Evaluation of Teaching Assistant Robot for Programming Classes

Kazuyoshi Yoshino and Shanjun Zhang

***Abstract*—This paper describes a robot for supporting teachers who are teaching computer programming classes. In its latest series of "Courses of Study", the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan strongly recommends the use of active learning systems and the introduction of computer programming education courses in elementary schools. Programming instruction typically includes explanations of the basic syntax used in programming languages, the application of that syntax, and related exercises. However, the teachers in programming classes commonly spend much more time correcting errors, that is, debugging their students' programs, than they spend teaching. These delays can affect the progress of programming lessons and the motivation of the participating students. With these points in mind, we have developed a teaching assistant robot that is designed to support efficient classroom management of programming classes by advising and assisting students who are encountering problems. Herein, we describe the tasks performed by the teaching assistant robot in a classroom environment in which actual programming lessons are assumed to be taught. In particular, we explain the problems encountered by students in the process of learning basic programming techniques, the causes of the problems, the method by which the teaching assistant robot identifies those problems, and the contents of advice provided by the teaching assistant robot corresponding to those problems. We also show the effectiveness of the teaching assistant robot by conducting evaluation experiments.**

***Index Terms*—Teaching assistant robot, supporting teachers, programming class, image processing, pepper robot.**

I. Introduction

The Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan, in its latest "Courses of Study" series, strongly recommends the use of active learning systems and the introduction of computer programming education courses in elementary schools. However, Japanese elementary schools face a growing shortage of teachers who can instruct such classes. As part of efforts to solve this problem, content development and teaching methods related to active learning; programming education; and science, technology, engineering, and math (STEM) education have been actively studied. In particular, there are numerous reports indicating that STEM education using robots as teaching aids can improve the motivation of the children and provide them heightened learning effects [1]-[6].

As part of our overall goal of solving the problem of students turning away from science subjects and furnishing them with basic engineering knowledge, we have been providing university classes, STEM education classes at elementary schools utilizing robots, and programming workshops using a vehicle robot [7]. We contend that the same educational effects that can be achieved by a trained teacher can also be obtained by practicing lessons that are developed by various researchers. However, to facilitate class progress, we think that, in addition to teaching ability, teachers need a heightened ability to respond to students having difficulty during lessons.

In our real-life experiences in programming classes and workshops, we have found that much more time is spent correcting errors, that is, debugging student programs, than is spent teaching. In addition, these errors vary by student, and we often encounter errors that we did not expect. Therefore, it was necessary to find a way to help these students that does not interrupt the class. As one example, Kim et al. said that it is important for teachers who lead programming classes to acquire the ability to debug programs created by students [8]. In that study, they summarized six common problems that children frequently encounter during programming classes by investigating the teachers' debugging processes.

One of the solutions is to have a robot support the teacher during such classes. Utilizing a robot creates an environment in which students can ask questions positively, without fear of being embarrassed. In previous research, robots have already been used to support children's learning in addition to teachers. For example, Han et al. used a robot to assist children in their English language studies and suggested that such robots are often more effective for facilitating children's learning than non-computer based media such as books with audio and Web-Based Instruction in [9]. In [10], Suzuki and Hanoh used a robot to support an expression-based education program for children. In this study, it is interesting to note that their robot provides students with hints that guide them to solutions instead of providing direct resolutions to the tasks provided.

We think that while it is important for children to learn in the classroom, it is also necessary for human teachers to teach children because children learn human characteristics, such as emotions, by interactive learning with other people. Therefore, in our proposed concept, a human teacher provides class instruction while a robot is available to help students having problems in the same class. With that point in mind, we have developed a teaching assistant robot that is capable of providing help and advice to students in trouble, thereby supporting efficient management of programming classes [11].

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This paper describes the tasks performed by the teaching assistant robot in an environment in which actual programming lessons are assumed to be taught. In particular, we explain the problems encountered by students in the process of learning basic programming techniques and the causes of the problems, the methods by which the teaching assistant robot evaluates the problems, and the contents of advice provided by the teaching assistant robot corresponding to those problems. We also show the effectiveness of our teaching assistant robot by conducting evaluation experiments.

