



# **An Inexpensive Autonomous Mobile Robot for Undergraduate Education: Integration of Arduino and Hokuyo Laser Range Finders**

## **Course Material**

---

**Yuki Ueyama**

---

**Dept. Mechanical Engineering, National Defense Academy of Japan**

---

# Course plan

---

Week	Learning contents
1	Introduction
2~3	Programming basis
4	Feedback control using LRF
5~8	Project work
9	Preparing presentation
10	Presentation

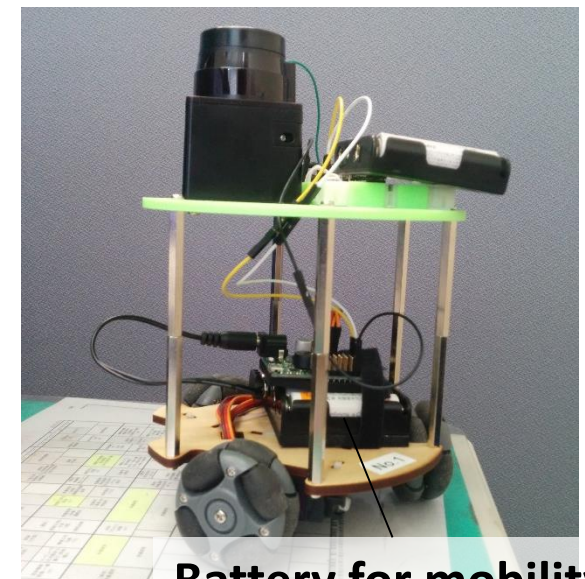
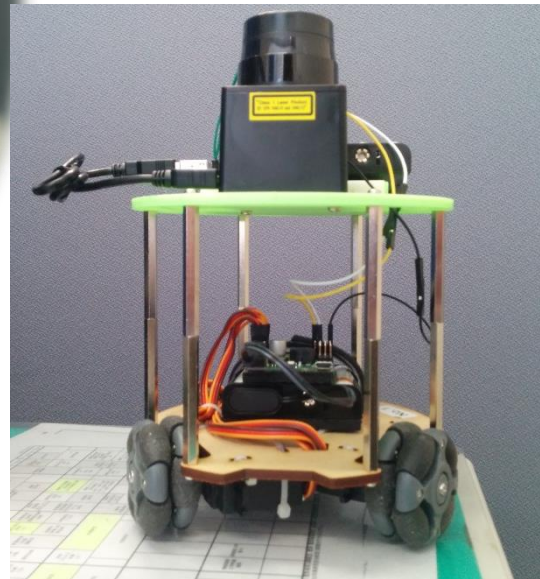
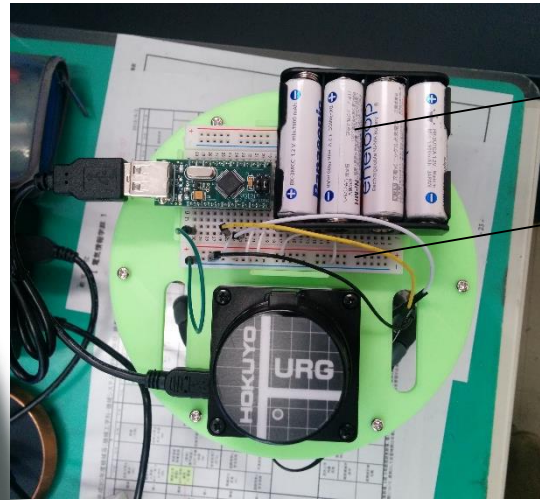
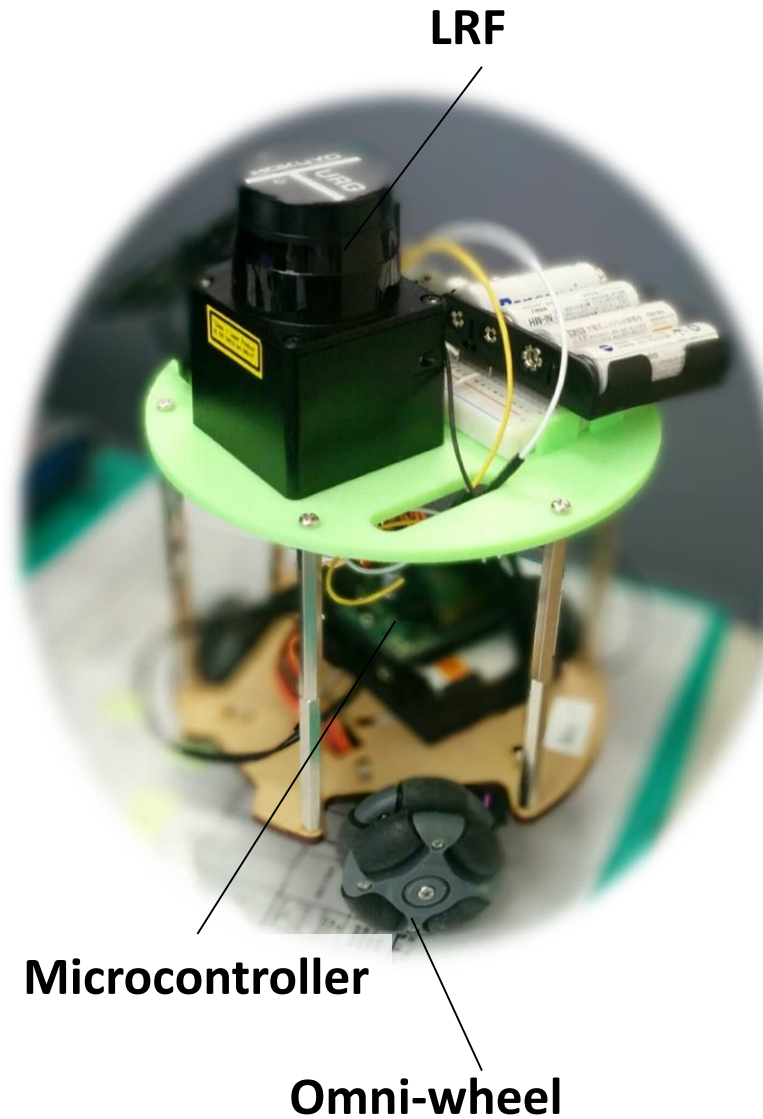
---

# Autonomous mobile vehicle



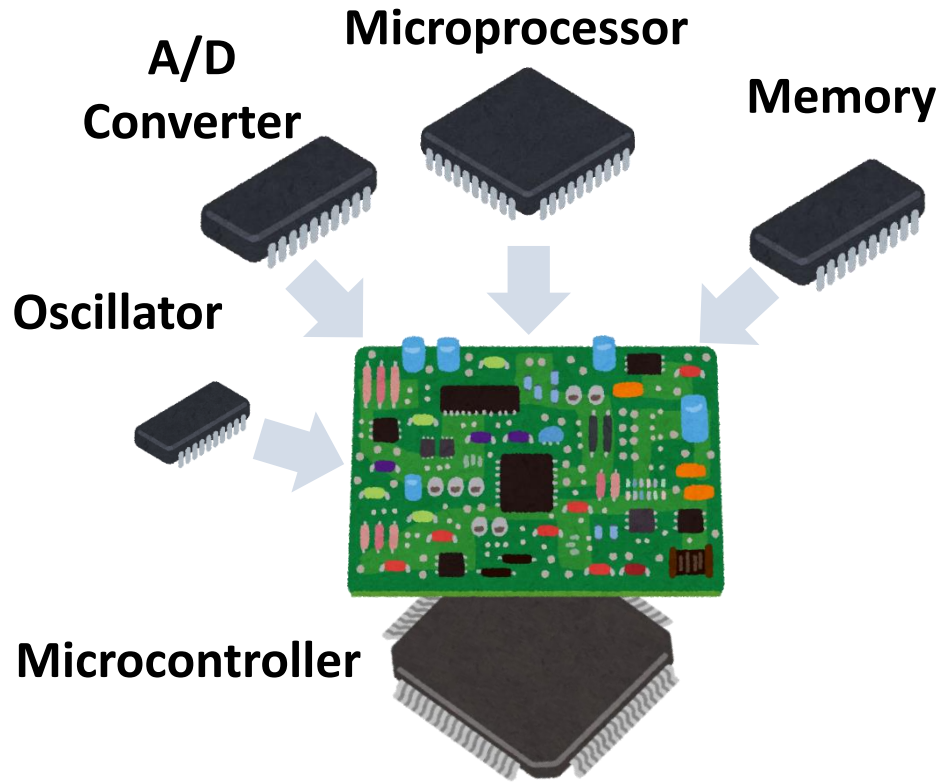
LiDAR (Light detection and ranging)  
LRF (Laser range-finder)

