Paper:

Design and Development of a Small Stereovision Sensor Module for Small Self-Contained Autonomous Robots

Kei Okada*, **Takeshi Morishita***,**, **Marika Hayashi***, **Masayuki Inaba***, **and Hirochika Inoue***

*Graduate School of Information Science and Technology, University of Tokyo
E-mail: k-okada@jsk.t.u-tokyo.ac.jp
**Kanagawa Prefectural Sagamidai Technical High School

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We designed a small stereovision (SSV) sensor module for easily adding visual functions to a small robot and enabling their use.

The SSV sensor module concept includes 1) a vision sensor module containing a camera and a visual processor and 2) connecting to a robot system through general-purpose interface. This design enables the use of visual functions as ordinary sensors such, as touch or ultra-sonic sensors, by simply connecting a general-purpose interface port such as an IO port or serial connector.

We developed a prototype module with small CMOS image sensors for a mobile phone and a 16 bit microprocessor. The 30×40mm prototype is small enough to attach even to palm-top robots. Our module demonstrates image processing including binarization, color extraction and labeling, and template matching. We developed self-contained robots, including a 2DOF head robot, a humanoid robot, and a palm-top robot, and realized vision-based autonomous behavior.

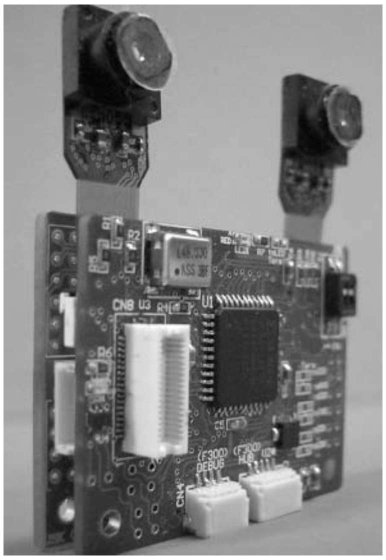


Fig. 1. Small stereovision sensor module.

Keywords: vision system, vision sensor, stereovision, small robot

1. Introduction

Experimental research using small robots enables researchers to realize real-world sensor-based recognition [1, 2].

To the vision sensor, sensor-based behavior is important because it is usable as a general sensor detecting cues such as color, motion, and pattern. Giving visual functions to small robots remains to be standardized.

Previous research has realized this in mainly two ways, using a radio-wave wireless camera [3] or using a regular NTSC or USB camera [4]. Using a radio-wave wireless camera, however, has problems with noise and using an NTSC or USB camera restricts robot behavior due to the camera's cable. It also requires a PC for visual processing, taking away from realizing a self-contained robot.

We developed a small vision sensor module (**Fig.1**) containing both a camera and an image processor, that is connected to robot system through a general-purpose interface such as an IO or a serial port and outputs the results of visual feature extraction such as colored region parameters or the results of template pattern matching. This design helps the module to be connected to a robot system and to use visual processing results easily. This vision sensor module enables self-contained robots with visual function to be developed easily.

We discuss small stereovision (SSV) sensor module design adding and enabling visual functions easily. We also developed a prototype SSV module using a small CMOS image sensor and a 16bit microprocessor. We connected the sensor to self-contained robots including a 2DOF head, ad humanoid robot, and a palm-top robot, and demonstrated autonomous behavior using visual information.

2. SSV Sensor Module

We designed the SSV sensor module (**Fig.2**) to enable users to use visual functions as ordinary sensors such as touch and ultra-sonic sensors simply by connecting a general-purpose interface port.

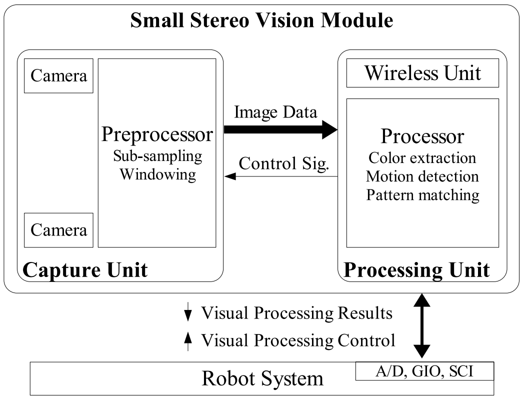


Fig. 2. Design of small stereovision sensor module.

