

Programmable Robot Teleoperation for Dummies

Remote control, monitoring, and analysis of robot behavior

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Overview

Robot Teleoperation

Remote control, monitoring, and analysis of robot behavior

Key Development:

Programmable teleoperation of a robot for any kind of robot actuation or even sensing.

Details:

The teleoperation includes both telemetry and telecommands between a computer and the robot's microcontroller. It can be applied to untether every lightweight cardboard-based robot used in lab.

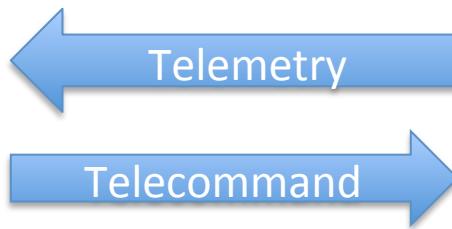
Accessibility:

This powerful interface program I developed is user-friendly with instructions available at:

<https://github.com/themichaeltsang/DashboardTeleoperation>

Teleoperation: Telemetry + Telecommand

- Wireless link between computer and robot via Bluetooth-Low-Energy

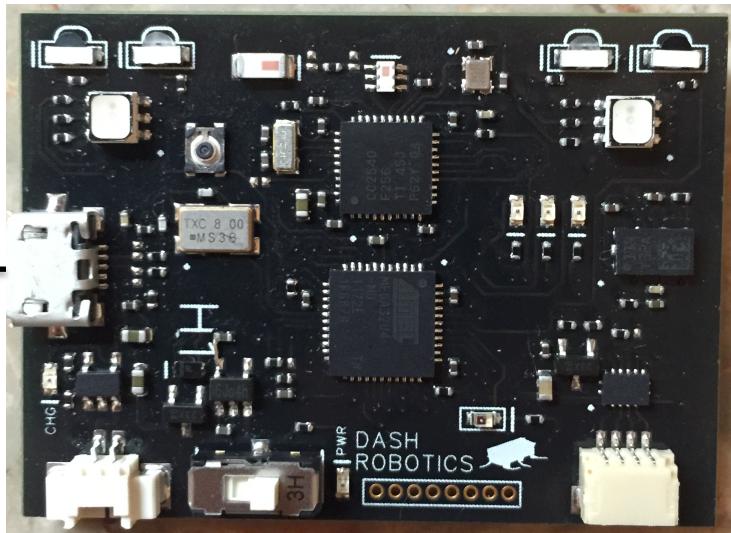


Mac OSX Supported, Requires Bluetooth 4.0

“Dashboard” Microcontroller Supported

Controller

Topview

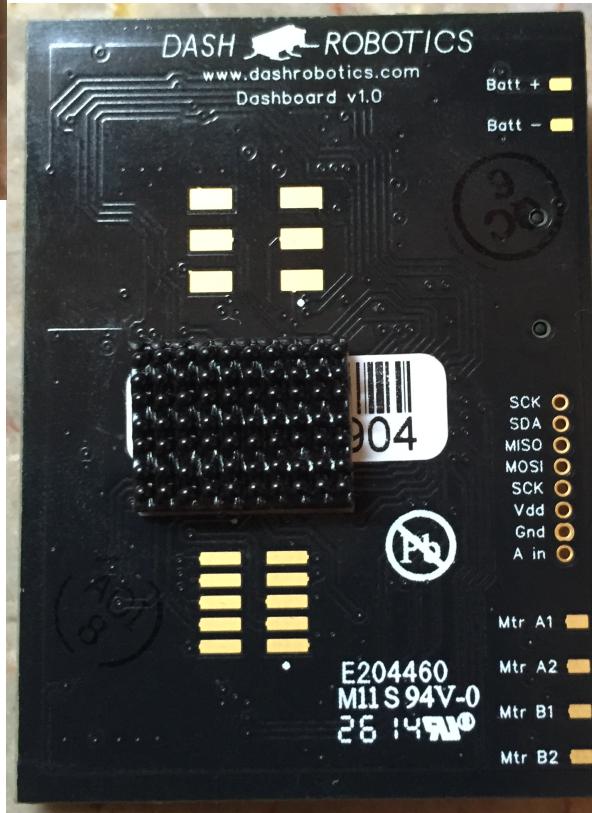


On-Off
Switch

Connect To Battery

Connect to dc
motors

Micro usb to computer for
Arduino programming



← “Expansion” Ports
See slide 32

Bottomview

Usage should be as easy as...

Set Keypress Definitions

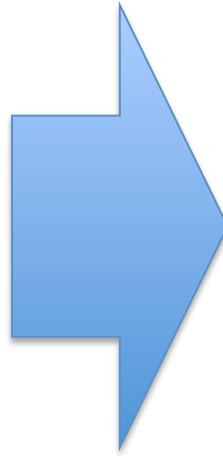
```
define( 'Start_Automation1_KEY', 'p' );
define( 'Start_Automation2_KEY', 'o' );
...
define( 'Run_Forward_KEY', 'a' );
define( 'Turn_R_KEY', 'd' );
define( 'Turn_L_KEY', 'a' );
...
define( 'Set_Servo1_Init_Position_KEY', 'z' );
define( 'Set_Servo1_Final_Position_KEY', 'x' );
...
```

Set Telemetry Parameters

```
define( 'Save_Sensor_Data', true );
define( 'Rate_of_Sensor_Data_Arrival', 100 ); //in Hz
```

Set Telecommand Parameters

```
define( 'Forward_Speed', 80 ); //unitless 1-100
define( 'R_Turn_Angular_Velocity', 70 ); //unitless 1-100
define( 'L_Turn_Angular_Velocity', 70 );
define( 'Turn_Duration', 300 ); //(ms)
...
```



After setting PARAMs,
Type into terminal:

node main.js

...and that's it!

