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ライントレースロボットの学習コースの設計と実践
～小学生、短期大学生と教師の3コースの比較～

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The purpose of this paper is to describe the implementation of a course for college students learning both hardware and software. The algorithms for sensors and actuators are the core point to learning a Line Following Robot. Following this, the author had opportunities to teach them to students in an elementary school. Most of the elementary school students could understand the key concepts and could modify the programs for it. There was also a workshop for teachers to master robot programming in Processing and in Scratch.

Key words : Arduino, Line Following Robot

1. Introduction

It is a good target for student to learn both hardware and software of computers. For instance, sensors are input devices for the computer, and actuators are output devices for it. Consequently, they are combined into a system. After that, programs are written to distinguish input and to compare with some criteria, then to control the output. In the course for college students, they learn all of them from designing the electronic circuits to develop controlling programs. However it is rather difficult for elementary school students to learn all of them. What should they focus on as a theme? Although this will not be discussed here, practical lectures for them will be given. Furthermore, the necessary points to learn are

concentrated, and a workshop for teachers to teach their students for learning the robotics programming is opened.

2. Hardware Components

There are a lot of microcomputer units, like Raspberry Pi, IchigoJam, Arduino, and others. We are able to build a Line Following robot by using any of them. However, there are some differences among them, i.e. their cost, and developing languages. The author attempted to prepare a practical and reasonable course for students and teachers. Arduino was developed as open hardware, so a lot of vendors provide quite cheaper compatible units. Furthermore, we have many alternative peripherals for this microcomputer unit. Therefore, Arduino was chosen from the other units.

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2.1 Microcomputer: Arduino UNO compatible

The candidates are Arduino UNO and Arduino nano – their hardware diagrams are the same, but their physical sizes are different. Tiny DC motors that have small power were chosen; all of the components for the robot must be light and small. Thus, the nano is better than the UNO. Also, attention was given to the whole cost of the robot, so Chinese compatible components were imported instead of the original ones. This will reduce the cost by up to about 80 percent. The pin assignment are as follows (Figure 1):

Arduino Nano V 3.0 GRBL Pinout		Pin diagram for Grbl v0.8 and v0.9	
ATmega328P			
Pinout Ref			Pinout Ref
D13	Spindle Direction	D13	Spindle Enable
3V3	Not Used	D11	Limit Z-Axis
VREF	Not Used	D10	Limit Y-Axis
A0	Reset/ Abort	D9	Limit X-Axis
A1	Feed Hold	D8	Stepper Enable/Disable
A2	Cycle Start/ Resume	D7	Direction Z Axis
A3	Coolant Enable	D6	Direction Y Axis
A4	(Not Used/ Reserve)	D5	Direction X Axis
A5	Probe	D4	Step Pulse Z Axis
A6	Not Used	D3	Step Pulse Y Axis
A7	Not Used	D2	Step Pulse X Axis
	5V	GND	
	RST	RST	
	GND	RX1	
	VIN	TX1	

Figure 1 Pin assignment of Arduino nano V3

2.2 Photo reflector: LBR-127HLD

The Line Following robot requires at least two eyes: the right Photo reflector and the left one. Two reflectors enable us to judge the relationship between the robot and the line. Since tuning the sensors is very delicate, the visible light spectrum must always be considered. Therefore, it was decided that an infrared sensor would be used. The electronic circuit is shown as follows (Figure 2):

2.3 DC Motor and Gearbox

The author designed the power supply for the robot. Four AAA battery were used for it, so the maximum voltage was DC 4.8 through DC 6.0 volts. Many people use Mabuchi's FA-130 as the DC motor, and Tamiya provides various types of