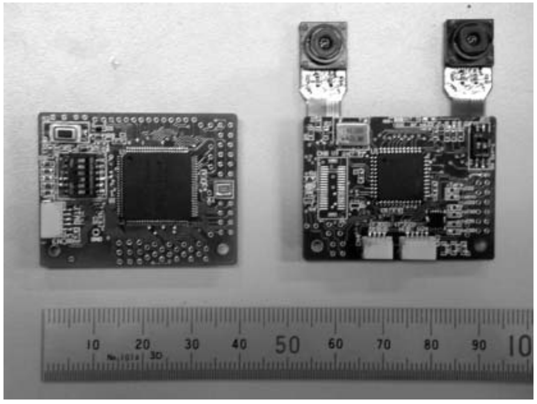


Fig. 3. Prototype of small stereovision sensor module.

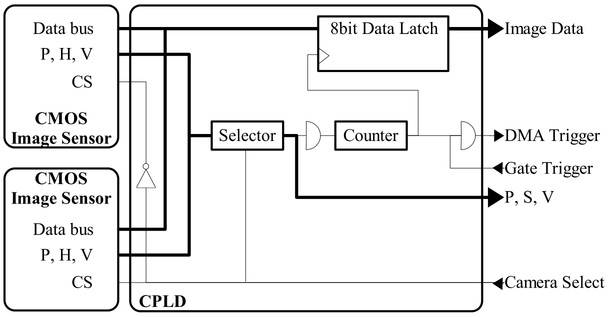


Fig. 4. Block diagram of stereo camera unit.

The module contains both a camera and visual processor, and a general-purpose interface is used for output. This enables connecting the modules as easily as any other sensor to IO or serial ports.

This presents the following advantages:

Easy Installation The module structure and general interface use for output realize a compact robot with visual functions simply by attaching the module to a robot.

Utility The module outputs the result of visual feature extraction, which is usually a dozen bits, though a general interface. The robot is thus uses the module as an ordinary sensors.

Functionality The module's general-purpose visual processor enables it to use image processing algorithms and detects multiple cues. We have implemented binarization, color extraction, and labeling and template matching so far.

In related works, Konolige developed a small, self-contained stereovision module using FPGA [5], that is specialized in depth image generation. Our module is multi-purpose and provides several visual functions. It also enables different robots to be equipped with visual functions, via a general-purpose interface as a module output port. We built several robots using the module, but there is, to our knowledge, no reports of Konolige's small stereovision module being used in small robot application.

3. Development of Prototype SSV Sensor Module

We developed a prototype hardware of the SSV sensor module with small CMOS image sensors for a mobile phone and 16 bit H8 microprocessor for visual processing (**Fig.3**).

The 30 × 40mm module consists of a stereo camera and visual processor. It has a general-purpose IO port, an I2C communication bus, and a serial port for an output interface. It is also connectable to a Bluetooth wireless communication module.

3.1. Stereo Camera Unit

The stereo camera has two CMOS image sensors and a programmable logic device, for controlling the cameras and image preprocessor. The programmable logic device generates image pixel clocks for the CMOS image sensor and subsampling and preserves image data from the cameras (**Fig.4**).

The camera outputs image data, a pixel clock (P), horizontal synchronization signal (H), and a vertical synchronization signal (V). Camera selection (CS) is connected to a controller to capture images separately.

In the prototype module, the programmable logic device generates a 12MHz camera pixel clock, and the camera outputs 144 × 96 pixel images. It also subsamples original images based on processing speed, I/O speed, and memory size of the visual processing module. The prototype module outputs 77 × 96 pixel image by skipping every horizontal synchronization signal.