Features: Telemetry

- Read sensor data for programs you write (see page ? for code)
- Automatically save live sensor data sent wirelessly from robot onto computer

| Sensor Data: Sat Nov 15 2014 21:26:27 GMT-0800 (PST) | | | | | | | |
|--|------------------|--------------------|---------------|-------------|-------------|------------|-------------|
| Expected Time (ms) | Actual Time (ms) | Yaw Rate (deg/sec) | Ambient Light | L Proximity | R Proximity | L Motor(%) | R Motor (%) |
| 0 | 65 | 8 | 21 | 709 | 675 | 0 | 0 |
| 100 | 133 | 4 | 20 | 710 | 677 | 0 | 0 |
| 200 | 134 | 0 | 20 | 710 | 677 | 0 | 0 |
| 300 | 200 | 8 | 21 | 706 | 674 | 0 | 0 |
| 400 | 269 | 4 | 22 | 703 | 671 | 0 | 0 |
| 500 | 336 | 4 | 24 | 700 | 670 | 0 | 0 |
| 600 | 404 | 8 | 24 | 698 | 668 | 0 | 0 |
| 700 | 404 | 0 | 23 | 699 | 669 | 0 | 0 |
| 800 | 470 | 4 | 22 | 699 | 669 | 0 | 0 |
| 900 | 538 | 8 | 21 | 701 | 671 | 0 | 0 |
| 1000 | 606 | 13 | 22 | 697 | 667 | 0 | 0 |
| 1100 | 606 | 0 | 24 | 694 | 663 | 0 | 0 |
| 1200 | 740 | -4 | 26 | 689 | 662 | 0 | 0 |
| 1300 | 808 | -13 | 26 | 692 | 664 | 0 | 0 |
| 1400 | 943 | -17 | 23 | 696 | 668 | 0 | 0 |
| 1500 | 1010 | 21 | 22 | ccc | ccc | 0 | 0 |

**Data saved in excel
(csv) format on
computer**

Sensor data will be appended to file sensorlog.csv with a timestamp header

Features: Telecommand

- Keypress Move Forwards, Right, Left (Slide 17 for code)
- Keypress Actuate Servo 1, 2, or 3
- Keypress to start custom teleoperation program you define
 - Automated control over dc motors, servos via telecommand
 - Simultaneous control of motors
 - Access to sensor readings via telemetry

Installation

Installation

1. Setup Microcontroller
2. Setup Computer

Setup Microcontroller

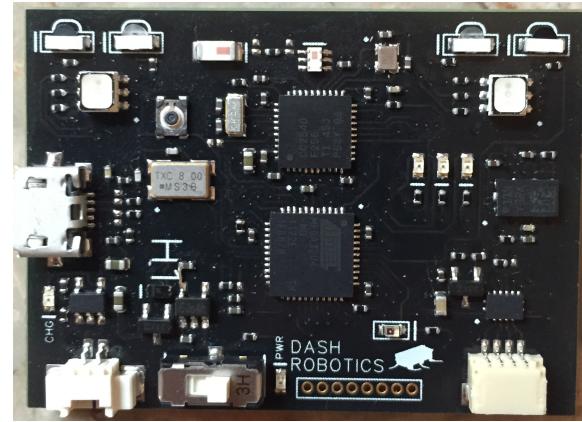
1. Load Custom Arduino Firmware

Visit:

<https://github.com/themichaeltsang/DashboardTeleoperation>

Follow these two points closely (copied from the link above)

- [Learn how to customize DashBoard firmware](#)
- Replace the folder “/libraries/DashBot” ... with the “/libraries” folder, found inside “custom_arduino_files” in [the Dashboard Teleoperation] repository



Only Dashboard from
Dash Robotics Supported

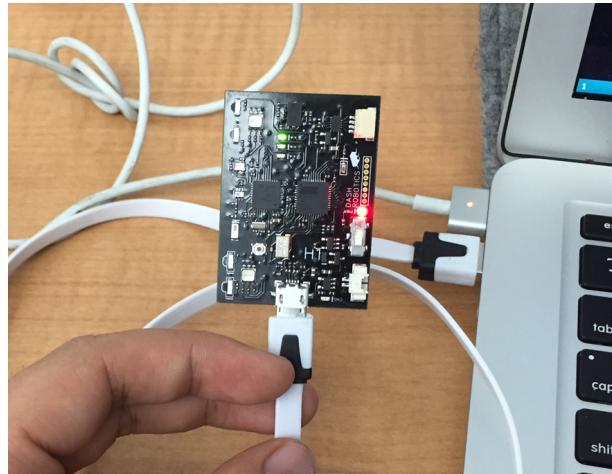
2. Connect Battery and Motors

Motors: (fill find model numbers later)

Battery: (fill find connector labels later)

[http://www.thunderpowerrc.com/Products/
Ultra-Micro](http://www.thunderpowerrc.com/Products/Ultra-Micro)

