

Irrigation Controller Using Beaglebone Green Wireless, Node.js, and EcmaScript 6

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May 28, 2017

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Chapter 1

Introduction

This is the documentation for an embedded GNU/Linux project using the Beaglebone Green Wireless (BBGW) development board. The project repository is located here:

<https://github.com/Greg-R/irrigate-control>

The Debian-based GNU/Linux distribution used on the BBGW can be downloaded from this page:

<http://beagleboard.org/latest-images>

The “IOT” (non-GUI) image was chosen, as this provides the shortest path to get the project up and running.

A listing of additional resources is found in the Resources chapter.

1.1 Project Goals

I’ve published two other projects on Hackster.io. These other projects are interesting, and good learning tools, but they do not do anything useful in the real world. After a couple of years of "going up the learning curve" on embedded device development, it was time to create something practical!

This project performs the simple home automation task of controlling a lawn irrigation system. For many years, I had been controlling the irrigation system manually by flipping a circuit breaker to turn the pump motor on and off. The old timing unit had failed years ago, and I had never replaced it. So now I wanted to be able to control the system via a web browser without having to leave my home office desk.

Although in principle the automation is simple, the underlying technology is complex! There was a significant investment in time learning the technology required to implement the project.

1.2 Technologies

The development board chosen is the Beagle Bone Green Wireless (BBGW). I have significant experience with the regular Beagle Bone Green, and the WIFI capability is required for this project. The board will be mounted remotely with access to power only (no wired ethernet is possible).

The Debian-based GNU/Linux distribution used on the BBGW can be downloaded from this page:

<http://beagleboard.org/latest-images>

The “IOT” (non-GUI) image was chosen, as this provides the shortest path to get the project up and running.

Node.js version v7.9.0 was used. This is a much later version than what is included in the image. A section on ungrading is included.

The project’s Javascript code uses several "EcmaScript 6" constructs. In my opinion this release of Javascript is a significant improvement in the language. Some of the strange quirks of Javascript are eliminated!

Two-way communication between the web browser and the BBGW was done with “WebSockets“. The client side WebSocket is built into the browser. Using the latest updates in Ubuntu 16.04, both Firefox and Chromium browsers include this capability. The Chrome browser of an Android phone was also found to work.

Here is a good reference on the client (browser) side WebSockets:

<https://developer.mozilla.org/en-US/docs/Web/API/WebSocket>

The server side uses a Node.js package called “ws”:

<https://github.com/websockets/ws>

Since this is a “real world” project, there has to be an interface with real actuators. This small “solid-state-relay” board proved to be ideal for taking the GPIO outputs of the BBGW and doing something real:

https://www.amazon.com/gp/product/B00ZZVQR5Q/ref=oh_aui_detailpage_o00_s00?ie=UTF8&psc=1

This board has four individual relays. This project uses only three.

Note that this type of relay can switch AC power only. This was ideal for this project, as the irrigation system is powered by 24VAC.

The other common components of the irrigation system are listed in the reference section at the end of this document.

“Universal IO” was used to set the pin multiplexer to GPIO mode:

