High School Educational Program Using a Simple and Compact Stereo Vision Robot

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1. Introduction

To promote and further encourage developments in the fields of science and technology in accordance with the Science and Technology Basic Law (hereinafter Basic Law), the Japanese Ministry of Education, Culture, Sports, Science and Technology is promoting various initiatives through measures that realize technological and scientific development according to the vision of the Basic Law. Realization of a personnel training program in science and technology is one of the primary targets of the Basic Law in order to maintain and elevate Japan's research, development capabilities and competitiveness in the international market. Various plans such as the 'Training and Development of Talented Individuals in Technology, Arts and Sciences plan', the 'I love Technology and Science Plan', and the development of digital science education teaching materials are also being carried out to realize the vision of the Basic Law. For example, in junior and senior high schools, the Japanese government has formulated and is promoting the 'Super Science High Schools' plan and the 'Science Partnership Program'. All these initiatives are aimed at providing personnel training in science and technology, which in turn promotes technical innovation and industrial competitiveness. As students are being increasingly exposed to advanced technologies, these programs intend to increase the educational incentive for students and provide them with a basic technology education (Ministry of Education, 2005).
Furthermore, the industrial education target in a high school course requires basic knowledge of each industrial field, practical and technical skills acquisition and an understanding of the role it plays in the modern society and environment. Therefore, in technical high schools, practice trainings and experiments are incorporated into the course syllabus as an educational program that encourages student interest in technology, promotes the student's practical knowledge and develops their skills positively.
Now, we see many teaching materials using REGO for studying basic technology. This REGO is the teaching materials which are easy to treat for programming education. However, students cannot acquire practical and technical skills of manufacturing by using the REGO materials (Josep et al., 2005).
On the basis of these plans and vision, the Kanagawa Comprehensive Technical and Science Senior High School (Kanagawa Sougou Sangyo H.S.) was founded in 2005. As this predecessor school was a technical high school, the learning environments are maintained such that the students are exposed to a wide range of technologies ranging from machine tools such as the NC and the milling machine to micro computer technology.

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The students participating in this program, who are active in both class and extracurricular activities, study not only the individual technologies but also systematic technical synthesis by gaining exposure to the entire process from design stage to manufacturing using robotic systems. As a result, these students have participated in robot contests and have won several awards.
In this chapter, we experimented our program for high school students as an educational subject, in order to show that this program can be used effectively for the high school student. We present the results of implementing a new educational program and materials for high school students by incorporating a small stereo vision sensor module for an autonomous, simple and compact robot (Fig. 1).

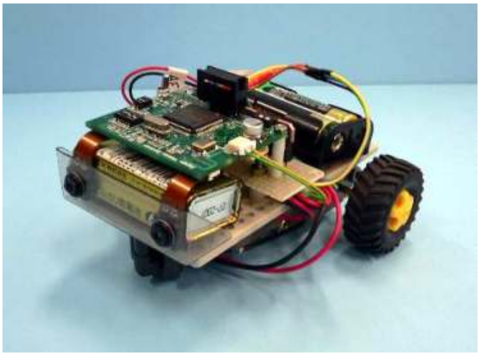


Fig. 1. Compact autonomous robot with stereo vision system constructed by high school students

2. Contents research purposes of the educational program

This chapter describes a new educational program to maximise the use of a simple and compact stereo vision robot. The research purposes of this educational program are summarized as follows:
1. Development of new educational methods and materials that differ from the conventional ones for application in a new technical field.
2. Investigation of both the field of technical interest and technical knowledge of the students and the presentation of new education curricula and materials suitable for the students.
3. Measure the educational effects of the proposed educational contents such as the educational method, practical training, cost, etc.
4. Measure student responses to the program, gauge their interest levels and obtain their opinions regarding the teaching materials.

3. Educational program features

Providing the students with an opportunity to study stereo image processing technology on a computer and handmade robot is one of the specific features of this educational program. We will teach students total system integration using a new educational framework that has not been previously attempted in an educational program. The flow of this educational program is summarized as follows:

1. Manufacturing a robot body as a control object.
2. Stereo image information processing exercise by using a computer.
3. Learning of control programming and systemization of the robot system.
4. Operating the autonomous stereo vision robot that performs feature extraction and distance measurement by processing images.