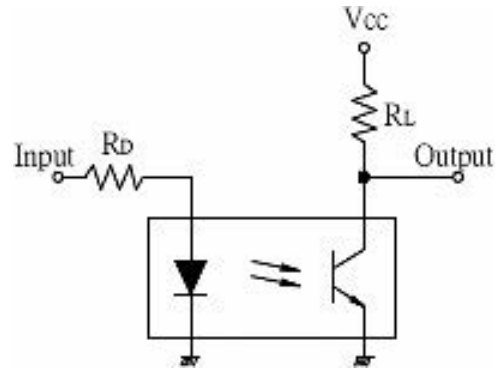


Figure 2 Test Circuit for LBR-127HLD

motor gearboxes for FA-130. However, an effort was made again to reduce the cost. A compatible motor from mainland China was chosen. After they were imported, there was a realization of the balance of the cost and the accuracy. In any event, there is a way to tune up the accuracy, i.e. program controlling the DC motor by the PWM (Pulse Width Modulator). The DC motor and gearbox is shown as follows (Figure 3):



Figure 3 DC motor and gearbox

2.4 DC Motor Driver: TA7291P

For forward rotation and reverse rotation of the DC motor, the simplest way is switching the plus and GND of the motor. However, this is not practical. Therefore, Toshiba's TA7291P was used as the DC motor controlling IC. It is very easy for a user to adjust the speed of the motor by using the PWM. The data sheet is as follows (Table 1):

Table 1 Data sheet of Toshiba's TA7291P

Sign	Pin	Explanations
Vcc	7	Power for Logic
Vs	8	Power for Output
Vref	4	Power for Control
GND	1	GND
IN1	5	Input
IN2	6	Input
OUT1	2	Output
OUT2	10	Output

The functions of TA7291P are as follows (Table 2):

Table 2 Functions of Toshiba's TA7291P

Input		Output		Mode
IN1	IN2	OUT1	OUT2	
0	0	∞	∞	Stop
1	0	High	Low	Clockwise
0	1	Low	High	Counter Clockwise
1	1	Low	Low	Break

2.5 Breadboard and Jumper Wires

How can the above components be utilized in a system? Students or teachers build up the system through trial and error. Thus, breadboard and jumping wires are preferred to soldering all of the parts on the printed circuit board. It looks like Figure 4 as shown below:



Figure 4 Breadboard and jumper wires

3. Application Development Environment

The program was developed on another operating system, Windows 10. After compiling the program, we transfer binary code from the OS to Arduino via a USB cable.

3.1 Arduino IDE 1.8.5

Arduino IDE is an open-source integrated

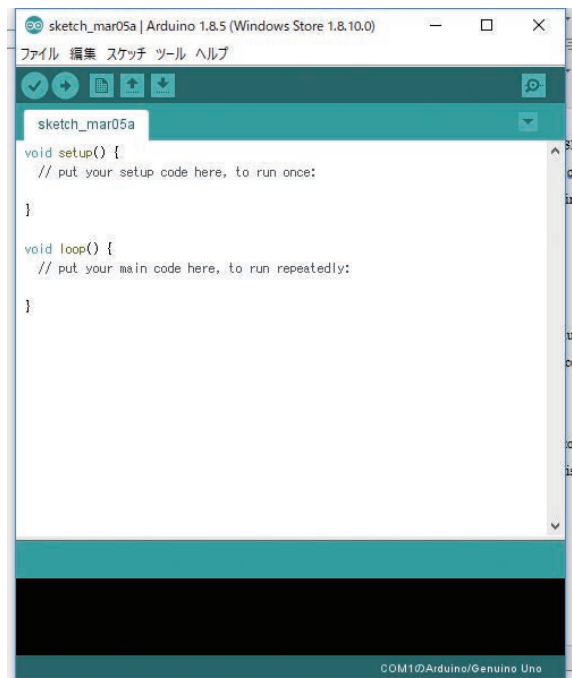


Figure 5 Arduino IDE ver.1.8.5

developing environment and runs on Windows, macOS and Linux. The latest version of it was used after being downloaded from the following URL: <https://www.arduino.cc/en/main/software> Processing is a programming language for Arduino. The source code is written in Processing. It is a command-case objective language.