<https://github.com/cdsteinkuehler/beaglebone-universal-io>

Chapter 2

System Diagrams

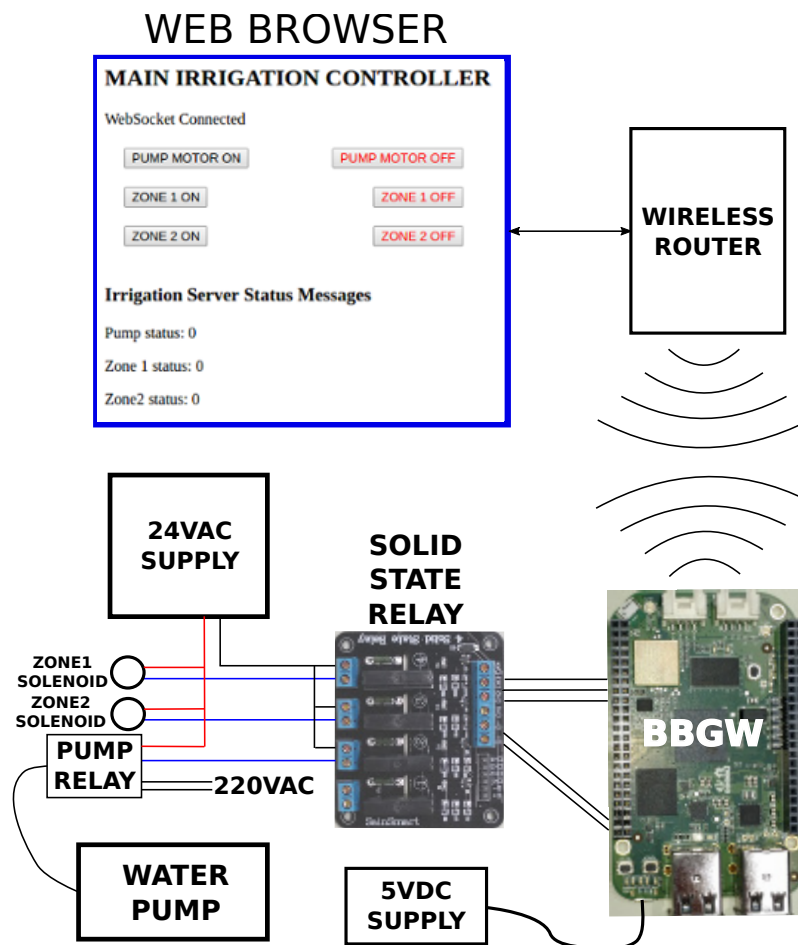


Figure 2.1: Beagle Bone Green Wireless Irrigation Control System

The above diagram shows the main components of the system. A reference section is included which has a complete parts list.

2.1 GNU/Linux Operating System on Host ARM Processor

The command `uname -a` on the BBGW used to develop this project reports this:

```
Linux beaglebone 4.4.48-ti-r88 #1 SMP Sun Feb 12 01:06:00 UTC 2017 armv7l  
GNU/Linux
```

Chapter 3

Ecmascript 6

This page shows which Ecmascript 6 features are implemented in major versions of Node:

<http://node.green/>

Javascript has become a feature rich and large language! Some of the ES6 constructs used in this project:

- class
- Map
- arrow function
- Proxy
- const and let

A good reference for ES6 is at the Mozilla Developer Network:

<https://developer.mozilla.org/en-US/docs/Web/JavaScript>

A quick summary of the ES6 constructs follows.

3.0.1 class

The new “class” keyword does not provide new functionality. What it does is allow a Javascript class object to be written in a more traditional object-oriented style. This does make things easier for a person used to other language’s syntax for defining classes.

3.0.2 Map

The “Map” is a new data structure object which is similar to what is called a “hash”, dictionary, or associative array. Prior to ES6, the Javascript object was used functionally as a Map, however, this was kind of a hack.

In this project, the Map object is used in the pumpActuator object.

3.0.3 Arrow Function

“Arrow Functions” are a simplification of the syntax used when defining a function. However, they are also important in determining the the scope of “this” within the function. The arrow functions capture the “this” of the enclosing scope. This was found to be convenient in the design of the pumpActuator class.

```
this.pumpMap = new Map([[ 'pumpmotor', 0 ],
                        [ 'zone1', 0 ],
                        [ 'zone2', 0 ]]);
```

The “pumpMap” is a simple data structure to store the state of the pumpmotor and the two zone actuators.

3.0.4 Proxy

Of the above ES6 constructs, the only one requiring detailed explanation is the “Proxy”. The construct is used to implement the so-call “Observer” pattern.

