https://doi.org/10.20965/jrm.2018.p0477



**Paper:**

# Development of Educational Service Robot and Practical Training

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[Received August 30, 2017; accepted March 19, 2018]

**As robot workshops for elementary and junior-high school students are being held across Japan, there is a large variety of teaching-material robots available for them. An increasing number of freshmen at colleges or universities already undertake some basic education on robotics before they enter a college or a university. On the other hand, as research and development of service robots is being promoted as a part of the measures to cope with the declining birthrate and the aging population of Japan, service robots are expected to come into much wider use. Under these circumstances, it is imperative for universities and technical colleges to enrich the contents of their robotics education, especially on service robots. However, there are no robots available as teaching materials. Therefore, we developed an educational service robot and used it to conduct practical trainings with the aim of motivating students to develop robots, as well as enhancing their motivations. This paper reports on the details of this project.**

**Keywords:** service robot, teaching material, leg wheel, arduino

## 1. Introduction

Since FY 2012, the Middle School Curriculum Guidelines have included the "programmed measurements and control" topic in the technology area of the "technology and home economics" subject for junior-high school students to learn. Moreover, robot workshops are being held for elementary and junior-high school students by universities and education-related companies across Japan [1–3, a]. Thus, an increasing number of junior-high school students have already learned robotics and their programs before they graduate from school. On the other hand, research and development of service robots is being promoted under the "New Robot Strategy" [b] as a part of the measures to cope with the declining birthrate and the aging population of Japan. Because of this, service robots are expected to come into much wider use. In fact, with cleaning robots on the shelves of electrical appliance stores and communication robots often found on the street corners, we can realize that robots have spread throughout our daily lives. In the United States, emphasis has been placed on STEM education since 2015 [c], and consequently, for robotics education, iRobot Inc. has sold the cleaning robot Roomba [d] as a teaching-material robot. STEM education movements are so globally spread that robots for STEM education [e] are readily available; however, these are mainly intended for high-school or lower-school students. Under these circumstances, it is imperative for universities and colleges of technology (hereinafter, technical colleges) to enrich robotics education not just in the robotics' department but also in other departments, especially on those related to service robots, which are expected to come into much wider use. As service robots contain the elemental technologies for conventional industrial robots, as well as new elemental technologies such as self-position estimation and environment recognition, it should be essential to provide students with the opportunity to learn such technologies in order to cultivate future engineers. It may be an effective way to incorporate service robots into ordinary experimental and practical training classrooms. Some universities and technical colleges already provide the students in their robotics' department with practical training using commercially available Turtlebots [f]. The Turtlebot, a platform for research and development of autonomous traveling robots, uses the robot operating system (ROS) as the operating system (OS), and may be too difficult for students other than those in the robotics' departments. Some universities reportedly provide rich contents of robotics education to the students of robotics' departments during their four-year tenure [3]; however, this content may be difficult to understand or implement for other departments. Other types of robotics and mechatronics education include: education aimed at cultivating students' creativity on the subject of robot production [4, 5]; education aimed at line tracers and factory automation (FA) systems construction [6]; and more advanced education contents such as environment recognition and middleware for robots as a curriculum for graduates [7, 8]. Although some of the above-mentioned education contents may be related to service robots, they are not mainly intended for service robots. To incorporate service robots into ordinary experimental and practical training classes at universities and technical colleges, therefore, we need teaching mate-

