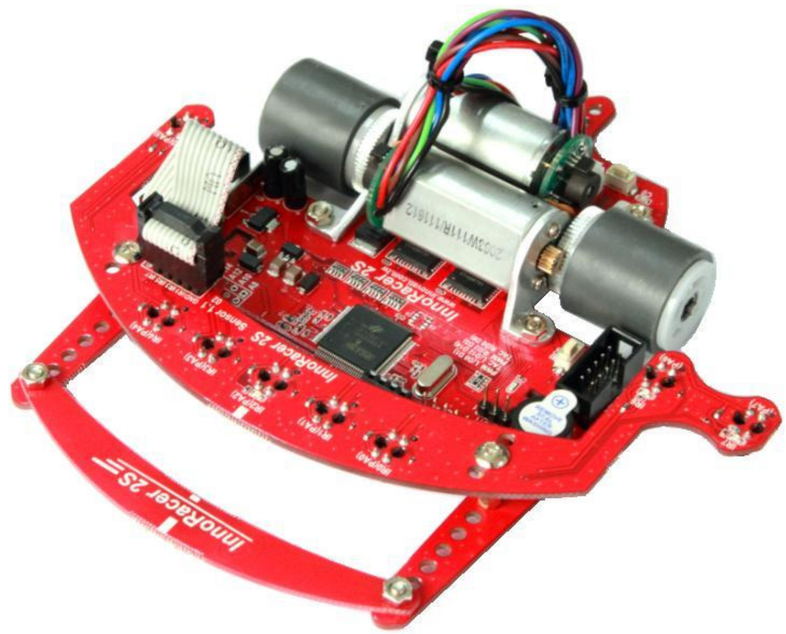
InnoRacer™ 2S User's Guide

Document Revision 1.0

2014.12.10



Passion for innovation

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Errata

We hope that our users will find this user's guide a useful, easy to use and interesting publication, as our efforts to do this have been considerable. Additionally, a substantial amount of effort has been put into this user's guide to ensure accuracy and complete and error free content, however it is almost inevitable that certain errors may have remained undetected. As Innovati will continue to improve the accuracy of its user's guide, any detected errors will be published on its website. If you find any errors in the user's guide please contact us via email service@innovati.com.tw. For the most up-to-date information, please visit our web site at http://www.innovati.com.tw.

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Overview

InnoRacer™ 2S is the second generation of Innovati's InnoRacer™ line follower series. Powered by 32-bit Cortex®-M3 controller running at 72MHz, it is capable of accessing reflective infrared sensors, accelerometer, gyroscope, motor tachometer data and executing PID control at a higher speed than ever and results in its excellent performance in line following competitions. InnoRacer™ 2S is provided with featured library and example program, which make it not only a great racing robot, but also an excellent platform in robotics education.

The program development is based on the KEIL™ C development environment. Featured library is provided to help you be familiar with advanced robotics technique. Should you have any questions, refer to our related Arminno™ user's manual and visit KEIL™ C official website for detailed information.

Features

- Using the Cortex®-M3 chip as controller, users can download and debug their programs through the LINKER board connecting to the InnoRacer™ 2S.
- Five reflective IR sensors for track detection.
- Two reflective IR sensors on the left side for curvature change mark detection.
- One reflective IR sensor on the right side for Start and Goal mark detection.
- A calibration button to adjust IR detection under different ambient lights.
- Reset button to restart the program.
- Four buttons with LEDs for users to define their own functions and indications.
- A buzzer for built-in low battery warning, mark detection or user's functions.
- Library functions for two DC motors 1024 steps speed control.
- PID control library functions for adjusting track following capability.
- Built-in sensors for y-axis acceleration and z-axis gyroscope measurement.
- Library for recording track information, including length, maximum or average acceleration and gyroscope values, curvatures and directions.
- One cmdBUS™ connector for Smart Modules expansion, such as Sonar module.