The instantiation of the “pumpHashProxy” is done in the constructor of the pumpActuator class:

```
this.pumpHashProxy = new Proxy(this.pumpMap, this.pumpObserver());
```

The Proxy’s constructor takes two arguments, which in this case is this.pumpMap and this.pumpObserver(). The second argument requires some explanation.

```
pumpObserver() {
  return {
    set: (target, property, value, receiver) => {
      console.log(`Setting ${property} to ${value}.`);
      this.pumpControl(property, value);
      target[property] = value;
      return true;
    }
  };
}
```

The above class method is a little bizarre. This method merely returns a Javascript object. The object in this case has a single key “set” and the value is an arrow function with four parameters: target, property, value, and receiver.

The Proxy creates a sort of “watcher” or “observer” of pumpMap. The proxy intercepts changes written to or read from the target object (the first parameter of the Proxy constructor).

Using the key “set” causes the function (the set key’s value) to be executed when the value is written to. Note that the function has access to the intercepted property and value, and these

are used in call the function “this.pumpControl”. This does the physical setting of the GPIOs. The data structure is also updated (`target[property]=value`) and “true” is returned to indicate a successful set.

The proxy does a sort of “intercept” of writes to the object and then can perform custom actions based on the the function assigned to “set”. Similar functionality for reads can be done with the “get” key. The object can contain both and custom read and write functions can be used. This is very powerful!

Functionally what the Proxy does is intercept the write to the data structure which stores the state of the pumpmotor and the zone solenoids. The intercept runs the “set” function and changes the physical state of the GPIOs.

The write to the data structure is done by the server in file `websocketserver.js`:

```
Object.assign(pumpObject.pumpHashProxy, controlObject);
```

The “controlObject” in this case is an incoming WebSocket message (using JSON notation) from the browser which looks like this example:

```
{"pumpmotor":0}
```

The write to the data structure in the `pumpActuator` object is done by the server in file `websocketserver.js`:

```
Object.assign(pumpObject.pumpMapProxy, controlObject);
```

The “Object.assign” is a shortcut which simply overwrites the value in `pumpMapProxy` with the value from `controlObject`. The Proxy intercepts this write, and then executes the custom set function.

The Proxy allows a custom behavior to be executed when a data structure is written to or read from. This is very powerful! In this particular project with only three controls it does not stand-out, however, this sort of “Observer” pattern is very scalable and could be very advantageous in a much larger and more complex system.

3.0.5 const and let

`const` creates a read-only reference to a block-scoped value. `let` is also block-scoped, but it is a variable.

`let` and `const` solve the crazy problem of hard to understand scope and “hoisting” of the `var` type variables of previous versions of Javascript. `var` was not used anywhere in this project.

`const` and `let` are a huge improvement to Javascript!

Chapter 4

GPIO Control with sysfs Virtual File System

This “sysfs” virtual file system the core functionality which allows the GPIOs to be controlled from user space.

Note that the BBGW must be correctly configured for GPIO output mode on the three control pins used to control the irrigation devices. This document will not cover this subject in detail, as this has been well-covered in numerous web articles and books.

A highly recommended resource is “Exploring Beaglebone” by Derek Molloy. (add footnote here)

The method of configuring the header pins to GPIO is covered in the chapter “Universal IO”. GPIO configuration must be complete before any of the commands shown below will function properly.

“POSIX” type operating systems, which includes Linux, are “file based”. That means the interface to everything is via writing to or reading from a file. In this case, the GPIO’s state is changed by writing a 0 or 1 to the appropriate file. Here is an example:

```
echo 1 > /sys/class/gpio/gpio50/value
```

The above changes the state of header pin P9.14 to “high” or an output of 3.3 volts. Echoing 0 changes the output to 0.0 volts. It’s that simple!