The CMOS image sensor is a CC-MYTCL33 (Miyota Co., Ltd), designed for mobile phones and able to output VGA (640 × 480) resolution at 30fps. The sensor is 9mm square. **Table 1** shows its specifications.

The programmable logic device for controlling the camera is the CPLD XC9572XL(Xilinx Inc). This CPLD

Table 1. Specification of CMOS image sensor.

Manufacture	Miyota Co., Ltd.
Product Number	CC-MYTCL33
External Size	$9.0 \times 9.0 \times 5.7$mm
Imaging Sensor	CMOS
Aray format	$640H \times 480V$ (VGA)
Pixel format	1/4 inch
Output data format	8bit (YCrCb or RGB)
Maximum frame rate	30fps (27MHz)
Power supply	2.8V
Power consumption	70mW (15fps, 12MHz)
Lens	2 plastic
View angle	H. 68.6, V. 43.9
Focal Length	3.38

Table 2. Specification of programmable logic device.

Manufacture	Xilinx Inc.
Product Number	XC9572XL
External Size	$10.0 \times 10.0 \times 1.2$mm
Maximum Usable gates	1600
Maximum system frequency	178MHz
Pin-to-pin Logic Delays	5ns
Power supply	3.3V

describes 1600 gate logic and is 10 × 10mm size. **Table 2** shows specifications.

3.2. Visual Processor

The visual Processor uses an embedded microprocessor for visual processing to write image data to DRAM using DMA transfer from the stereo camera. The processor applies visual processing algorithms and output to a general IO or serial communication port or I2C bus. The H8/30698 (Renesas Co., Ltd, **Table 3**) is used as a microprocessor for the visual processor.

We have implemented functions for a microprocessor including DMAC control for capturing images, noise reduction, color extraction, binarization, centroid calculation, radius calculation, shape recognition, stereo based distance calculation, pattern matching and attention area tracking.

Computation time for applying color extraction, binarization and centroid calculation is 180ms, which is 6fps. It takes 80ms for image capture and 100ms for visual processing.

3.3. Performance Evaluation

This section evaluates the performance of SSV sensor module prototype hardware.

One of the module's basic functions is colored object location detection. This segments an input image into several regions by color extraction, then calculates the location of a target region in image coordinates (**Fig.5**).

We used the image centroid position of the target region and the position with the greatest width and height in the target region for evaluation. We applied two noise reduction filters for the position with the greatest width and height in the target regions: a 2-neighbor filter similar to a conventional 4-neighbor noise reduction filter but checking only left and right pixel, and an offset filter.

Table 3. Specification of H8 microprocessor.

Manufacture	Renesas Co., Ltd.
Product Number	H8/3069
System frequency	25MHz
Power supply	5V
FLASH/RAM	512KB/16KB
DMA Controller	4ch
Timer	16bit 3ch, 8bit 4ch
SCI	3ch
10bit A/D	8ch

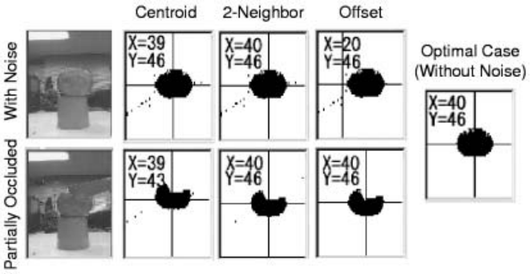


Fig. 5. Comparison of target location detection methods.