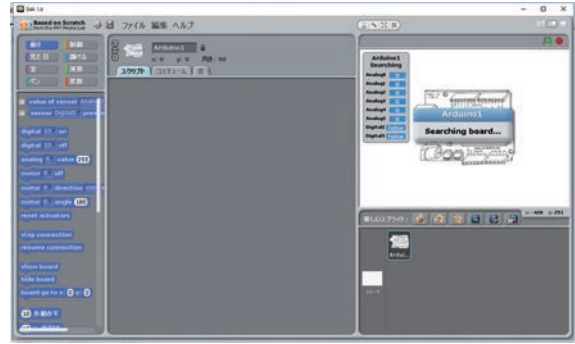


Figure 6 S4A ver. 1.6

3.2 USB-Serial Driver: CH340

Either Windows, macOS or Linux has a USB-Serial driver for the standard Arduino microcomputer board. However, the cheaper compatible board usually uses other USB-Serial chips, in this case, CH340. Thus, we have to install its driver into the OS manually. We have to confirm the installation of the driver by seeing the device driver on Windows 10.

3.3 Installations and Configurations

First of all, we have to specify the type of Arduino and the number of the COM port on the Arduino IDE. Then we can start writing and/or modifying the source code, compiling it, and transferring the binary code.

3.4 S4A 1.6

It is not easy for students of elementary school to remember the commands and grammar of Processing language. In such a case, S4A is a very useful IDE for Brick-based visual IDE. It provides beginners with how to create codes in visual parts. It looks like Figure 6 as shown below:

4. Algorithm

First of all, students should classify the following four relation cases in which a Line Following Robot is on the line (Table 3):

4.1 PWM to calibrate speed for both DC motors

The PWM (Pulse Width Modulation) is used for controlling the speed of the DC motor. The Digital Storage Oscilloscope (DSO, Figure 7) has a lot of visualizations for change in voltage with time. DSO enables college students and teachers to see whether their codes are correct or not.

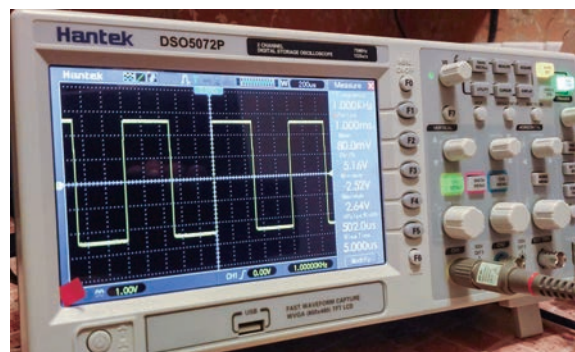


Figure 7 DSO is used for observation of PWM

Table 3 Relationships between sensors and motors

Sensors	Left	Right	Left	Right	Left	Right	Left	Right
Threshold	White	White	Black	White	White	Black	Black	Black
Motor	Clockwise	Clockwise	Stop	Clockwise	Clockwise	Stop	Clockwise	Stop
Robot	Forward		Turn left		Turn right		Turn right	

4.2 Threshold to distinguish Black and White

After we code the serial console, students can simultaneously see the values of the photo reflector by the Console. They should write down the values while they put black and white papers in front of the photo reflector.