4.0.1 Controlling the GPIOs using Javascript

The command shown above is typed and executed in a bash shell. How is this done from Javascript? A module from Node.js is used to accomplish this:

https://nodejs.org/api/child_process.html

For example, the bash command shown above would be executed as follows in Javascript:

```
const exec = require('child_process').exec;  
exec('echo 1 > /sys/class/gpio/gpio50/value');
```

This is the simplest possible usage; an optional callback function as a second option is possible. The callback option is used in the in the “pumpActuator” class, and the callback is used to emit an event from the pumpActuator Object. This event is subscribed to by the WebSocket server, and when the event fires it sends a message to the web page controller to indicate that the control function has changed state. The web page is updated to indicate the new state.

The class method looks like this:

```
pumpControl(pumpgpio, command) {
  const exec = require('child_process').exec;
  exec(`echo ${command} > ${this.pumpGpioMap.get(pumpgpio)}`, (error,
  stdout, stderr) => {
    // If error, do not update the status of the controls.
    if (error) {
      console.error('exec error: ${error}');
      return;
    } else {
      console.log('Status message emitted from ledActuator:
      ${pumpgpio} is set to ${command}.');
      // Send a JSON object with the value being an array.
      this.emit('statusmessage', `["${pumpgpio}",${command}]`);
    }
  });
}
```

Chapter 5

An HTML5 Controller

The controller GUI is an HTML5 web page. The project was developed with the Chromium browser in Ubuntu 16.04.

There was no attempt to fix problems with cross-browser compatibility issues. Plain HTML5 and CSS was used throughout. This is a bare-bones interface with no fancy features.

MAIN IRRIGATION CONTROLLER

WebSocket Connected

PUMP MOTOR ON

PUMP MOTOR OFF

ZONE 1 ON

ZONE 1 OFF

ZONE 2 ON

ZONE 2 OFF

Irrigation Server Status Messages

Pump status: 0

Zone 1 status: 1

Zone2 status: 0

Irrigation Scheduling

Start Irrigation Date: 06/06/2017

Stop Irrigation Time: 06:00 AM

Stop Irrigation Time: 07:00 AM

Schedule Irrigation

Current Irrigation Schedule

Date: Tuesday, June 6th 2017

Start: 6:00:00 AM

Stop: 7:00:00 AM

Current Time

Tuesday, June 6th 2017, 9:02:04 PM

Figure 5.1: The Irrigation Controller as seen with a Chromium Browser

Manual control buttons for the zone solenoids and the pump motor are at the top. The user can enter a schedule date and start and stop times. Clicking the “Schedule” button sends the requested irrigation schedule to the server. The server responds with a message which updates the displayed schedule.

Chapter 6

Setting the BBGW to Local Time

The default time setting of the BBGW was found to be UTC. It was desired to have this set to local time.

Fortunately, there is a web page by Derek Molloy which covers this subject in detail:

<http://derekmolloy.ie/automatically-setting-the-beaglebone-black-time-using-ntp/>

CHECK IF DEFAULT IMAGE HAS ACTIVE NTP

The change to local time is done by removing an existing file, and then adding a symbolic link:

```
cd /etc
rm localtime
ln -s /usr/share/zoneinfo/America/New_York /etc/localtime
```

In the above example, the time zone is set to North America Eastern (New York). A complete listing of the possibilities is found in `/usr/share/zoneinfo`. Simply find the appropriate path for you time zone and create the link.

The time zone setting will take effect upon the next boot.

Chapter 7

Irrigation Scheduler Class

The Scheduler class is responsible for activating the irrigation system at the time specified by the user. The user enters the start and stop timing using the web browser controller. The watering times are equally split between the two zones.

The timing function might seem simple. However, it proved challenging to implement with simple code.

Two excellent Node packages were used:

<https://www.npmjs.com/package/node-cron>

and

<https://www.npmjs.com/package/moment>

The Node-cron package manager implements a functionality similar to a “cron job” in a POSIX operating system. The function provided is a time-delayed task set by the user. In this project, four jobs are required, and thus four node-cron tasks are created by a method of the Scheduler class.

