

# Wacky Racers 2019 Instructions

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## 1 Introduction

The purpose of this assignment is to design, build, and program an embedded system using an ARM microcontroller and surface mount technology.

The goal for each group of four students is to build a remote controlled vehicle (the Wacky Racer) and its controller (the Wacky Hat). At the conclusion of the assignment there will be a number of competitions.

Each group is comprised of two sub-groups of two students. One of these subgroups constructs the Wacky Racer and the other constructs the Wacky Hat. You may be asking why is the Wacky Hat called the Wacky Hat? Well, a hat that controls a remote vehicle using head motions is not an ordinary hat!

## 2 Requirements

The following requirements are mandatory. Any variation needs to be approved by Ben Mitchell. These will be notified to the rest of the class through the Wacky Racers Forum on Learn.

### 2.1 Wacky racer

1. The chassis is to be constructed by each group. These can be 3-D printed, constructed from Perspex or wood, etc. A standard chassis is available. The electronics must be visible on top of the chassis.
2. Have a standard working bump sensor (supplied).
3. Locomotion can only use two 6 V DC motors (supplied).
4. Everything must be powered from a single NiMH battery pack (supplied).
5. Use a single four layer printed circuit board of dimension 85 mm×64 mm.
6. Use an ARM microcontroller (Atmel SAM4S8).
7. Drive the motors using H-bridges (Texas Instruments DRV8833 dual H-bridge is recommended).
8. Regulate the nominal battery voltage to 5 V with a buck regulator IC (ADP2302ARDZ-50).
9. Interface to a game board (supplied) using UART over an 8-wire ribbon cable.

10. Be decorated with an LED strip (supplied) controlled by the game board.
11. Use a USB interface for debugging.
12. Use a serial wire debug interface for MCU programming/debugging.
13. Have adequate battery fusing.
14. Have a sleep button.
15. If the battery voltage drops below 1 V/cell, an LED should flash and high power draw devices should be disabled.
16. Interface to the controller with a wireless interface (no Bluetooth or WiFi). We suggest the Nordic nRF24 SMD module.
17. Be humorous.

Each Wacky Racer can have an appendage to provide assistance during the capture the flag competitions. The appendage can be controlled with a three pin servo interface and/or by a MOSFET.