II. System Configuration

Our system consists of a robot, a computer, and a communications network device. This study used a robot named Pepper, which is produced by Softbank Corporation as a teaching assistant robot. Pepper has a touch screen display mounted on his chest, and a head that is equipped with a red-green-clue (RGB) color camera, a microphone, and speaker. Computer-processed video and voice data are transmitted from Pepper via a network communication device that connects the robot to the processing computer. Pepper's behavior was programmed using the Choregraphe and Python programming languages. Vision processing was programmed using Microsoft Visual C++ 2015 and the OpenCV 3.0 image processing library.

In some programming classes, students learn programming algorithms using a vehicle robot as a teaching aid. Our research uses the LEGO MINDSTORMS EV3 produced by LEGO Education as the teaching material robot because even elementary school students can easily assemble and program a robot using that product. Programs for EV3 can be made using EV3 Software on a personal computer (PC) or tablet computer, such as an iPad. Since the LEGO MINDSTORMS EV3 Software is a block-based programming application, even elementary school students can create programs intuitively.

Our concept aims for the realization of a teaching assistant robot based on the assumption that students can learn programming by creating instructions for a vehicle robot that they have assembled using LEGO MINDSTORMS EV3. Fig. 1 shows a classroom using Pepper as a teaching assistant robot and a travel course for an EV3 robot, while Figs. 2 and 3 show an example of a traveling robot made by a student using LEGO MINDSTORMS EV3 and an example program for the EV3 robot, respectively. In this example program, the robot moves forward and then moves backward by one revolution of two motors when it touches a wall.

Fig. 1. The Pepper teaching assistant robot in a classroom situation.

Fig. 2. Vehicle robot example.

Fig. 3. Example program for EV3 vehicle robot.

III. Course Flow and Tasks of Teaching Assistant Robot

In this study, the programming education is provided by a teacher and teaching assistant robot during four classes: 1) introduction to programming concepts, 2) assembly of an EV3 vehicle robot by students, 3) basic programming of the vehicle robot, and 4) challenge task to evaluate student understanding of the programming lessons. The total course time is 180 minutes, which is equivalent to four general elementary school classes in Japan. As stated above, we developed and evaluated a teaching assistant robot that can be applied to such programming classes. The following subsections describe the detailed contents of each class and the methods by which the teaching assistant robot interacts with students and supports the teacher in each class.

A. *Introduction to Programming*

In the introduction to programming class, as part of efforts to encourage student interest in robot programming, the teacher gives an explanation of robot mechanisms and reviews a variety of robots that actually perform activities in the modern world. Also in this introduction class, the teaching assistant robot is present to encourage student interest in robots and programming. Since Pepper is a robot, it is given the chore of explaining the roles of robots and their mechanisms, demonstrating them with gestures, and then supplementing those explanations with videos and computer graphics using the display screen on its chest. Listening to the conversation between the robot and the teacher is also a good way to stimulate student interest in the lesson. In the future, we will develop new ways in which Pepper can interact with students and answer their questions.

B. *Vehicle Robot Assembly*

In the vehicle robot assembly class, students use the LEGO MINDSTORMS EV3 kit to assemble a vehicle robot using an assembly procedure written by the authors. The vehicle robot is shown in Fig. 2. Even elementary school students can assemble the vehicle robot in about 20 minutes.

In the assembly class, the teaching assistant robot provides advice to clarify instructions in the assembly procedure manual and checks the vehicle robot assembled by the students. In the task where the robot clarifies explanations to students, we assume that the students having difficulty will call on the teaching assistant robot by raising their hand. In the task of checking the completed vehicle robot, the teaching assistant robot confirms the structure and wire connections of the vehicle robot assembled by the students.

C. Detection of Students Having Difficulty

In this paper, we assume that the teaching assistant robot identifies students having difficulty in the classroom when they signal the robot by raising their hand. In operation, the teaching assistant robot scans the classroom during the class, identifies such students, and then travels to their location.

Students who raise their hands are detected by processing images obtained from the RGB camera mounted in the head of the teaching assistant robot. Our system first converts the RGB image obtained by the camera to a hue, saturation, and value image in order to make skin colors easier to find. Then, the teaching assistant robot detects skin-colored pixels from the converted image. The detected skin pixels include the face of the students having trouble, the hands of the students that are raised, and the faces and hands of the other students.