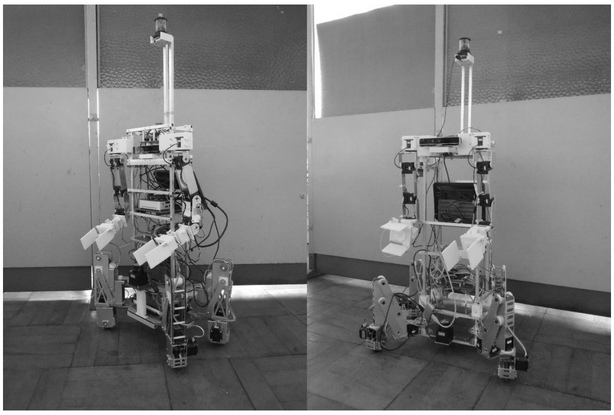


**Fig. 1.** Robot appearance (left: first unit; right: second unit).

**Table 1.** Robot specifications (first unit).

| | |
|---|---|
| Size (W×D×H) [mm] (With omnidirectional camera) | 500×230×780 (H1140) |
| Weight [kg] | 10.5 |
| Degree of freedom | Arm 5×2 Leg 3×4 |
| Movement speed [m/s] | 0.6 |
| Payload of arm [kg] | 0.5 |
| Variable height [mm] | 250 |
| Main controller | Intel NUC 6I3SYK |
| Sub controller | Arduino MEGA 2560 |
| Servo unit (Arm, Leg) | Futaba RS405CB |
| Servo unit (Hand) | Futaba RS304MD |
| Stepping motor | ShinanoKenshi P-PMSM-U42D2LP-P |
| Motor driver | adafruit MotorShield V2.3 |
| Battery (for drive) | AZ ITZ5S-FP |
| Battery (for control) | JIT MPB32000 |
| Monitor | Century LCD-8000VH2B |
| Omnidirectional camera | Viston VS-C14U-33-ST |
| RGB-D camera | Intel Realsense SR300 |
| Laser range scanner | HOKUYO URG-04LX-UG01 |

rials to learn service robots.

As the number of students who have finished basic robotics education before entering a university is growing, as described above, it may be possible to request them to get hands-on experience and practical training of new elemental technologies using teaching-material robots at an early stage, which would then motivate them to develop robots and enhance their motivations. In the above-mentioned context, this paper describes the education service robot that we have developed considering a life-support type service robot, which is the most familiar to us among service robots. This paper also reports the practical training that we have conducted using the developed education service robot.

## 2. Development of Educational Service Robot

### 2.1. Concept

We have developed a robot incorporating easy-to-obtain components and one that is easy-to-produce at the engineering department of a university or a technical college, in order to inspire the students' interest in mechatronics and robotics. The robot has leg wheels [9] capable of climbing stairs or steps. The maximum height of the steps it can climb is 180 mm, and the robot can be adjusted based on the stairs available in the university. The education service robot was designed in a way to aid the training of technical elements such as self-position estimation, environment recognition, and object recognition. Focusing on practical training efficiency, the robot can be separated into the arm and leg parts. We have produced two robot units with basically the same specifications, apart from small improvements to the second robot unit. **Fig. 1** shows the appearances of the developed two robot units; and **Table 1** describes the specifications of the first robot unit as a representative robot.

### 2.2. Robot Control System

We used a micro personal computer of NUC standard (hereinafter, PC) for the main controller and an ArduinoMEGA2560 for the subsystem. Commands from the PC are transmitted to the Arduino via serial communication. Connected to the PC are an omnidirectional camera to estimate the robot's self-position, a laser range sensor to recognize the environment, and an RGB-D camera to detect an object and measure its distance, thus allowing the robot to perform image processing and robot's operation planning. With the Arduino, the servomotors and a stepper motor are controlled based on the commands sent from the PC by the serial communication. RS485 was used for the communication with the servomotors. We created serial level converter circuits from the maker's published home page, and used commercially available Arduino shields for the stepper motor driver. The robot control system of the above-mentioned architecture enabled us to take advantage of the Arduino's PWM function and the AD-converter function, as well as to use various commercially available shields. Arduino alone is capable of operating the robot body, enabling us to practically train the basic robot control with the arms and legs. **Fig. 2** shows the control system configurations.

### 2.3. Robot Arm Part

The robot arm part is five-axially configured to facilitate its inverse kinematics. In order to actuate its shoulders, elbows, and wrists, mainly made of 1.5-mm-thick aluminum plates, a high torque servo motor was used at each joint for the shoulder's pitch axis, yaw axis, the elbow's pitch axis, and the wrist's pitch axis, to ensure an arm's maximum load capacity of approximately 500 g.

A small and affordable servomotor was used for the yaw axis and to facilitate the opening and closing of the hand portion in order to make the arm lightweight and to enable students to easily improve the design. We created