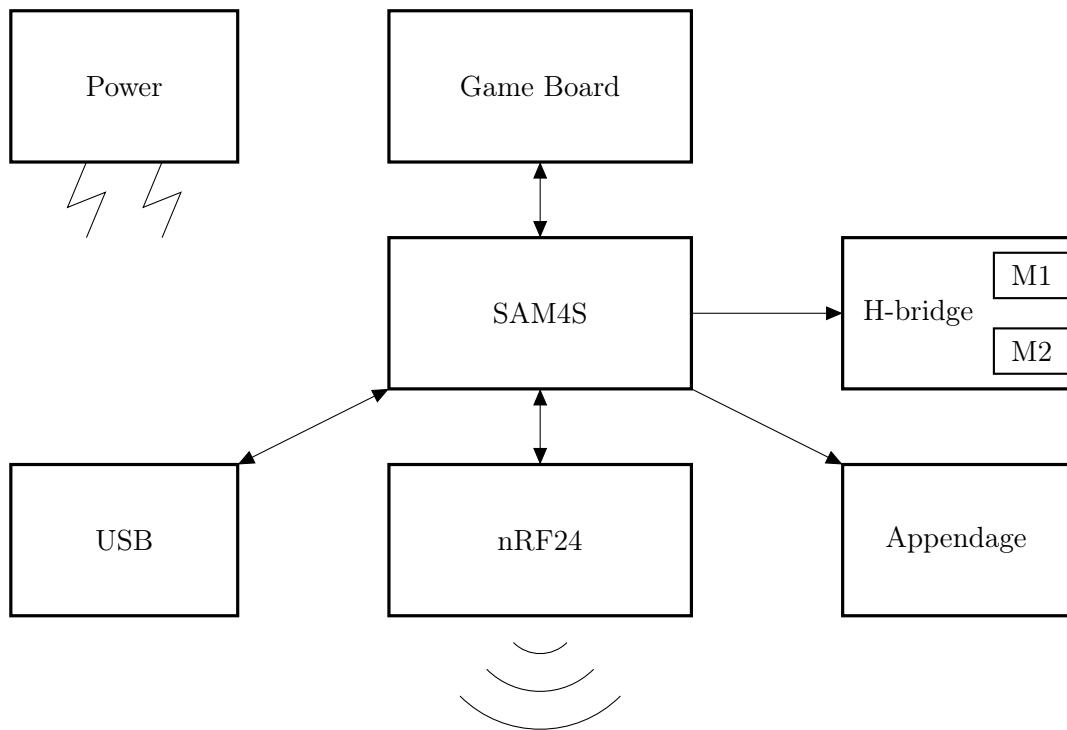


Figure 1: Racer board top level diagram.

## 2.2 Wacky hat

1. Construct a Wacky Hat that contains all the electronics.
2. Everything must be powered from batteries.
3. Have adequate battery fusing.
4. Use a single four layer printed circuit board of dimension 85 mm×64 mm.

5. Use an ARM microcontroller (Atmel SAM4S8).
6. Regulate the nominal 6 V battery voltage to 5 V with a buck regulator IC (ADP2302ARDZ-50).
7. Interface to a game board (supplied) using UART over a 8-wire ribbon cable.
8. Be decorated with an LED strip (supplied) controlled by the game board.
9. Use an I2C IMU (MPU-9250) for head motion detection.
10. Use a USB interface for debugging.
11. Use a serial wire debug interface for MCU programming/debugging.
12. Have a joystick in case the IMU does not work.
13. Have a sleep button.
14. If the battery voltage drops below 1 V/cell, an LED should flash and high power draw devices should be disabled.
15. Play sound when sent the kill command by the game board.
16. Interface to the vehicle with a wireless interface (no Bluetooth or WiFi). We suggest the Nordic nRF24 SMD module.
17. Be humorous.

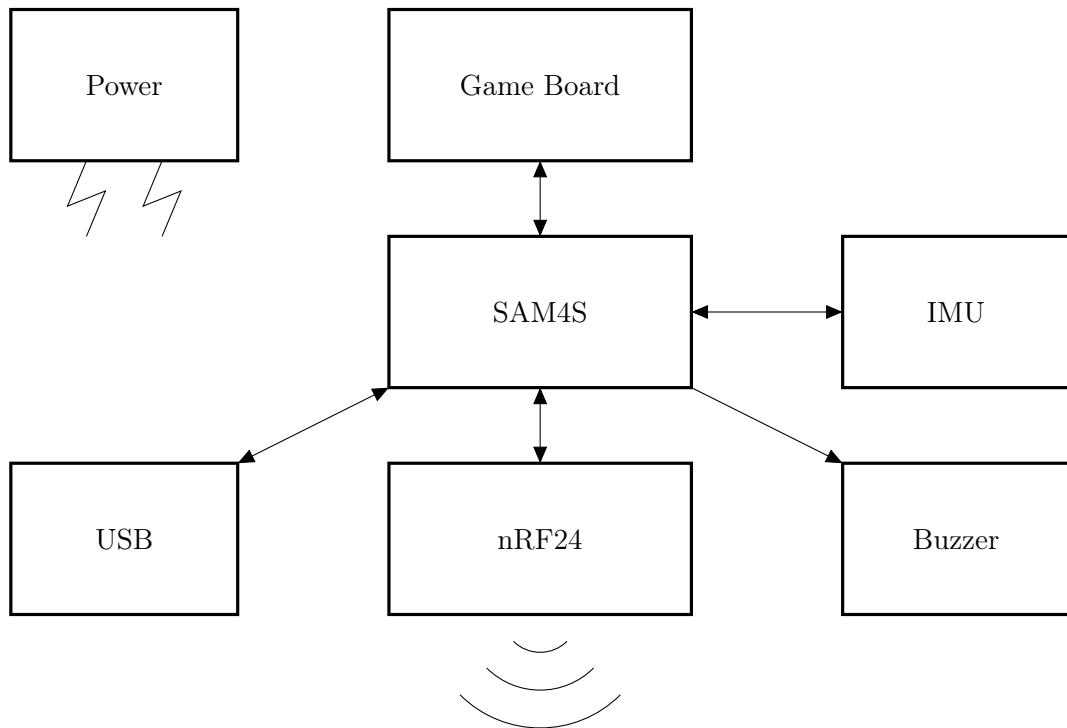


Figure 2: Racer hat top level diagram.