System Diagram

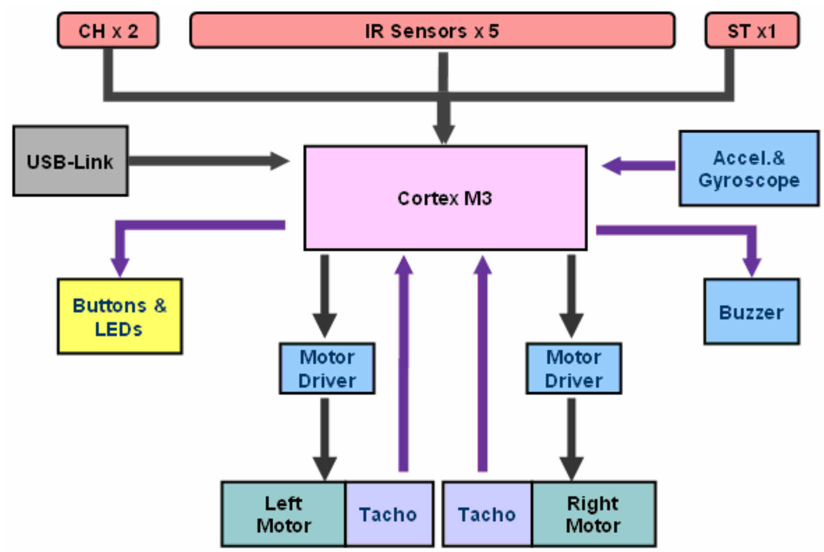

Fig 1 System Diagram

Key Components

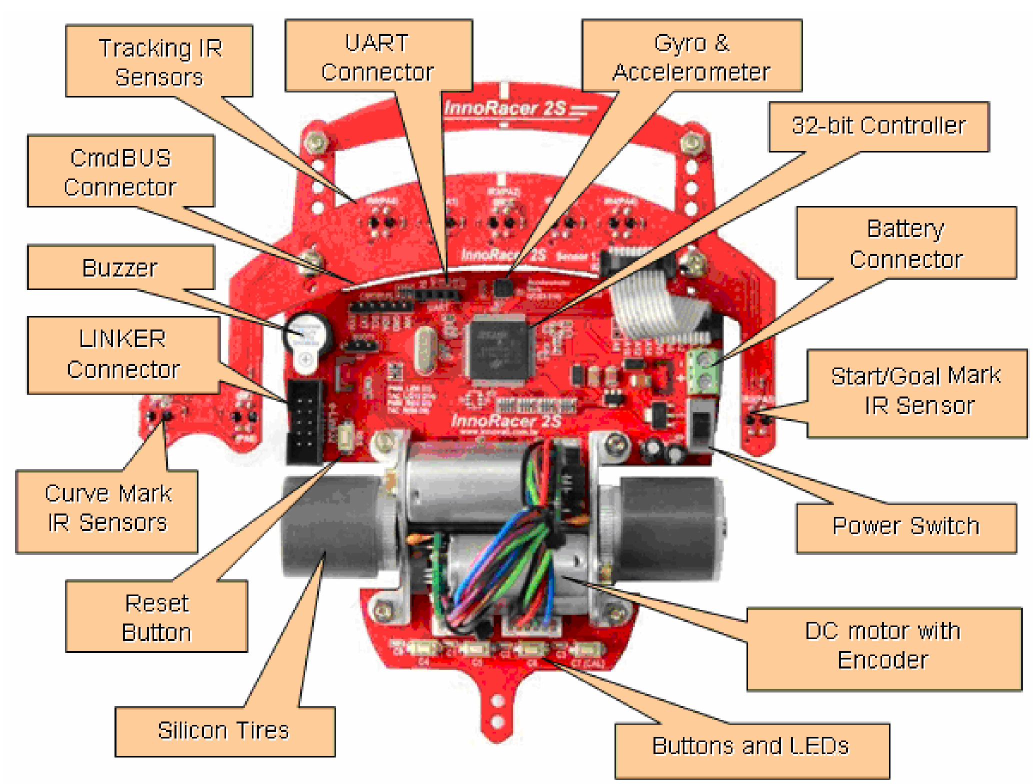

Fig 2 Key Component Placement

Controller – Cortex®-M3

Cortex®-M3 is the main controller of the InnoRacer™ 2S line follower. Users can edit and compile their program with the ARM® Cortex® environment and download through a USB cable to the LINKER board. If you are not familiar with the system, please refer to the relevant manuals for more detailed information.

Reflective Infrared Sensors

In the front of the InnoRacer™ 2S line follower, there are 5 reflective infrared sensors which are used to detect the track. On the right side, there is one infrared sensor which is used to detect the Start or Goal mark, indicating the beginning and the end of the track. On the left side, there are two infrared sensors which are used to detect the curve change marks throughout the whole route. The track is divided into segments for route memorization by the curve change marks.

Due to the different ambient light and surface material, the infrared sensing results may vary under different situations. To eliminate the variance, calibration is required. By long pressing the rightmost button at the tail of the follower labeled CAL, built-in calibration function will be invoked, the LED near the CAL button will be lit to indicate the calibration is in process. Put the InnoRacer™ 2S on the track and move it back and forth slowly with all the infrared sensors passing the black and white area of the track several times. Press the CAL button again to finish the calibration process and the LED will turn off. The infrared detection range of each infrared sensor is measured and normalized internally for analog infrared intensity sensing use.

Buzzer

The buzzer is mainly used to generate automatically a 0.1 seconds beep sound each time a curve change mark is detected during the route memorization process. The buzzer is controlled through the built-in commands. Please refer to the command set for other buzzer-related commands. Nevertheless, you may still use the BuzzerOn() command to generate beep sounds in your own application.

DC Motors

The InnoRacer™ 2S is equipped with two spur brushed DC motors. Hall Effect sensor board is affixed to detect the polarity change of the motor when rotating, through which you can calculate the distance that each wheel has travelled. This information is used for route memorization. Note that the DC motor electric brush wears out when spinning against the mechanical part, the DC motors lifetime is limited. Running at a high speed for a long time will further shorten the life of the DC motors.

Refer to Tutorial Programs section in the appendix for more information about how to control the DC motors with the given speed parameters.

Accelerometer and Gyroscope

The InnoRacer™ 2S is equipped with a three-axial accelerometer and gyroscope to measure the acceleration force in x- and y-axis and angular accelerating force in z-axis, through which you can calculate the curve radius and direction. This information is used for route memorization.

The x-axial acceleration is defined in the lateral axis of the InnoRacer™ 2S and the y-axial acceleration is in the longitudinal axis of the InnoRacer™ 2S. Please refer to the following picture.

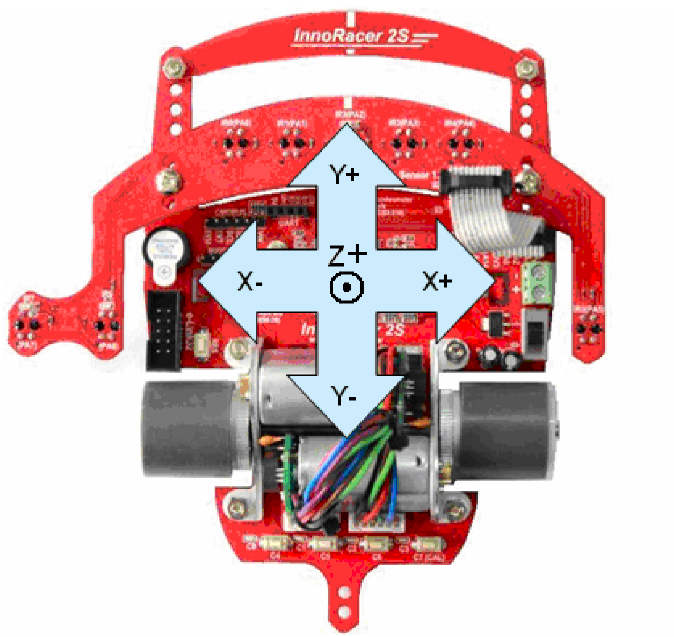

Fig 4 Acceleration Directions

Refer to Tutorial Programs section in the appendix for more information about how to save the current x- and y-axial acceleration values for calibration at a standstill position and display them in the Terminal Window.

Linker Board

Use the Linker Board to download or debug your program to the InnoRacer™. Note that always turn off the power on the line follower first before you plug in or remove the Linker board. Connect the flat cable of the Linker board on the Linker Connector of the InnoRacer™ 2S line follower . Then connect the Linker board to your computer through a USB cable. Now turn on the power of the line follower to download or debug your program. You may use the power from USB cable without turning on the power on the line follower, but function is limited.

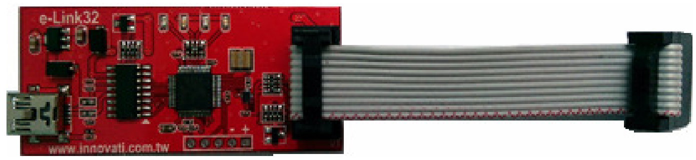

Fig 3 Linker Board with Flat Cable

Batteries and Chargers

The InnoRacer™ 2S is designed to be powered with 11.1 volts LiPO battery pack. Note that a low battery situation may cause permanent damage to the LiPO battery pack, turn on the low battery warning function all the time to protect your battery. To power the line follower, the slide switch on the right side should be slide to 1 position.

