract the spine of books. First, a differentiation filter is applied to the image for extracting vertical edges (Fig.9(a)), and lines are matched from a differentiation image. To detect straight lines, the Hough transform was

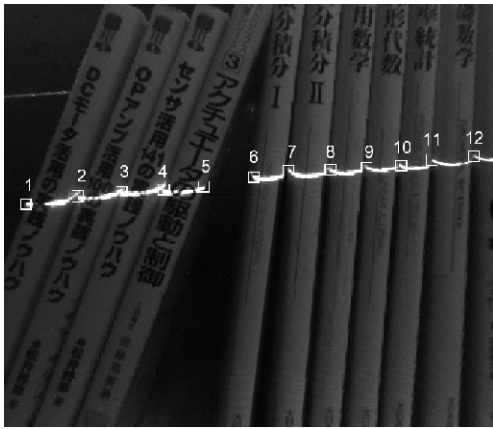


Fig. 8. The bookshelf picture with recognized boundary positions.

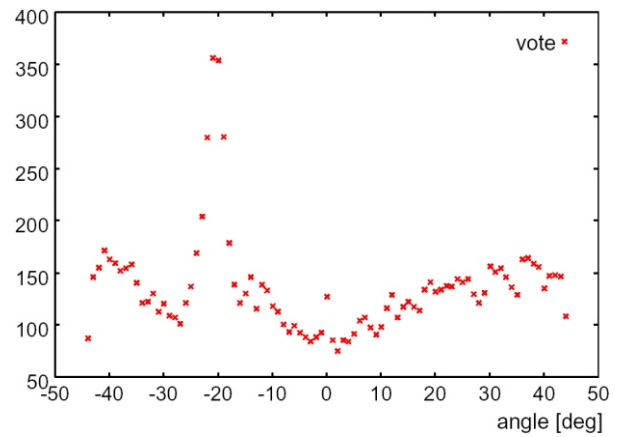


Fig. 10. The number of the white points included to a rectangle area.

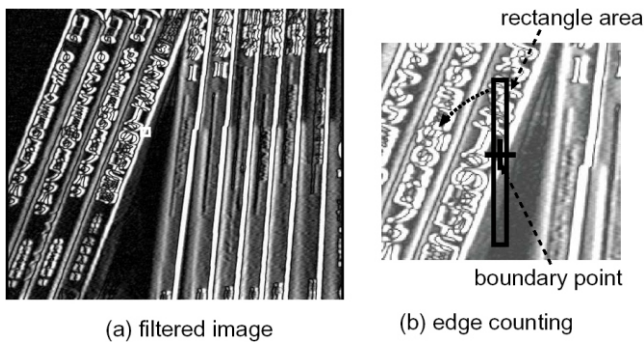


Fig. 9. The method for book posture recognition.

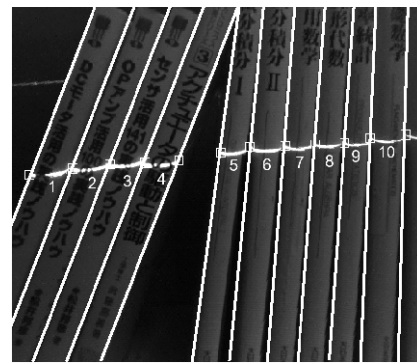


Fig. 11. The measurement of the degree of inclination of the books.

used. In this example, the boundary location of a book is already known as discussed in the previous section. Since the edge of a spin passes along the boundary location, it acquires the angle of a book as follows:

It considers the 100 5 pixel rectangle, focusing on the point of the calculated boundary location (Fig.9(b)) and the number of white pixels in the domain is also determined. This rectangle is rotated from -45 to $+45$, and when the rectangle overlaps the edge of the spin, the total number of white pixels becomes largest. The relationship between the angle of rectangular area and the number of white pixels is shown in Fig.10. In this example, the angle of 21 had the largest number of points and indicates the degree of inclination of the book. In this way, the image in which the boundary line is computed from the original image is shown in Fig.11. Measurement of inclination takes about 1 second, and measurement accuracy is about 2° , sufficient for manipulation.