# Robot used in this course



Battery for mobility

# Microcontroller



## Arduino boards:

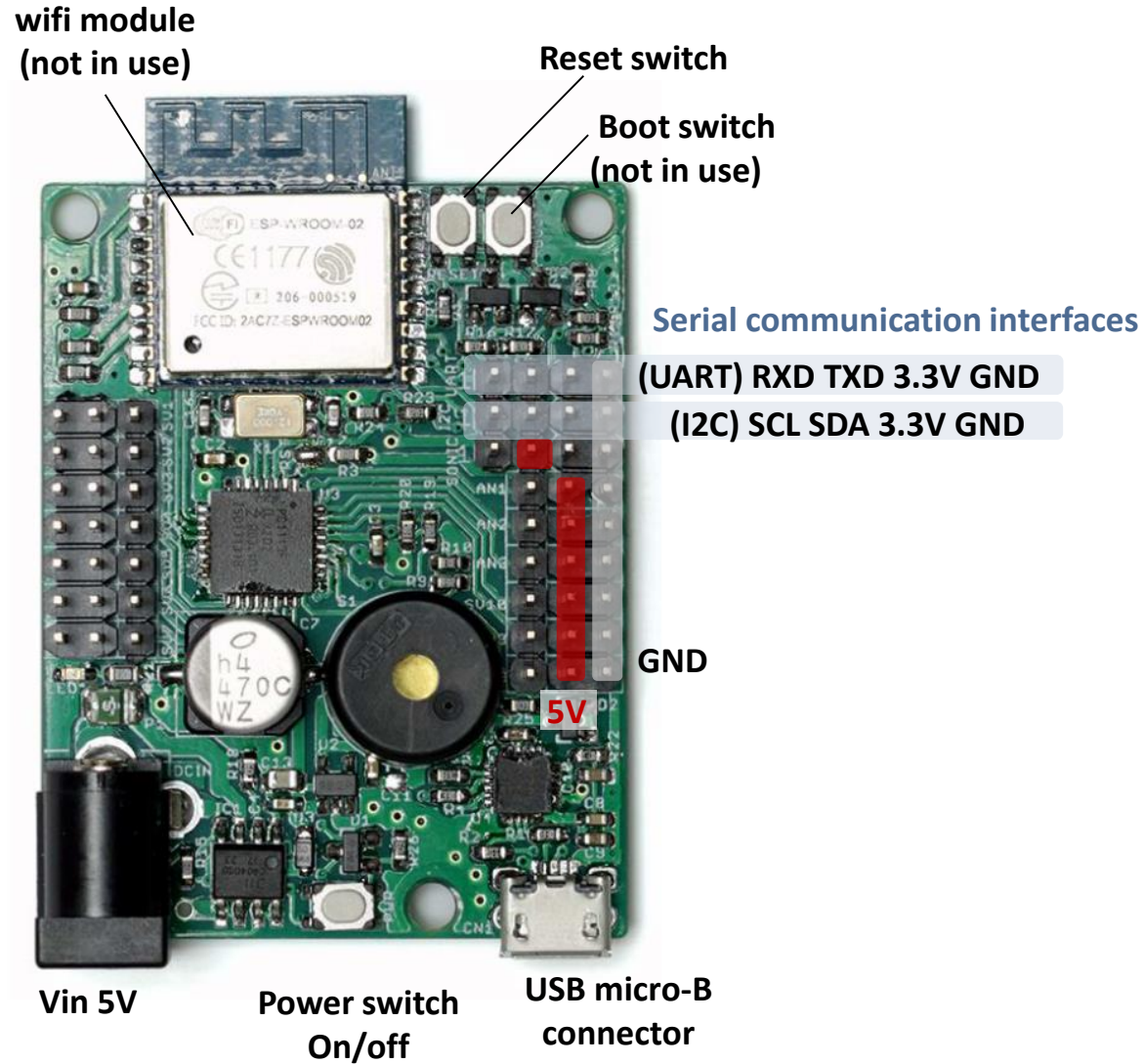


- Small computer integrated into an IC chip.
  - Processor, Memory, I/O
- Compact & low-cost.
- Embedded in appliances.

- Arduino is a family of single-board microcontrollers as open-source design.
- Easy to use for development and prototyping.



## v-duino board (Compatible with Arduino)



---

# Embedded programming

---

- Variable
  - Conditional statements (IF, ELSE)
  - Loop iteration (FOR, WHILE)
  - Function
  - Arrays
  - Servo motor
  - Serial communication
-

# Arduino program (sketch) structure

```
SerialTest0 | Arduino 1.8.8
ファイル 編集 スケッチ ツール ヘルプ

SerialTest0 $

#include <vs-rc202.h>

void setup() {
  initLib();           //Initilize vs-rc202 library
  servoEnable(1, 1);    //Enable SV1 PWM
  setServoMovingTime(1000); //Set moving time to the target position
  Serial.begin(115200);  // 115200bpsでシリアルポートを開く
}

void loop() {
  setServoDeg(1, 0);    //Set SV1 servo target position
  moveServo();          //Start to move servo
  delay(1200);
  setServoDeg(1, 500);
  moveServo();
  delay(1200);
  /* シリアルモニタ
   に表示*/
  Serial.println("Hello World!");
}
```

SerialTest0, 26 MHz, 40MHz, DIO, 2M (1M SPIFFS), 2, v2 Lower Memory, Disabled, None, Only Sketch, 115200

## Library (header file)

- Loads a set of functions for control motors.

## setup() function

- Called when a sketch starts.

## loop() function

- Loops consecutively, after executing a setup() function.

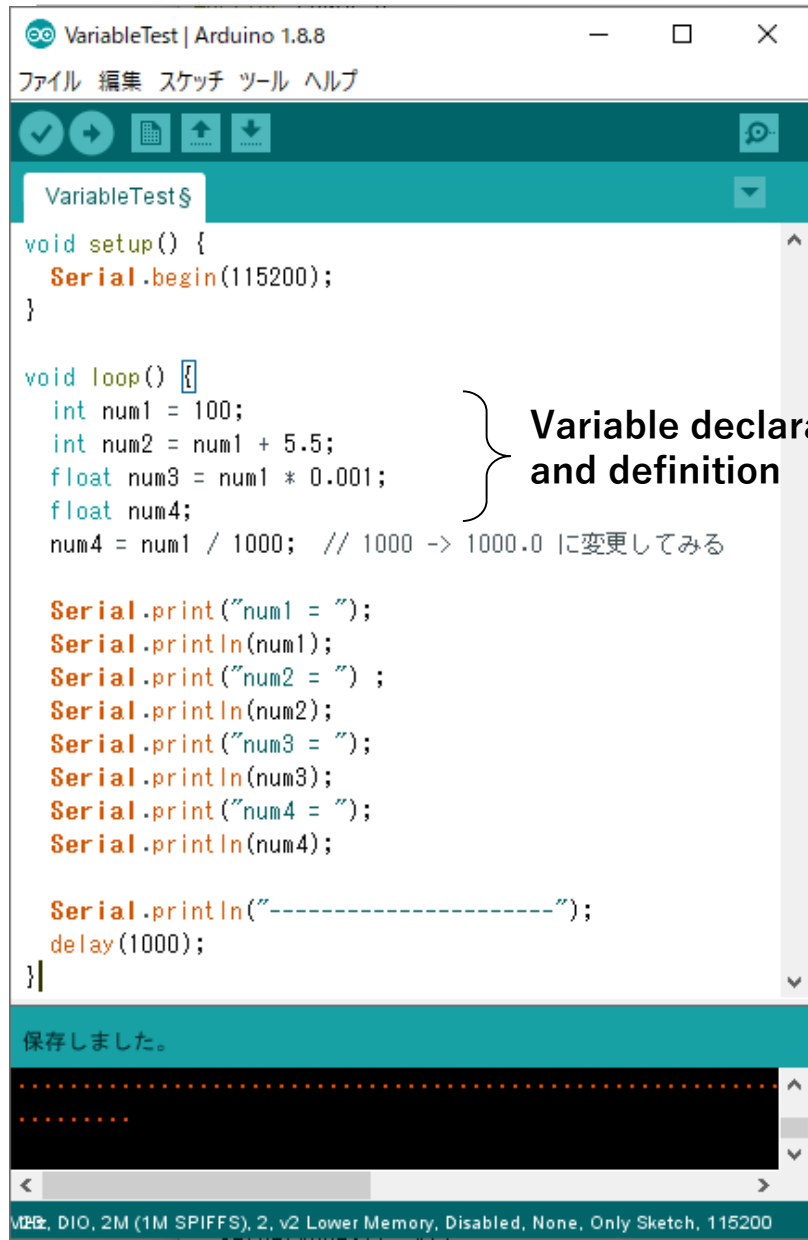
Serial monitor  
(Outputs of the sketch)

```
COM6
Hello World!
Hello World!
Hello World!
Hello World!
Hello World!
```