Command Set

The following table lists all the unique commands provided for the InnoRacer 2S. Note that essential words in the commands will be written in **bold** type and ***italics*** bold type. The bold type word must be written exactly as shown, whereas the italic bold type words must be replaced with user values. Note that the C language is case-sensitive.

To invoke the functions, declare innoRacer2 class first in your program, for instance, **innoRacer2** ***myRacer***.

Command Syntax	Description
Motor Speed Control Commands	
ForwardL(*Speed*)	Sets the forward/backward speed of left or right side motor by ***Speed*** or both ***SpeedL*** and ***SpeedR*** ranging from 0 ~ 1024 respectively. The motor rotating
ForwardR(*Speed*)	
ForwardLR(*SpeedL*, *SpeedR*)	

BackwardL(*Speed*) **BackwardR(*Speed*)** **BackwardLR(*SpeedL*, *SpeedR*)**	direction is defined from the InnoRacer™ 2S viewpoint. You may use the **SetVal** commands, which use positive and negative values for different rotation direction, instead of forward and backward terms.
StopL() **StopR()** **StopDual()**	Stops left, right or both motors.
BrakeL() **BrakeR()** **BrakeDual()**	Brakes left, right or both motors.
SetVelL(*Vel*) **SetVelR(*Vel*)** **SetVelLR(*VelL*, *VelR*)** **SetVelDual(*Vel*)**	Sets the speed of the motor A, B or both specified by ***Vel*** or both ***VelA*** and ***VelB*** ranging from -1024 ~ 1024 respectively. The absolute value stands for speed and positive and negative sign stands for rotation direction.
SetMotorDeadZone(*Speed*)	Motors start to rotate at a minimum current. Use ***Speed*** to specify the current with its PWM value. Usually a value around 130 of PWM duty is proper.
Infrared Sensing Commands	
GetIr(*IR*)	Gets the digital values (1 or 0) of all eight infrared sensors, combining in one data byte with value ranging from 0 ~ 255 and stores in variable ***IR***. The five least-significant bits for line tracking sensors and the higher 3 bits for start/goal and curve changing mark detection.
GetAnalogIr(*ID*, *IR*)	Gets the infrared intensity value ranging from 0 ~ 4095 and stores in variable ***IR***. The infrared sensor unit is specified by ***ID*** ranging from 0 ~ 7.
IrCal(*Mode*)	Sets the IR calibration mode by ***Mode*** ranging from 0 ~ 4. 0: Calibrate until calibration button pressed. 1: Calibrate for 10 seconds and exit calibration. 2: Calibrate for 20 seconds and exit calibration. 3: Calibrate for 30 seconds and exit calibration. 4: Calibrate for 60 seconds and exit calibration.
GetIrCal(*ID*, *Min*, *Max*)	Gets the minimum and maximum infrared intensity of specified IR sensor during calibration and stores them in variable ***Min*** and ***Max***. The IR sensor is specified by

	ID ranging from 0 ~ 7. The infrared intensity value ranges from 0 ~ 4095.
SetIrThreshold(*Rate*)	Sets the threshold percentage value specified by ***Rate*** ranging from 0 ~ 100. You can use this setting to change the infrared sensibility. The default value is 50.
SetIrMode(*Mode*)	Sets the IR sensors track detection method by ***Mode*** with value 0 for digital mode or 1 for analog mode. The default value is 0.
SetIrMask(*Mode*)	Sets the curve changing mark IR detection method by ***Mode***. With value 0, both IR6 and IR7 are used for detection; value 1, only IR6 is used for detection; value 2, only IR7 is used for detection.
PID Commands	
SetP(*Val*)	Sets the P, I or D parameter by ***Val***. The value ranges from 0 ~ 255.
SetI(*Val*)	
SetD(*Val*)	
SetScalar(*Val*)	Sets the PID parameters scalar by ***Val***, as a multiple of the original PID values. In our program, we set to 4.
SetErrScale(*Err1*, *Err2*, *Err3*, *Err4*, *Err5*, *Err6*, *Err7*, *Err8*)	Sets the error values by ***Err1*** through ***Err8*** ranging from 0 ~ 127 as feedback for PID control for various IR detection situations. The default values of ***Err1*** ~ ***Err8*** are 1~8 respectively.
Speed Setting and Control Commands	
SetSpdCtrlL(*SpdMin*, *SpdMax*)	Sets the minimum and maximum speed of the left and right motor by ***SpdMin*** and ***SpdMax*** for PID speed control. ***SpdMin*** and ***SpdMax*** range from -1024 ~ 1024. ***SpdMax*** should be greater than ***SpdMin***, otherwise the command will be ignored.
SetSpdCtrlR(*SpdMin*, *SpdMax*)	
SetStraight(*SpeedL*, *SpeedR*)	Sets the straight line speed of the left and right motor by ***SpeedL*** and ***SpeedR*** ranging from -1024 ~ 1024 for PID speed control.
SetStraightSpd(*Speed*)	Sets the straight line speed of the left and right motor by ***Speed*** which specifies the traveled distance in 10ms period. A value of 7 is about moving 1 cm distance in 10ms.
SpdCtrlOn(*Mode*)	Starts the PID speed control in mode specified by ***Mode***. 0: Any change of speed settings will terminate the PID

	speed control automatically. 1: PID control continues regardless of the speed settings change.
SpdCtrlOff()	Stops the PID speed control. The InnoRacer™ 2S will run with the last given speed settings.
ClearRec()	Clears all the recorded track section information.
SetCtrlFreq(*Period*)	Sets the speed control frequency by ***Period***, with 0.5ms unit. In our sample program, we set it to 4.
Tachometer Commands	
SetTachInL(*TACH*) **SetTachInR(*TACH*)** **SetTachInLR(*TACHL*, *TACHR*)**	Sets the tachometer start counting value of the left, right or both motors by ***TACH*** or both ***TACHL*** and ***TACHR***. , ranging from 0 ~ 65535.
TachInL(*TACH*) **TachInR(*TACH*)** **TachInDual(*TACHL*, *TACHR*)**	Gets the tachometer counter value of the left, right or both motors and stores in variable ***TACH*** or in both ***TACHL***, and ***TACHR***, ranging from 0 ~ 65535.
Track Recording Commands	
StartRec(*Mode*)	Starts to record the track information. If the ***Mode*** is set to 1, the track information will be saved to FLASH memory also. Otherwise, it will not be saved to FLASH memory.
StopRec()	Stops recording the track information.
GetRecStatus(*Status*)	Gets the track recording status and saves in variable ***Status***. 0: not recording, either not started yet or finished. 1: recording in progress and Start Mark not yet detected. 2: recording in progress, and has past Start Mark.
GetSecLen(*Num*, *LengthL*, *LengthR*)	Gets the traveled length of the left and right wheel in section ***Num***, ranging from 0 ~ 255 and stores the lengths in variable ***LengthL*** and ***LengthR*** ranging from 0 ~ 4294967295. The length is expressed in tachometer counts as the unit.
GetSecCnt(*Cnt*)	Gets the curve change mark counts and stores in variable ***Cnt***, ranging from 0 ~ 255.
GetCurSecTach(*LengthL*, *LengthR*)	Gets the traveled length of the left and right wheel of current section and stores the lengths in variable ***LengthL*** and ***LengthR*** ranging from 0 ~ 4294967295.