To identify them, the teaching assistant robot first detects the faces of the students that are looking at it using the Haar-like feature detection method [12]. To facilitate this, we used the frontal classifier file face from the OpenCV library. Figs. 4 and 5 show an input image and a detected student's frontal face, respectively, based on the input images. The position of the detected face is marked with a blue square.

Fig. 4. Input image in a classroom during class.

Fig. 5. Result of a detected student's frontal face.

Since the raised hand of a student can be expected to be above his or her face, students with raised hands are detected based on the position of their hand in relation to their detected frontal face. Accordingly, the teaching assistant robot detects skin-colored pixels in a local region above the position of the detected student's face as his or her raised hand. The position of the detected hand is extracted by removing noise and computing the center of gravity of the detected skin-colored pixels. Fig. 6 shows a position result of a raised student's hand extracted from the image shown in Fig. 4. The hand position is drawn with a blue circle. The teaching assistant robot can first identify the student who raised his or her hand, and then speak the student's name while moving to his or her position.

Fig. 6. Result of a detected student's raised hand.

D. Confirmation of Vehicle Robot Wire Connections

The wire connections of the vehicle robot assembled by the students are confirmed using a hardware page in the EV3 software displayed on a tablet. The hardware page in the EV3 software shows the proper wire connections of the motors and sensors with the EV3 intelligent block, as shown in Fig. 7. After the student calls the teaching assistant robot, he or she shows the teaching assistant robot a hardware page on the tablet. The teaching assistant robot then captures an image of the tablet that shows the hardware page.

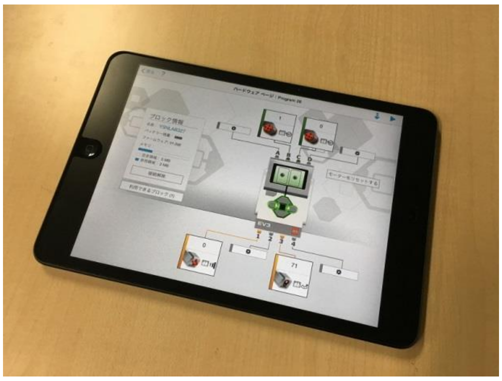
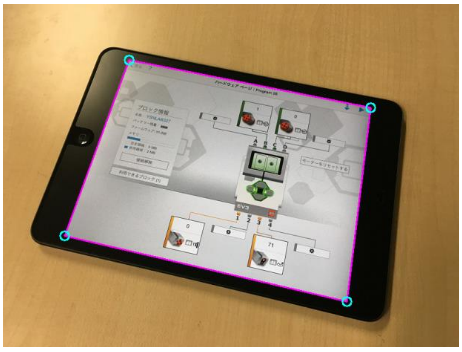
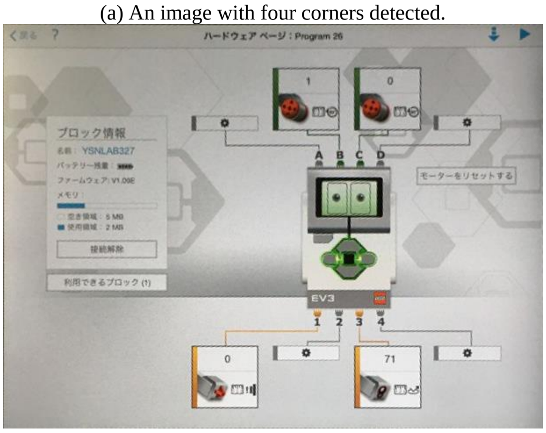


Fig. 7. A hardware page in the EV3 software.

However, since the orientation of the student's tablet is not fixed, the teaching assistant robot must first detect the four corners of the tablet display from the captured image, and then obtain a fixed view of the hardware page image, which it then manipulates to an overhead view by performing perspective transform from the four corner coordinates. Figs. 8(a) and 8(b) show the detected four corners of a captured image and the hardware page image as viewed from directly above it.



(a) An image with four corners detected.