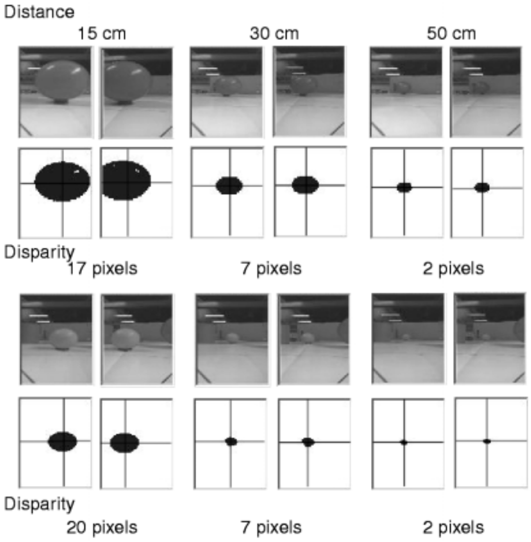


Fig. 6. Stereo disparity calculation using color extraction.

We applied these to a noisy and to occluded images using the 2-neighbor filter method.

Figure 6 shows stereo-based disparity calculation of a colored object. At a 15cm distance with a large colored target, part of the target is hidden due to incorrect location, so disparity differs from the result using a small colored target (**Fig.7**). We used the sum of absolute differ-

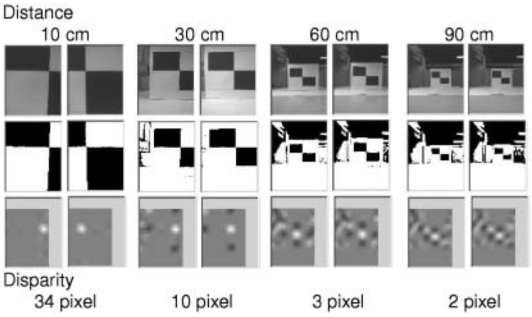


Fig. 7. Stereo disparity calculation using template pattern matching.

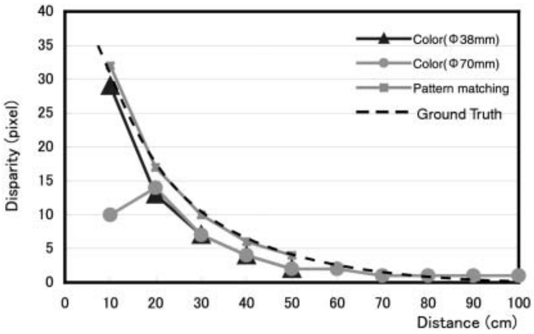


Fig. 8. Comparison of disparity calculation using color and template.

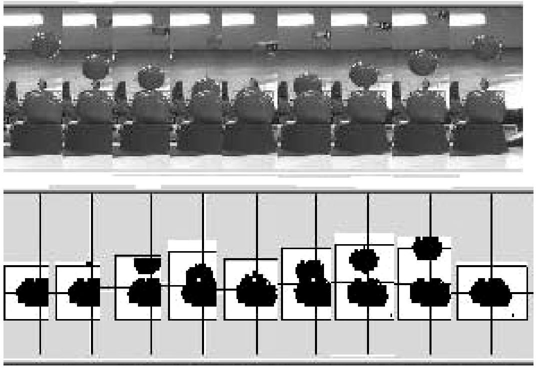


Fig. 9. Target object tracking.

ence (SAD) as pattern matching. **Fig.8** shows a disparity calculation result and true data. Two colored objects and one template pattern are the target. The graph shows that disparity calculation using this stereo module gives good results.

Figure 9 shows tracking results that first detect the target area using color extraction and shift attention based on the previous result. In this experiment, one ball moves from right to left and another from above and bounces. Images at top show the attention area while the robot is tracking the ball and those at bottom show results of colored ball detection.

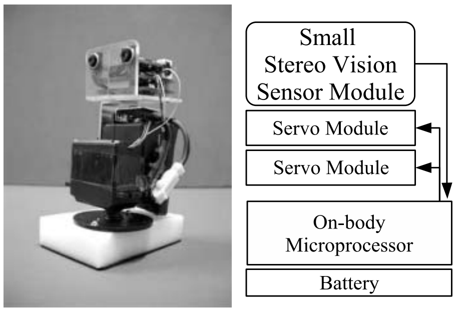


Fig. 10. Self-contained 2DOF head robot with SSV sensor module.