	The length is expressed in tachometer counts as the unit. Note that this command takes effect if track recording mode is activated.
GetTotalLen(*LengthL, LengthR*)	Gets the up-to-now total traveled length of the left and right wheel and stores the lengths in variable ***LengthL*** and ***LengthR*** ranging from 0 ~ 4294967295. The length is expressed with tachometer counts as the unit. Note that this command takes effect if track recording mode is activated.
Accelerometer and Gyroscope Commands	
GetAyGz(Ay, *Gz*)	Gets the current y-axial acceleration value and z-axial gyroscope value, ranging from -2048 ~ 2047 and stores them in variables ***Ay*** and ***Gz***.
GetSecMaxAyGz(*Num*, Ay, *Gz*)	Gets the maximum y-axial acceleration value and maximum z-axial gyroscope value of the section specified by ***Num*** and stores the values in variables ***Ay*** and ***Gz***. The value of ***Num*** ranges from 0 ~ 255 and the values of ***Ay*** and ***Gz*** range from -2048 ~ 2047.
GetSecAvgAyGz(*Num,* Ay*, Gz*)	Gets the average y-axial acceleration value and maximum z-axial gyroscope value of the section specified by ***Num*** and stores the values in variables ***Ay*** and ***Gz***. The value of ***Num*** ranges from 0 ~ 255 and the values of ***Ay*** and ***Gz*** range from -2048 ~ 2047.
SensorCal()	Sets the current y-axial acceleration value and z-axial gyroscope value as their calibration values.
Load0AyGz(*Ay, Gz*)	Gets the calibration values of y-axial acceleration value and z-axial gyroscope value and stores them in variable ***Ay*** and ***Gz, value*** range from -2048 ~ 2047.
Miscellaneous Commands	
SetOutsideMode(*Mode*)	Sets the run-away behavior by variable ***Mode***. Value 0: keeps running; value 1: stops; value 2: brakes.
SetLineColor(*Color*)	Sets the track color by variable ***Color***. Value 0 (the default value) for white and 1 for black color.
BuzzerOn()	Activates buzzer to beep for 0.1s.
AutoBeep(*Mode*)	Activates the auto-beeping function by ***Mode*** when a curvature change mark is detected. Default value is 0. 0: deactivates auto-beeping function 1: activates auto-beeping function

	The beep sound lasts for 0.1s each time.
SetCrossCount(*Count*)	Sets the cross distance in ***Count***, ranging from 0~255. When an intersection is encountered, left and right IR sensors sense the track with a time difference. This command helps you assign a distance, within which the intersection will not be mistaken as a curve change mark or a Start/Goal mark. Every 3 counts is about 1mm in distance.
LowBatteryAlarmOn()	Turns on low battery alarm function.
LowBatteryAlarmOff()	Turns off low battery alarm function.
Status **= CheckLowBattery()**	Checks battery status and returns its status to variable ***Status***. If battery voltage is low, value 1 will be retuned, otherwise value 0 will be returned.
Status **=GetButton0State()**	Gets Button 0, Button 1, Button 2 or Button 3 and returns its status to variable ***Status***. If button is pressed, 0 will be returned. If button is not pressed, 1 will be returned.
Status **=GetButton1State()**	
Status **=GetButton2State()**	
Status **=GetButton3State()**	
LedOn()	Turns on all LEDs.
Led0On()	Turns on LED0, LED1, LED2 or LED3.
Led1On()	
Led2On()	
Led3On()	
LedOff()	Turns off all LEDs.
Led0Off ()	Turns off LED0, LED1, LED2 or LED3.
Led1Off ()	
Led2Off ()	
Led3Off ()	

Appendix A --- Tutorial Programs

To help you be familiar with the InnoRacer™ 2S, some tutorial programs with brief introduction are provided in this section. To maintain the tutorial programs free of error and up-to-date, they are subject to change without notice.

For new users, who are not familiar with the BASIC Commander®, please refer to the “Arminno™ User's Manual” for more detailed information.

Ex. 1 --- Blinking an LED

This program gives the basics of lighting an LED. There are 4 LEDs on the InnoRacer™ 2S board, namely Led0, Led1, Led2 and Led3. They can be controlled via microcontroller I/O pins: PC0, PC1, PC2 and PC3. The following example shows how to use the Led0On() and Led0Off() commands to control the Led0 to blink.

```
#include "arminno.h"
#include "innoRacer2.h"
innoRacer2 myRacer;

int main(void)
{
    while(1)                        //infinite loop
    {
        myRacer.Led0On();           //turn on LED 0
        Pause(5000);                //wait 0.5 sec.
        myRacer.Led0Off();          //turn off LED 0
        Pause(5000);                //wait 0.5 sec.
    }
}
```

Ex. 2 --- Light LED If Button Pressed

In addition to the 4 LEDs, there are also 4 buttons on the InnoRacer™ 2S board, they can be accessed via microcontroller I/O pins: PC4, PC5, PC6 and PC7. The following example shows how to use the GetButton0State() command to detect the Button0 status. If Button0 is pressed, use Led0On() command to turn on Led0, otherwise use Led0Off() commands to turn off Led0.

```
#include "arminno.h"
#include "innoRacer2.h"
innoRacer2 myRacer;

int main(void)
{
    while(1)            //infinite loop
    {
        if(myRacer.GetButton0State()==0)    //check Button0 status
            myRacer.Led0On();       //turn on LED0 if key pressed
        else
            myRacer.Led0Off();      //turn off LED0 if key not pressed
    }
}
```

Ex. 3 --- Motor Speed Control

There are two DC motors on the InnoRacer™ 2S board. This program shows how to control the DC motors with the speed control commands of the InnoRacer™ 2S library. To prevent the InnoRacer™ 2S from running away, keep it off the ground when executing the program.

To input speed parameters in this program, point the cursor to the Serial Window and key in two speed parameters and your input values will be displayed in the Serial Window.