☒ 自動スクロール ☐ タイムスタンプを表示 CRおよびLF 115200 bps 出力をクリア



# Variable



```
void setup() {  
  Serial.begin(115200);  
}  
  
void loop() {  
  int num1 = 100;  
  int num2 = num1 + 5.5;  
  float num3 = num1 * 0.001;  
  float num4;  
  num4 = num1 / 1000; // 1000 -> 1000.0 に変更してみる  
  
  Serial.print("num1 = ");  
  Serial.println(num1);  
  Serial.print("num2 = ");  
  Serial.println(num2);  
  Serial.print("num3 = ");  
  Serial.println(num3);  
  Serial.print("num4 = ");  
  Serial.println(num4);  
  
  Serial.println("-----");  
  delay(1000);  
}
```

Variable declaration  
and definition

**int num1 = 100;**

Type    Variable's name    Value  
(Not necessary for  
the declaration)

Type	Description
void	Represents the absence of type.
char	A single octet (one byte).
int	Integer value.
float	Floating point value.

- A variable is a storage location paired with an associated symbolic name.
- Required to choose a type of variable according to data.

# IF/ELSE 1/2

Arduino 1.8.8

ファイル 編集 スケッチ ツール ヘルプ

✓ → 📄 ⬆ ⬇

IfTest

```
void setup() {
  Serial.begin(115200);
}

int counter = 0;

void loop() {
  Serial.print(counter);

  if(counter < 10){
    Serial.println(": 10未満");
  }
  else if(counter == 10){
    Serial.println(": 10と等しい");
  }
  else{
    Serial.println(": 10より大きい");
  }

  counter = counter + 1;
  delay(1000);
}
```

ボードへの書き込みが完了しました。

1024, DIO, 2M (1M SPIFFS), 2, v2 Lower Memory, Disabled, None, Only Sketch, 115200

**Global variable**

- Declared outside of a loop() function.

```
if (condition A) {
    // Do stuff if the condition A is true.
}
else if (condition B){
    // Do stuff only if the condition A is false,
    // and the condition B is true.
}
else {
    // Do stuff if both of the conditions A and B are false.
}
```

## Multiple conditions :

(and)

```
if (condition A && condition B) {
    // Do stuff if both of the conditions A and B are true.
}
```

(or)

```
if (condition A || condition B) {
    // Do stuff
    // if at lease one of the conditions A and B is true.
}
```

# IF, ELSE 2/2

## Conditional expressions :

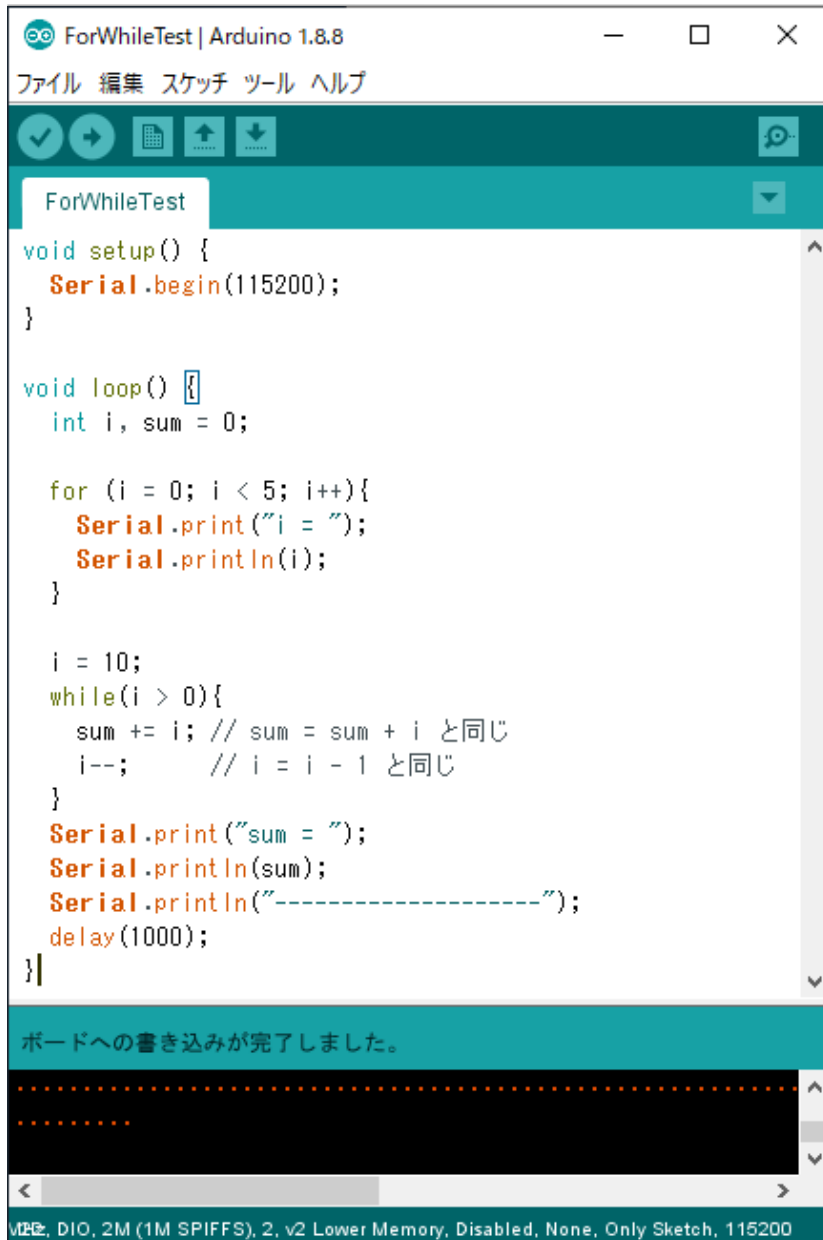
Exp	Description
A == B	Equal A to B.
A != B	Not equal A to B.
A < B	A is less than B.
A > B	A is grater than B.
A <= B	A is less than or equal to B.
A >= B	A is greater than or equal to B.

## Switch case :

```
switch (variable) {  
    case value1 :  
        // Do stuff if variable = value1  
        break;  
    case value2 :  
        // Do stuff if variable = value2  
        break;  
    case value3 :  
        // Do stuff if variable = value3  
        break;  
        .  
        .  
        .  
    default :  
        // Do stuff if there is no match above cases  
}  

```

# FOR, WHILE



The screenshot shows the Arduino IDE interface. The title bar reads 'ForWhileTest | Arduino 1.8.8'. The menu bar includes 'ファイル', '編集', 'スケッチ', 'ツール', and 'ヘルプ'. The toolbar contains icons for checking, running, serial monitor, and uploading. The sketch name 'ForWhileTest' is shown in a dropdown menu. The main text area contains the following code:

```
void setup() {  
  Serial.begin(115200);  
}  
  
void loop() {  
  int i, sum = 0;  
  
  for (i = 0; i < 5; i++){  
    Serial.print("i = ");  
    Serial.println(i);  
  }  
  
  i = 10;  
  while(i > 0){  
    sum += i; // sum = sum + i と同じ  
    i--;     // i = i - 1 と同じ  
  }  
  Serial.print("sum = ");  
  Serial.println(sum);  
  Serial.println("-----");  
  delay(1000);  
}
```

At the bottom, a status bar indicates 'ボードへの書き込みが完了しました。' (Upload completed). The bottom-most status bar shows hardware details: 'USB, DIO, 2M (1M SPIFFS), 2, v2 Lower Memory, Disabled, None, Only Sketch, 115200'.