4. Pre-analysis of participant students

While developing a program, a teacher always considers the relationship between the contents of the educational material and the academic aptitude of the students involved. This also holds true for technical education. Pre-analysis performed by the participating students is thus an important element for developing the lesson. In the analysis method, a questionnaire on the related technology is administered to ten students (Table 1).

This questionnaire is designed to check the student's technical skill and attitudes with regards to robots, vision sensors, and other technical elements involved in the program, in order to have a record of the technical knowledge of the students. Figure 2 shows the results of the questionnaires. All answers were either 'Yes' or 'No'. The numbers in Figure 2 denote the actual questions.

Based on the results of the questionnaire, we observed that everyone had been exposed to all or most of the technical skills related to this program. The cause of this, as shown by the results, is that the target students have received technical education for one year or more, and have received additional mechatronics education by participating in extracurricular activities. The positive responses obtained in the questionnaires revealed that the students were capable of using various technical tools; however, their technical knowledge was still not very high. Thus, it was considered that the knowledge of the students participating in this educational program was quite high as compared to that of high school students.

Further, the results of the attitude section indicated that none of the students wanted to use a vision sensor (Q1 = 0%). This shows that technical education in high schools does not typically include a study of vision sensors.

This questionnaire also revealed that the present condition of the education level in technical high schools lags behind in the field of vision technology. On the other hand, since the results indicate that all the students are interested in robots (Q2 = 100%), it is considered that the students participating in this program show interest and are highly motivated to work in this field.

5. Educational objectives

Based on the results obtained from the questionnaire, we developed the educational objectives and curriculum for this program. In Japan, the educational objectives of a technical high school curriculum comprise teaching fundamentals of both industrial mechanical science and information technology, practical training related to these fundamentals, mechanical drafting, etc. We set up the educational objectives of this program by considering the objectives of a technical high school—special knowledge, technology and ability for functional integration; these are ingrained through the fundamental study of the proposed vision technology using both experiments and training. Spontaneous study attitude and problem solving ability are also improved by this program. Also, the fundamental understanding of the relationship among mechanics, hardware, software and vision technology is increased, and the students gain interest in general technical fields, especially mechatronics.

Section	Question
Mechanism /Hardware	Q1. Can you use a saw well? Q2. Can you cut sheet metal by shirring machine? Q3. Can you file well? Q4. Can you use slide calipers and a height gage? Q5. Can you use a drilling machine? Q6. Have you used a lathe? Q7. Have you used a milling machine? Q8. Can you understand a machine design? Q9. Can you draw a machine design? Q10. Can you understand a data sheet? Q11. Can you look for a data sheet by yourself? Q12. Have you made electronic circuit? Q13. Have you soldered? Q14. Have you used cutting pliers and a nipper? Q15. Can you use an electronic millimeter? Q16. Have you used an oscilloscope? Q17. Can you understand a circuit schematic? Q18. Can you draw a circuit schematic? Q19. Do you know a polar semiconductor? Q20. Have you used a sensor? Q21. Have you used a microcomputer? Q22. Can you select parts required for an electronic circuit? Q23. Have you made an electrical system by using semiconductor module?
Software	Q1. Have you used C language? Q2. Have you used both input and output function of data in a microcomputer? Q3. Can you use condition branch of “IF” sentence? Q4. Can you use a repetition of a “For” sentence? Q5. Have you use interruption process? Q6. Do you know how to use a function? Q7. Can you perform of LED control? Q8. Have you used a Motor Driver IC? Q9. Can you write a program in a microcomputer? Q10. Have you read a book about a microcomputer?
Attitude (interest)	Q1. Have you want to use a vision sensor? Q2. Are you interested in a robot?

Table 1. Technical level questionnaire for students before program (Answer is "Yes" or "No")

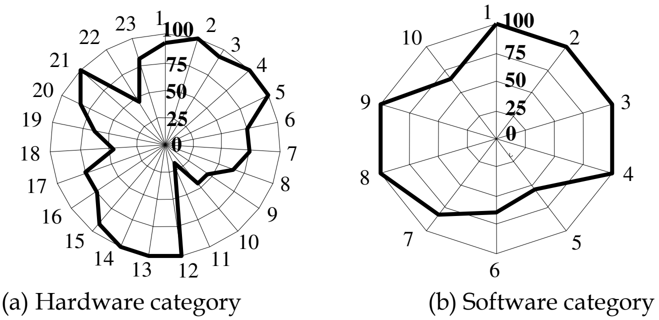


Fig. 2. Results of the technical skills questionnaires (Circled number denotes the technical question number. Radius of the circle indicates the frequency of 'Yes' responses.)