Setup Microcontroller: Using Arduino Software with the Dashboard



Connect Dashboard to USB on Computer, turn on the Dashboard

1)

```
sketch_dec09a | Arduino 1.0.5
sketch_dec09a | DashFirmware_v1_1 §

/*
basic Dash firmware.
*/
//libraries
#include <EEPROM.h>
#include <DashBot.h>
#include <VarSpeedServo.h>

DashBot myrobot; //gyro, motors, controller, LEDs, eyes

void setup() {
  myrobot.dashRadioSetup();
}

void loop(){
  myrobot.dashPacketHandler();
}
```

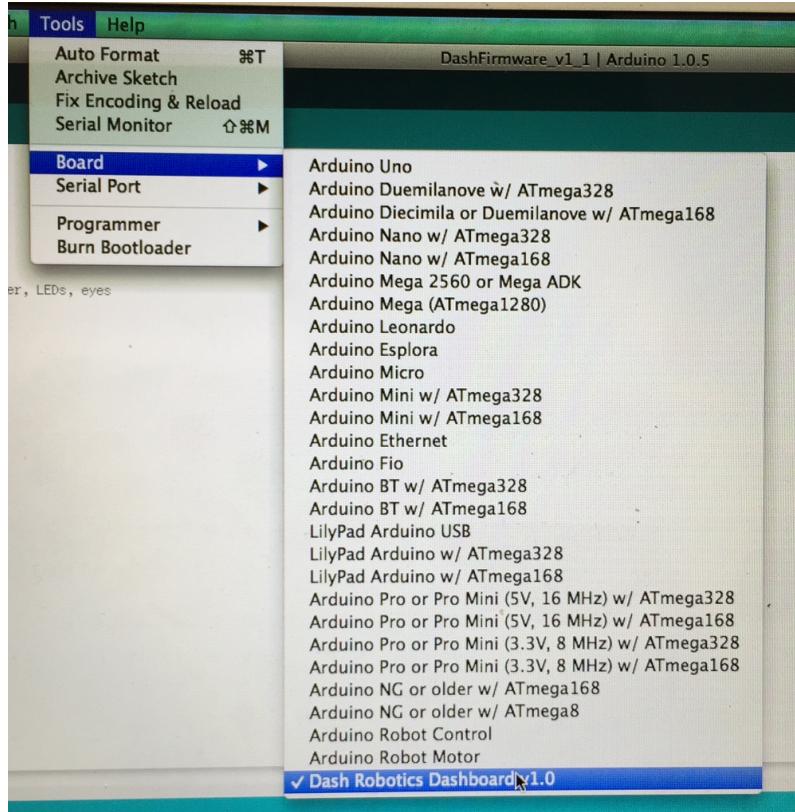
Download and Install Arduino Software (Arduino IDE)
<http://arduino.cc/en/main/software>

Open DashFirmware_v1_1.ino provided in
<https://github.com/themichaeltsang/DashboardTeleoperation>

2)

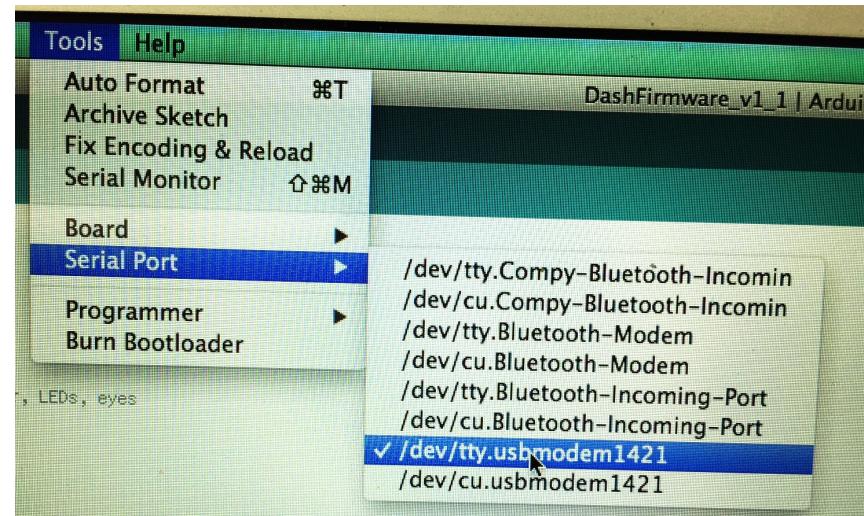
Note that the Dashboard runs custom Arduino UNO software, so it behaves like an arduino

Setup Microcontroller: Using Arduino Software with the Dashboard



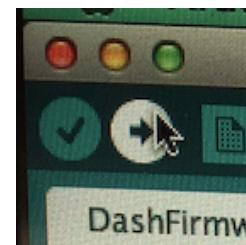
Select Dashboard from Tools > Board

3)



Select tty.usbmodemxxxx from Tools > Serial Port

4)



5) Press Upload

Note that the Dashboard runs custom Arduino UNO software, so it behaves like an arduino

Setup Computer

1. Use Mac Computer with OSX

Tested with 2009 Macbook and newer

Tested with OSX 10.9.2 and newer

2. Attach Bluetooth 4.0 Dongle if Computer doesn't have it.

Set the dongle as default bluetooth by following these instructions:

<http://www.geekguides.co.uk/414/how-to-select-a-bluetooth-adapter-in-os-x/>

3. Install Node js

Click Install at: <http://nodejs.org/>

4. Download code repository at

<https://github.com/themichaeltsang/DashboardTeleoperation>

Setup Computer: Text Editor

- Recommendation:
 - Use the text editor, sublime text :
<http://www.sublimetext.com/> (shown in slide 18)
 - Sublime text is easy on the eyes and nicely highlights keywords in many different programming languages
 - It also supports multi-window view, and multi-character selection.
 - My favorite commands are
 - “cmd ?” macro to comment out (deactivate) a selection of text
 - “Find All” after typing the “cmd f” macro, so you can, in one step, change a variable name appearing throughout an entire document to a new name
 - I recommend adding Sublime linter to auto-find syntax errors for you
 - [http://youtu.be/uP2pkvHh2pY?
list=PLLnpHn493BHEYF4EX3sAhVG2rTqCvLnsP](http://youtu.be/uP2pkvHh2pY?list=PLLnpHn493BHEYF4EX3sAhVG2rTqCvLnsP)

Setup Computer: Terminal Basics

- Terminal is a native program on Mac OSX
- Open Terminal
- Type ls
 - Will show you the contents of the folder you are currently in
- Type cd <folder name>
 - Enters a folder in the current directory
- Type cd ..
 - Moves you to folder enclosing the one you are currently in
- ls and cd are critical to navigating to the Teleoperation program directory, so you can run the program yourself

More guidance:

<http://mac.appstorm.net/how-to/utilities-how-to/how-to-use-terminal-the-basics/>

Sublime text and Terminal Workflow

The diagram illustrates the workflow for teleoperation program development. It shows two main windows: 'main.js' in Sublime Text and 'Terminal'. The Sublime Text window displays code for three servos (Servo1, Servo2, Servo3) with initial positions, final positions, speeds, and automation definitions. The Terminal window shows the command 'node main.js' being run. A large blue circle highlights the servo definitions in the Sublime Text code. Two arrows point from this circle to specific lines of code in the Sublime Text window: one arrow points to the 'servo1_control(180, 50);' line at line 18, and another points to the 'servo2_control(180, 50);' line at line 32. A third arrow points from the Terminal window to the 'node main.js' line in the Sublime Text code. A large blue box labeled 'Sublime Text' is positioned above the terminal area.

```
PARAMS.js
12 //EDIT PARAMETERS HERE
13 //TELEMETRY
14 define( 'Save_All_Sensor_Data', true ); //Output to CSV file
15 define( 'Rate_of_Sensor_Data_Arrival', 10 ); //(<= 100Hz)
16
17 //DC MOTORS
18 define( 'Forward_Speed', 80 ); //1-100
19 //define( 'Backward_Speed', 50 );
20 define( 'R_Turn_Angular_Velocity', 70 ); //1-100
21 define( 'L_Turn_Angular_Velocity', 70 );
22 define( 'Turn_Duration', 300 ); //(ms)
23
24 //SERVOS
25 define( 'Servo1_Port', MOSI );
26 define( 'Servo2_Port', SDA );
27 define( 'Servo3_Port', MISO );
28
29 define( 'Servo1_Initial_Position', 0 ); //0-180 degrees
30 define( 'Servo1_Final_Position', 180 ); //0-180 degrees
31 define( 'Servo1_Speed', 40 ); //0=no speed, 1-255 slower to faster
32 define( 'Servo2_Initial_Position', 0 ); //0-180 degrees
33 define( 'Servo2_Final_Position', 180 ); //0-180 degrees
34 define( 'Servo2_Speed', 40 ); //0=no speed, 1-255 slower to faster
35 define( 'Servo3_Initial_Position', 0 ); //0-180 degrees
36 define( 'Servo3_Final_Position', 180 ); //0-180 degrees
37 define( 'Servo3_Speed', 40 );
38
39 //KEYPRESS DEFINITIONS - trigger "on-the-fly" control
40 define( 'Start_Automation1_KEY', 'p' );
41 define( 'Start_Automation2_KEY', 'o' );
42 define( 'Start_Automation3_KEY', 'i' );
43
44 define( 'Run_Forward_KEY', 'w' );
45 //define( 'Run_Backward_KEY', 's' );
46 define( 'Turn_R_KEY', 'd' );
47
48
49
50
51
52
53
54
55
56
57
58

main.js
14 //Example Sketch - Conventional Sequence
15 function automode_sketch1() {
16     servo1_control(180, 50); //t_0
17     setTimeout(function(){
18         servo1_control(180, 50);
19         servo2_control(180, 50);
20     }, 2000 / t_0);
21 }
22
23
24
25
26
27
28
29 motorDrive(60,100,3000);
30 servo2_control(180, 50);
31 }, 2000 / t_3
32 );
33 setTimeout(function(){
34     servo1_control(0, 50);
35     servo2_control(0, 50);
36 }, 4000 / t_4
37 );
38 }
39
40
41
42
43
44 //Example Sketch - with "For" Loop
45 function automode_sketch2() {
46
47     for(var i = 0; i <= 180; i += 30){
48         (function(i){
49             setTimeout(function() {
50                 servo1_control(i,50);
51                 servo2_control(i,50);
52             }, 50*i);
53         });
54         setTimeout(function() {
55             servo1_control(180,50);
56             servo2_control(180,50);
57         }, 500 + 50*i);
58     };
59 }

Terminal
bash          node
DashboardTelemetry — node — 80x12
Michael$ node main.js
SEARCHING FOR DASH
```

Usage

Usage

1. Set Parameters in PARAMS.js in root directory
2. Run “node main.js” in the same directory using Terminal
3. Press user-defined keys to trigger robot behaviors. User-defined keys are set in PARAMS.js