Note that the DC motor electric brush wears out when spinning against the mechanical parts, the DC motors lifetime is limited. Running at a high speed for a long time will further shorten the life of the DC motors.

```
#include "arminno.h"
#include "innoRacer2.h"
innoRacer2 myRacer;

int main(void)
{
    int iVelL,iVelR;    //left and right motor speed variables
    while(1)
    {
        printf("\033[J\n");     //clear window

        printf("Please enter the value of iVelL and iVelR... \n");
        scanf("%d%d",&iVelL,&iVelR);    //scan speed parameters
        printf("L:%d R:%d\n",iVelL,iVelR);  //display values
        myRacer.SetVelLR(iVelL,iVelR);      //set speed
        printf("\nPress Any Key to Stop...\n");
        scanf("%d",&iVelR);                 //scan for any key input
        myRacer.BrakeDual();                //stop both motors
    }
}
```

Ex. 4 --- Get Infrared Detection Values

There are total 8 infrared sensors used by the InnoRacer™ 2S. Five of them are used to detect the position of the track. One on the right-hand side is used to detect the Start and Goal mark and two on the left-hand side are used to detect the curve change marks. This program shows how to read the infrared detection results and displays them in the Serial Window.

```
#include "arminno.h"
#include "innoRacer2.h"
innoRacer2 myRacer;

int main(void)
{
    unsigned char bIR,i;
```

```
    while(1)
    {
        myRacer.GetIr(bIR);          //get IR values
        printf("\033[0;0f IR:");     //move cursor to position 0,0
        for (i=0;i<8;i++)
        {
            printf("%d",bIR&1);      //display in binary format
            bIR>>=1;
        }
    }
}
```

Ex. 5 --- Tracking with 3 Infrared Sensors

There are 5 infrared sensors on the InnoRacer™ 2S, which can be used to detect the position of the track. This program starts with an easier way to detect the track by using the middle 3 of them. The error values are for tutorial purpose only. You may try to find your own error values as the feedback for better tracking performance.

```
#include "arminno.h"
#include "innoRacer2.h"
innoRacer2 myRacer;

const short sErrSet[]={-200,-80,-40,0,40,80,200};  // error table
const short Normal_Speed_R = 220;   // mid speed of right motor
const short Normal_Speed_L = 220;   // mid speed of left motor
int main(void)
{
    unsigned char bIR;
    short R,L,Err;
    while(1)
    {
        myRacer.GetIr(bIR);          //get IR values
        bIR>>=1;

        //select the error value according to the track position
```

```
        switch (bIR&0x07)
        {
            case (2): //010, track under the middle sensor
                Err = sErrSet[3];
                break;
            case (6): //011, track under the middle and right sensor
                Err = sErrSet[4];
                break;
            case (4): //001, track under the right sensor
                Err = sErrSet[5];
                break;
            case (3): //110, track under the middle and left sensor
                Err = sErrSet[2];
                break;
            case (1): //100, track under the left sensor
                Err = sErrSet[1];
                break;
            case (0): //000, off road, select large error for recovery
                if(Err<0)
                    Err = sErrSet[0];
                else if (Err>0)
                    Err = sErrSet[6];
                break;
            }
        R = Normal_Speed_R - Err;
        L = Normal_Speed_L + Err;
        myRacer.SetVelLR(L,R);  //adjust motors speeds
    }
}
```

Ex. 6 --- Tracking with 5 Infrared Sensors

In this program, we use all of the 5 infrared sensors on the InnoRacer™ 2S for tracking. For smaller curve radius, 3 IR sensors might not be enough to follow the line. In this situation, 5 infrared sensors will be useful. The error values are for tutorial purpose only. You may try to find your own error values as the feedback for better tracking performance.

```
#include "arminno.h"
#include "innoRacer2.h"
innoRacer2 myRacer;

const short sErrSet[]={-200,-160,-120,-80,-40,0,40,80,120,160,200};
const short Normal_Speed_R = 220;   // mid speed of right motor
const short Normal_Speed_L = 220;   // mid speed of left motor
int main(void)
{
    unsigned char bIR;
    short R,L,Err;
    while(1)
    {
        myRacer.GetIr(bIR);         //get IR values

        //select the error value according to the track position
        switch (bIR&0x1F)
        {
            case (4): //00100, track under the middle sensor
                Err = sErrSet[5];
                break;
            case (12): //00110
                Err = sErrSet[6];
                break;
            case (8): //00010
                Err = sErrSet[7];
                break;
            case (24): //00011
                Err = sErrSet[8];
                break;
            case (16): //00001
                Err = sErrSet[9];
                break;
            case (6): //01100
                Err = sErrSet[4];
                break;
            case (2):  //01000
                Err = sErrSet[3];
```

```
                break;
            case (3): //11000
                Err = sErrSet[2];
                break;
            case (1): //10000
                Err = sErrSet[1];
                break;
            case (0): //000, off road, select large error for recovery
                if(Err<0)
                    Err = sErrSet[0];
                else if (Err>0)
                    Err = sErrSet[10];
                break;
            }
        R = Normal_Speed_R - Err;
        L = Normal_Speed_L + Err;
        myRacer.SetVelLR(L,R);      //adjust motors speeds
    }
}
```

Ex. 7 --- PID Control Basics

This program shows how to employ the PID control on the InnoRacer™ 2S. The PID parameters given in this program are just for tutorial purpose only. You may find your own PID parameters for different track conditions by trial and error.

```
#include "arminno.h"
#include "innoRacer2.h"
innoRacer2 myRacer;

// error table
const short sErrSet[]={-200,-160,-120,-80,-40,0,40,80,120,160,200};
const short Normal_Speed_R = 220;   // mid speed of right motor
const short Normal_Speed_L = 220;   // mid speed of left motor
//PID parameters
const char SCALE = 0;
```

```
const char kP = 1;
const char kI = 0;
const char kD = 10;

int main(void)
{
    unsigned char bIR;
    short R,L,Err,PreErr,Integral,Derivative,Out,Control;

    //infinite loop, detecting track and adjust motors accordingly
    while(1)
    {
            myRacer.GetIr(bIR);         //get IR values

        //select error according to the track position
        switch (bIR&0x1F)
        {
            case (4): //00100
                Err = sErrSet[5];
                break;
            case (12): //00110
                Err = sErrSet[6];
                break;
            case (8): //00010
                Err = sErrSet[7];
                break;
            case (24): //00011
                Err = sErrSet[8];
                break;
            case (16): //00001
                Err = sErrSet[9];
                break;
            case (6): //01100
                Err = sErrSet[4];
                break;
            case (2):  //01000
                Err = sErrSet[3];
                break;
```

```
        case (3): //11000
            Err = sErrSet[2];
            break;
        case (1): //10000
            Err = sErrSet[1];
            break;
        case (0): //000, off road, select large error for recovery
            if(Err<0)
                Err = sErrSet[0];
            else if (Err>0)
                Err = sErrSet[10];
            break;
        }
    //PID calculation
    Integral = Integral + Err;
    Derivative = Err - PreErr;
    Out = (kP*Err)+(kI*Integral)+(kD*Derivative);
    PreErr = Err;
    Control = Out>>SCALE;

    //change motors speeds according to PID calculation
    R = Normal_Speed_R - Control;
    L = Normal_Speed_L + Control;

    // limit check
    if (R>1024)
        {
            R = 1024;
        }
    else if (R<-1024)
        {
            R = -1024;
        }

    if (L>1024)
        {
            L = 1024;
        }
```

```
        else if (L<-1024)
            {
                L = -1024;
            }
        myRacer.SetVelLR(L,R);  //adjust motors speeds
    }
}
```