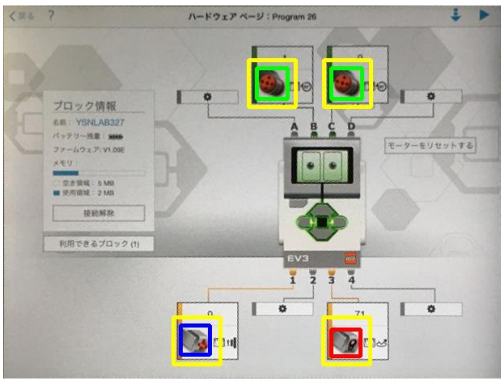


(b) The perspective-transformed hardware image.

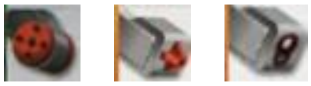
Fig. 8. Corner detection and perspective-transformed hardware image.

The vehicle robot wire connections are confirmed by detecting the position of motors and sensors using the template matching method, and then comparing the detected position of sensors and motors with their correct positions. Using the input image shown in Fig. 8, Fig. 9(a) shows the detection of two motors with a green square, a touch sensor with a blue square, and a color sensor with a red square using the template images shown in Fig. 8(b). The yellow colored rectangles in Fig. 9(a) show the correct positions of the motors and sensors.

If any wire connections are incorrect, the teaching assistant robot informs the student which connections are wrong. There are two possible wire connection mistakes. One is when the cable is not connected to an EV3 intelligent block, as shown in Fig. 10(a), the other is when the cable is connected to an incorrect port, as shown in Fig. 10(b). For both cases of (a) and (b), the teaching assistant robot respectively advises the student, "The cable connection is incorrect. Please connect the cable of the touch sensor to Port 1," or "The cable connection is incorrect. Please reconnect the cable of the color sensor from Port 4 to Port 3".

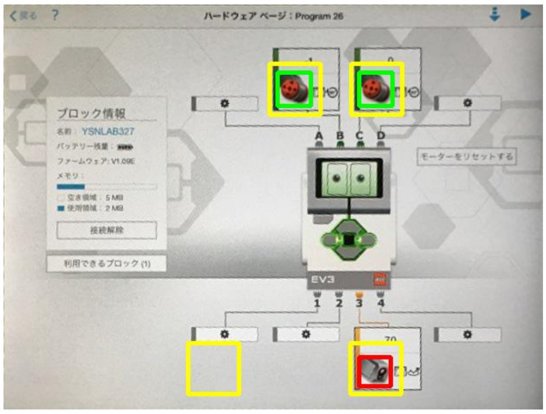


(a) Image of detected motors and sensors.

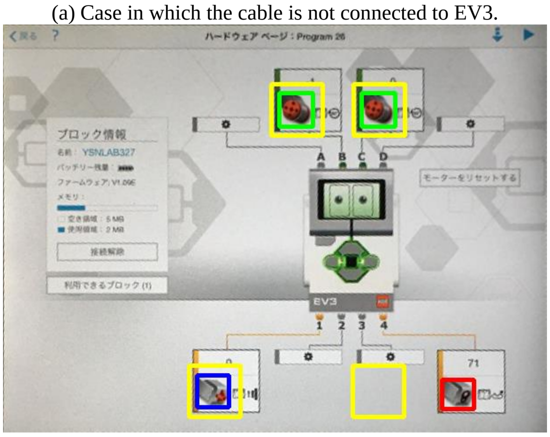


(b) Template images of motors, touch sensor, and color sensor.

Fig. 9. Image showing detected motors and sensors.



(a) Case in which the cable is not connected to EV3.



(b) Case in which a cable is connected to an incorrect port.

Fig. 10. Cases of incorrect wire connections.

E. Basic Programming Learning

In the programming basic learning class, the teacher leads students and lectures on the basic operation of the LEGO MINDSTORMS EV3 software. For example, students learn how to instruct a vehicle robot to move forward, change its direction to the right, and use its touch or color sensors. A sample program of the vehicle robot equipped with a touch sensor is shown in Fig. 3.

The task of the teaching assistant robot in the vehicle robot programming class is to advise students who are encountering problems creating a program with EV3 and who have raised their hands to ask for help. Mistakes in the vehicle robot program are detected by evaluating the robot's behavior. If the vehicle robot moves in an unintended manner, the teaching assistant robot advises the student about which parts of the program to check and modify.