6. Educational material

6.1 Small stereo vision sensor one board module

Figure 3 shows the small Stereo Vision One board sensor module (SVO sensor module) that we developed for this program. Two sets of CMOS image sensors are mounted such that the module can obtain a stereo pair image. We can obtain the position of the three-dimensional coordinates—x, y and z—or achieve color extraction, feature extraction or distance measurement by processing the information obtained from this stereo pair image. The calculated results from this module can be output using general-purpose interface ports such as general IO, serial communication port and A/D and D/A ports. Furthermore, a 16 bit microprocessor installed in this module can perform basic visual processing calculations

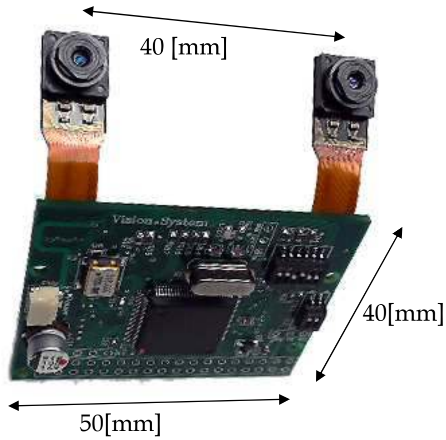


Fig. 3. Small Stereo Vision One Board Sensor Module

for image processing. We have implemented functionalities for capturing images, noise reduction, color extraction, binarization, centroid calculation, radius calculation, shape recognition, stereo image based distance calculation, pattern matching and attention area tracking. These functionalities enable us to use any image processing algorithm in order to

take complete advantage of the vision sensors. In addition, when using a multiple sensor system, this SVO sensor module can be implemented easily in various robots because a general interface is employed as an output port. This module can be used as an image recognition module attached to a simple robot for this program (Okada et al., 2005; Morishita, T.& Yabuta, T., 2007).
In related works, Konolige developed a small, self-contained stereo vision module using FPGA(Kurt, 1997), which is particularly useful for depth image generation. Our sensor module provides several visual functions for multiple purposes and can be easily implemented in various types of robots—it can be attached as a visual sensor as it has a general-purpose interface.

6.2 Educational stereo vision robot

The educational robot developed for this program is a simple and compact robot with a stereo vision system. As conventional educational targets are only concerned with exposure to the manufacturing process, the contents of their corresponding exercises focus only on this process. On the other hand, the educational target of this program is aimed at covering a wide spectrum of technologies ranging from mechanical manufacturing processes to software technology. Therefore, the time spent in manufacturing the mechanism and hardware is limited to about 1/3 of the entire curriculum educational time. We selected a robot with a simple structure in order to ensure that it is manufactured within the assigned time. Figure 4 shows a simple block diagram for the stereo vision robot system; the dashed line represents the portion of the electronic circuit to be manufactured. Students fabricated this portion using a few general electric parts and under the considerations of a circuit diagram provided as educational material. In this educational program, students can attain the fundamental skills of fabricating an electronic circuit and learn to read a fundamental circuit diagram. While integrating machine and hardware parts of the electrical circuit, a technical sense of system integration is cultivated. The educational curriculum developed is shown in Table 2. All the parts and components selected for this educational system are low cost and are easily available in order to ensure that the parts can be sourced easily and are economically efficient and maintainable(Fig. 5).