The Moment package provides a robust data and time module which is more flexible than the native Javascript Date object. The module’s mode of operation is a little unusual, however, the documentation is excellent and the user should have no problem using the extensive feature set.

Irrigation Scheduling

Start Irrigation Date: 06/06/2017

Stop Irrigation Time: 06 : 00 AM

Stop Irrigation Time: 07 : 00 AM

Schedule Irrigation

Current Irrigation Schedule

Date: Tuesday, June 6th 2017

Start: 6:00:00 AM

Stop: 7:00:00 AM

Current Time

Monday, June 5th 2017, 8:22:27 PM

Figure 7.1: The Web Browser Irrigation Scheduler

Chapter 8

JSON Messaging with WebSocket

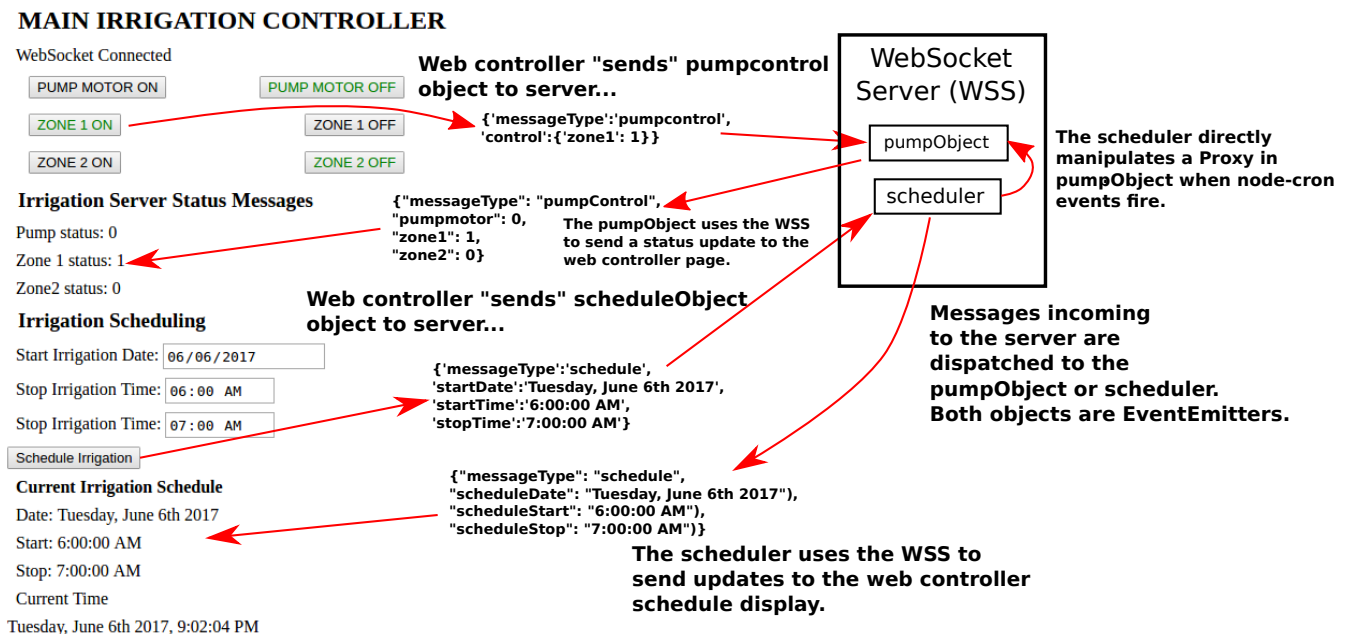


Figure 8.1: JSON Objects are passed between the Web Page Controller and the Server

The above diagram shows the flow of data between the web browser controller and the BBGW server.