In our previous study [11], we summarized the motion evaluation of a vehicle robot equipped with a touch sensor, the causes that would result in unintended vehicle robot movements, and the content that the teaching assistant robot uses when advising students on how to modify the program. This paper describes the methods used by the teaching assistant robot to evaluate a vehicle robot that has been programmed by the students, identify mistakes in student programs, and advise students on how to correct their mistakes. In the case discussed below, the program is intended to instruct the vehicle robot to follow a black line using a color sensor.

The lessons for learning basic programs use the course shown in Fig. 11. Students run the vehicle robot within the course and learn the basic LEGO MINDSTORMS EV3 programs. Mistakes in the vehicle robot programs made by students are identified by evaluating the trajectory of the vehicle robot within the course.

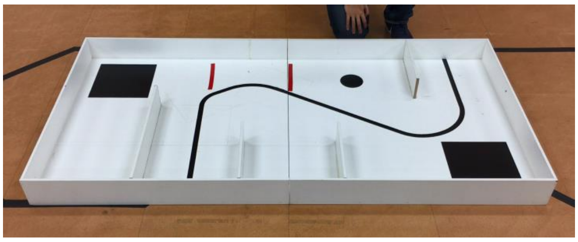


Fig. 11. Course for learning basic vehicle robot programming.

The vehicle robot trajectory is detected using the background subtraction method for image processing. This method obtains a subtraction image by computing the difference in pixel value between a background image showing only the course and an input image in which a vehicle robot is on the course. Pixels of the vehicle robot are detected by binarizing the obtained subtraction image. The position of the vehicle robot on the course is obtained by computing the center of gravity of the detected pixels. After removing noise from the binarized images, the teaching assistant robot can obtain the trajectory of the vehicle robot on the course by applying this operation to each input image [11].

Vehicle robot trajectory evaluations are set according to learning contents of programming using a sensor. Based on our experience gained via a programming workshop using a vehicle robot, we explore the most frequent student mistakes, explain to the students how they can identify these mistakes from the vehicle robot's trajectory, and then offer them advice on how to correct those mistakes.

F. Evaluation and Advice Regarding a Vehicle Robot with an Ultrasonic Sensor

In the program learning problem for equipping the vehicle robot with an ultrasonic sensor, the students practice programming the robot to detect a wall with the ultrasonic sensor and then turn to avoid hitting the wall.

Fig. 12 shows an example trajectory of the vehicle robot engaged in the practice task of negotiating a course using the ultrasonic sensor. The trajectory is shown with green circles. In the practice task, the vehicle robot moves forward, turns right at the first wall, turns right after passing the second wall, and then stops in front of the third wall. Fig. 12 also shows the correct trajectory movements of the vehicle robot.

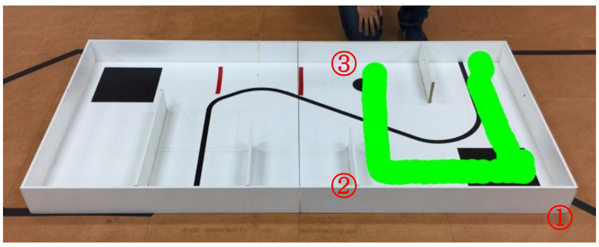
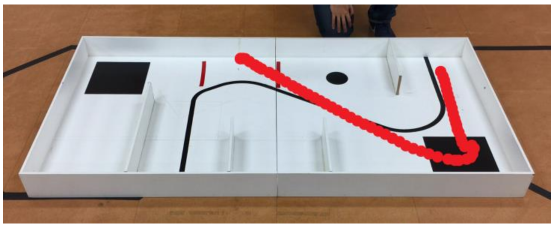


Fig. 12. Trajectory of the vehicle robot in the practice task.

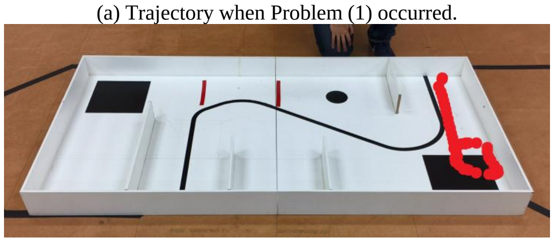
When programming the vehicle robot for the practice task, the students tend to encounter the following problems:

1) The turning angle is too large.
2) The turning angle is too small.
3) The distance to the wall is too close at the turning time.
4) The robot turns in the wrong direction.