Ex. 8 --- PID Control (Digital Mode)

We practice the PID control in the previous program and now we start to use the unique built-in PID control functions. There are two modes available, one is the digital mode, which interprets all the infrared reflection intensity values as logic 0 or 1 and the other is the analog mode, which interprets all the infrared reflection intensity values as analog values with wider range. Let's start with the digital mode first.

```
#include "arminno.h"
#include "innoRacer2.h"
innoRacer2 myRacer;

#define FREQ_CTRL 4

const short NORMAL_SPEED_L = 130;
const short NORMAL_SPEED_R = 130;

const short kP=22;
const short kI=0;
const short kD=240;

// Error values
#define PID_SCALAR   4
const short sStrErr[]={18,30,48,78,126,144,330,534};

// module initialization
void Init(void)
{
```

```
    // set PID values
    myRacer.SetCtrlFreq(FREQ_CTRL);
    myRacer.SetP(kP);
    myRacer.SetI(kI);
    myRacer.SetD(kD);
    myRacer.SetScalar(PID_SCALAR);
    // set error values
   myRacer.SetErrScale(sStrErr[0], sStrErr[1], sStrErr[2], sStrErr[3],
sStrErr[4], sStrErr[5], sStrErr[6], sStrErr[7]);

    // set the mid speed
    myRacer.SetStraight(NORMAL_SPEED_L,NORMAL_SPEED_R);
    // set the Digital mode
    myRacer.SetIrMode(0);
    // set the track color
    myRacer.SetLineColor(0);
    //set motor dead zone
    myRacer.SetMotorDeadZone(136);
}

int main(void)
{
    unsigned char bIR ;
    Init();
    do {
        myRacer.GetIr(bIR);
    } while((bIR & 0x04) == 0x00); //check if in central position
    myRacer.BuzzerOn();

    Pause(20000);
    myRacer.SpdCtrlOn(0); //enable PID control
    while(1);   //infinite loop
}
```

Ex. 9 --- PID Control (Analog Mode)

As mentioned in the previous example, there are two modes available, one is the digital mode, which interprets all the infrared reflection intensity values as logic 0 or 1 and the other is the analog mode, which interprets all the infrared reflection intensity values as analog values with wider range. Now we try the analog mode, which has a better resolution in locating the track. Let's check it out!

```
#include "arminno.h"
#include "innoRacer2.h"
innoRacer2 myRacer;

#define FREQ_CTRL 4

const short NORMAL_SPEED_L = 130;
const short NORMAL_SPEED_R =  130;
const short kP=22;
const short kI=0;
const short kD=240;

// Error values
#define PID_SCALAR  4
const short sStrErr[]={18,30,48,78,126,144,330,534};

// module initialization
void Init(void)
{
    // set PID values
    myRacer.SetCtrlFreq(FREQ_CTRL);
    myRacer.SetP(kP);
    myRacer.SetI(kI);
    myRacer.SetD(kD);
    myRacer.SetScalar(PID_SCALAR);
    // set error values
    myRacer.SetErrScale(sStrErr[0], sStrErr[1], sStrErr[2], sStrErr[3],
sStrErr[4], sStrErr[5], sStrErr[6], sStrErr[7]);
    // set the mid speed
    myRacer.SetStraight(NORMAL_SPEED_L,NORMAL_SPEED_R);
```

```
    // set the Analog mode
    myRacer.SetIrMode(1);
    // set the track color
    myRacer.SetLineColor(0);
    //set motor dead zone
    myRacer.SetMotorDeadZone(136);
}

int main(void)
{
    unsigned char bIR ;
    Init();
    do {
        myRacer.GetIr(bIR);
    } while((bIR & 0x04) == 0x00); //check if in central position
    myRacer.BuzzerOn();

    Pause(20000);
    myRacer.SpdCtrlOn(0); //enable PID control
    while(1);    //infinite loop
}
```

Ex. 10 --- Using Gyroscope and Accelerometer

There is a gyro and two-axis accelerometer built-in on the InnoRacer™ 2S, which are used to sense the dynamic parameters. However, when running on the track, accelerometer in x direction is not used, in this program, we learn how to access accelerometer in y direction and gyro value on the z-axis.

```
#include "arminno.h"
#include "innoRacer2.h"
innoRacer2 myRacer;
short AccY, GyroZ;
int main(void)
{
    while(1)
```

```
    {
        myRacer.GetAyGz(AccY, GyroZ);   //get Acc in Y and gyro in z
        printf("\033[0;0f Accelerometer Y:");   //move cursor to 0,0
        printf("%d", AccY);
        printf("   Gyro Z:");
        printf("%d", GyroZ);
        printf("\033[K");        //clear to end of line
    }
}
```

Ex. 11 --- Route Memorization

Route memorization is an important feature for InnoRacer™ 2S, so it can run as fast as possible on all route sections. This program shows how to record the track information.

```
#include "arminno.h"
#include "innoRacer2.h"
innoRacer2 myRacer;

#define FREQ_CTRL   4
#define CROSS_COUNT   14 // intersection bias

const short NORMAL_SPEED_L = 130;
const short NORMAL_SPEED_R = 130;

//--------------------------------------------------------
// set PID values
//--------------------------------------------------------
const short kP=22;
const short kI=0;
const short kD=240;
//--------------------------------------------------------
// set error values
//--------------------------------------------------------
#define PID_SCALAR  4
```

```
const short sStrErr[]={18,30,48,78,126,144,330,534};

unsigned char bStatus;
unsigned char bIR;
//-------------------------------------------------------
//  module initialization
//-------------------------------------------------------
void Init(void)
{
    //set PID values
    myRacer.SetCtrlFreq(FREQ_CTRL);
    myRacer.SetP(kP);
    myRacer.SetI(kI);
    myRacer.SetD(kD);
    myRacer.SetScalar(PID_SCALAR);

    myRacer.SetStraight(NORMAL_SPEED_L,NORMAL_SPEED_R);
    myRacer.SetIrMode(1);

    //set error values
   myRacer.SetErrScale(sStrErr[0], sStrErr[1], sStrErr[2], sStrErr[3],
sStrErr[4], sStrErr[5], sStrErr[6], sStrErr[7]);
  myRacer.SetCrossCount(CROSS_COUNT); //set intersection bias
    //set motor dead zone
    myRacer.SetMotorDeadZone(136);
}

int main(void)
{
    Init();
    myRacer.AutoBeep(1);    //enable auto beep
    //check if in central position
    do {
        myRacer.GetIr(bIR);
    } while((bIR & 0x04) == 0x00);

    myRacer.BuzzerOn();
    Pause(20000);
```

```
    myRacer.StartRec(1);    //enable route recording

    //check if route recording started?
    do {
        myRacer.GetRecStatus(bStatus);
    } while(bStatus != 1);

    //start PID control
    myRacer.SpdCtrlOn(0);

    //check if the Start mark is detected?
    do {
            myRacer.GetRecStatus(bStatus);
    } while (bStatus != 2);

    //check if the Goal mark is detected?
    do {
        myRacer.GetRecStatus(bStatus);
    } while(bStatus != 0);

    //stop route recording
    myRacer.StopRec();
    myRacer.StopDual();
}
```