“Javascript Object Notation” (JSON) is used the format used for the messages. These “Objects” are really used as associative arrays would be used in other programming languages. In fact, ES6 includes a formal associative array called Map. However, JSON is a de-facto standard for this sort of simple message passing, and the JSON related tools are easy to use.

To send a JSON Object with WebSocket, it is first necessary to “stringify” the object. This is done with the `JSON.stringify()` method. On the receiving end, the `JSON.parse()` method is used to translate back to a Javascript Object. After that, the Object is used with the normal key/value syntax of Javascript.

8.1 Example JSON Messages

Thanks to WebSocket being bidirectional, it is easy to pass messages in both directions between the web browser controller and the server. There are a total of four message types; two for browser to server and two for server to browser.

8.1.1 Browser to Server Hardware Control Message

This message indicates the device to be controlled and the desired state:

```
{'messageType': 'pumpControl', 'control': {'zone1': 1}}
```

The key “messageType” indicates to the server that this message should be routed to the pumpActuator Object. The “control” key’s value is another JSON object, and this Object has as its key the device to be controlled, and the value is the desired state.

A little bit of Javascript trickery is involved to use this piece of incoming data:

```
Object.assign(pumpObject.pumpMapProxy, dataObject.control);
```

The pumpActuator object has a data structure containing the current state of the zone solenoids and the pump motor. The data structure is an ES6 “Map”, which is a true associative array.

So what the Object.assign(arg1, arg2) method does is overwrite key:value pair located in arg1 with the key:value pair in arg2.

Due to the write being done through a Proxy Object, another function is called which physically changes the state of the correct GPIO, and then it sends another object back to the web browser to update its status display.

It could be the case that the ES6 Proxy Object will become a preferred method for managing state in Javascript based embedded devices. The interested reader is encouraged to check out the documentation at this link:

https://developer.mozilla.org/en-US/docs/Web/JavaScript/Reference/Global_Objects/Proxy

8.1.2 Server to Browser Hardware Status Message

When the project was first started, the buttons in the web browser to turn the hardware components on and off was simple DOM updates of the button colors.

However, this does not indicate the true state of the hardware in the case of a communications breakdown between browser and server.

The design was revised to update button indicators only upon receipt of a message from the server indicating a successful hardware state change.

The pumpActuator object emits “pumpStatusMessage”, and then only if a WebSocket is open the status message is sent to the browser. The web browser parses the message and uses DOM Javascript manipulation to update the displayed hardware status.

```
{'messageType':'pumpControl', 'pumpmotor':0, 'zone1':1, 'zone2':0}
```

8.1.3 Browser to Server Scheduling Message

The system user can input a date, start, and stop times for irrigation to happen automatically in the future. Simple HTML5 form fields are used to gather the user’s input, and then a “Schedule Irrigation” button is clicked. If a valid WebSocket is open, a scheduling JSON object is sent to the server.

```
{'messageType':'schedule', 'scheduleData':'Tuesday June 6th 2017',  
'scheduleStart':'6:00:00 AM', 'scheduleStop':'7:00:00'}
```

The websocketserver determines the “messageType” is schedule, and then dispatches the message to the Scheduler Object.

8.1.4 Server to Browser Schedule Display Update Message

The Scheduler has the necessary logic to drive the hardware per the schedule.

The browser’s displayed schedule is updated by the server, not by the browser. Thus the server sends the scheduling message back to the browser, but only if the message is first processed by the Scheduler object and also a valid WebSocket is open. The message is identical to the browser to server message.

The scheduling display is updated using DOM Javascript methods.

Chapter 9

Solid State AC Relays

Figure 9.1: DRV8833 Break-out board (2 boards showing with view of top and bottom sides)

The recommended motor driver IC is the Texas Instruments DRV8833:

<http://www.ti.com/lit/ds/symlink/drv8833.pdf>

This device works perfectly with this project and is inexpensive. Several eBay sellers offer a “break-out board” with the IC and several external components mounted with break-board friendly header pin holes. The board shown in the photo above even includes a surface mounted LED power indicator!