Figs. 13(a) and (b) show the trajectory when Problems (1) and (4) occur at the first wall, respectively. The trajectories are drawn with red circles in the figures. Here, it can be seen that the radius of the red circle is shorter than that of the green circle in order to reduce the fluctuation influence of the vehicle robot movements.



(a) Trajectory when Problem (1) occurred.



(b) Trajectory when Problem (4) occurred.

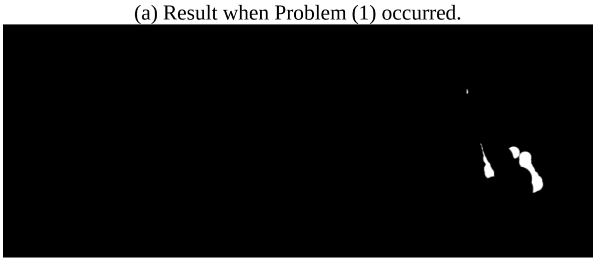
Fig. 13. Trajectory of the vehicle robot in the practice task.

Evaluations of the vehicle robot trajectory on the course were performed using the cumulative distance of the vehicle robot movements on the course in the input image, and then comparing the obtained trajectory with the correct trajectory. The cumulative distance traveled when the vehicle robot has correctly reached the goal position in the practice task is already known. If there is no change in the cumulative distance of the vehicle robot during a certain frame, this means that the vehicle robot has stopped partway. Therefore, the teaching assistant robot can detect the position of a wall where the vehicle robot has stopped by comparing the obtained cumulative distance with the cumulate distance to each wall.

Robot movement is distinguished by performing a not-and (NAND) operation of the trajectory in which the vehicle robot was able to turn correctly and the trajectory when the student programmed the vehicle robot. If the student-programmed vehicle robot can turn correctly, the resulting image of the NAND operation is shown in black because both trajectories coincide. To perform this processing, the radius of the circle of the correct movement trajectory is lengthened in order to reduce the influence of robot movement fluctuations. However, if the student's vehicle robot cannot turn correctly, the resulting NAND operation image includes some white pixels.

Figs. 14(a) and 14(b) show the result when the NAND operation is performed between the trajectories shown in Figs. 12 and 13. As shown in Fig. 14, differences in the position where white pixels can be seen depend on the cause. For example, numerous white pixels are present on the left side with respect to the moving direction of the correct trajectory when Problem (4) occurred. From this result, it can be inferred that the vehicle robot has moved to the left of the correct trajectory.

(a) Result when Problem (1) occurred.

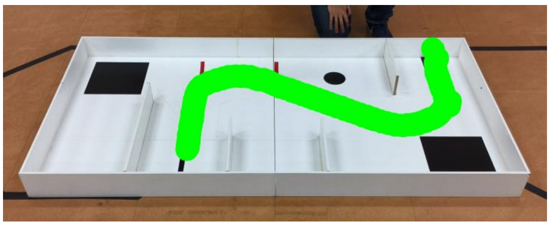


(b) Result when Problem (4) occurred.
Fig. 14. Result after performing NAND operation.

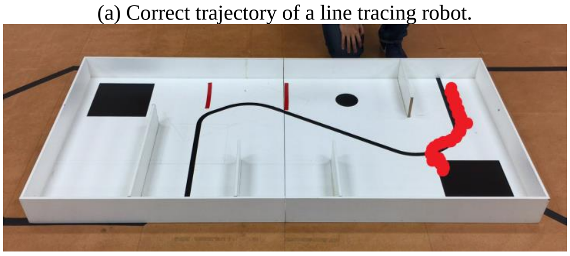
The teaching assistant robot can distinguish the position of the wall where the vehicle robot movement problem occurred from the accumulated distance, and can use the NAND operation result to estimate how it deviates from the correct trajectory. Therefore, the teaching assistant robot can advise the student, "Please check the turn angle at the Nth wall in your program".