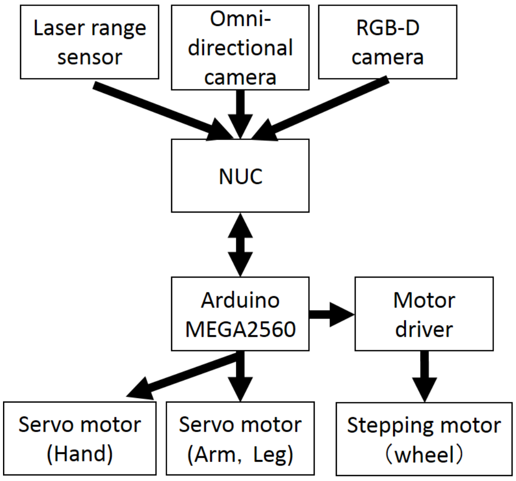
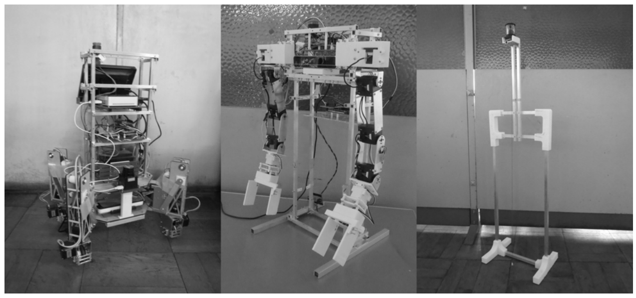



**Fig. 2.** Control system configurations.



(a) Leg part (b) Arm part (c) Omnidirectional camera part

**Fig. 3.** Robot unit.

converter circuits for the latter servomotor's TTL-level serial communications, which are made through separate serial ports which are different from the ones used by the servomotors at the arm part.

### 2.4. Robot Body and Leg Part

The robot's body frame is made of aluminum hollow square bars, aluminum plates, and resin universal plate.

The body has a computer, a small monitor, and a battery mounted inside. Each leg of the robot has a three-axial parallel mechanism per leg. With a servomotor used at each leg joint, similar to the one for the arm, the robot body can be lifted by flexing all four legs. The wheels, driven by the stepper motors, can move in any direction by turning the tires toward the direction it is required to go. They were configured to facilitate the odometer calculations.

## 3. Example of Practical Training with Robot

The developed robot possesses the basic hardware functions for a service robot. It is adaptable to any practical training contents from basic to real-life problems, according to the instructors' ideas. Here, we report the practical training of basic contents provided to the fifth graders in the Mechatronics Course of Osaka Prefecture University College of Technology (hereinafter, our school).

### 3.1. Practical Training Contents

In our school, the second graders receive practical training with a line tracing robot, and the third graders undergo microcomputer training with Arduino, which includes controlling DC motors, stepper motors, and radio-controlled servomotors.

In the basic research curriculum, the fourth graders produce a system with built-in infrared sensors and motors controlled by microcomputers [10]; however, there is no practical training pertaining to full-scale robots such as industrial robots. As for the classroom lecture, the third graders learn programming in C language and the fourth graders learn classical control theory. The fifth graders do not learn robotics as a class subject because it is taught in the first semester of the fifth grade, which coincides with the practical training period with the developed service robot. Under these circumstances, the students have not yet learned robot's arm control, self-position estimation, or image processing, which are the subjects to be dealt with in the practical training with the developed service robot. The extent of their knowledge at this point is merely programming in C language and motor control with the Arduino microcomputer. In the practical training with the developed service robot therefore, we first impart a lecture regarding the outlines of the robot arm's kinematics, self-position estimation, and image processing, as basic contents. Because the OS used for all practical training is Microsoft Windows and no other OS would be used, we also use Windows as the OS for the practical training with the developed service robot. As there is no artificial intelligence (AI) curriculum in the Mechatronics Course, we have omitted AI training as well. We have aimed to develop very simple programs by using VC++ of VisualStudio2013 for PC and Arduino IDE for Arduino in the program development environment. And we used openCV for image processing.

In the practical training, wherein a maximum of eighteen students can practice with two robot units, a robot is divided into three parts as shown in **Fig. 3**: the leg part (including body), the arm part, and the omnidirectional camera part. The students are divided into six groups of 2 to 3 individuals. Two groups can participate in the practical training at the same time. With the practical training given in the fifth to eighth period, with each class hour being of 45 min, one practical training session lasts 180 min and these are conducted three times. **Table 2** lists the training items and points.