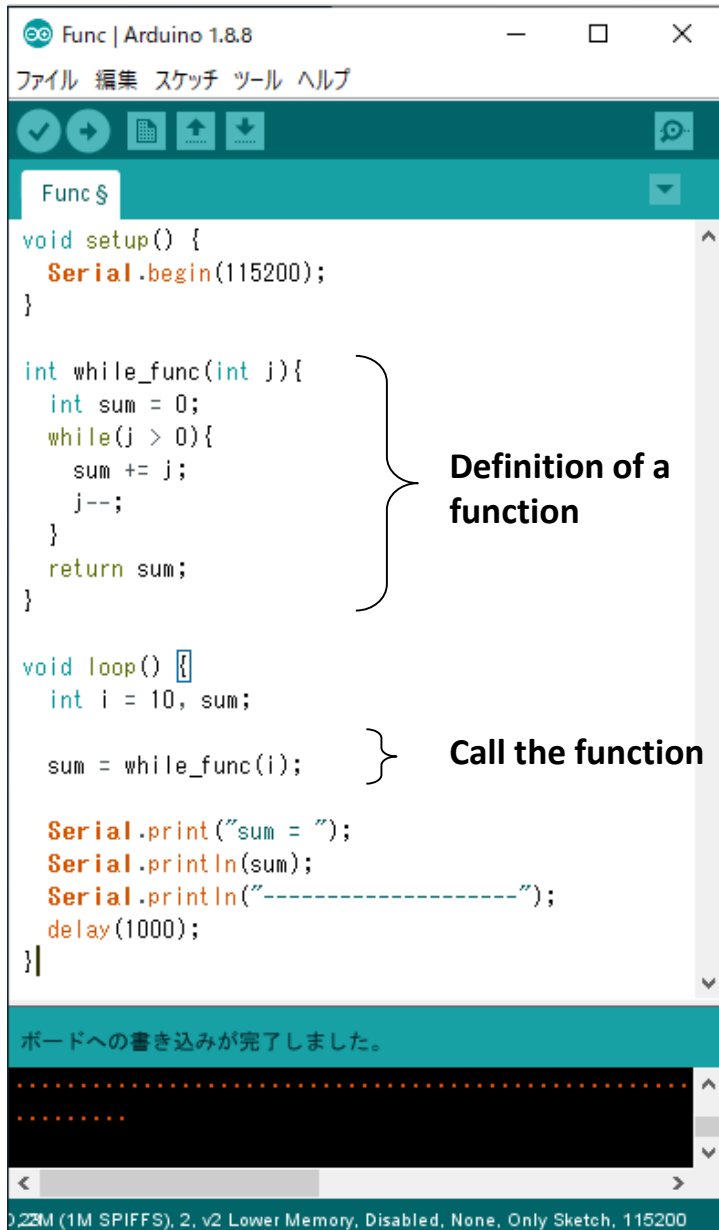
## for loop :

```
for (initialization; condition ; increment) {  
    // Do stuff repeatedly for the condition is true.  
    .  
    .  
    .  
}
```

## while loop :

```
while (condition A) {  
    // Do stuff repeatedly while the condition A is true.  
    .  
    .  
    .  
}
```

# Function



The screenshot shows the Arduino IDE interface with a sketch named 'Func'. The code is as follows:

```
void setup() {  
  Serial.begin(115200);  
}  
  
int while_func(int j){  
  int sum = 0;  
  while(j > 0){  
    sum += j;  
    j--;  
  }  
  return sum;  
}  
  
void loop() {  
  int i = 10, sum;  
  
  sum = while_func(i);  
  
  Serial.print("sum = ");  
  Serial.println(sum);  
  Serial.println("-----");  
  delay(1000);  
}
```

Annotations in the image:

- A bracket on the right side of the `while_func` function definition is labeled "Definition of a function".
- A bracket on the right side of the `sum = while_func(i);` line in the `loop` function is labeled "Call the function".

At the bottom, a status bar indicates "ボードへの書き込みが完了しました。" (Upload to board completed.) and a progress bar shows the upload progress.

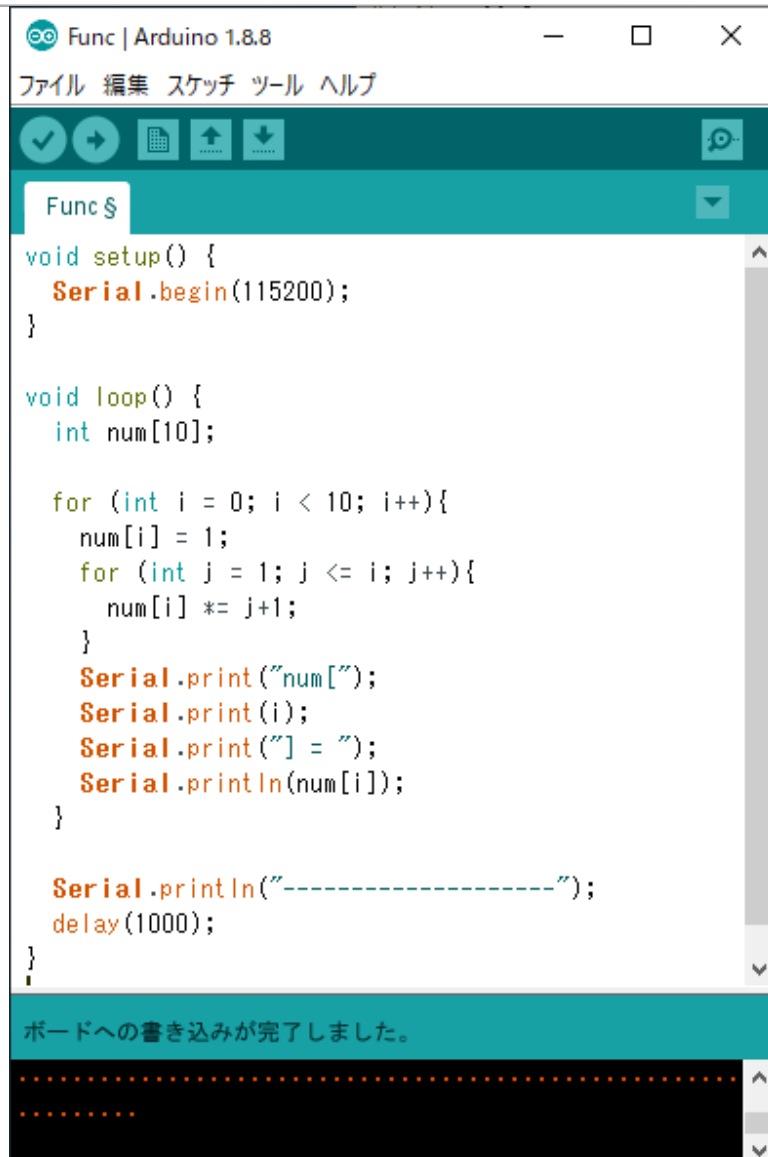
## Function with return value :

```
Return-type function (argument1, argument2, ...) {  
    // statements  
    .  
    .  
    .  
    return value;  
}
```

## Function without return value :

```
void function (argument1, argument2 , ...) {  
    // statements  
    .  
    .  
    .  
}
```

# Arrays



```
Func | Arduino 1.8.8
ファイル 編集 スケッチ ツール ヘルプ

Func $
void setup() {
  Serial.begin(115200);
}

void loop() {
  int num[10];

  for (int i = 0; i < 10; i++){
    num[i] = 1;
    for (int j = 1; j <= i; j++){
      num[i] *= j+1;
    }
    Serial.print("num[");
    Serial.print(i);
    Serial.print("] = ");
    Serial.println(num[i]);
  }

  Serial.println("-----");
  delay(1000);
}
```

ボードへの書き込みが完了しました。

**int num[3] = {1, 2, 3};**

Type      Array name[size]      Initial values  
(Required unique name)      (Not necessary for declaration)

num[0]	num[1]	num[2]
1	2	3

If the size of the array is 3, the array is start from index 0 as num[0] to last to index 2 as num[2].