If you need more guidance, consult:

[https://github.com/themichaeltsang/
DashboardTeleoperation](https://github.com/themichaeltsang/DashboardTeleoperation)

Usage: 1) Set Parameters

```
PARAMS.js
11 //EDIT PARAMETERS HERE
12 //TELEMETRY
13     define( 'Save_All_Sensor_Data', true ); //Output to CSV file
14     define( 'Print_Live_Sensor_Data_to_Terminal', false );
15     define( 'Rate_of_Sensor_Data_Arrival', 10 ); //(<= 100Hz)
16
17 //DC MOTORS
18     define( 'Forward_Speed', 80 ); //1-100
19     //define( 'Backward_Speed', 50 );
20     define( 'R_Turn_Angular_Velocity', 70 ); //1-100
21     define( 'L_Turn_Angular_Velocity', 70 );
22     define( 'Turn_Duration', 300 ); //(ms)
23
24 //SERVOS
25     define( 'Servo1_Port', MOSI );
26     define( 'Servo2_Port', SDA );
27     define( 'Servo3_Port', MISO );
28
29     define( 'Servo1_Initial_Position', 0 ); //0-180 degrees
30     define( 'Servo1_Final_Position', 180 ); //0-180 degrees
31     define( 'Servo1_Speed', 40 ); //0=no speed, 1-255 slower to faster
32     define( 'Servo2_Initial_Position', 0 ); //0-180 degrees
33     define( 'Servo2_Final_Position', 180 ); //0-180 degrees
34     define( 'Servo2_Speed', 40 ); //0=no speed, 1-255 slower to faster
35     define( 'Servo3_Initial_Position', 0 ); //0-180 degrees
36     define( 'Servo3_Final_Position', 180 ); //0-180 degrees
37     define( 'Servo3_Speed', 40 );
38
39 //KEYPRESS DEFINITIONS - trigger "on-the-fly" control
40     define( 'Start_Automation1_KEY', 'p' );
41     define( 'Start_Automation2_KEY', 'o' );
42     define( 'Start_Automation3_KEY', 'i' );
43
44     define( 'Run_Forward_KEY', 'w' );
45     //define( 'Run_Backward_KEY', 's' );
46     define( 'Turn_R_KEY', 'd' );
47     define( 'Turn_L_KEY', 'a' );
48
49     define( 'Set_Servo1_Init_Position_KEY', 'z' );
50     define( 'Set_Servo1_Final_Position_KEY', 'u' );
51
```

Default parameters shown

Usage: 2 & 3) Run in Terminal

```
Michaels-MacBook-Air-7:DashboardTelemetry Michael$ node main.js
SEARCHING FOR DASH
DASH DISCOVERED
    Initializing gyro
    Saving sensor data, appended to sensorlog.csv
RUNNING...

Press keys defined in PARAMS.js:
    Start Automode1: p
    Start Automode2: o
    Start Automode3: i
    Run Forward: w
    Turn Right: d
    Turn Left: a
    Set Servo1 initial: z
    Set Servo1 final: x
    Set Servo2 initial: c
    Set Servo2 final: v
    Set Servo3 initial: b
    Set Servo3 final: n
```

Run “node main.js”, press keys according to definitions (definitions will be shown in Terminal for your convenience)

Usage Notes

- Every keypress command triggers a response from the Dashboard near instantaneously.
- It's very fluid to control the Dashboard controller remotely
- Note that signals are being sent from the controller constantly, so sending signals back to the controller in a data stream at the same time may interrupt the bluetooth communication process

Telemetry

Telemetry Parameters

In PARAMS.js

```
//TELEMETRY
define( 'Save_All_Sensor_Data', true ); //Output to CSV file
define( 'Print_Live_Sensor_Data_to_Terminal', false );
define( 'Rate_of_Sensor_Data_Arrival', 10 ); //(<= 100Hz)
```

This parameter enables or disables sensor data recording on the computer. If true, data will be appended to sensorlog.csv. (see next slide)

If false, data will not be appended.

If you would like a new file to be made, delete sensorlog.csv and set to true, and a new sensorlog.csv will be created with new sensor data

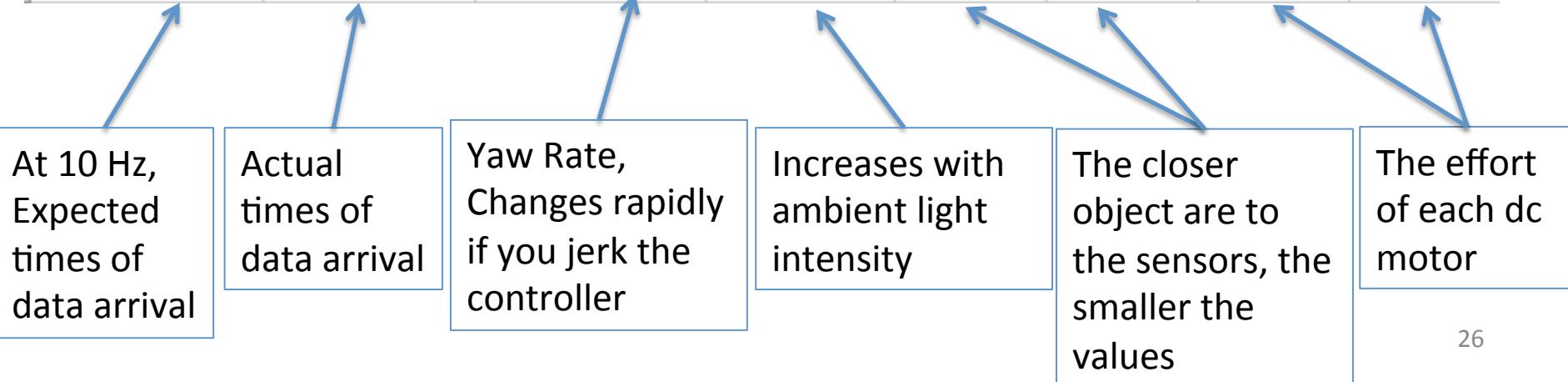
Good for observing live changes
In sensor readings