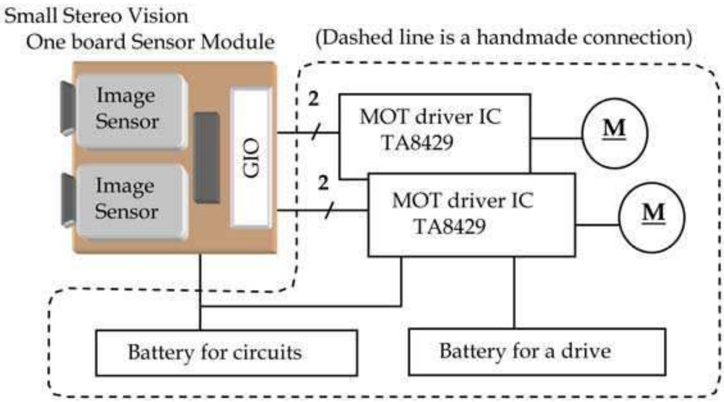


Fig. 4. Block Diagram for Educational Robot System

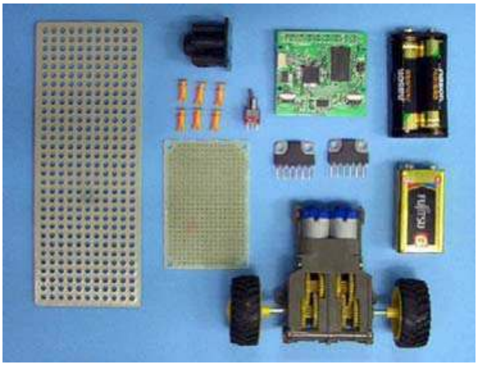


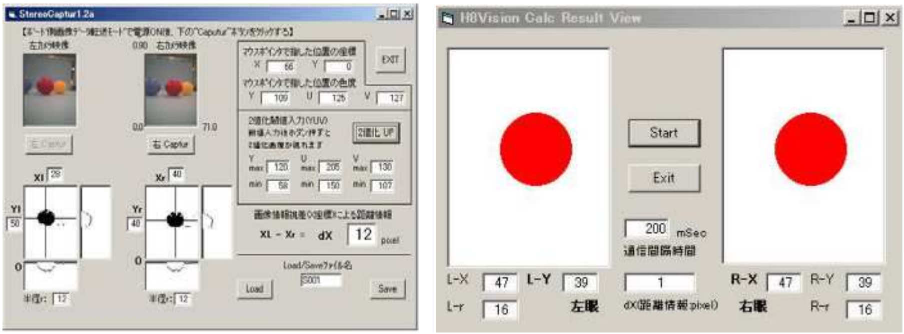
Fig. 5. Main parts of the robot system

Subject	Contents
Robot Manufacturing (1^{st} - 2^{nd} week)	1) Guidance 2) Manufacturing the robot body 3) Manufacturing the motor control circuit board
	4) Manufacturing the motor control circuit board 5) Stereo vision module mounting 6) Connection and operation check
Image information processing basics and handling(3^{rd} week)	7) Color system, binarization, noise reduction 8) Stereo vision module handling exercise
Stereo vision basic learning (4^{th} week)	9) Image data processing using viewer 10) Data reduction/graph (disparity - distance) 11) Visual information processing programming exercise
Experiment of vision robot (5^{th} - 6^{th} week)	12) Viewer handling for image processing operation 13) Object tracking control programming 14) Operation check and debugging 15) Color extraction tracking robot control experiment
	16) Distance recognition programming 17) Operation check and debugging 18) Distance recognition robot control experiment

Table 2. An example of the educational curriculum

6.3 Viewer for vision technology

Figure 6 shows the screenshots of both the sampled data image from the vision sensor and visual image analysis results for the operation. By using the viewer shown in Figure 6(a), students can obtain not only a color image of an object but also a binary image, a representative point of the object and the disparity of the stereo image. Figure 6(b) shows the real time processing results of the position, distance and size of the object. Due to the stereo vision sensor, the resultant values are three-dimensional (in x, y and z coordinates).



(a) Visual processing view (b) Processing result view

Fig. 6. Vision system information viewer for education

6.4 Curriculum

One subject consists of six training classes with four hours of exercise time. For example, if a four-hours class is conducted once per week, it would takes six weeks to cover all the subjects; this implies a total of 24 hours of exercise time. Moreover, this curriculum can be implemented as a conventional one. In this case, one subject is equivalent to two classes of the conventional curriculum and the 1st, 2nd & 3rd, 4th subjects can be taught under the conventional curriculum as mechatronics technology, basic image information technology and an autonomous robot exercise with vision system. These classes are considered to be taught in relation with each other. Under this arrangement, a special one subject class can be opened and an individual teacher can be assigned for each subject.