3. Book Manipulation

3.1. Mobile Manipulator

We aimed a mobile robot able to handle overall book consultation from shelf extraction, turning pages, and browsing for books in an all-in-one system. The robot should be a size enabling to move freely in a library.

The mobile robot used in this research is a YAMABICO mobile robot developed at our laboratory [7]. YAMABICO has two independent steering wheels and is 50cm in cubic size without actuators. By default, it moves autonomously along a specified line [11].

The robot is integrated by a 6-degree-of-freedom (DOF) manipulator 1,100mm long designed and built at our laboratory. To extract books from and return them to a shelf, a 200mm manipulator is added to the mobile robot, enabling the manipulator to technically locate items between 400mm and 1,100mm above the ground.

A mechanical gripper was designed to extract books from and insert them into shelves. It also was added to the manipulator hand. The hand consists of a gripper having two flat fingers that slide left and right symmetrically. The hand holds a book up to 50mm thick

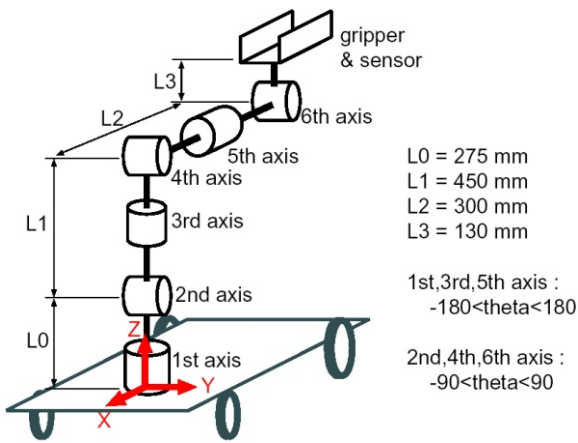


Fig. 12. Structure of manipulator and determined parameters.

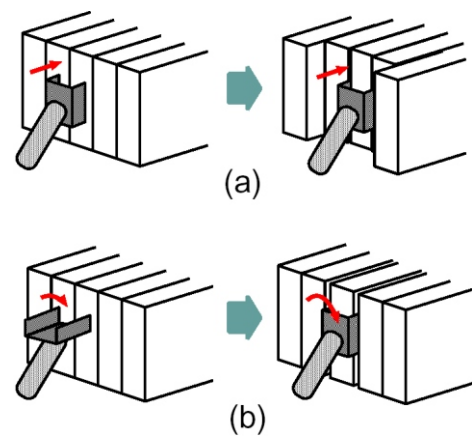


Fig. 13. Method for book grasping. (a) A vertical modality pushes the book into an undesirable situation. (b) Entering an inclined trajectory.