### 3 Game board

Each sub-group must assemble a game board as part of the SMT Lab induction process.

The game board interfaces to each Wacky Racer and Wacky Hat using a UART interface. Its purpose is to communicate with a game server over WiFi for coordination of competitions. It controls a string of programmable LEDs used to identify each Wacky Hat and Wacky Racer. It also interfaces to a bump sensor that is required for entry into the capture the flag competition.

The electrical interface to the game board is shown in Table 1. The game board requires at least 300 mA at all times and 1 A when the LEDs are connected, we recommend using a MOSFET to switch the power to the game board. Your MCU reset pin (nRST) must be connected to  $\overline{\text{RESET}}$ .

For more information, see the game board documentation.

+5V	1	2	RX
GND	3	4	TX
NC	5	6	GND
$\overline{\text{RESET}}$	7	8	+5V

Table 1: Game board interface. Do not connect to the NC pins.  $\overline{\text{RESET}}$  is driven by the game board and is connected to the SAM4S  $\overline{\text{NRST}}$  pin. RX is the TX signal from the game board and is connected to one of the SAM4S USART RX pins. TX is connected to the corresponding SAM4S USART TX pin.

## 4 Assignment schedule

There is a planned activity for the timetabled lab in the Embedded Systems Lab (ESL):

Week	Task
1	Altium tutorial 1 (schematics)
2	Milestone: schematic submission for review
3	Schematic review
4	Altium tutorial 3 (PCB)
5	Early PCB review & submission
6	PCB review & submission
7	Late PCB review & submission
8–10 (break)	PCB population, chassis/hat construction
11	Lab work
12	Milestone: IMU/motors
13	Milestone: radio control
14	Milestone: Functionality
15	Competitions

The blinky test falls in the mid-semester break but is one of the major steps to finishing this assignment. It requires having a functional PCB with a microcontroller that turns on properly, a functional toolchain and the ability to download code into the microcontrollers flash memory. *Do not underestimate how tricky this can be.*

## 5 Assessment

The marks breakdown (max. 100) is:

Early PCB submission	5 marks
IMU/motor milestone	5 marks
Radio control milestone	5 marks
Functional assessment	25 marks
Board inspection	30 marks
Competition	10 marks
Individual critique	20 marks

There are five milestones. To achieve the associated marks, they must be demonstrated to a T.A. by 5 pm. If you need an exception to this, see Ben Mitchell with a *very* good reason. The milestone requirements are:

**Schematic review** Submit your A3 schematic on Learn for review. Lose 10 marks if you miss the submission time.

**PCB review** Demonstrate PCB layout on ESL computer for review. 5 marks for submitting the PCB in week 5, 0 marks for week 6, -5 marks for submitting in week 7, and -10 marks after that.

**IMU/motors** For the Wacky Hat, demonstrate output of IMU readings to a PC using USB CDC. For the Wacky Racer, demonstrate control of the motors from a PC using USB CDC. 5 marks.

**Radio control** Demonstrate sending commands from the Wacky Hat to the Wacky Racer over a radio link. 5 marks.

**Functionality** Demonstrate a full set of functionality (listed below) including all of the previous milestones and interfacing with the game board. 25 marks.