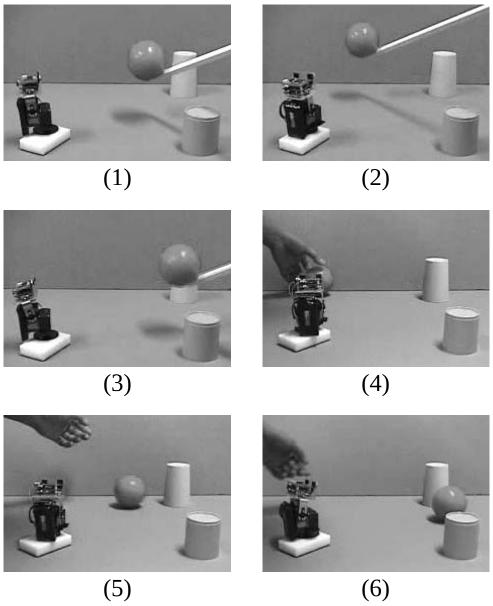


Fig. 11. Colored ball detection and tracking behavior by the 2DOF head robot.

4. Small Self-Contained Robot with SSV Sensor Module

We built several self-contained robots with SSV sensor module prototype hardware including a 2DOF head, a humanoid robot, and a palm-top robot.

This shows that the module design concept, which involves (1) easy connection of visual processing functions to a robot, (2) easy use of visual function results, are realized in prototype hardware.

4.1. 2DOF Head

The 2DOF head (**Fig.10**) has two servo motors corresponding to the head's yaw and pitch angles. It has a built-in microprocessor for controlling joint angles and the SSV sensor module. To control servo motors, the processor generates a PWM signal, receives color object detection results from the module, and controls each joint to track the colored target object (**Fig.11**). The robot tracks a red ball on the tip of the bar in **(1)** to **(3)**. In **(4)** to **(6)**, the robot

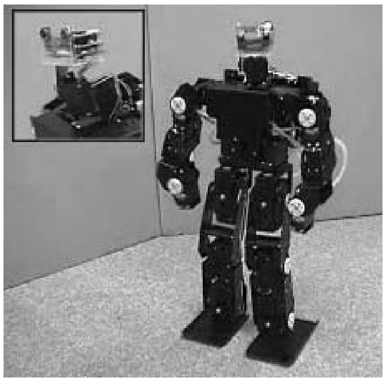
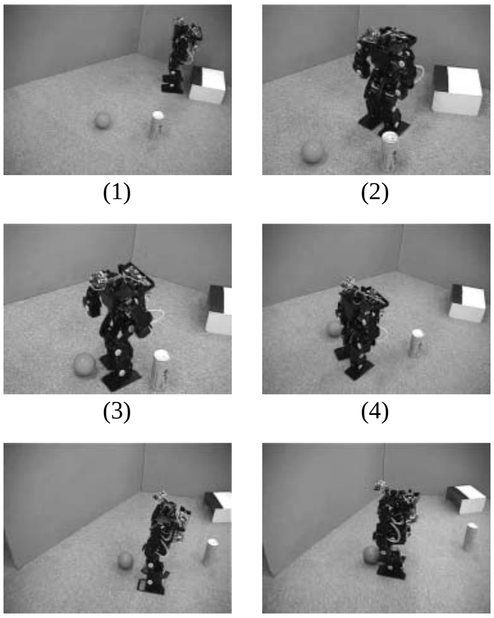


Fig. 12. Small humanoid robot with SSV sensor module.



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

Fig. 13. Vision based ball detection and dribbling behavior of the humanoid robot.

tracks a ball rolled by a person. The embedded robot's battery makes it fully self-contained robot.

4.2. Humanoid Robot

The small humanoid robot using the modules (**Fig.12**) makes from a commercially available kit with 6DOF for each legs, 4DOF for each arm, and 2DOF for the neck. Its microprocessor controls the entire robot. We added the SSV module to the head, and connected to the microprocessor on the back through a serial interface. Note that this robot also uses a built-in battery.