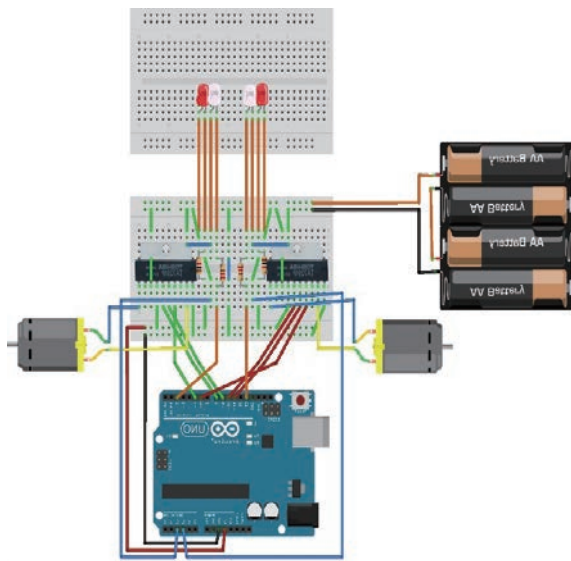


Figure 8 Physical components of the Line Following Robot

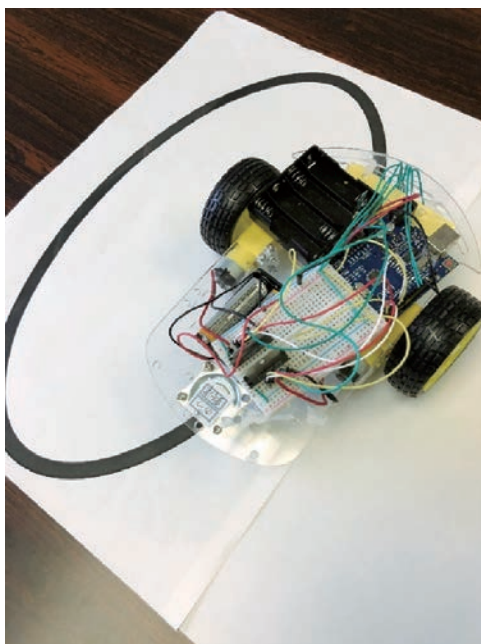


Figure 9 A Line Following Robot on a test course

5. Learning Contents

Here follows an explanation of the contents of learning in the previous sections. The weight of contents is carefully selected for elementary school students, college students and teachers, respectively. The following sections will explain

```

/*-----*/
const int lPin4 = 3; // 左モータ (Vref)
const int lPin5 = 2; // 左モータ (IN1)
const int lPin6 = 1; // 左モータ (IN2)
const int rPin4 = 6; // 右モータ (Vref)
const int rPin5 = 5; // 右モータ (IN1)
const int rPin6 = 4; // 右モータ (IN2)
const int lLED = 13; // 左LED
const int rLED = 12; // 右LED
/*-----*/
int lVal = 0; // 左センサの取得値の初期値
int rVal = 0; // 右センサの取得値の初期値
/*-----*/
int lAlpha = 110; // 左センサの値がこの値以下なら白と判定する閾値
int rAlpha = 110; // 右センサの値がこの値以下なら白と判定する閾値
/*-----*/
int forward(int pin3, int analog, int pin1, int pin2); // 車体を前進させる関数
int stop(int pin1, int pin2); // 車体を停止させる関数

void setup() {
/*-----*/
pinMode(lPin4, OUTPUT); // 左モータ (Vref)用に出力として設定
pinMode(lPin5, OUTPUT); // 左モータ (IN1)用に出力として設定
pinMode(lPin6, OUTPUT); // 左モータ (IN2)用に出力として設定
pinMode(rPin4, OUTPUT); // 右モータ (Vref)用に出力として設定
pinMode(rPin5, OUTPUT); // 右モータ (IN1)用に出力として設定
pinMode(rPin6, OUTPUT); // 右モータ (IN2)用に出力として設定
pinMode(lLED, OUTPUT); // 左LED用に出力として設定
pinMode(rLED, OUTPUT); // 右LED用に出力として設定
/*-----*/
Serial.begin(9600); // シリアル通信速度を9600に設定
}

void loop() {
/*-----*/
digitalWrite(lLED, HIGH); // 左LEDを点灯
digitalWrite(rLED, HIGH); // 右LEDを点灯
/*-----*/
lVal = analogRead(1); // 左センサをアナログ1で入力
rVal = analogRead(2); // 右センサをアナログ2で入力
Serial.print("左="); // 左の取得値を表示
Serial.print(lVal); // 左の取得値を表示
Serial.print("右="); // 右の取得値を表示
Serial.println(rVal); // 右の取得値を表示
/*-----*/
if (lVal < lAlpha && rVal < rAlpha) { // 左センサ=白 かつ 右センサ=白
forward(lPin4, 255, lPin5, lPin6); // 左モータを正転(出力調整: 無=0~255=最大)
forward(rPin4, 255, rPin5, rPin6); // 右モータを正転(出力調整: 無=0~255=最大)
delay(40); // この状態を40m秒間維持
}
/*-----*/
else if (lVal > lAlpha && rVal < rAlpha) { // 左センサ=黒 かつ 右センサ=白
stop(lPin5, lPin6); // 左モータを停止
forward(rPin4, 255, rPin5, rPin6); // 右モータを正転(出力調整: 無=0~255=最大)
delay(30); // この状態を30m秒間維持
}
/*-----*/
else if (lVal < lAlpha && rVal > rAlpha) { // 左センサ=白 かつ 右センサ=黒
forward(lPin4, 255, lPin5, lPin6); // 左モータを正転(出力調整: 無=0~255=最大)
stop(rPin5, rPin6); // 右モータを停止
delay(30); // この状態を30m秒間維持
}
/*-----*/
else if (lVal > lAlpha && rVal > rAlpha) { // 左センサ=黒 かつ 右センサ=黒
forward(lPin4, 255, lPin5, lPin6); // 左モータを正転(出力調整: 無=0~255=最大)
forward(rPin4, 255, rPin5, rPin6); // 右モータを正転(出力調整: 無=0~255=最大)
delay(40); // この状態を40m秒間維持
}
/*-----*/
stop(lPin5, lPin6); // 左モータを停止
stop(rPin5, rPin6); // 右モータを停止
delay(250); // この状態を250m秒間維持
}
/*-----*/
int forward(int pin3, int analog, int pin1, int pin2) { //車体を前進させる関数
analogWrite(pin3, analog);
digitalWrite(pin1, HIGH);
digitalWrite(pin2, LOW);
}
/*-----*/
int stop(int pin1, int pin2) { //車体を停止させる関数
digitalWrite(pin1, LOW);
digitalWrite(pin2, LOW);
}
}
    
```