Functionality requirements:

Wacky racer	Wacky hat
Blink LED	Blink LED
Drive motors forward/backward	Read from IMU
Speed control of motors	Calculate speeds from IMU
Steering control	Joystick control
Receive radio message	Send radio message
Dies on bump	Plays sound on bump
Report group info to game board	Report group info to game board
Low voltage indication	Low voltage indication

In previous years some students achieved the milestones by only showing demo code. This will be not be allowed this year for various reasons, the first of which, is that it makes your life easier for the functional assessment at the end. *If you cannot show the functionality of a previous milestone during any assessment, you will fail that assessment and lose any marks from the previous milestone.*

Up to 5 bonus marks can be awarded for extra functionality such as:

Wacky racer	Wacky hat
Control appendage	Plays sounds
Upload LED pattern to game board	Upload LED pattern to game board
Sleep mode	Sleep mode

## 6 Competition

There will be one organised competition of capture the flag. Teams of three will compete against each other to score the most points. The details of this will be released at a later date. Prizes will be awarded for the best Wacky Racers and Wacky Hats, with a bias towards the wacky. Note that this does not stop you from playing your own games against each other in the lab to sharpen your skills.

### 6.1 Capture the flag

The game is played between two teams (blue, and orange) in an arena. The field is split into two halves, both of which contain a capture zone, and a flag station as shown in Figure 3. The two teams are placed in their respective halves, and behind their flag station. When the game starts the Wacky Racers are free to move around. The object of the game is to travel into the opponents half, take their flag by driving onto their flag station, and return the flag to their capture zone to score a point.

The capture zones and the flag stations are raised platforms that the Wacky Racers will drive onto as shown in Figure 4. They are fitted with RFID readers, LEDs, and a WiFi connection back to the game server.

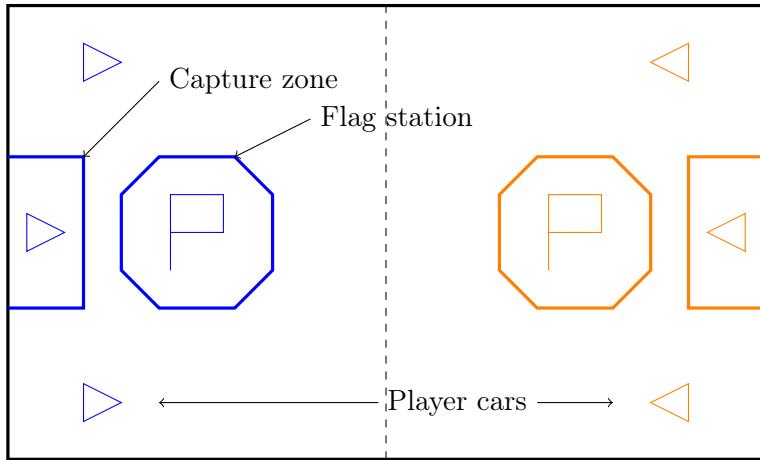


Figure 3: Diagram of the play field before release (not to scale). Obstacles will be placed in the mid-field area to cause futher mayhem and shenanigans.