7. Educational practice

7.1 Manufacturing of the educational robot

Manufacturing the educational robot comprises the assembly of an actuator system, manufacturing the motor drive circuit and system integration with a vision sensor (Fig. 7(a)).
The time allowance planned originally allotted time for the systematization and manufacturing of the electronic circuitry module, such as manually fabricated connections and soldering. A generous time distribution is important for the composition or connection check of circuits, although the time provided in class to perform these checks is usually not sufficient. We could effectively use the time for performing important checks by simplifying the construction of the robot (Fig. 7(b)).

7.2 Basic Learning from image information processing

This section outlines the basic learning from image information processing using the viewer shown in Figure 6. The obtained information can be summarized as follows: 1) the relationship between the YIQ color specification system generated by the vision sensor module and the RGB color specification system of the viewer, 2) the method for converting YIQ to RGB, 3) image binarization method for extracting image color information, 4) noise reduction method, 5) method for calculating the representative point of an object based on its image coordinates and 6) method to use this sensor module and transmit image information to a computer.

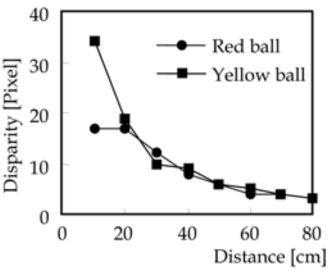
7.3 Stereo vision basic learning

This section describes the basic learning achieved from the stereo vision. We explained that when a stereo pair image is obtained in parallel, the distance information Z can be acquired from the disparity in the image. We used two colored balls for this experiment—a yellow ball (table tennis ball) of 38 mm and a red ball(soft-ball) of 76 mm. These balls are placed at intervals of 80 to 10 cm from the vision sensor, and then the students are asked to record the disparity value of the representative point computed from a binary image Figure 8(b).

(a) Hardware manufacturing process

(b) Connection check and debugging

Fig. 7. Practice in manufacturing and an experiment



(a) Graphical experimental data

Distance [cm]	Disparity [pixel]	
	Red ball (Φ 76 mm)	Yellow ball (Φ 38 mm)
10	17	34
20	17	19
30	12	10
40	8	9
50	6	6
60	4	5
70	4	4
80	3	3

(b) Numerical experimental data

Fig. 8. Disparity vs. distance experimental results obtained by students

We then asked the students to plot these disparity values on a graph. We explained that the distance data obtained from the disparity value changes with the change in disparity. Since the two curves are in agreement, the distance measurement can be performed independent of the target size, as shown in Figure 8(a).

7.4 Operation experiment of a stereo vision robot

This exercise is an autonomous control experiment of the stereo vision robot. First, the coordinate system was explained before the experiment; this is because it is important to obtain the relationship between the object position and the results obtained from the calculation of the vision sensor data. Next, the branch control algorithm was applied to motor control in order to realize a simple robot motion. The focus of this programming exercise is on both to set up the threshold of feature extraction for the image processing and to generate a motor control program. This exercise is related to both the software and hardware fields, which makes this an essential exercise to grasp these relationships.

Therefore, we made the students verify normal signal transfer between the software and hardware before conducting the experiment. Since debugging a program is also important for acquiring programming skills, a considerable amount of time is assigned for the debugging process (Fig. 7(b)).

After all pre-exercise conditions are fulfilled, the two experiments shown in Figure 9 were conducted. In the first experiment, an object was tracked by color extraction. In other words, the autonomous robot can detect an object by color detection and can trace it by determining the direction in which the object moves. The second experiment was a stop point control experiment of the autonomous robot. In this experiment, the robot stops at a set distance from the object by using the distance measurement function; this can be realized by the comparison between the pre-assigned distance and the distance measured by the vision sensor. By using the stop experiment data, the students compared the actual stop data and the pre-experiment data of Figure 8 (section 7.3). When the actual experiment and pre-experiment data were observed to be in good agreement with each other, the students achieve a sense of surprise, admiration and technical satisfaction.