This parameter sets the rate at which data will be emitted from the dashboard. Because some data processing is required to interpret the data from the computer, the computer does not read the data fast enough at high rates.

10 Hz is safe. You may try pushing the rate to 100 Hz

Telemetry File: sensorlog.csv

| Sensor Data: Sun Dec 07 2014 12:37:49 GMT-0800 (PST) | | | | | | | | |
|--|------------------|--------------------|---------------|-------------|-------------|------------|-------------|--|
| Expected Time (ms) | Actual Time (ms) | Yaw Rate (deg/sec) | Ambient Light | L Proximity | R Proximity | L Motor(%) | R Motor (%) | |
| 0 | 133 | 4 | 732 | 291 | 374 | 0 | 0 | |
| 100 | 201 | 4 | 727 | 294 | 377 | 0 | 0 | |
| 200 | 336 | 4 | 717 | 299 | 383 | 0 | 0 | |
| 300 | 403 | 4 | 708 | 304 | 388 | 0 | 0 | |
| 400 | 538 | 4 | 705 | 304 | 389 | 0 | 0 | |
| 500 | 606 | 4 | 707 | 303 | 388 | 0 | 0 | |
| 600 | 741 | 4 | 705 | 304 | 389 | 0 | 0 | |
| 700 | 808 | 4 | 708 | 304 | 389 | 0 | 0 | |
| 800 | 943 | 4 | 711 | 305 | 387 | 0 | 0 | |
| 900 | 1011 | 4 | 708 | 307 | 389 | 0 | 0 | |
| 1000 | 1146 | 4 | 706 | 309 | 390 | 0 | 0 | |
| 1100 | 1213 | 4 | 706 | 308 | 390 | 0 | 0 | |
| 1200 | 1348 | 4 | 705 | 309 | 390 | 0 | 0 | |
| 1300 | 1416 | 4 | 707 | 308 | 390 | 0 | 0 | |



Sensor Read Functions

Read Yaw Rate

```
readGyroDeg(function(yaw_rate){  
    //YOUR CODE HERE that depends on yaw_rate  
});
```

Read Ambient Light Intensity

```
readAmbLight(function(amb_light){  
    //YOUR CODE HERE that depends on amb_light  
});
```

Read L and R Proximity

```
readLeftProximity(function(l_IR)){  
    //YOUR CODE HERE that depends on l_IR  
});
```

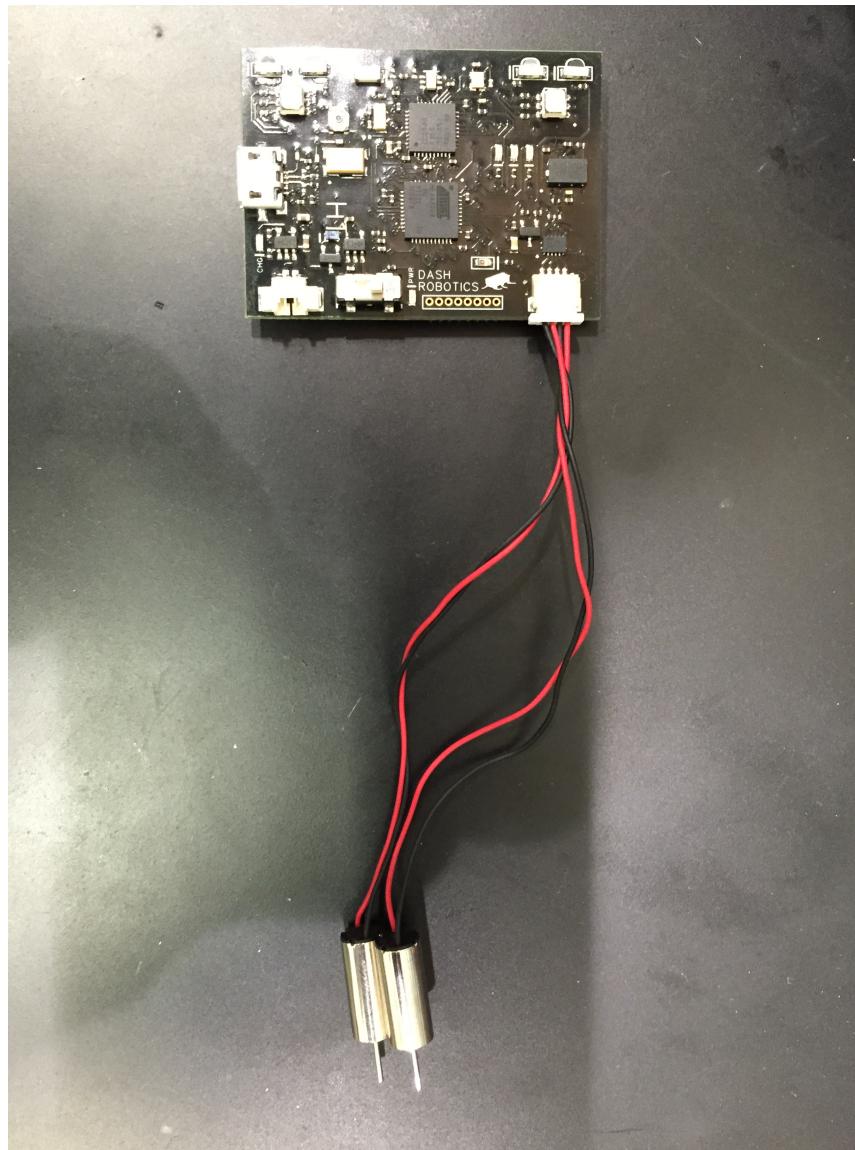
```
readRightProximity(function(r_IR)){  
    //YOUR CODE HERE that depends on r_IR  
});
```