**Two-dimensional array :**

**int num[2][2] = {{1, 2}, {3, 4}};**

num[0][0]	1	2	num[0][1]
num[1][0]	3	4	num[1][1]



# Servo motor using serial comm

```
SerialTest | Arduino 1.8.8
ファイル 編集 スケッチ ツール ヘルプ

SerialTest$

#include <vs-rc202.h>

void setup() {
  initLib();           //Initialize vs-rc202 library
  servoEnable(1, 1);    //Enable SV1 PWM
  setServoMovingTime(1000); //Set moving time to the target posit
  Serial.begin(115200);  // 115200bpsでシリアルポートを開く
}

int spd = 0;

void loop() {
  char sgn;           // + or -

  if (Serial.available() > 0) { // 受信したデータが存在する
    sgn = Serial.read();

    if (sgn == '+') { // 入力された文字が+のとき
      spd = spd + 100;
    } else if (sgn == '-') { // 入力された文字が-のとき
      spd = spd - 100;
    }
  }

  setServoDeg(1, spd); //回転速度をspdに設定
  moveServo();
  delay(1200);

  Serial.print("回転速度:"); // 受信データを表示
  Serial.println(spd);
}

630Hz, 40MHz, DIO, 2M (1M SPIFFS), 2, v2 Lower Memory, Disabled, None, Only Sketch, 115200
```

Press 'Enter' after input '+' or '-'.

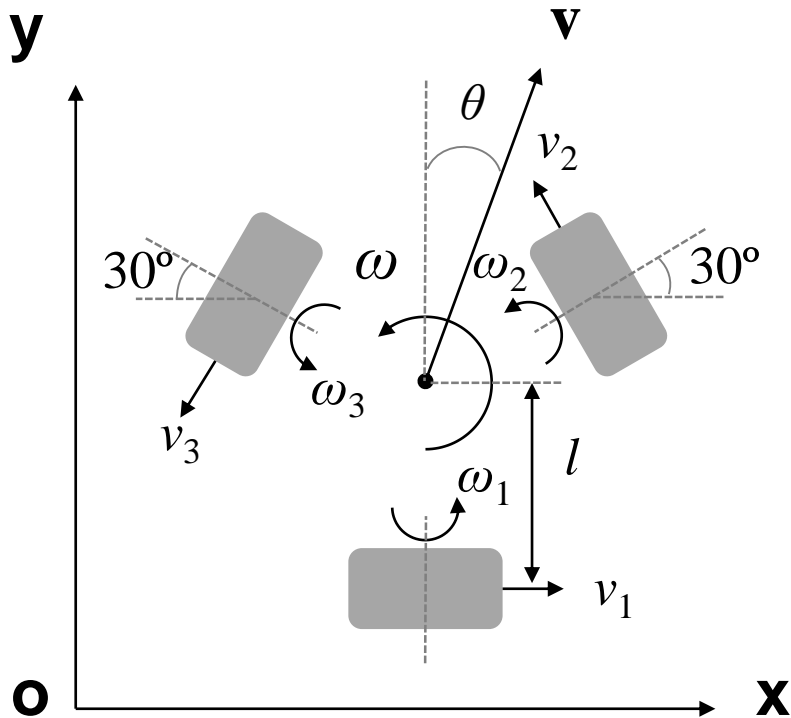
```
COM6
+| 送信

回転速度:0
回転速度:100
回転速度:100
回転速度:100
回転速度:100
回転速度:100
回転速度:0
回転速度:0
回転速度:0
回転速度:0
回転速度:0
回転速度:0
回転速度:0
回転速度:0

☒ 自動スクロール ☐ タイムスタンプを表示
CRおよびL... 115200 bps 出力をクリア
```

# Kinematics of the mobile robot 1/2

Velocity in the body coordinates :



$$\mathbf{v} = \begin{bmatrix} v_x \\ v_y \end{bmatrix} = \begin{bmatrix} v \sin \theta \\ v \cos \theta \end{bmatrix}$$

Velocity of the wheels :

$$\begin{bmatrix} v_1 \\ v_2 \\ v_3 \end{bmatrix} = \begin{bmatrix} r\omega_1 \\ r\omega_2 \\ r\omega_3 \end{bmatrix} = \begin{bmatrix} 1 & 0 & l \\ -\sin 30^\circ & \cos 30^\circ & l \\ -\sin 30^\circ & -\cos 30^\circ & l \end{bmatrix} \begin{bmatrix} v_x \\ v_y \\ \omega \end{bmatrix}$$

$r$  : Radius of the wheel

# Kinematics of the mobile robot 2/2

## Relationship between the world and body coordinates :

$$\begin{bmatrix} v_x \\ v_y \end{bmatrix} = \begin{bmatrix} \cos \phi & \sin \phi \\ -\sin \phi & \cos \phi \end{bmatrix} \begin{bmatrix} v_x^w \\ v_y^w \end{bmatrix}$$

$\phi$  : Heading direction of the robot

Velocity in the body coordinates

Velocity in the world coordinates

## Velocity of the wheels :

$$\begin{bmatrix} v_1 \\ v_2 \\ v_3 \end{bmatrix} = \begin{bmatrix} 1 & 0 & l \\ -\sin 30^\circ & \cos 30^\circ & l \\ -\sin 30^\circ & -\cos 30^\circ & l \end{bmatrix} \begin{bmatrix} \cos \phi & \sin \phi & 0 \\ -\sin \phi & \cos \phi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} v_x^w \\ v_y^w \\ \omega \end{bmatrix}$$

$$= \begin{bmatrix} \cos \phi & \cos \phi & l \\ -\sin(\phi + 30^\circ) & \cos(\phi + 30^\circ) & l \\ \sin(\phi - 30^\circ) & -\cos(\phi - 30^\circ) & l \end{bmatrix} \begin{bmatrix} v_x^w \\ v_y^w \\ \omega \end{bmatrix}$$

where

$$\phi = \int \omega dt$$

# Feedforward control

---

- Make a sketch to circle around an obstacle.

---

# Feedback control using LRF

---

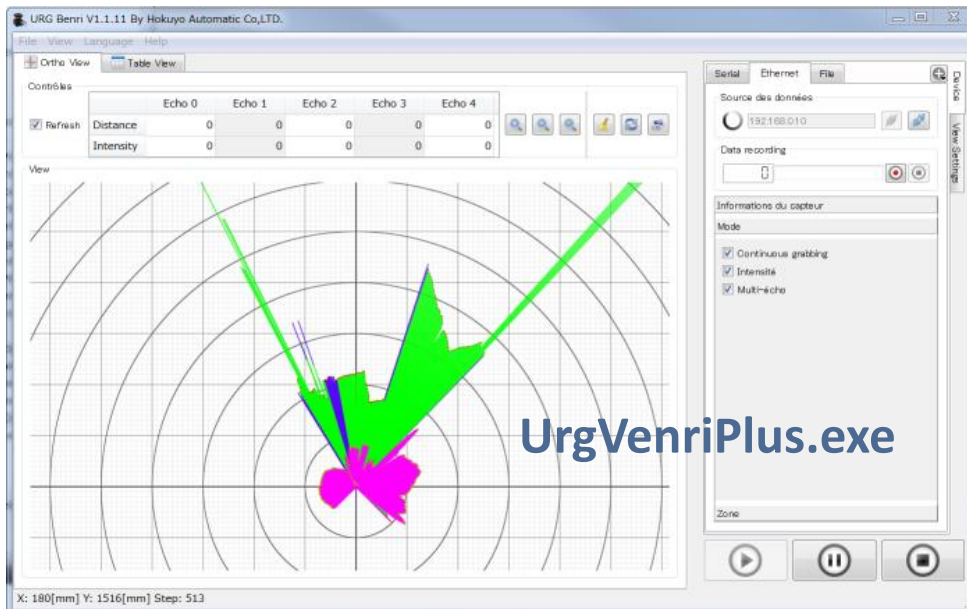
- Operation verification of Hokuyo LRF
  - How to use breadboards
  - Connect the LRF to Arduino
  - Control the robot using the LRF
-