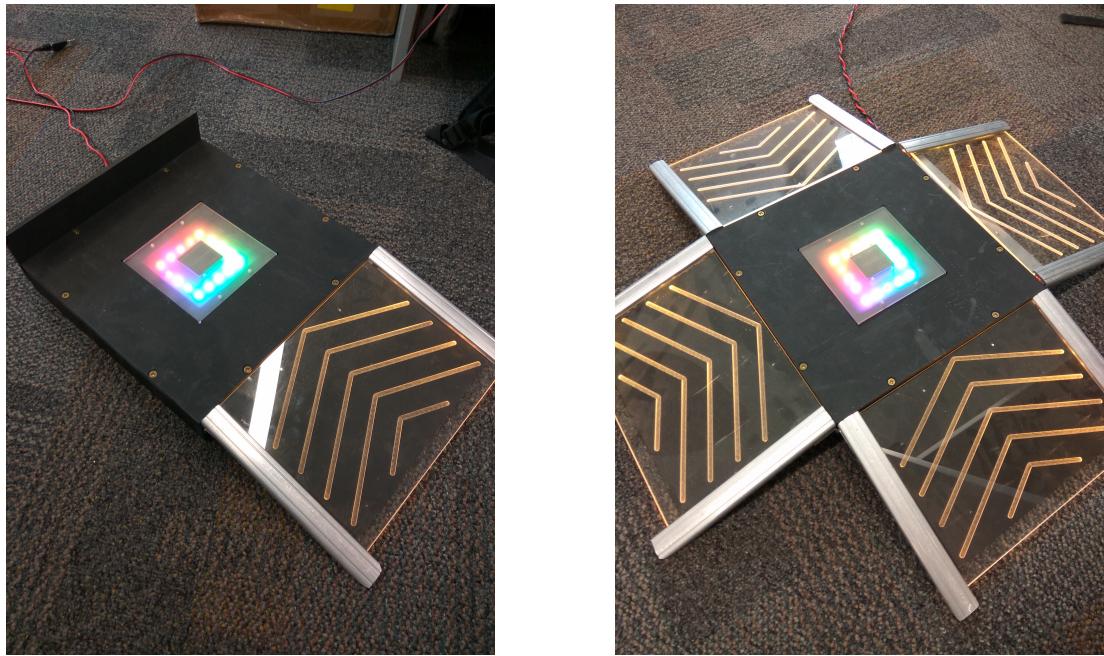


Figure 4: Capture zone and Flag station from Wacky Racers 2018.

## 7 Technical stuff

Read this section carefully. There are clues as to how we mark your PCBs at the end of the assignment.

### 7.1 Version control

Use version control for everything, or else! Learning git is a skill you will not regret.

Your group leader should create a forked copy of the wacky-racers-2019 git project and then add the other group members to the project. This can be done by:

1. Go to <https://eng-git.canterbury.ac.nz/wacky-racers/wacky-racers-2019>
2. Click ‘Fork’ button. This will create a copy of the main repository for the project.
3. Click on the ‘Settings’ menu then click the ‘Expand’ button for ‘Sharing and permissions’. Change ‘Project Visibility’ to ‘Private’.
4. Click on the ‘Members’ menu and add group members as Developers.
5. Using a bash terminal (or other useful shell), enter the command:

```
$ git clone --recursive https://eng-git.canterbury.ac.nz/your-userid/wacky-racers-2019.git
```

If you do not want to have to enter your password for every git push/pull operation, you should set up ssh-keys and use:

```
$ git clone --recursive git@eng-git.canterbury.ac.nz:your-userid/wacky-racers-2019.git
```

6. Add a remote URL for the main repository.

```
$ cd wacky-racers
$ git remote add upstream https://eng-git.canterbury.ac.nz/wacky-racers/wacky-racers-2019.git
```

Again if you do not want to manually enter your password, you can use:

```
$ cd wacky-racers
$ git remote add upstream git@eng-git.canterbury.ac.nz:wacky-racers/wacky-racers-2019.git
```

If we add more demo code or tweak the instructions in the main repository, you can get the updated stuff using:

```
$ git pull upstream master
```

## 7.2 Components

1. We recommend that you use components in the ECE Altium library. These are stocked in the SMT lab. For any other components you may require, see Scott Lloyd in the SMT lab.
2. The Wacky Racer batteries are Radient Superpax 3000 mA-hr 7.2V NiMH with male Tamiya power connector. To preserve the battery life it is imperative to not draw current when the battery voltage is below 6 V.

## 7.3 Schematics

1. Have a look at the Altium tutorial on ecewiki.
2. Have a read of the schematic guidelines on ecewiki.
3. Add you and your partner’s name to the title block on your schematic.

4. Save PDF files of your schematics in your source repository. **Note, when debugging your PCBs, we will not help you until you show us your schematic.**
5. We bet that you will not have enough test points to clip an oscilloscope probe to. Do not think you can hold the probe tip against an MCU pin. Ensure you give a meaningful name to the test point. A ground test point is essential for an oscilloscope earth clip. Keep this clear of other test points since the clip may short against them. You will probably require at least two ground points.
6. Checking the schematic is the most crucial part of the assignment. If the schematic is wrong then your PCB will be wrong. So, schematics must be thoroughly checked by another person.
7. Consider fall-back options if you have a problem with your PCB.

The IMU for the Wacky Hat is tiny and we **strongly recommend** that you provide an alternative connector for connecting the following IMU module: MPU-9250 on AliExpress

Similarly for the Wacky Hat, in case the H-bridge fails, provide two three-pin servo connectors so that external Electronic Speed Controllers (ESC) can be used to drive the motors.