The connections to the board are as follows:

1. ULT PIN:mode set. Low level is sleep mode
2. OUT1,OUT2:1-channel H-bridge controlled by IN1/IN2
3. OUT3,OUT4:2-channel H-bridge controlled by IN3/IN4
4. EEP PIN:Output protection. Default no need to connect.
5. VCC:3-10V
6. GND

From the above list, only 2, 5 and 6 are used in this project.

IN1 is connected to the PWM output of the BBG, which is header P9.42. The GND pin requires a connection to one of the grounds on the BBG such as P8.1 or P8.2.

VCC should be connected to an 8Volt DC power supply, however, the exact voltage is not critical. A solid ground connection should be made between the 8Volt supply and the DRV8833 board.

OUT1 and OUT2 should be connected to the motor power terminals.

Chapter 10

Configuration of the Beagle Bone Green Wireless

The default configuration of the Beagle Bone Green Wireless is as a “access point” (a wireless router). This is not a desired configuration for a dedicated embedded device as used in this project.

The following process re-configures the BBGW to a non-access point mode.

The goal is to have a working wireless substitute for the ethernet connector which does not exist on the BeagleBone Green Wireless. This is as a typical "headless" embedded project with the primary access using a terminal and ssh.

Download and expand the IOT bone image per this link and flash to micro-sd. I used this one:

<https://debian.beagleboard.org/images/bone-debian-8.7-iot-armhf-2017-03-19-4gb.img.xz>

Write the image to the micro-sd (I put the micro-sd in a USB adapter plugged into my Ubuntu workstation):

```
sudo dd if=bone-debian-8.7-iot-armhf-2017-01-15-4gb.img of=/dev/sdb bs=8M
```

Eject the micro-sd from workstation and insert in the BBGW micro-sd slot. Connect a USB 3.3V serial device to the "debug serial header". The USB network connection could be substituted, however, my experience with this is that using the serial device is solid and will work consistently. Also, since the BBGW doesn't have a dedicated power connector. It uses the micro-USB. It is my preference to use a high-current dedicated USB power supply and ignore this as a possible network connection.

Power-up the BBGW and wait for the boot process to complete. Open a (bash) terminal and use the screen utility to connect via the serial USB device.

```
screen /dev/ttyUSB0 115200
```

I had to hit enter after the above command to get to the login prompt. The login user is debian and the password is tempwd.

You may have to install screen:

```
sudo apt-get install screen
```

After logging in, a good thing to do first is to run this shell script:

```
cd /opt/scripts/tools
sudo ./grow_partition.sh
```

Next:

```
ifconfig
```

You should see 4 different network resources (not showing the full output here):

```
SoftAp0
lo
usb0
wlan0
```

The network resource SoftAp0 represents an "access point". The BBGW is configured as a wireless router! That is not the desired configuration, and fortunately this is easily removed. Edit the file:

```
/etc/default/bb-wl18xx
```

Change the line:

```
TETHER_ENABLED=yes
```

to

```
TETHER_ENABLED=no
```

Save and exit, and reboot, and login.

ifconfig should now show only 3: lo, usb0, and wlan0.

Now to configure WIFI! It is assumed you have a home wireless router and you know the SSID and passphrase. The router should be configured for DHCP (automatic assignment of IP addresses). From a terminal:

```
sudo connmanctl
connmanctl> scan wifi
Scan completed for wifi
connmanctl> services
    (your router broadcast)          (router info)
connmanctl> agent on
Agent registered
connmanctl> connect (copy router info here)
Agent RequestInput (router info)
    Passphrase = [ Type=psk, Requirement=mandatory, Alternates=[ WPS ] ]
    WPS = [ Type=wpspin, Requirement=alternate ]
Passphrase? (your passphrase)
```

```
Connected (router info)
connmanctl> quit
```

The above configuration is permanent and will survive reboot. An outstanding page with good info on connman:

<https://wiki.archlinux.org/index.php/Connman>

Another very good thing is to login to your router and use this to determine if your BBGW is successfully connected. And remember the router may have security settings which may block it from connecting. Also, rather than attempting to force a fixed IP address on the BBGW, I used the "address reservation" feature so that the IP address assigned by the router will be the same each time it connects. This is done using the MAC address of the BBGW.