# Hokuyo LRF

**URG-04LX-UG01 (Hokuyo automatic)**

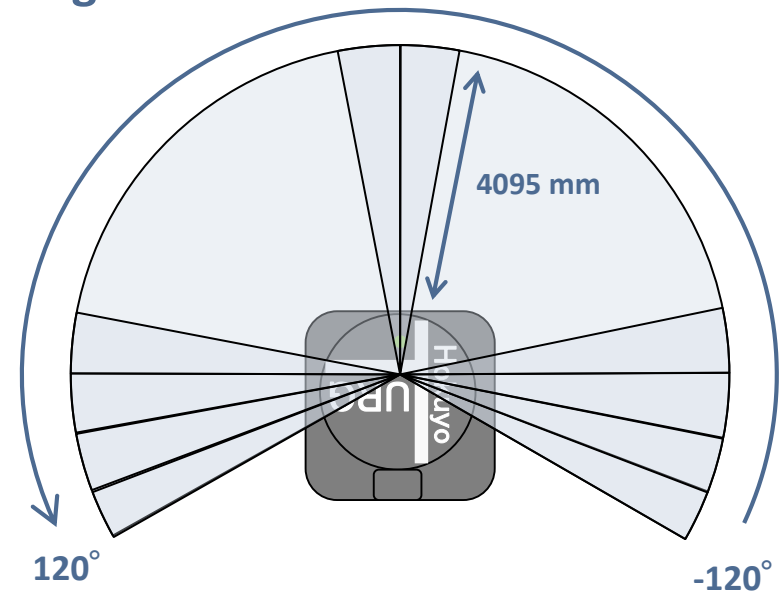


**Operation verification :**



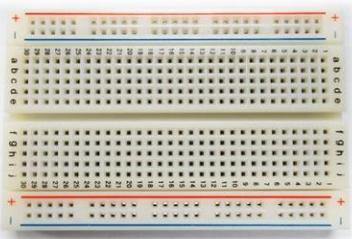
**Measureable range:**

**Scanning direction**



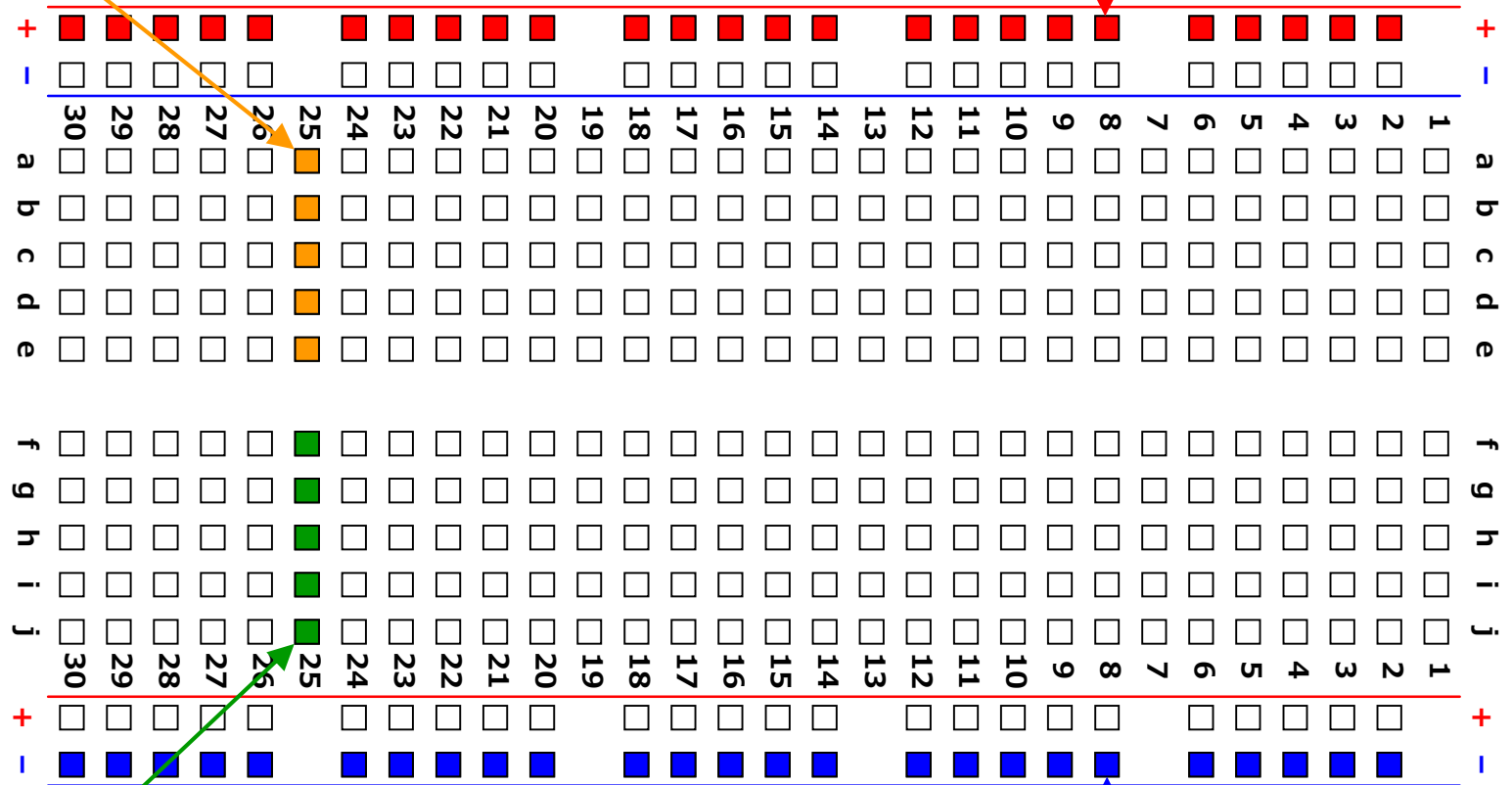


# Breadboard



Conducting (same current flow)

Conducting



Conducting

conduction

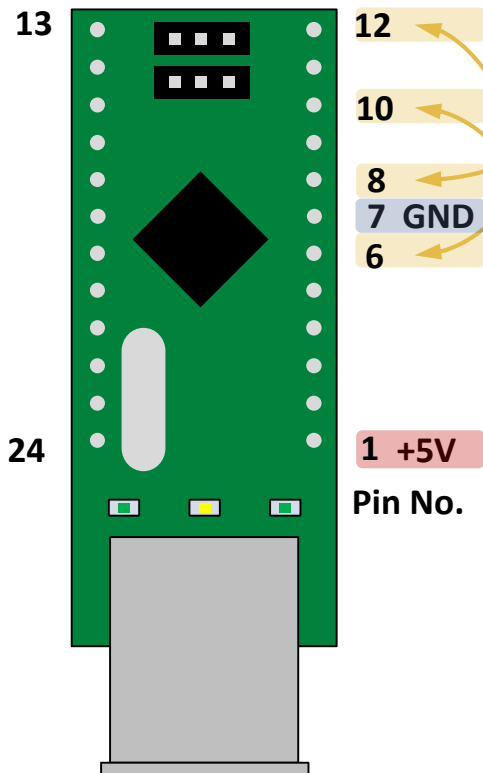
Not conducting between  
lines of (a)-(e) and (f)-(j).

# Connect LFR to v-duino (1) 1/3

## Convert USB to serial comm interface (UART) :

USB host driver (VDIP1)

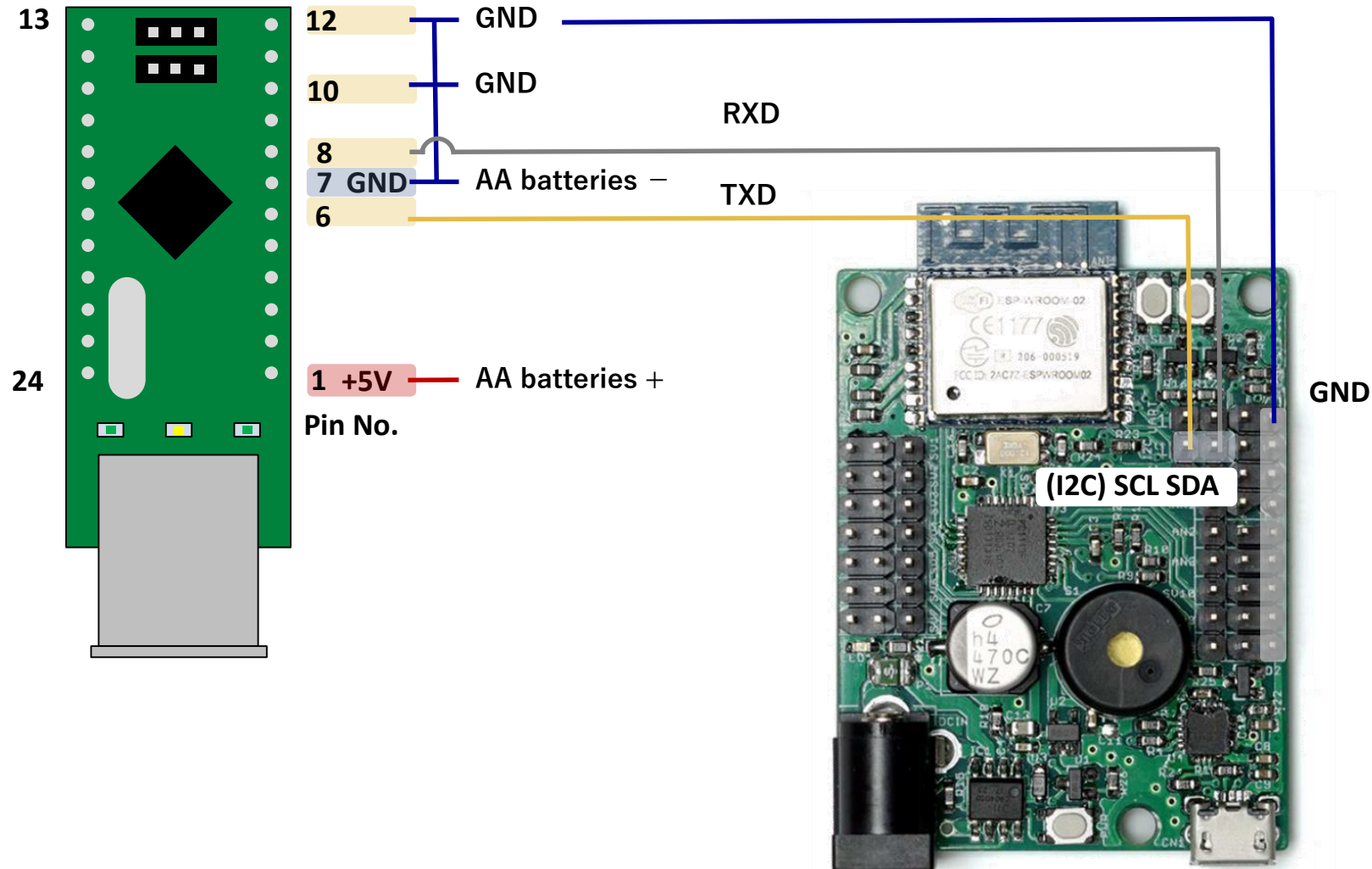
I/O pin configuration for UART interface