8. It would be useful to have a jumper or two connected to a PIO pin so that you can configure your board. For example, if a jumper is in, use the joystick, otherwise use the IMU.

## 7.4 PCBs

1. Your four-layer PCBs are going to be manufactured by PCB Zone in Auckland. They produce a PCB solder mask and plated through holes. We will be putting several groups's boards onto a panel to reduce costs.
2. It is important that you check footprints for parts thay you create. We will impose a 10% penalty for each rerun of a PCB, say due to a footprint mistake. Get your partner to check.
3. PCB layouts must be thoroughly checked by another person.
4. A PCB track can blow faster than a fuse. So keep high current tracks fat and short.
5. Clearly mark the positive and negative battery connections on the silk screen.
6. Some of the chips can get hot so thermal considerations are required. Follow the manufacturers' guidelines in the datasheets.
7. The switching regulators can interfere with the radios.
8. Use a design rule check to see if any of the following constraints are violated:
  - Minimum trace width (0.15 mm)
  - Minimum trace clearance (0.15 mm)
  - Minimum via size (0.3 mm hole, 0.6 mm outer diameter)
  - Minimum hole size (0.3 mm)
  - Minimum annular ring (0.1 mm)

For every violation of one these rules, we will deduct 1% from your final mark.

9. Check the PCB checklist on ecewiki before submission.

## 7.5 Assembly

1. Finding shorts is extremely frustrating so maximise clearances and test for shorts before populating components.
2. Components can be put through the oven on the reverse side although heavy components may need to be glued.
3. Never assume where pin 1 is on an IC; check the datasheet.

## 7.6 Software

1. We highly recommend using a personal laptop with Linux installed if possible. A virtual machine running on Windows is acceptable for this. You will need to check instructions on ecewiki for how to install the required toolchain.
2. We do not support embedded systems development on Windows, but it is possible.
3. If you are not using version control for this you are foolish.
4. Inspect MPH's sample code.

## 7.7 Programming

1. If you are trying to program the SAM4S for the first time and are feeling tired or impatient, then do something else.
2. For the first program, do not use batteries or a USB connection. The ST-Link adapter will provide 3.3 V to the MCU.
3. Detailed instructions can be found at [http://ecewiki.elec.canterbury.ac.nz/mediawiki/index.php/Wacky\\_racers\\_software](http://ecewiki.elec.canterbury.ac.nz/mediawiki/index.php/Wacky_racers_software).

## 7.8 Debugging

1. Start running small programs (such as the provided demo programs) to test each feature separately.
2. An oscilloscope is your friend.
3. It is possible to use the GDB debugger but you need to know what you are doing, especially with optimised code.
4. Drawing a diagram of what you think is happening is highly recommended. A simple circuit diagram or timing diagram will often help you realise what you have missed and let you fix it without asking for help.

## 7.9 Possibly asked questions with answers

- *Why use the SAM4s MCU?* For this application most MCUs would suffice, even an 8-bit AVR microcontroller. To level the playing field, I have chosen a MCU most students would not have used before. This is an ARM based MCU made by Atmel I have used this in a number of projects. Indeed we used to teach it in ENCE361. There are many other similar MCUs made by different manufacturers such as the STM32 that would just as suitable.

- *Why use a four layer PCB?* Come to lectures to find out!
- *How was the PCB size chosen?* This was so twenty boards would fit on an A3 panel to reduce manufacturing costs.
- *Why use 7.2 V NiMH batteries for the Wacky Racers?* These were a legacy of previous Wacky Racers. They are also safer than lithium batteries.
- *Why can't I program my device using Windows?* Due to various aspects of the Windows ecosystem, setting up a fully functional build environment is more complicated, will often vary from machine to machine, will often break filepaths, and will often cause bizarre compilation errors. Use at your own risk, we will not assist in debugging issues related to Windows.
- *Can you please fix my problem for me?* Due to limited TA time available, we will only provide debugging assistance to students who have a printed A3 schematic sheet in front of them and have already tried looking up the problem on the ecewiki.

## 8 Changelog

- Version 2: removed battery monitoring from the functional assessment list. Clarified low battery voltage requirement.
- Version 3: loosened the assignment schedule to make term 2 less stressful.