In the first half of the first day of the practical training, the training curriculum is introduced to all the participants as a lecture. From the second half of the first day up to the second day, each group alternately practices three training items. On the third day of the practical training, each

**Table 2.** Training items and points.

| | Training Items | Training Points |
|---|---|---|
| Training 1 (90 min) | Control of RGB-D Sensor and Arm | Basics of RGB-D Sensor<br>Control of Arm's Kinematics<br>Coordination of Sensor and Arm |
| Training 2 (90 min) | Omnidirectional Camera and Self-Position Estimation | Basics of Omnidirectional Camera<br>Recognition of Markers by Colors<br>Self-Position Estimation Method |
| Training 3 (90 min) | Laser Range Sensor and Leg Control | Basics of Laser Range Sensor<br>Control and Movements of Leg Wheels<br>Coordination of Sensor and Leg Part |
| Training 4 (180 min) | Transfer of Object | Integration of Training 1 to 3<br>Robot's Attitudes and Movements<br>Motion Planning on Sensor Data |

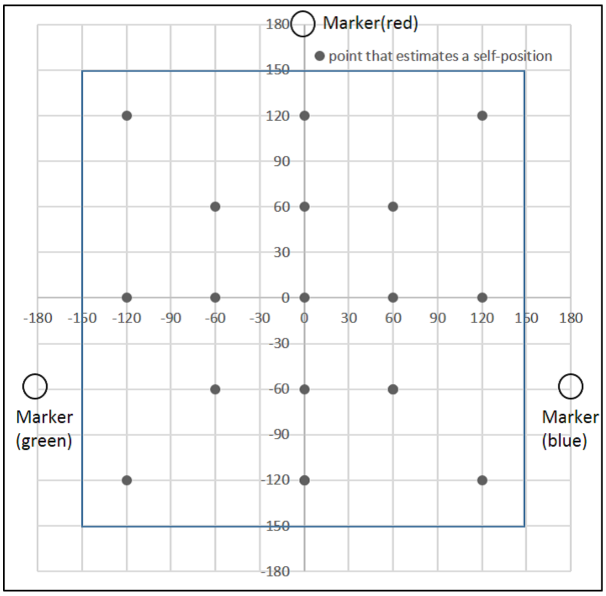



**Fig. 4.** Field.

group practices transferring an object as part of the Training 4 module, by integrating the arm part and the leg part. The robot is operated on the field of a $3 \times 3$ m flat floor surface with self-position estimation markers arranged as in **Fig. 4**: the markers are made of red, green, and blue drawing paper and are cylindrically shaped, 79 cm high and 30 cm in diameter.

### 3.1.1. RGB-D Sensor and Arm Control

In the RGB-D sensor and arm control training, we wrapped a vinyl chloride pipe of 48 mm in diameter with purple colored paper, which represents a cup as an assumed object. The object is to be detected by its color the same way as for the markers, which, though not so practical, is easy to understand for the students that engage themselves in the training for the first time and can adjust the parameters by the hue-saturation-value (HSV) values only; this also ensures that extensive time is not consumed during the training. The object's position is captured by the depth meter installed in the RGB-D sensor. Based on the depth of the object, its three-dimensional coordinates from the camera origin are calculated and converted to arm coordinates in order to command the robot to grasp the object. In the training, in consideration of the students' curriculum contents and training hours, the camera and the arm are installed in such a way that their respective coordinates should align in parallel with each other so that the students can easily translate the coordinates. In the above-mentioned arrangement of the camera and the arm, the positional relations between the object and the robot are limited; however, in the future, we plan to provide the camera with panning and tilting functions.

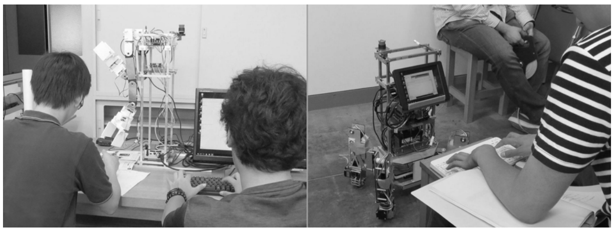
Arm control is performed by transmitting commands from the PC to the Arduino through serial communication. The commands are the transmission of the target coordinates to the arm and the instruction to resolve the arm's inverse kinematics by the Arduino's program for the respective joints' operating angles. We preprogrammed the arm's inverse kinematics for use in the training owing to time constraints. The arm is operated by the most basic way of moving the joints one by one, and it does not make any linear interpolations. We have intentionally simplified the program so that even students who are not familiar with programming can understand the contents. We plan to improve the program into one for linear interpolations and additional tasks as a future practical issue.