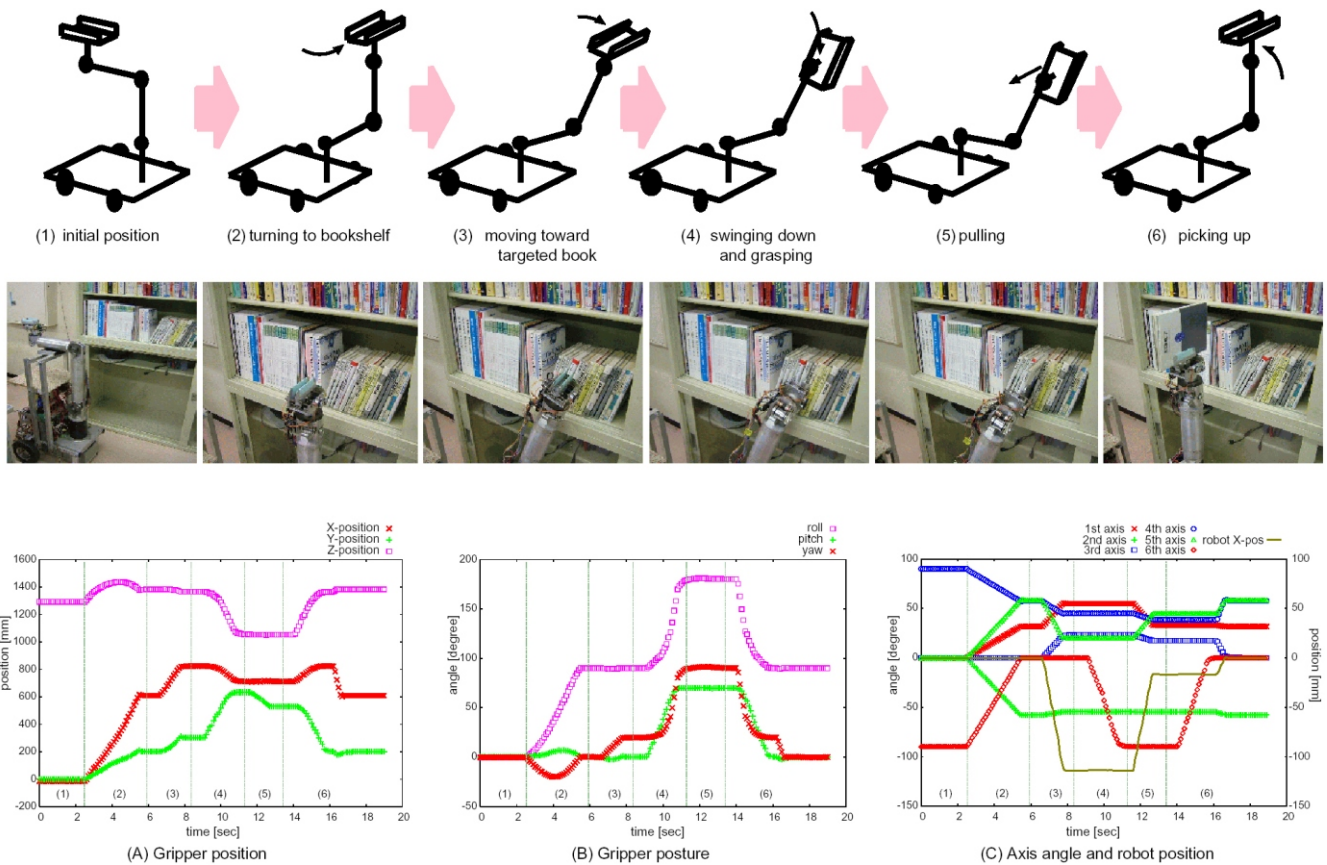


Fig. 14. Scenes of extracting and gripper's trajectory.

and weighing up to 400g. **Fig.12** shows the manipulator and parameters. The robot moves its hand to any location including mobile base movements, and rotating joints 1 to 5 of the manipulator. Joint 6 is used only for inserting books into a shelf.

3.2. Extraction Design

We approached several implementations to evaluate the most suitable performance. The robot hand must be displaced in front of the target book, which is between other books. The hand must then open adequately to

match the book's thickness, i.e., move into the shelf horizontally between books. The target success rate is about 50%, however because the robot hand pushes books on both sides of the target-book and deteriorates control of the desired location (**Fig.13(a)**). Among methods tested to overcome this problem, swinging the gripper down from above (**Fig.13(b)**) had the highest fault tolerance. The sequence for picking up a book is as follows:

1. The robot takes an image of the bookshelf, and looks for the location of each book using the range sensor.
2. The hand is moved to in front of the target book and positioned in the same angle by moving the base and rotating axes 1 to 5.
3. The gripper is opened up to the width of the target-book.
4. The wrist is rotated 90 and the gripper swung down and inserted in both sides of the book using only axis 6.
5. The gripper grasps and picks the book up.

3.3. Experimental Results

The system we have developed was used to pick up books at a specific site at our laboratory. Book extraction and trajectory data for the gripper are shown in **Fig.14**.