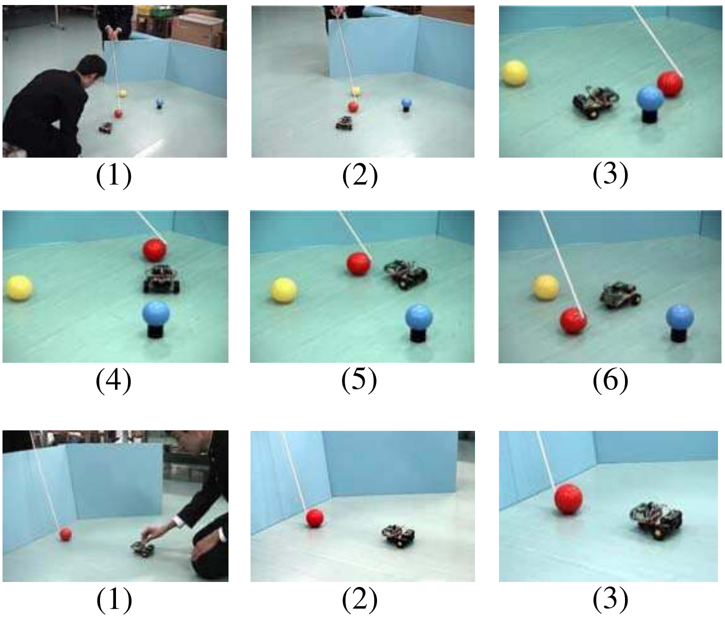


Fig. 9. Schematic figures of the color ball tracking experiment and distance measurement experiment by using the robot

8. Results after exercise

After the completion of all the exercises, we investigated both the student attitudes toward this program and the achievements of the program by using the questionnaire, in order to verify the effect of this educational program.

8.1 Skill level investigation

This questionnaire is divided into four groups in agreement with that of the curriculum. The first group comprises four questions that can be answered as either 'Yes' or 'No' (Table 3(a)). Figure 9 shows the questionnaire results; these results reveal that almost all students chose 'Yes' as an answer for each question. This educational program is planned such that it provides systematic exposure to practical technologies such as software, hardware and mechanical manufacturing process by using the vision robot. It helps students assimilate vision technology fundamentals as well as practical technologies. Thus, it can be implied that the higher the satisfaction for each a questionnaire item, the more enthusiastically the students tackled the teaching materials with interest and concern.

These results reveal that the targets of this educational program have been realized. Thus, an overall positive response to the questionnaire in relation to the basic technical education reiterates the success of this program. On the other hand, when the contents of questions marked as 'No' were investigated, it was found that they are related to either systematization or programming. Since these questions depend on the student's skill in the technical field, the answers differ based on each student's technical knowledge. Therefore, the items related to these questions must be carefully arranged from the viewpoints of teaching material, time distribution and improvement in the educational method.

8.2 Attitude survey

In order to understand student attitudes to the related technical fields of this program, we conducted the attitude survey, shown in Table 3(b). In this investigation, the students could evaluate each question by assigning one of the five grades—very satisfied, generally satisfied, normal, generally unsatisfied and very unsatisfied.

The results are shown in Table 4. Based on the pre-program questionnaire, we can see that the students were interested in robot manufacture but did not know about either vision sensors or image recognition technology until this program. On comparing the results of the questionnaire shown in Table 3, which records both academic achievements and student's attitude toward robot technology after the program, with that of the pre-program questionnaire, the following could be seen: (1) This curriculum motivated the students, as illustrated by the responses of all the students that 'making a robot is pleasant'. (2) Although there were a few differences in opinion among the students, almost all of them answered 'We were able to enjoy programming'. (3) All students also answered 'We have experienced constructing the vision robot'. This is a natural answer obtained based on the usage of these education materials. However, it is an important result for the students who did not have any prior knowledge of vision sensors, as indicated by the preliminary survey, and gained exposure to a new technical field through participation in this educational program. This result implies a significant educational result. (4) In addition, this educational program for fundamental vision technical education did not require detail learning of its contents. After the program, the students without vision technology experience felt "This technology is an important technology". This is an interesting result and has an important educational value.