### 3.1.2. Omnidirectional Camera and Self-Position Estimation

The basic self-position estimation method that we used for the training is by means of angles [11]. Specifically, the robot's self-position is estimated by recognizing the markers by their colors with the omnidirectional camera and by detecting the angles resulting from the markers arranged in the three directions. The robot's self-position is estimated at each point marked black in **Fig. 4**, and its accuracy is verified by comparing the estimated values and the actual coordinates. As it is already known that the above-mentioned self-position estimation method produces the most accurate self-position estimation when the markers are positioned at equal angles of 120° to each other, the students can learn that the said self-position estimation method characteristically can estimate the robot's self-position more accurately in the center of the field than around the field. The robot also needs to be aware of its self-position estimation method's accuracy when it moves towards a target position.

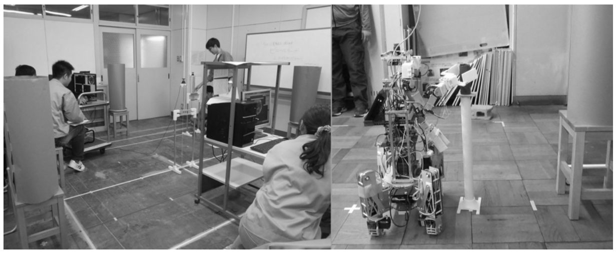
### 3.1.3. Laser Range Sensor and Control of Legs

In the laser range sensor and leg control trainings, in order to learn the movements of the leg wheels, the students practice the commands for moving the robot forward, backward, left and right, and rotating on a given spot. As the commands are pre-programmed in the Arduino the same way as for the arm control, the robot can make such movements based on the commands transmitted from the PC to the Arduino. Next, the students check the robot's surrounding environment by using the laser



(a) Arm part (b) Leg part

**Fig. 5.** Trainings 1 and 2.



(a) Omnidirectional camera (b) Transfer of object

**Fig. 6.** Trainings 3 and 4.

range sensor. In the trainings, the students simply determine from the sensor data whether there is any obstacle or not in the specified range ahead of the robot and stop the robot from moving when there is any obstacle. As the program for drawing sensor data by the openCV graphic function is readily available, the students can view whether, where, and if there are any obstacles, walls, or other objects. Thus, they can obtain data about the obstacle's width and other properties by viewing the graphic screen and analyzing the output data.

### 3.1.4. Transfer of Object

In practical Training 4, integrating practical Training 1 to 3, the students are assigned the task to move the robot in the $x$- and $y$-axial directions and to any arbitrary attitudes and angles to the target position from any arbitrary positions. This task starts with the robot in a 0° attitude and arranged at 0° at an arbitrary position on the field. In addition, students are presented with a sample program for moving the robot to the target position in the $y$-axial direction only. When the robot is successfully moved to the target position, their next task is to get the robot to grasp the object. The groups of students who have surplus time could attempt to tackle the task of moving the robot to avoid any obstacles arranged and to grasp an object.

## 3.2. Training Practice

**Figure 5(a)** shows the students practicing the training with the robot's arm part. No group of students had any problems with the procedures to transmit commands from the PC to the Arduino owing to their simplicity. However, for the majority of groups, the inverse kinematics calculations generally required a significantly larger time than expected, and thus, it was given as a take-home assignment to the students.

**Figure 5(b)** shows the students practicing the training with the robot's leg part. As the leg part is fixed in the attitude in the interests of practicing hours, the students can move the robot with the leg wheels simply by directing the tires to any desired directions; the students appeared to quickly understand the commands for moving the robot.

In the training to detect an obstacle with the laser range sensor, which was a novelty for many of the students, the students look at the graphic screen displaying the sensor-acquired data or the obstacle and the wall that change almost in real time as the robot moves. In the training to move the robot avoiding the obstacle, some groups of students who were skilled at programming tackled the task without trouble; however, other groups had extensive trouble moving the robot to avoid the obstacles as they intended.

**Figure 6(a)** shows the students practicing the self-position estimation with the omnidirectional camera. With the camera installed at the specified points on the field in **Fig. 4**, the students compared the self-position estimation results at the respective points. As the HSV values need to be set by a program upon detecting the markers, we preprogrammed the display to show the HSV values at the respective points by clicking on the screen displaying the images captured by the omnidirectional camera, so that we could confirm the HSV values of each marker.

**Figure 6(b)** shows the students practicing the roundup trainings to get the robot to transfer an object. Three groups of students alternately operate one robot unit.