Based on results of experiments, we concluded that the gripper could approach a book within 2mm to insert itself smoothly. Since sensor measurement accuracy is 1mm and the actuator operates accurately within a 1mm error range, the designed motion would enable the system to take books from a shelf.

We obtained 80% successes during experiments. In overall performance, the speed of the robot during navigation mode was 30cm/s and the time required to pick up a book about 30s. The main source of failure in experiments was positioning error (in the order of millimeters) due to wavering of the manipulator in book extraction. When the gripper with position error moves toward the targeted book, it mistakenly pushes the book. Then two events can happen either the gripper fails to grab the book or grabs it and drops it. To decrease failure, the robot must check motion again, after bookshelf extraction to confirm that the desired book has been taken. If there exists a failure, then a retry should be automatically executed.

4. Conclusions

We demonstrated the usefulness of a mobile robot in actively in a daily living environment. Book extraction is required to realize remote book browsing by a robot for use in a general library. We proposed recognizing the described pose-feature of a book and integrated it in the robot's inner. Experiments showed the feasibility and applicability of the proposed system. In future work, we will test and evaluate our system in a real library

environment after combining the browsing mechanism into the mobile manipulator.

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Name:
Tetsuo Tomizawa

Affiliation:
Ph.D candidate, Systems and Information
Engineering, University of Tsukuba

Address:

1-1-1 Tennodai, Tsukuba 305-8573, Japan

Brief Biographical History:

2001- Bachelor's degree from University of Tsukuba in College of
Engineering Systems

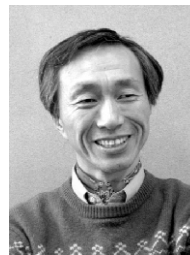
2003- Master's degree from University of Tsukuba in Systems and
Information Engineering

Main Works:

Research of the remote operatable mobile robot for assisting human life
T. Tomizawa, A.Ohya and S.Yuta, "Remote Book Browsing System
using a Mobile Manipulator", Proceedings of 2003 IEEE International
Conference on Robotics and Automation, pp. 256-261, Sep. 2003.

Membership in Learned Societies:

IEEE Robotics and Automation Society
The Robotics Society of Japan (RSJ)



Name:
Shin'ichi Yuta

Affiliation:
Professor, Institute of Engineering Mechanics
and Systems, University of Tsukuba

Address:

1-1-1 Tennodai, Tsukuba 305-8573, Japan

Brief Biographical History:

1975- Ph.D from Keio University in Electrical Engineering

1978- Institute of Information Sciences and Electronics, University of
Tsukuba

1998- Institute of Engineering Mechanics and Systems, University of
Tsukuba

Main Works:

Experimental research in autonomous mobile robot, Intelligent control,
Sensor signal processing, Controller architecture for intelligent machine
M. Tomono and S. Yuta, "Object-Based Localization and Mapping
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DGPS and Odometry Data Fusion", Proceedings of the 2003 IEEE
International Conference on Robotics and Automation, pp. 1978-1984.

Membership in Learned Societies:

The Japan Society of Mechanical Engineers (JSME)
The Robotics Society of Japan (RSJ)
IEEE Robotics and Automation Society
The Japanese Society of Instrumentation and Control Engineers (SICE)



Name:
Akihisa Ohya

Affiliation:
Associate Professor, Institute of Information
Sciences and Electronics, University of
Tsukuba

Address:

1-1-1 Tennodai, Tsukuba 305-8573, Japan

Brief Biographical History:

1992- Ph.D from Keio University in Electrical Engineering

1992- Institute of Information Sciences and Electronics, University of
Tsukuba

Main Works:

"Vision-Based Navigation by a Mobile Robot with Obstacle Avoidance
using Single Camera Vision and Ultrasonic Sensing", IEEE Trans. on
Robotics and Automation, Vol.14, No.6, pp. 969-978, 1998.

Membership in Learned Societies:

The Japan Society of Mechanical Engineers (JSME)
The Robotics Society of Japan (RSJ)
IEEE Robotics and Automation Society
The Japanese Society of Instrumentation and Control Engineers (SICE)