G. *Evaluation and Advice Regarding a Line Tracing Vehicle Robot Using a Color Sensor*

In the learning problem of the programming a line tracing robot using the color sensor, the students tend to find that the vehicle robot cannot follow the curve and thus deviates from the black line. This problem occurs when the robot speed is set too fast. Fig. 15(a) shows the trajectory of the line tracing robot when the vehicle robot can trace the black line correctly, while Fig. 15(b) shows the vehicle robot deviating from the black line. The trajectories are drawn by green and red circles. The green circle radius is longer than the red circle radius in order to reduce the influence of vehicle robot movement fluctuations.



(a) Correct trajectory of a line tracing robot.



(b) Incorrect trajectory of a line tracing robot.
Fig. 15. Line tracing vehicle robot trajectories.

Robot movements are distinguished by performing a NAND operation of the trajectory, during which the vehicle robot could trace the black line correctly and the trajectory when the students program operated the vehicle robot. If there are no pixels visible in the resulting image, the result of the NAND operation performed on both trajectories indicates that the student's vehicle robot could trace the black line correctly. However, if some pixels can be seen in the resulting image, as shown in Fig. 16, the results indicate that the student's vehicle robot could not trace the black line correctly. In this case, the robot advises the student, "Please check the robot speed".

Fig. 16. Result image of NAND operation performed between Figs. 15(a) and (b).

H. *Challenge Task*

In the challenge task class, the students are given opportunities to utilize the skills learned in the basic programming classes, including the handling of touch, color and ultrasonic sensors. They are also encouraged to think about strategies and algorithms and use them when creating programs in order to solve the challenge tasks imposed by their teachers. In this situation, the teaching assistant robot needs to be able to fully comprehend the discrimination results of problems in the vehicle robot using each sensor because it is possible that each student will make a different program. This is problematic because, in addition to analyzing the trajectory of the vehicle robot, the teaching assistant robot also needs to be capable of recognizing the program created by the student, and then distinguishing any mistakes it might contain. We will work on solving this problem in the next step.

IV. Experimental Results for Evaluating Teaching Assistant Robot Abilities

We performed experiments to evaluate the abilities needed by the teaching assistant robot to support teachers in a class. In this paper, experiments were conducted in an environment that closely resembles an actual class was taking place.

A. *Detection of Students with Raised Hand*

We performed experiments to evaluate the teaching assistant robot's ability to detect students who raised their hand in a class. In these experiments, we assumed a class in which there are four students seated at one table. Good results were obtained in experiments when only one student raised his or her hand.

Fig. 17 shows a result image in which two students who raised their hands were detected. In this figure, detected face positions are represented by a square and detected hand positions are indicated by a circle. When these marks are drawn in the same color, the robot has judged that they belong to the same person. As shown in the figure, since the teaching assistant robot is looking for a hand in close vicinity to the students' face, it is possible to distinguish and detect each student’s hand.

Fig. 17. Detection of two students with raised hands.

Fig. 18 shows an image taken when a student sitting near a student who raised his hand looked at the teaching assistant robot. The teaching assistant robot detected the face of the student because he was looking at it. However, when searching for a raised hand based on the position of the student's face, the teaching assistant robot detected the raised hand of another nearby student. The result showing two color circles at the hand position of the left front student indicates that the teaching assistant robot has identified the hand of one student as belonging to two students. In such cases, the teaching assistant robot can avoid misunderstandings by moving closer to the student who is raising his or her hand, and then performing the identification procedure again.

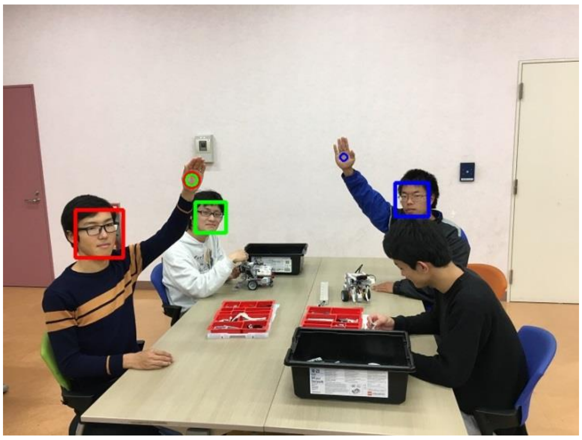


Fig. 18. Student misdetection example.