No group of students had any problem with the simple task of moving the robot in the $x$- and $y$-axial directions. In the task of turning the robot of an arbitrary attitude into the desired one, however, some groups of students successfully turned the robot toward the direction closer to the object and other groups nearly rotated the robot vainly in only one direction in a full circle. The roundup training required a long time for all the groups, but they all finally attained the task of moving the robot in an arbitrary attitude from an arbitrary position to the target attitude and position. This concludes the regular class hours. Because we told the students that they could continue the training if they wished, more than half of the total groups stayed on to continue the training and nearly half of the total groups successfully operated the robot to grasp the object.

The groups of students that are not proficient at programming could not successfully operated the robot for the following reasons: they could not properly connect or switch the robot's plural motions; or although properly programmed, the conditions for switching the robot's motions were so strict that they simply get the robot to repeat the same motions. To overcome such difficulties, the students need to better grasp the robot's characteristics and reflect them into the program, which would require more time and experience.

**Table 3.** Questionnaire survey findings.

| Questions | | | (a) Quite successful | (b) Fairly successful | (c) Partly unsuccessful | (d) Totally unsuccessful | Unanswered |
|---|---|---|---|---|---|---|---|
| Regarding Training 1 | 1 | Have you come to understand the basics of RGB-D sensors? | 7 (21%) | 20 (61%) | 6 (18%) | 0 (0%) | |
| | 2 | Have you come to understand the arm's kinematics? | 2 (21%) | 17 (52%) | 12 (36%) | 2 (6%) | |
| | 3 | Have you come to understand the coordination between RGB-D sensors and arms? | 6 (18%) | 18 (55%) | 9 (27%) | 0 (0%) | |
| Regarding Training 2 | 1 | Have you come to understand the basics of omnidirectional cameras? | 10 (30%) | 17 (52%) | 6 (18%) | 0 (0%) | |
| | 2 | Have you come to understand the basics of self-position estimation? | 12 (36%) | 18 (55%) | 3 (9%) | 0 (0%) | |
| Regarding Training 3 | 1 | Have you come to understand the basics of laser range sensors? | 10 (30%) | 19 (58%) | 4 (12%) | 0 (0%) | |
| | 2 | Have you come to understand how to move the robot's leg part? | 10 (30%) | 20 (61%) | 3 (9%) | 0 (0%) | |
| | 3 | Have you come to understand the coordination between laser range sensor and the robot's motions? | 8 (24%) | 20 (61%) | 5 (15%) | 0 (0%) | |
| Regarding Training 4 | 1 | Have you come to understand self-position estimation and how to move the robot toward a target position? | 8 (24%) | 19 (58%) | 6 (18%) | 0 (0%) | |
| | 2 | Have you successfully detected an obstacle with the laser range sensor and operated the robot to avoid it? | 3 (9%) | 14 (42%) | 10 (30%) | 5 (15%) | 1 |
| | 3 | Have you successfully operated the robot to grasp an object after moving it? | 3 (9%) | 12 (36%) | 9 (27%) | 4 (12%) | 5 |
| General | 1 | Have you come to understand that self-position estimation is essential for a service robot? | 20 (61%) | 13 (39%) | 0 (0%) | 0 (0%) | |
| | 2 | Have you come to understand that environment recognition is essential for a service robot? | 20 (61%) | 12 (36%) | 1 (3%) | 0 (0%) | |
| | 3 | Have you come to understand that object recognition is essential for a service robot? | 18 (55%) | 14 (42%) | 1 (3%) | 0 (0%) | |
| | 4 | Have you come to get interested in service robots? | 16 (48%) | 8 (24%) | 8 (24%) | 1 (3%) | |
| | 5 | Are you interested in developing such a robot if there is an opportunity to do so in the future? | 9 (27%) | 9 (27%) | 12 (36%) | 3 (9%) | |

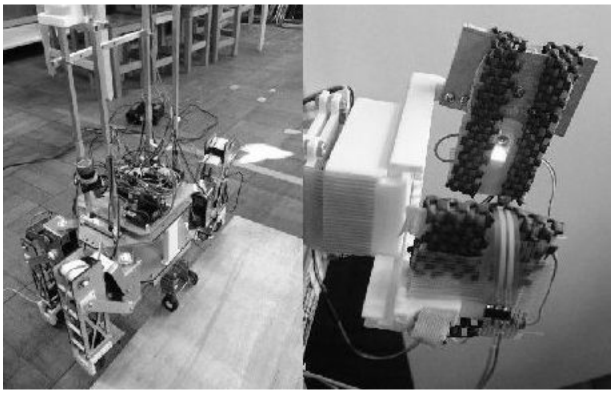
### 3.3. Questionnaire Survey on Practical Trainings

After the completion of practical training, we conducted a questionnaire survey with individual student participants, in which the students were asked to choose one option from among the following four choices: (a) very successful; (b) fairly successful; (c) partly unsuccessful; (d) totally unsuccessful.