No.	Name	Type	Description	
6	TXD	Output	Transmit asynchronous data output	
8	RXD	Input	Receive asynchronous data output	
9	RTS#	Output	Request to send control signal	Not use
10	CTS#	Input	Clear to send control signal	
11	DTR#	Output	Data terminal ready control signal	Not use
12	DSR#	Input	Data set ready control signal	
13	DCD#	Input	Data carrier detect control input	
14	RI#	Input	Ring indicator control input	Not use
15	TXDEN#	Input	Enable transmit data for RS485 designs	

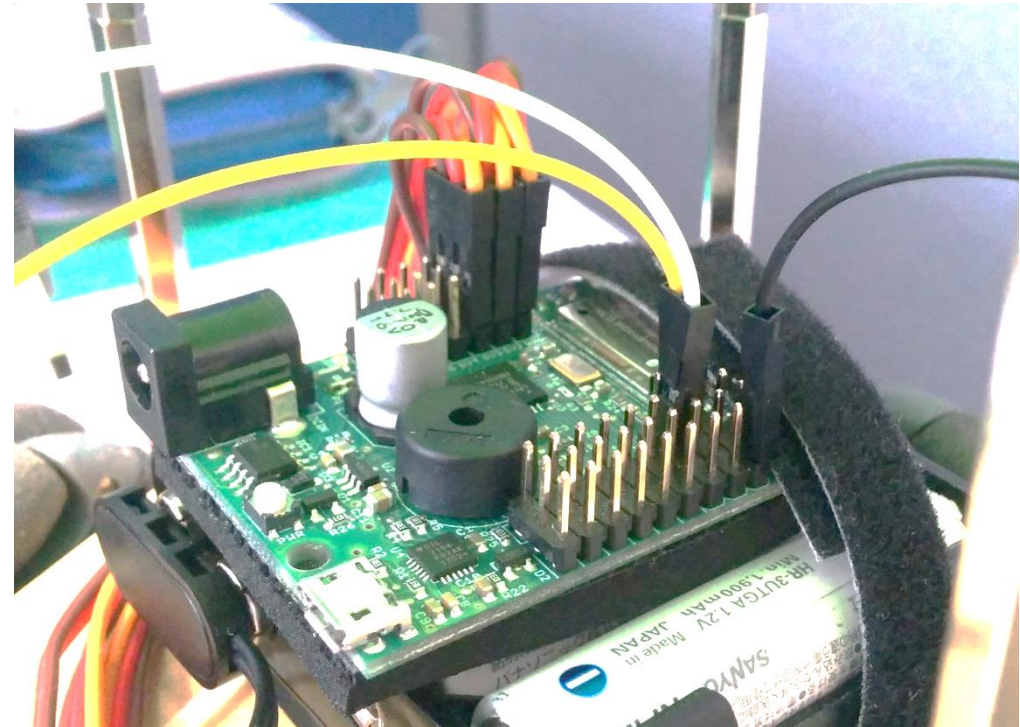
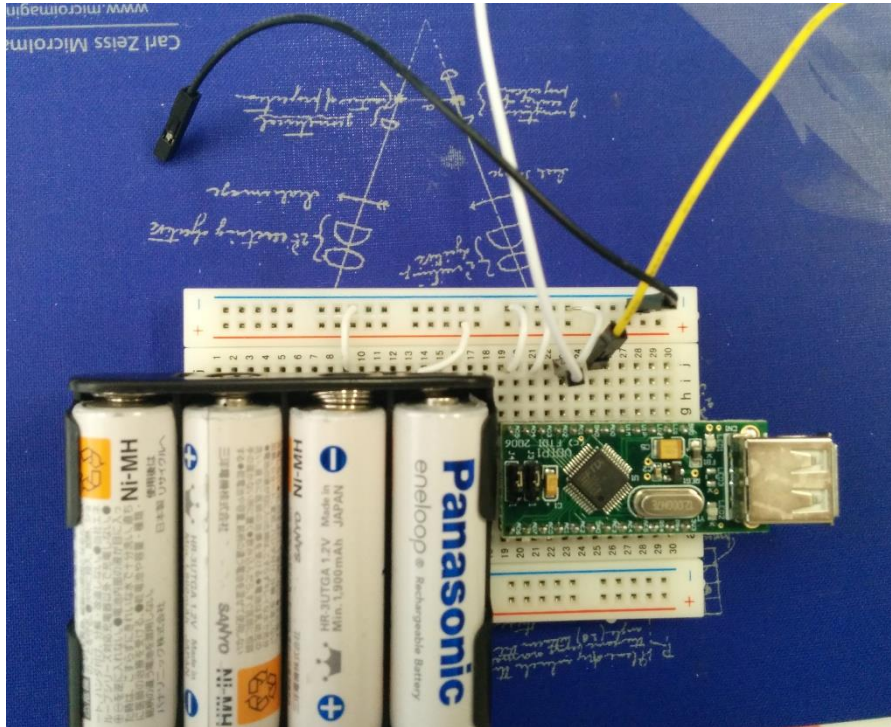
# Connect LFR to v-duino (1) 2/3