(a) Academic achievements (answer in either "Yes "or "No")

Section	Question
Robot manufacture	Q1. Could you use the tools? Q2. Did you have enough time to manufacture the robot in the class? Q3. Could you solder the electrical circuit? Q4. Could you make an electrical circuit by using the electrical diagram?
Basic image information processing	Q5. Did you understand the relationship between YIQ and RGB color systems? Q6. Did you understand the binarization process? Q7. Did you understand the noise reduction method? Q8. Could you transfer the image information data into a computer?
Stereo vision technology	Q9. Could you perform color extraction on the viewer? Q10. Did you understand the calculation of the representation point by using binary information data on the viewer? Q11. Could you measure the disparity property on the viewer? Q12. Could you draw the graph by using the disparity data?
Tracking experiment	Q13. Could you generate a program by using the representation point? Q14. Could you complete the tracking program by using the representation point? Q15. Could you verify the operation of both the software and hardware systems? Q16. Could you realize the tracking experiment of a target by using color extraction results?
Distance Recognition Experiment	Q17. Could you use the distance information in programming? Q18. Could you verify program execution? Q19. Could you realize the distance recognition experiment? Q20. Could you check the correspondence of experience data with the distance data estimated by the disparity data?

(b) Attitude survey (five-grade evaluation)

Impression	Q21. Is manufacturing a robot a pleasant task? Q22. Is programming enjoyable? Q23. Do you have experience in vision robot systems? Q24. Is this technology important?

Table 3. Questionnaires of both academic achievements and student's attitude toward robot technology after program

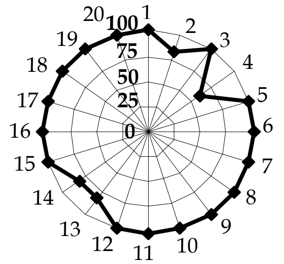


Fig. 9. Results of the academic achievements questionnaire (Circled number indicates the questionnaire number. Radius of the circle indicates the frequency of the 'Yes' responses.)

A21	Very pleasant 80%, pleasant 20%
A22	Very enjoyable 60%, Enjoyable 20%, Normal 20%
A23	Very realized 100%
A24	Significant agreement 80%, agreement 20%

Table 4. Attitude survey result

9. Conclusion

We developed practical high school educational material for a stereo vision autonomous simple and compact robot, which has not been previously reported until now in the technical education field. The results of this program are summarized as follows: The opinions of the high school students, which can be verified from the pre-program questionnaire, and the final questionnaire was 'We never had an opportunity to touch the vision technology until now, which is considered to become an important future technology'.

This opinion is almost similar to that expressed by both the first and second grade students from an undergraduate engineering university; this is because both the technical knowledge and the educational environment are almost the same as that of the technical high school students. This educational program can impart practical education including vision technology fundamentals, which have a far-reaching impact.

The salient features of this program can be summarized as follows: 1) As the educational program was formulated to encourage the pleasure of experimenting with robot technology in practical exercises, it motivated the students positively. 2) This program was intended to cultivate each basic technology and technological capability, interest and awareness among the students. 3) Furthermore, the educational materials also attained the educational goal as set in the beginning.

As for the student's opinion regarding the vision sensor, the application of vision technology in robotics is important in the field of robot research. However, the conventional educational materials use infrared sensors for basic technical education, which is not an actual vision sensor. This vision sensor module holds significant potential in education since the module is compact, has high usability and is very affordable. Visual information processing has long been researched; however, educational programs that use this technology are relatively uncommon. In order to make visual information processing technology familiar in general use, we believe that the educational material using simple, compact and low cost visual processing modules is of significant value in future educational materials.

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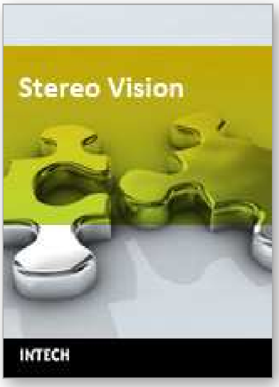

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The book comprehensively covers almost all aspects of stereo vision. In addition reader can find topics from defining knowledge gaps to the state of the art algorithms as well as current application trends of stereo vision to the development of intelligent hardware modules and smart cameras. It would not be an exaggeration if this book is considered to be one of the most comprehensive books published in reference to the current research in the field of stereo vision. Research topics covered in this book makes it equally essential and important for students and early career researchers as well as senior academics linked with computer vision.

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