**Table 3** summarizes the questionnaire survey findings by the number of respondents and their ratio (%) to the total of 33 students who have participated in the trainings. We can see from **Table 3** that approximately 80% of the students well understood the basics of respective sensors; nearly 50% of the students had some or great difficulties with such practical contents as avoiding an obstacle and grasping an object after moving the robot; a similar ratio of the students responded the same way as to the arm's kinematics. This may be attributed to the rather short length of time available to explain and teach the kinematics to them. Although geometrical solutions of inverse kinematics require no extensive mathematical knowledge, considering that the students are not so familiar with representing the arm's structure by mathematical formulae, they may need slightly more time to learn and practice the subject. As for the training of avoiding an obstacle, students who are not so familiar with programming may find it difficult to combine plural motions as well. The questionnaire survey findings show that we require more time for the training of these subjects, and that we must provide sample programs for a combination of plural motions.

The questionnaire survey findings also show that the students fully understand that self-position estimation, environment recognition, and object recognition are essential technologies for a service robot. 70% of the students responded that their interest in service robots was enhanced, and more than 50% of the students positively responded that they wished to develop a service robot.

Thus, we believe that the practical training proved effective for motivating the students to develop a robot and to enhance such motivations. We were impressed by the



(a) Climbing steps (b) Improvement of the hand

**Fig. 7.** Examples of practical issues.

students' remarks at the end of the practical trainings wherein they stated that they wish they had undertaken such training earlier.

### 3.4. Practical Issues

Apart from the above-mentioned training, we have addressed practical issues as a part of the FY 2016 special study at the advanced course of our school and the fifth-graders' graduate study. In the special study, we attempted to get the robot to climb and descend steps with its leg wheels. At first, we attempted to get the robot to climb and descend steps with its four leg wheels only, although we now have experimentally confirmed its possibility, to find, not surprisingly, that it requires complex leg motions as well as a considerably long time. Therefore, we decided to add auxiliary wheels as shown in **Fig. 7(a)** to find that the leg motions became simpler and faster. In the graduate study, we added a pressure sensor and the mouse's optical sensor to the hand portion of the arm part as shown in **Fig. 7(b)** to develop the function to automatically adjust the hand's gripping force to ensure that no object could slip off the hand. The teaching-material service robot that we developed has a simple aluminum-framed structure as described above so that it can be adapted to numerous improvements including hardware improvements.

## 4. Conclusion

We developed a teaching-material service robot, as service robots are expected to come into increasingly wider use in the future. Because we used readily available components as much as possible, the robot was designed to be produced at low cost. Among the sensors used, the omnidirectional camera is already out of production and is getting increasingly difficult to procure; however, some newly manufactured omnidirectional camera models are available, and we have experimentally confirmed that a robot can estimate its self-position with our handmade omnidirectional camera [12].

Using our developed robot, we have imparted practical training of self-position estimation, environment recognition, and object recognition to our students, as elemental technologies for a service robot. The practical training and post-training questionnaire survey findings prove the effectiveness of our developed robot as a teaching-material service robot. Providing such training to students at an early stage seems effective for motivating them to develop robots, as well as for enhancing their motivations. Our developed robot is equipped with a moving mechanism, arms, and sensors and is far from being a completed model. We have rather aimed at developing as simple a robot as possible so that instructors can freely use it as a teaching-material according to the training levels. We have confirmed our developed robot's flexibility by practicing training pertaining to basic issues to real-life problems.

In the future, we plan to adapt the system to ROS in order to conduct experiments and practical training on SLAM and other platforms.

**Acknowledgements**

This study was supported by the JSPS Grants-in-aid for Scientific Research 15K00947.

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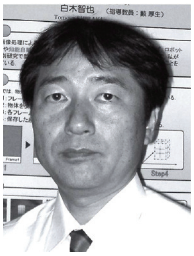

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