Ex. 12 --- Retrieving Route Information

In previous exercise, we recorded all the sections of route information. In this program, we display all the sections of route information in the Debug Window. If you encounter a route memorization problem, this is a very useful debug tool to identify where the problem is.

```
#include "arminno.h"
#include "innoRacer2.h"
innoRacer2 myRacer;
```

```
int main(void)
{
    unsigned char SecCnt;
    short L, R, MaxAcc, AvgAcc, MaxGyro, AvgGyro;

    myRacer.GetTotalSecCnt(SecCnt); //¨get total section number

    printf("Count = %d\r\n", SecCnt);
    printf("   \t L  \t R   \tMaxAcc\tAvgAcc\tMaxGyro\tAvgGyro\r\n");

    //read information sequentially
    for(unsigned char i = 0 ; i < SecCnt ; i++) {
        myRacer.GetSecLen(i, L, R);
        myRacer.GetSecMaxAyGz(i, MaxAcc, MaxGyro);
        myRacer.GetSecAvgAyGz(i, AvgAcc, AvgGyro);
    printf("%3d\t%4d\t%4d\t%6d\t%6d\t%6d\t%6d\r\n", i, L, R, MaxAcc,
    AvgAcc, MaxGyro, AvgGyro);
    }
}
```

Ex. 13 --- Acceleration

We know how to record the information of all the sections of the route. Now we can start to use this information to speed up our InnoRacer™ 2S. There are many different approaches or strategies to speed up the InnoRacer™ 2S. In this program, we learn the basics of acceleration according to the route information. The InnoRacer™ 2S starts to accelerate after the Start mark is detected and stops.

```
#include "arminno.h"
#include "innoRacer2.h"
innoRacer2 myRacer;

#define FREQ_CTRL 4
#define CROSS_COUNT 14    // intersection bias
#define STOP_TACH 100
const short NORMAL_SPEED_L = 130;
```

```
const short NORMAL_SPEED_R = 130;
const short CRAZY_SPEED_L = 150;
const short CRAZY_SPEED_R = 150;
//--------------------------------------------------------
// set PID values
//--------------------------------------------------------
const short kP=22;
const short kI=0;
const short kD=240;
//--------------------------------------------------------
//  set error values
//--------------------------------------------------------
#define PID_SCALAR   4
const short sStrErr[]={18,30,48,78,126,144,330,534};

unsigned char bStatus;
unsigned char bIR;
unsigned short LenL,LenR;

//--------------------------------------------------------
//  module initialization
//--------------------------------------------------------
void Init(void)
{
    //set PID values
    myRacer.SetCtrlFreq(FREQ_CTRL);
    myRacer.SetP(kP);
    myRacer.SetI(kI);
    myRacer.SetD(kD);
    myRacer.SetScalar(PID_SCALAR);

    // set the mid speed
    myRacer.SetStraight(NORMAL_SPEED_L,NORMAL_SPEED_R);
    // set the Analog mode
    myRacer.SetIrMode(1);

    //set error values
   myRacer.SetErrScale(sStrErr[0], sStrErr[1], sStrErr[2], sStrErr[3],
```

```
sStrErr[4], sStrErr[5], sStrErr[6], sStrErr[7]);
  myRacer.SetCrossCount(CROSS_COUNT);
    //set motor dead zone
    myRacer.SetMotorDeadZone(136);
}
int main(void)
{
    Init();
    myRacer.AutoBeep(1);    //enable auto beep

    //check if in central position
    do {
        myRacer.GetIr(bIR);
    } while((bIR & 0x04) == 0x00);

    myRacer.BuzzerOn();
    Pause(20000);

    myRacer.StartRec(1);    // analog mode

    //check if route recording started?
    do {
        myRacer.GetRecStatus(bStatus);
    } while(bStatus != 1);

    myRacer.SpdCtrlOn(0);   //enable PID control

    // check if Goal mark is detected?
    do {
            myRacer.GetRecStatus(bStatus);
    } while (bStatus != 2);

    // set higher speed
    myRacer.SetStraight(CRAZY_SPEED_L,CRAZY_SPEED_R);

    do{
        myRacer.GetTotalLen(LenL,LenR);
    }while(LenL < STOP_TACH);
```

```
    //stop route recording
    myRacer.StopRec();
    myRacer.StopDual();
}
```