Figure 10 A sample source code

them in detail.

5.1 Hardware

Figure 8 and the Figure 9 are physical images of the whole parts for a Line Following Robot.

5.2 Software

A sample source code (Figure 10) is written in Processing language, and after a flowchart explains that the Line Following Robot can run on the black curve on a white floor.

College students wrote a source code for a Line Trace Robot. However, elementary school students only modified several parts of a sample code, especially values of both thresholds and PWMs.

6. Lectures for Students and Teachers

The learning points for students in elementary school, students in college, and teachers are summarized in Table 4.

6.1 College Students

College students studied all of the topics of Table 4. Students were assigned to groups of eight people which tried using the PBL (Project Based Learning). They fixed several problems, such as determining parameters for the threshold of Photo reflectors, and values of PWM of DC motors.

Table 4 The courses for students and teachers

Target	College Students	Elementary School Students	Teachers
Date	July 2017 through June 2018	October 2017 through February 2018	December 26, 2017
No. of attendants	43	20	25
Grade	Freshman	4th to 6th	Elementary School to High School
Size of group	7 to 8 persons	4 persons	Individual
Amount of time	90 min × 8	45 min × 5	120 min × 1
Hardware	Arduino UNO	○	×
	LBR-127HLD	○	×
	FA-130	○	×
	TA7291P	○	△
	Breadboards & Jumper Wires	○	×
	Others	○	×
Software	Arduino IDE (Processing)	○	×
	CH340 driver	○	×
	S4A	○	○
	Algorithm	○	△
	PWM	○	○
	Threshold	○	○

6.2 Elementary School Students

Elementary school students only checked the values of Photo reflectors and the gaps between the robot and the course. They determined the parameter values, and after they considered the relationships between the values and phenomenon.