After the above configuration is done, shutdown and remove the USB serial device. Power up the BBGW and wait for it to boot, and then using a terminal and ssh you should be able to connect to the BBGW as if an ethernet cable was connected:

```
ssh debian@(the assigned IP address)
```

After logging in you should have internet connectivity, so don't forget to:

```
sudo apt-get update
```

Here is an example USB serial device. This should be on your tool kit list:

https://www.amazon.com/gp/product/B01AFQ00G2/ref=oh_aui_search_detailpage?ie=UTF8&psc=1

Chapter 11

Device Tree Requirements

This project requires only three GPIOs. Rather than editing device tree files, and having to deal with potential bugs caused by this, the excellent config-pin utility was used. This utility is provided by the Universal IO project.

The Universal IO project is located at this Github repository:

<https://github.com/cdsteinkuehler/beaglebone-universal-io>

Universal IO is included with the most recent Debian-based IOT images.

The setting of the three GPIOs is done by the pumpActuator class. This is most appropriate, as the class uses these GPIOs to control the irrigation devices. The GPIO configuration is done by the class constructor:

```
setGpio(headerPin) {  
    const exec = require('child_process').exec;  
    console.log('Setting header pin ${headerPin} to GPIO mode.');
```

```
    exec('config-pin ${headerPin} low_pd');
```

```
}
```

Note the use of the Node.js “child_process” as described in the chapter on GPIO control with sysfs.

The three pins are set to GPIO low state and pull-down mode via these three lines in the class constructor using the above method:

```
this.setGpio('P9.14');  
this.setGpio('P9.15');  
this.setGpio('P9.16');
```

This partitioning of the GPIO mode set functioning into the pumpActuator class is appropriate and eliminated the requirement for an auxiliary shell script for control of header pin modes.

Chapter 12

Running the Project

Chapter 13

Setting up a systemd Irrigation Service

systemd is responsible for booting up the user space in Debian (and other) GNU/Linux distributions including the BBGW.

This system can be used to start the Node.js server as an “irrigation” service.

This is easy to accomplish and can be done by creating a single text file:

```
/etc/systemd/system/irrigation.service
```

Here is the contents of the file irrigation.service:

```
[Unit]
Description=Irrigation Control Server

[Service]
ExecStart=/usr/bin/node /home/debian/irrigate-control/software/node/server.js

[Install]
WantedBy=graphical.target
```

The [Unit] section provides a short description of the service which is printed out when the service is interrogated.

The [Service] section is the complete path to the node command followed by the path to the server.js file. This is the “service” which will be “daemonized” at boot.

The [Install] section indicates the default state in which the service should be started. The default state can be found by using this command:

```
systemctl get-default
```

In the case of the IOT distribution used by this project, the response is:

```
graphical.target
```

Once the service unit file is in place, enable the service like this:

```
systemctl enable irrigation
```

The irrigation service will now start at boot time! Set a bookmark in your browser, and simply click to go straight to the irrigation control page.

To permanently disable the service:

```
systemctl disable irrigation
```

When debugging, it may be necessary to temporarily stop the service. Use this command:

```
systemctl stop irrigation
```

To start the service again:

```
systemctl start irrigation
```

Chapter 14

Resources

14.1 Github repository for this project

<https://github.com/Greg-R/>

14.2 Beagle Bone Green Wireless

<https://www.seeedstudio.com/SeeedStudio-BeagleBone-Green-Wireless-p-2650.html>