Ex. 14 --- Ready to Go

Finally, we add more functions in this program. By pressing button 0 to select recording mode, InnoRacer™ 2S will execute route memorization run. After the route is successfully recorded, press button 1 and InnoRacer™ 2S will execute racing run. If you encounter problem during the runs, connect InnoRacer™ 2S to your development environment and press button 2 to display all the route records for your analysis. Now you are almost ready to put your InnoRacer™ 2S line follower on the racing course to compete. After learning all the basics required, try to develop your own racing strategies and have fun!

```
#include "arminno.h"
#include "innoRacer2.h"
innoRacer2 myRacer;

#define FREQ_CTRL   4
#define CROSS_COUNT  4 // intersection bias

const short NORMAL_SPEED_L = 130;
const short NORMAL_SPEED_R = 130;

const short CRAZY_SPEED_L = 400;
const short CRAZY_SPEED_R = 400;

const short STOP_SPEED_L = 0;
const short STOP_SPEED_R = 0;

const short kP=22;
const short kI=0;
const short kD=240;
```

```
const float StopLevel = 3;
const short soffset = 136;

//--------------------------------------------------------
//  set error values
//--------------------------------------------------------
#define PID_SCALAR   4
const short sStrErr[]={18,30,48,78,126,144,330,534};

//--------------------------------------------------------
//  Accelerating parameters
//--------------------------------------------------------
const short STOP_TACH = 200;
const short ACC_TACH = 50;
const short HOLD_STOP = 100;
const short ACC_G = 100;
unsigned char bStatus;
unsigned char bIR;
unsigned char bCnt, bNxtCnt, bLevel;
short iAy, iGz;
short wSecLenL, wSecLenR, wStopLen,wPreLen;
short wCurCntL, wCurCntR;

//--------------------------------------------------------
//  module initialization
//--------------------------------------------------------
void Init(void)
{
    //set PID values
    myRacer.SetCtrlFreq(FREQ_CTRL);
    myRacer.SetP(kP);
    myRacer.SetI(kI);
    myRacer.SetD(kD);
    myRacer.SetScalar(PID_SCALAR);

    myRacer.SetOutsideMode(1);
    // set error values
```

```
   myRacer.SetErrScale(sStrErr[0], sStrErr[1], sStrErr[2], sStrErr[3],
sStrErr[4], sStrErr[5], sStrErr[6], sStrErr[7]);

    //set speed related values
    myRacer.SetStraight(NORMAL_SPEED_L,NORMAL_SPEED_R);

    myRacer.SetCrossCount(CROSS_COUNT);
    myRacer.SetIrMode(1);
    myRacer.SetIrMask(1);

    myRacer.SetLineColor(0);
    myRacer. SetMotorDeadZone(soffset);

}
//----------------------------------------------------------
// route recording function
//----------------------------------------------------------
void REC_ROUTE(void)
{
    myRacer.AutoBeep(1);    //enable auto beep

    //check if in central position
    do {
        myRacer.GetIr(bIR);
    } while((bIR & 0x04) == 0x00);
    myRacer.BuzzerOn();

    Pause(20000);
    myRacer.StartRec(1);    // analog mode

    //check if route recording started?
    do {
        myRacer.GetRecStatus(bStatus);
    } while(bStatus != 1);

    myRacer.SpdCtrlOn(0);   //enable PID control

    // check if Goal mark is detected?
```

```
    do {
            myRacer.GetRecStatus(bStatus);
    } while (bStatus != 2);

    // check if Goal mark is detected?
    do {
        myRacer.GetRecStatus(bStatus);
    } while(bStatus != 0);

    //stop route recording
    myRacer.StopRec();
    Pause(3000);
    myRacer.StopDual();
}

void CheckCount(short wTarCntL)
{
    short wCurCntL, wCurCntR;
    do {
        myRacer.GetCurSecTach(wCurCntL, wCurCntR);
    } while(wCurCntL < wTarCntL);
}

//---------------------------------------------------------
// racing function
//---------------------------------------------------------

void RACE_ROUTE(void)
{
      short SecLen[256], AvgG[256];
   unsigned char Cnt,bCrazy;

        //check if in central position
        do {
            myRacer.GetIr(bIR);
        } while((bIR & 0x04) == 0x00);
        myRacer.BuzzerOn();
        Pause(20000);
```

```
      bCnt = 0;
      bNxtCnt = 0;
  wStopLen = 0;
  bCrazy = 0;

      myRacer.GetSecAvgAyGz(bNxtCnt, iAy, iGz);
      myRacer.GetSecLen(bNxtCnt, wSecLenL, wSecLenR);
  myRacer.AutoBeep(0);

      myRacer.StartRec(0);
      //check if route recording started?
      do {
          myRacer.GetRecStatus(bStatus);
      } while(bStatus != 1);

      myRacer.SetStraight(NORMAL_SPEED_L,NORMAL_SPEED_R);
      myRacer.SpdCtrlOn(0);
      // check if Goal mark is detected?
      do {
          myRacer.GetRecStatus(bStatus);
      } while(bStatus != 2);


   // ¨check straight route to use high speed
 do {
          myRacer.GetSecCnt(bCnt);
          if (bNxtCnt==bCnt)
          {
              bNxtCnt ++;
              if((iAy < ACC_G) && (iAy > -ACC_G) && (wStopLen > 0))
              {
                  myRacer.SetStraight(CRAZY_SPEED_L,CRAZY_SPEED_R);
                  CheckCount(wStopLen);
                  myRacer.SetStraight(STOP_SPEED_L,STOP_SPEED_R);
                  Pause(HOLD_STOP);

   myRacer.SetStraight(NORMAL_SPEED_L,NORMAL_SPEED_R);
```

```
                }
                myRacer.GetSecAvgAyGz(bNxtCnt, iAy, iGz);
                myRacer.GetSecLen(bNxtCnt, wSecLenL, wSecLenR);
                if (wSecLenL >ACC_TACH)
                {
                    wStopLen = wSecLenL - STOP_TACH;
                }
                else
                {
                    wStopLen = 0;
                }
            }
        myRacer.GetRecStatus(bStatus);
    } while(bStatus != 0);
    Pause(1500);
    myRacer.BrakeDual();
}

void PrintData()
{
    unsigned char SecCnt;
    short L, R, MaxAcc, AvgAcc, MaxGyro, AvgGyro;

    myRacer.GetTotalSecCnt(SecCnt);
    printf("Count = %d\r\n", SecCnt);
    printf("   \t L  \t R   \tMaxAcc\tAvgAcc\tMaxGyro\tAvgGyro\r\n");

    for(unsigned char i = 0 ; i < SecCnt ; i++)
    {
            myRacer.GetSecLen(i, L, R);
            myRacer.GetSecMaxAyGz(i, MaxAcc, MaxGyro);
            myRacer.GetSecAvgAyGz(i, AvgAcc, AvgGyro);
            printf("%3d\t%4d\t%4d\t%6d\t%6d\t%6d\t%6d\r\n", i, L, R,
MaxAcc, AvgAcc, MaxGyro, AvgGyro);
    }
}

int main(void)
```

```
{
    for(int i = 0 ; i < 3 ;i++) {
        myRacer.LedOn();
        Pause(2000);
        myRacer.LedOff();
        Pause(2000);
    }
    Init();
    while(1) {
        //check if button is pressed
        if(myRacer.GetButton0State() == 0) {
            myRacer.Led0On();
            REC_ROUTE();
            myRacer.LedOff();
        }
        else if(myRacer.GetButton1State() == 0) {
            myRacer.Led1On();
            RACE_ROUTE();
            myRacer.LedOff();
        }
        else if(myRacer.GetButton2State() == 0) {
            myRacer.Led2On();
            PrintData();
            myRacer.Led2Off();
        }
    }
}
```

Appendix B --- Sample Course

This is a sample course with a minimum curvature of 10cm. The actual size is 180 cm x 400 cm. There could be different racing games with similar rules. Refer to their official document and modify the course and program accordingly.