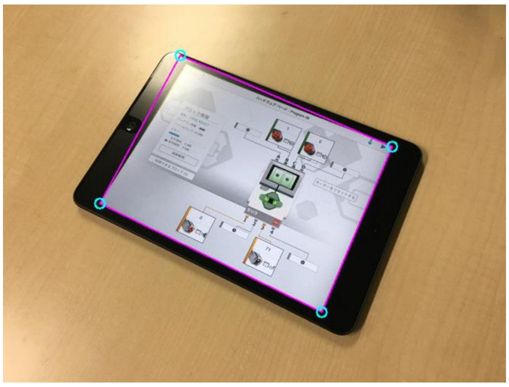
When two or more students raise their hands, the teaching assistant robot moves to the student in order of the times at which each student raised his or her hand. When multiple students raise their hands at the same time, the teaching assistant robot moves to a location nearest the position of the vehicle robot.

B. *Evaluation of Vehicle Robot Wire Connections*

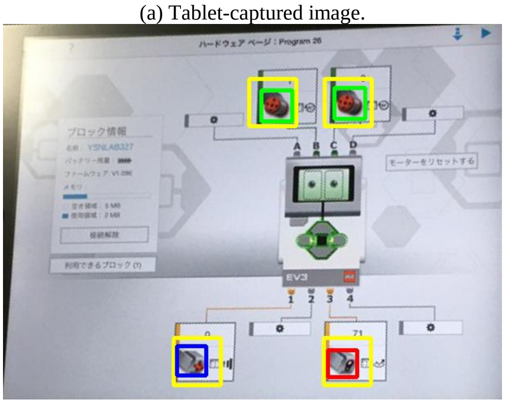
In this subsection, we report on experiments performed to confirm the teaching assistant robot’s ability to evaluate the wire connections of a vehicle robot assembled by a student. More specifically, we conducted experiments on the performance of perspective transformation and the detection of motor and sensor positions via template-matching using 20 images captured by a tablet placed on a desk. Good results were obtained in these experiments.

Fig. 19(a) shows a captured tablet image while Fig. 19(b) shows an image of the detected motors and sensors. In Fig. 19(b), even though the position of the motors and the sensors can be accurately detected, the perspective transformation image result was distorted. This is because the correct corner of the hardware page could not be detected due to the influence of lighting, as shown in Fig. 19(a).

When the captured image is affected by lighting, such as in a situation when the entire hardware page does not fit in the captured image because the tablet is too close to the teaching assistant robot, or when the hardware page is small in an image because the tablet is too far from the teaching assistant robot, the teaching assistant robot cannot perform the correct perspective transformation correctly in order to detect the motors and sensors. In such cases, the teaching assistant robot tells the students, "Please reorient the tablet" and performs reprocessing.



(a) Tablet-captured image.



(b) Motor and sensor image detection result.

Fig. 19. Misdetection examples.

V. Conclusion

In this paper, we report on a teaching assistant robot that efficiently and smoothly helps students who are having difficulty in programming classes, thus providing important support to the teachers of such classes. The teaching assistant robot is capable of detecting the faces and raised hands of students having difficulties, confirming the wire connections of a vehicle robot assembled by students, checking student vehicle programs by evaluating the vehicle robot’s trajectory, and providing advice to students who are having trouble during the class.

The results of experiments conducted in an environment that closely resembles an actual programming class showed that the technologies required for the teaching assistant robot had been established. Although there were some cases where the results were not good, the causes of those problems were found and methods for avoiding them were devised.

In our future work, we will establish a method that can correctly evaluate multiple algorithms in the challenge task, develop a method for responding to oral questions from students, and perform experiments using the developed teaching assistant robot in an actual elementary school classroom.

CONFLICT OF INTEREST

The authors declare no conflicts of interest associated with this manuscript.

AUTHOR CONTRIBUTIONS

KY designed the study; KY performed to data analysis; SZ managed the analyses of the study and literature searches; KY wrote the initial draft of the manuscript; SZ critically reviewed the manuscript; all authors had approved the final version of the manuscript.

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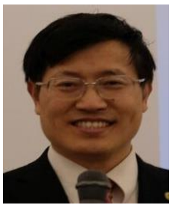

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