These functions, to be used in main.js, are valid for automatically controlled events, triggered by:

Start_Automation1_KEY,
Start_Automation2_KEY,
or
Start_Automation3_KEY

Telecommand: DC & Servo Motors

DC Motor Connection



DC Motor Parameters

In PARAMS.js

```
//DC MOTORS
define( 'Forward_Speed', 80 ); //1-100
define( 'R_Turn_Angular_Velocity', 70 ); //1-100
define( 'L_Turn_Angular_Velocity', 70 );
define( 'Turn_Duration', 300 ); //(ms)
```

These parameters are only valid for manually controlled events, triggered by:

Run_Forward_KEY, Turn_R_KEY, or Turn_L_KEY

DC Motor Control Function

- Drive the Motors for a specified time

`motorDrive (left_motor_speed, right_motor_speed, duration_of_run)`

motor_speed acceptable range of values: 0 no speed, 1-100 slower to faster

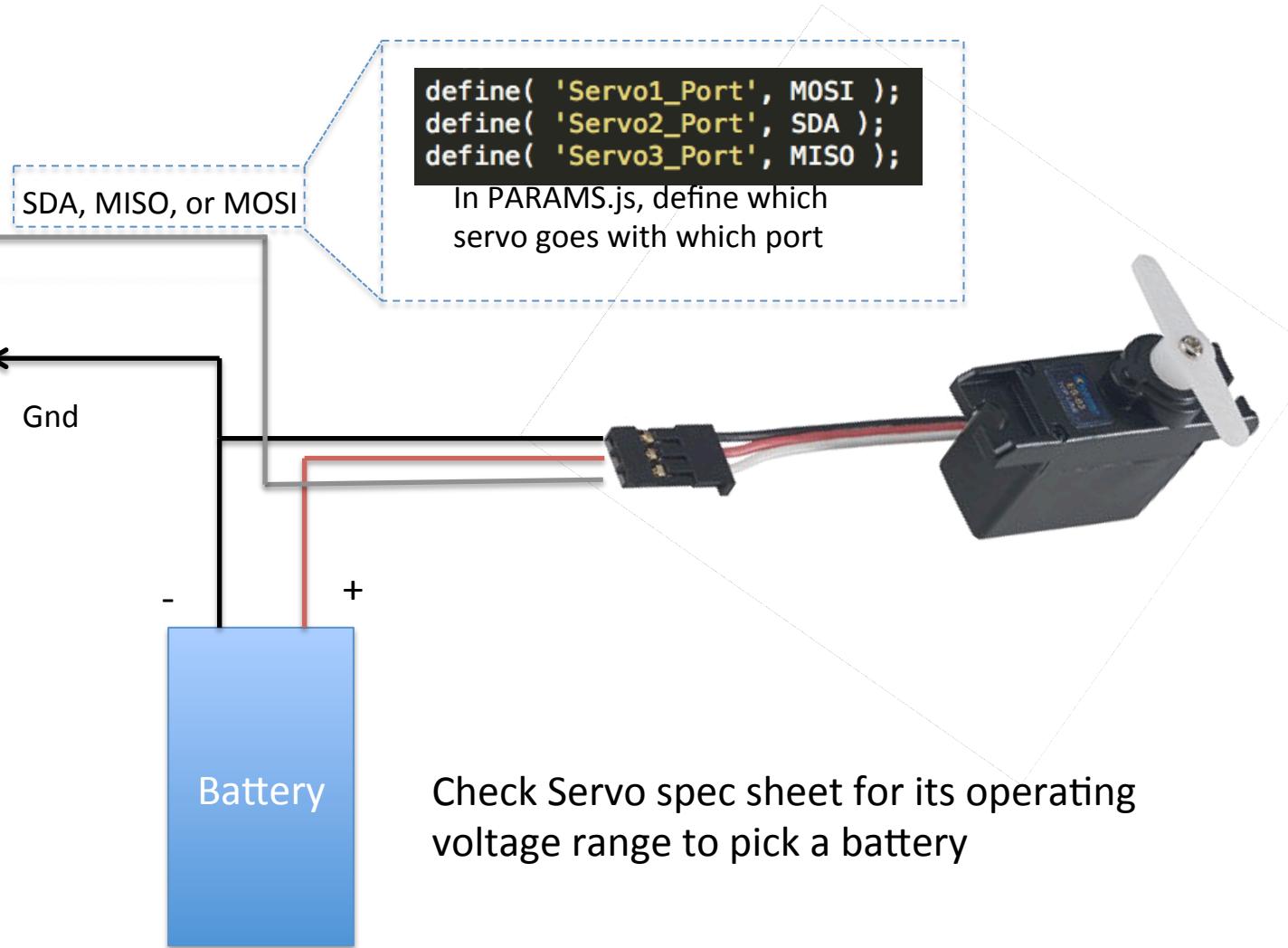
These functions, to be used in main.js, are valid for automatically controlled events, triggered by:

Start_Automation1_KEY, Start_Automation2_KEY,
or Start_Automation3_KEY

Servo Motor Connection



Dashboard
backside



If you'd like to add more servos (up to 3), you can use the same battery

Servo Motor Parameters

In PARAMS.js

```
define( 'Servo1_Initial_Position', 0 ); //0-180 degrees
define( 'Servo1_Final_Position', 180 ); //0-180 degrees
define( 'Servo1_Speed', 40 ); //0=no speed, 1-255 slower to faster
define( 'Servo2_Initial_Position', 0 ); //0-180 degrees
define( 'Servo2_Final_Position', 180 ); //0-180 degrees
define( 'Servo2_Speed', 40 ); //0=no speed, 1-255 slower to faster
define( 'Servo3_Initial_Position', 0 ); //0-180 degrees
define( 'Servo3_Final_Position', 180 ); //0-180 degrees
define( 'Servo3_Speed', 40 );
```

These parameters are only valid for manually controlled events, triggered by:

Set_Servo1_Init_Position_KEY, Set_Servo1_Final_Position_KEY,
Set_Servo2_Init_Position_KEY, Set_Servo2_Final_Position_KEY,
Set_Servo3_Init_Position_KEY, or Set_Servo3_Final_Position_KEY

Servo Motor Control Functions

```
servo1_control(position, speed)  
servo2_control(position, speed)  
servo2_control(position, speed)
```

position acceptable range of values: 0-180 degrees

speed acceptable range of values: 0-255, recommend 50. Passed around 70,
servo may not move to desired position

These functions, to be used in main.js, are valid for automatically controlled events,
triggered by:

Start_Automation1_KEY, Start_Automation2_KEY,
or Start_Automation3_KEY

Customization: User-defined Robot Behaviors

Program Customization: Basics

On the top of the main.js file:

```
function automode_sketch1() {
    servo1_control(180, 50); //t_0
    setTimeout(function(){
        motorDrive(100, 100, 800);
    }, 100 //t_1 (ms)
);
    setTimeout(function(){
        motorDrive(100, 50, 8000);
    }, 1000 //t_2
);
    setTimeout(function(){
        servo1_control(0, 50);
        servo2_control(0, 50);
    }, 4000 //t_3
);
}
```

Start moving servo at t = 0

setTimeout:
Delay the block of code until time:
 $t = 100\text{ms}$

At $t = 1\text{s}$, drive left motor at full capacity and right motor at half capacity for 8s

At $t = 4\text{s}$, actuate both servos, moving both of them to 0 degrees position at 50 speed

Program Customization: For loop

The “For” loop allows you to loop repeatable behavior:

What this code does is move servos by increments of 30 degrees in 1.5s intervals until the servos hit the position of 180 degrees.

All the while, the dc motors are moving at full speed uninterrupted.

```
function automode_sketch2() {  
    for(var i = 0; i <= 180; i += 30){  
        (function(i) {  
            setTimeout(function() {  
                servo1_control(i,50);  
                servo2_control(i,50);  
                motorDrive(100,100,1500);  
            }, 50*i  
        );  
    })(i);  
}
```

Run this block of code at times dependent of the iteration value i:

This allows you to loop repeatable behavior

Program Customization: Incorporating Sensor Readings

In this code the dc motors continuously run when the ambient light is dark, and they stop running in bright ambient lighting. The dc motors will run again whenever it is dark again. In this code, sensor data is read at 1 Hz.

```
function automode_sketch3() {
  for(var i = 0; i <= 10000; i += 10){
    (function(i) {
      setTimeout(function() {
        readAmbLight(function(raw) { ←
          console.log(raw);
          if (raw<70){
            motorDrive(100,100,1000);
          }
          else{
            motorDrive(0,0,1000);
          }
        });
      }, 100*i
    })(i);
  }
}
```

raw is the ambient light sensor reading, which is used in the next two lines of code

In-Depth: Information Transfer over Bluetooth

Bluetooth Low Energy

- Bluetooth Low Energy was the key development in Bluetooth 4.0, and it is the wireless communication link between the dashboard and remote controllers.

Communicating with Bluetooth Low Energy

- The dashboard sends and receives “serial packets” to transfer data wirelessly to and from an external controller.
- These packets are 14 bytes long each.
-more on this later

Sending and Receiving Packets in the Code

Previous Attempts and Failures

Research Path

Developing Programmable Teleoperation

RedBearLabs
Failure

LightBlue iOS
app

noble:
read and write
Bluetooth data

softpwm

Pololu
Micro
maestro

varspeedservo

Research to find appropriate ways to
communicate with Dashboard from
computer

Research to find appropriate ways
to control servos from Dashboard

Significance of Each Step

- RedBearLabs
- LightBlue
- Noble
- Softpwm
- Pulolu micro maestro
- varspeedservo

More on this later...