6.3 Teachers

The simple circuit was designed in which an Arduino nano can control both one photo reflector and one DC motor driver IC on the breadboard (Figure 11). The author taught them two topics. The First topic was how they should determine both the threshold of sensors and PWM value for the DC motor. The second topic was how they

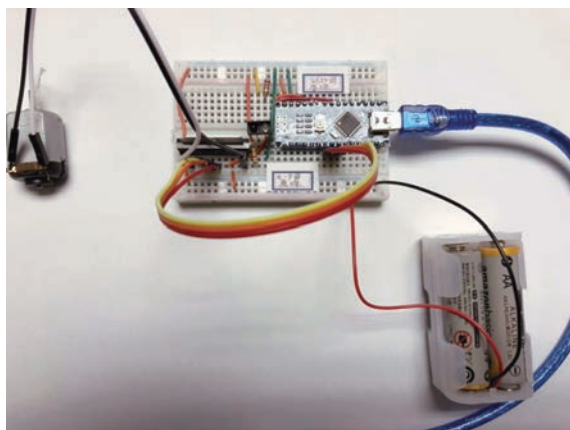


Figure 11 An Arduino can control a photo reflector and DC motor driver IC

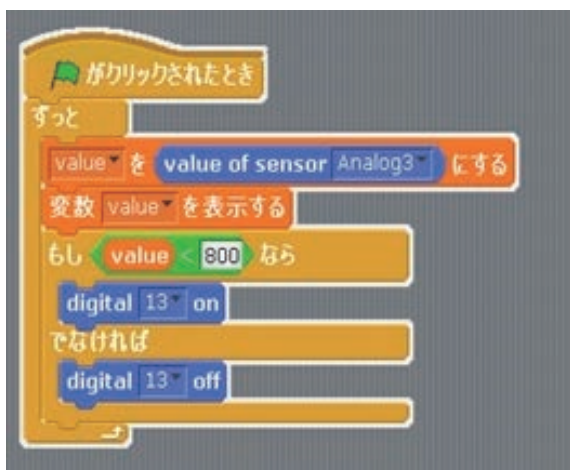


Figure 12 The value of Sensor is connected on D13

could write programs in two languages, Processing and Scratch.

Finally, the author described controlling programs which were a sketch in Processing (Figure 10) and a project in Scratch (Figure 12 and Figure 13).

7. Conclusions

First of all, the robot building is the best learning target for integrating both hardware and software. Second, software, especially programs, can absorb the imbalance among the hardware parts. Thus, students must master this to adjust the parameters by measuring the behaviors. For instance, the thresholds of both photo reflectors distinguishing between black and white on the floor, and the PWM parameter adjusting the torques of both DC motors.

References

- 1) Shouhei YANO and Prawet UEATRONGCHIT, "Computer Vision Guidance of a Line Following

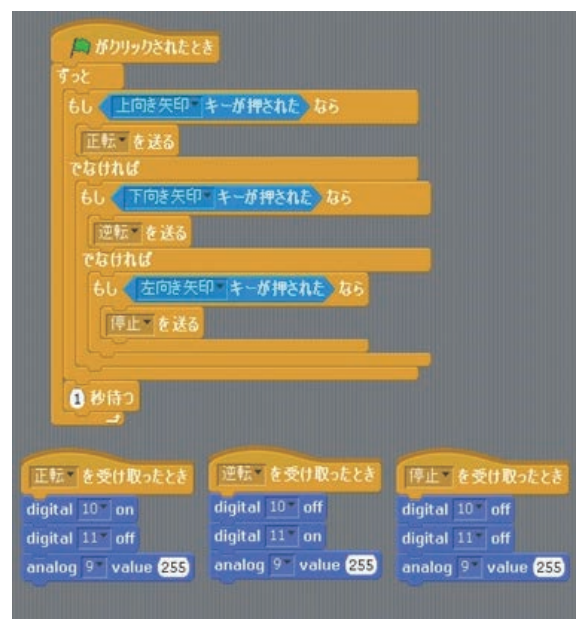


Figure 13 Cursor keys control DC motor in Scratch

Robot using Mobile Phone - Description of How to Create Machines for Contest with Thai-Nichi Institute of Technology”, Memoirs of Nagaoka National College of Technology, No. 50, (2014), pp. 87-96.

2) Arduino IDE

<https://www.arduino.cc/en/main/software>

3) CH340 driver

http://www.wch.cn/download/CH341SER_ZIP.html