## Software serial comm :



# Connect LFR to v-duino (1) 3/3

## Software serial comm :



# Receive data from the LRF

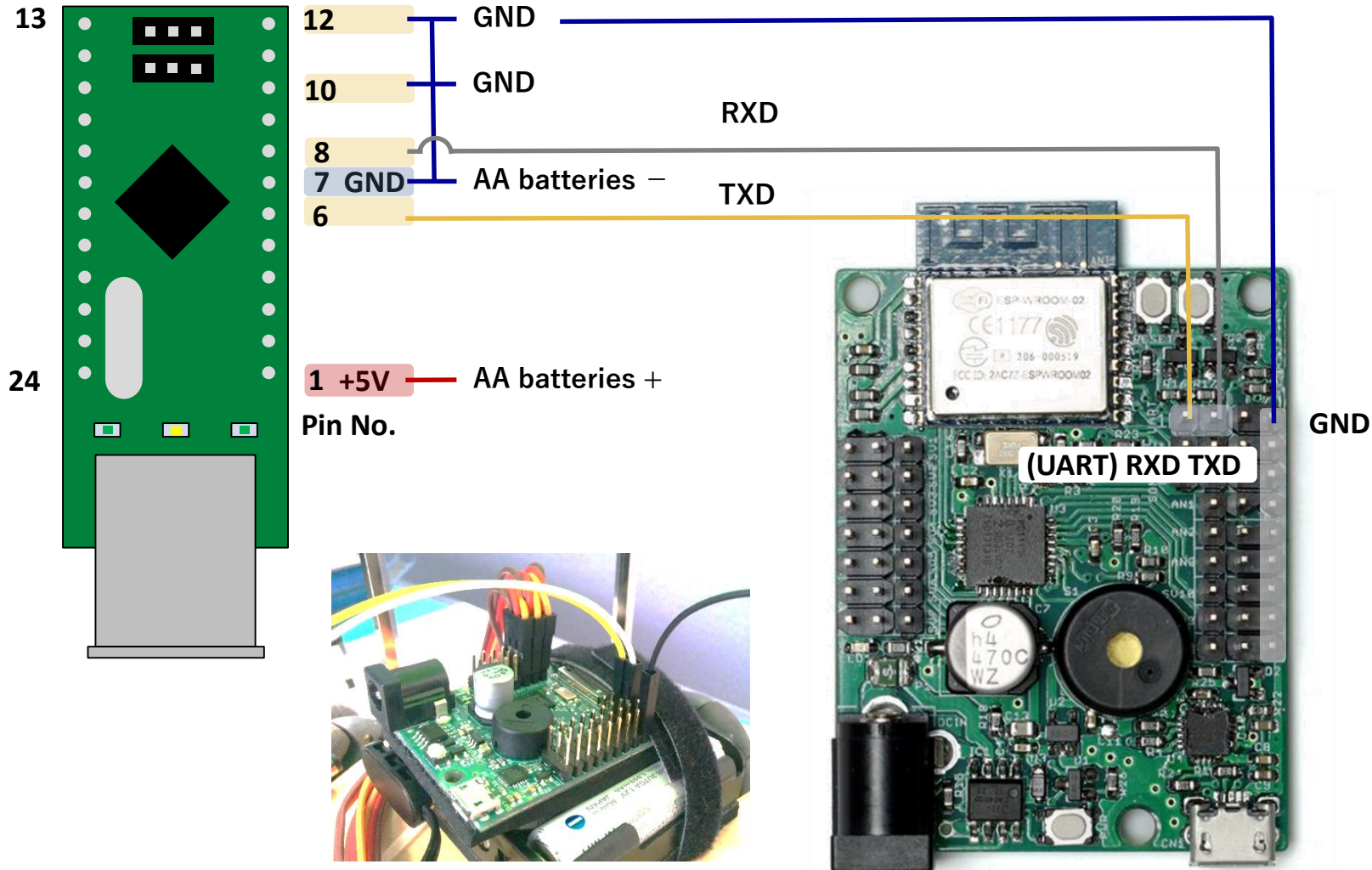
```
COM6
送信
110 - 120 deg: 731 =====
-----
-120 - -110 deg: 422 =====
-110 - -100 deg: 699 =====
-100 - -90 deg: 1208 =====
-90 - -80 deg: 1182 =====
-80 - -70 deg: 1181 =====
-70 - -60 deg: 1191 =====
-60 - -50 deg: 1255 =====
-50 - -40 deg: 1354 =====
-40 - -30 deg: 592 =====
-30 - -20 deg: 478 =====
-20 - -10 deg: 453 =====
-10 - 0 deg: 421 =====
0 - 10 deg: 421 =====
10 - 20 deg: 443 =====
20 - 30 deg: 457 =====
30 - 40 deg: 481 =====
40 - 50 deg: 521 =====
50 - 60 deg: 590 =====
60 - 70 deg: 714 =====
70 - 80 deg: 719 =====
80 - 90 deg: 207 =====
90 - 100 deg: 193 =====
100 - 110 deg: 196 =====
110 - 120 deg: 734 =====
-----
☐ 自動スクロール ☐ タイムスタンプを表示
CRおよびL... 9600 bps 出力をクリア
```

- Execute 'SampleLRF.ino'.
- Detect the range of  $-120^{\circ}$ ~ $120^{\circ}$  with  $10^{\circ}$  separation.
- The maximal detectable length is about 4 m.



# Connect LFR to v-duino (2)

## Hardware serial comm :

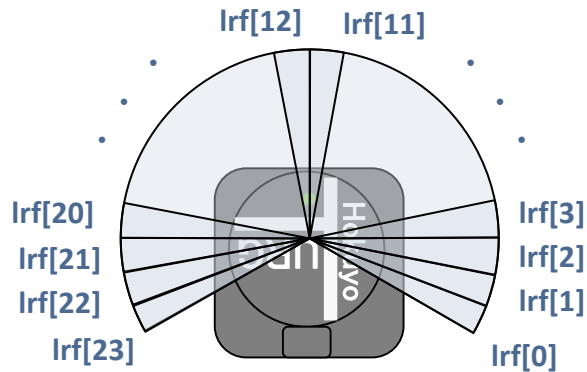




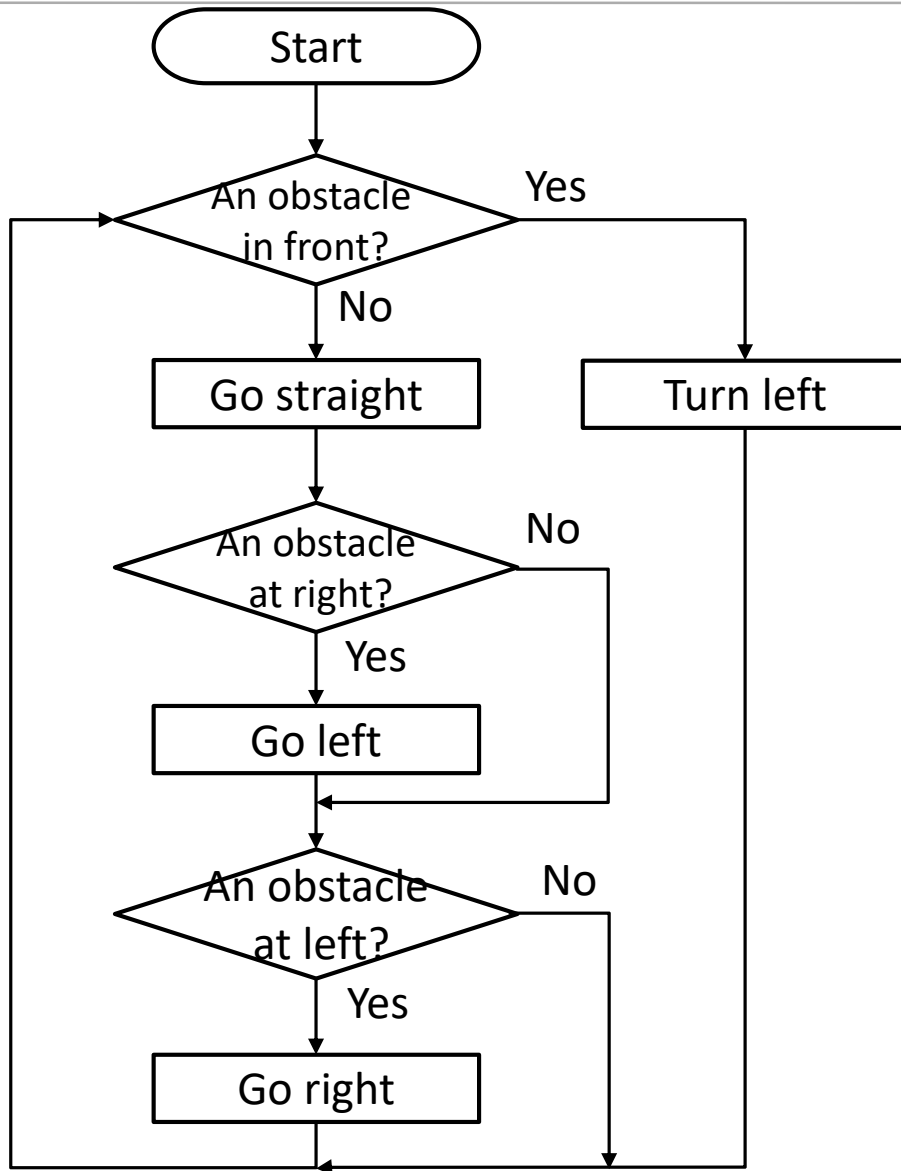
# Feedback control using LRF

- Make a sketch referring 'SampleObstacleAvoidance.ino' to circle around an obstacle using the LRF.

## Data assignment of the LRF :



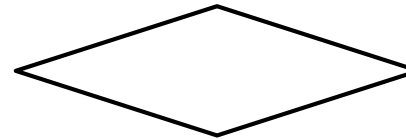
# Flowchart



**Start/end**



**Process**



**Decision (yes/no)**

■ **Make a flowchart of your sketch circling an obstacle.**

# Final Project

---

■ TBA