Figure 13 shows soccer dribbling behavior by detecting color using visual processing and changing the direction of walking. Forwarding and turning are preprogrammed and visual information is used for controlling head angles and the direction of walking.

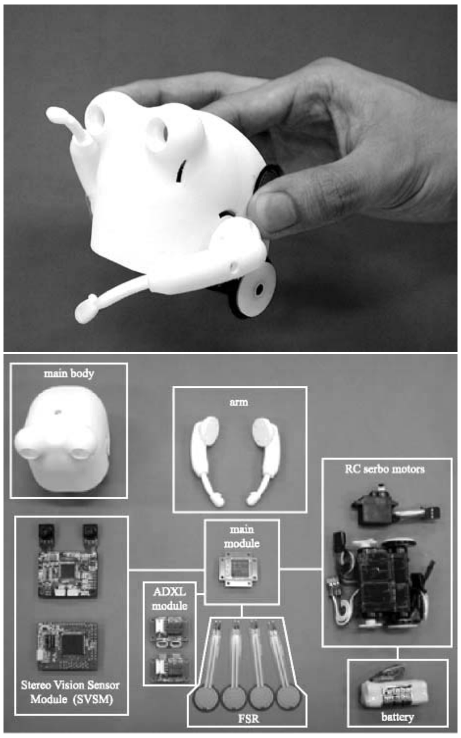
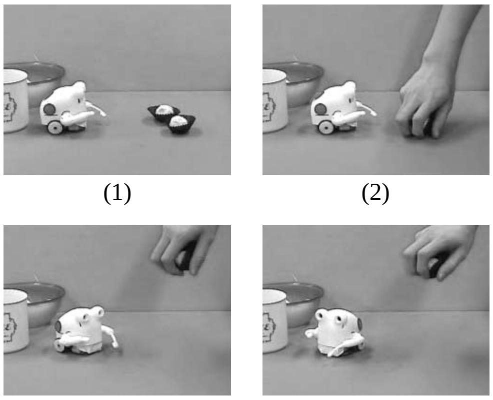


Fig. 14. Small palm-top robot with SSV sensor module.



(1) (2) (3) (4)

Fig. 15. Vision based alarming behavior of the palm-top robot.

4.3. Palm-Top Robot

The palm-top mascot robot (**Fig.14**) has 2 wheels, 2 arms, touch sensors, accelerometer, stereovision sensor, and battery, and a module for Bluetooth communication. **Fig.15** shows vision-based alarming action in which the robot monitors some cakes, detects someone taking on through color-based skin detection and sounds an alarming.

5. Conclusion

We have presented an SSV sensor module enabling a small robot to be added and use visual functions easily.

We designed a vision sensor module containing camera and visual processor and connected to a robot system through a general-purpose interface such as an IO or serial line port.

Users add visual functions to their robots by simply connecting our module to a general-purpose interface as ordinary sensors such as touch sensors.

We developed prototype hardware with small CMOS image sensors for a mobile phone and a 16 bit H8 microprocessor for visual processing.

We also built several self-contained robots with this hardware including a 2DOF head, a humanoid robot, and a palm-top robot.

Projected works includes improving visual processing time using a high frequency pixel clock or more sophisticated CPLD logic. Using memory in the microprocessor would also increase throughput time.

This module has great potential in education because it has compact and inexpensive. Visual information processing has long a history and well known for its utility in research, but it is not so well know to general public. Education using mechatronics is a popular high school course, but a few have applied visual information processing.

We believe that a compact, inexpensive visual processing module such as we have designed is good teaching material for disseminating visual information processing technology more widely among the general public.

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Name:
Kei Okada

Affiliation:
Research Associate, Graduate School of Information Science and Technology, The University of Tokyo

Address:
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

Brief Biographical History:
2002 Doctor of Graduate School of Information Engineering, The University of Tokyo
2002- Research Associate at Professional Programme for Strategic Software, Graduate School of Information Science and Technology, The University of Tokyo

Main Works:
- "Rapid Development System for Humanoid Vision-based Behaviors with Real-Virtual Common Interface," 2002 IEEE/RSJ Intl. Conf. on Intelligent Robots and Systems (IROS'02), pp. 2515-2520, 2002.
- "Integration of Real-time Binocular Stereo Vision and Whole Body Information for Dynamic Walking Navigation of Humanoid Robot," Intl. Conf. on Multisensor Fusion and Integration for Intelligent Systems (MFI'03), pp. 131-136, 2003.

Membership in Learned Societies:
- The Robotics Society of Japan (RSJ)
- Information Processing Society of Japan (IPSJ)

Name:
Takeshi Morishita

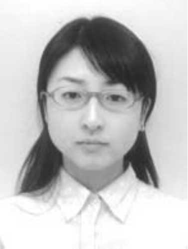
Affiliation:
Kanagawa Prefectural Sagamidai Technical High School

Address:
1-11-1 Sagamidai, Bunkyo, Kanagawa 228-0807, Japan

Brief Biographical History:
1990 Bachelor of Department of Electrical Engineering, Tokai University
1990-1994 Fuji Xerox
1994- Teacher at Kanagawa Prefectural Sagamidai Technical High School

Main Works:
- "Motion Estimation of Object with Modeling Difficulty using Fuzzy Reasoning," Bacheler Thesis, 1990.
- 2000, 2001, 2002 FSI-All Japan Robot-Sumo Tournament, 2nd Prize

Membership in Learned Societies:
- Japan Society for Fuzzy Theory and Intelligent Informatics (SOFT)



Name:
Marika Hayashi

Affiliation:
Master course student, Graduate School of Information Science and Technology, The University of Tokyo

Address:
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

Brief Biographical History:
2004 Bachelor of Engineering, Department of Mechano-Informatics, The University of Tokyo

Main Works:
- "Acquisition of Behavior Modifier based on Geometric Proto-Symbol Manipulation and its Application to Motion Generation," 2004 IEEE/RSJ Intl. Conf. on Intelligent Robots and Systems (IROS'04), pp. 2036-2041, 2004.

Membership in Learned Societies:
- The Robotics Society of Japan (RSJ)

Name:
Hirochika Inoue

Affiliation:
Professor, Department of Mechano-Informatics, School of Information Science and Technology, The University of Tokyo

Address:
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

Brief Biographical History:
1970- Electrotechnical Laboratory (ETL), Ministry of International Trade and Industry (MITI)
1978- Associate Professor at The University of Tokyo
1984- Professor at The University of Tokyo

Main Works:
- Manipulation, Real-time Robot Vision, Vision based Robotics, Robotic System Integration, R&D of Humanoid Platform and its Application to Human Friendly Tasks

Membership in Learned Societies:
- Institute of Electrical and Electronics Engineers (IEEE)
- The Japan Society of Mechanical Engineers (JSME)
- The Robotics Society of Japan (RSJ)
- The Japanese Society of Instrumentation and Control Engineers (SICE)

Name:
Masayuki Inaba

Affiliation:
Professor, Department of Mechano-Informatics, The University of Tokyo

Address:
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

Brief Biographical History:
1986- Doctor of Engineerging, Graduate School of Information Engineering, The University of Tokyo
1986- Lecturer at the University of Tokyo
1989- Associate Professor at the University of Tokyo
2000- Professor at the University of Tokyo

Main Works:
- "A Platform for Robotics Research based on the Remote-Brained Robot Approach," The International Journal of Robotics Research, Vol.19, No.10, pp. 933-954, 2000.

Membership in Learned Societies:
- The Japan Society of Mechanical Engineers (JSME)
- The Robotics Society of Japan (RSJ)
- The Japanese Society of Instrumentation and Control Engineers (SICE)