Honours
Literature Review

Shaw Eastwood, s.eastwood@rgu.ac.uk

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1 Abstract

This report will review the literature surrounding sensor networks, embedded devices, network topologies and sensors used.

2 Background

The current system for monitoring rivers and bodies of water involves building small concrete huts that record and store data locally. The cost of building these huts makes them prohibitive and is inefficient with today's technology. A person is sent periodically to collect this information manually. Figure I shows one of these monitoring stations found along the River Beauly.

Figure 1: SEPA Monitoring Station [Wallace, 2012]

In 2005 the WFD reported 285 type 1a and 1b at risk bodies of water. [SEPA, 2007] By 2006 253 stations such as the one pictured in Figure 1 were in place across Scotland representing 10% of the countrys total water bodies and 26% of the 989 at risk rivers as of 2009. [SEPA, 2009]

Figure 2: Monitoring Stations in Scotland [SEPA, 2006]

The reason for this can be attributed to the cost of these monitoring stations, with the solution proposed in this paper cost could be greatly reduced to a fraction of this. [SEPA, 2016] Alternatives to this using more modern technology are still highly expensive and cost prohibitive [The IoT Marketplace, 2015]

2.1 Open Source

Many commercial applications developed are built with a propriety licence which prohibits the reading or sharing of the code. This is the antithesis of Open Source, which has slowly been gaining traction from large companies, dispelling the myth that it is hobbyist code at best. For example, Red Hat Inc. was valued at 35 billion during its recent acquisition [Hammond et al., 2018]. This is no better seen than in the worldwide adoption of Apache, a *http daemon* that runs many websites from hobby to major company (Apple.com, Adobe.com etc.) [Q-

Success, 2012]. Further projects such as the Linux kernel, originating from Linus Torvalds has seen a massive adoption, most strikingly in the supercomputing market where it has completely dominated the top 500 supercomputers (ranked by TFlops). [TOP500, 2015]

The field of environmental monitoring is largely untapped, with much of the current solutions being closed source and expensive [The IoT Marketplace, 2015]. There is little interaction from the community and even less interoperability from the technologies deployed. There's also the consumer aspect, where environmentally conscious individuals want to help monitor the local environment. An attempt was made to crowd source the collection of atmospheric data [OK Lab Stuttgart, 2015] across Europe and beyond with small sensor units developed during workshops.

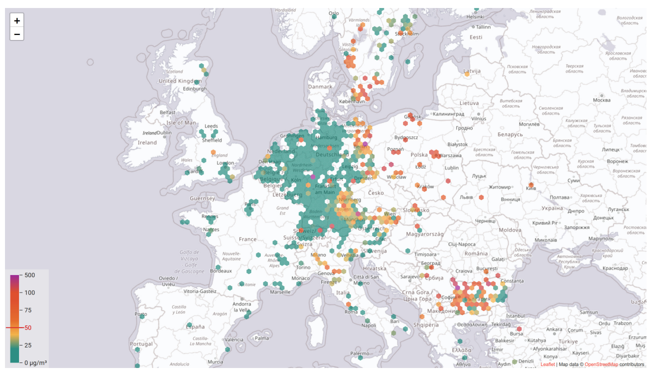

Figure 3: Air Quality Map [OK Lab Stuttgart, 2018]

This model of crowd sourced deployment means anyone can get involved, and it ensures that the data is freely available to all. This is also a key principle for this project, and the Open Database License [Open Data Commons, 2011] will ensure the data can be used freely.

3 Endpoint Devices

The Internet of Things (IoT) is a burgeoning field that has seen a massive boom in the Smart Devices market. [Lueth, 2018] IoT devices are defined by their low cost and low power and their ability to communicate with each other on the same LAN and have a degree of interoperability. [Vujovic et al., 2014]. With the ever increasing rise of such devices the availability of low cost SoC (System On a Chip) devices increases with it. Many vendors have begun targeting the SoC devices after the Raspberry Pi Foundation unveiled the Raspberry Pi 1. Today there exists a myriad of low cost SoCs with differing qualities for differing use cases. [Larabel, 2018] Many System On a Chips are available in the current market. Two of the largest names include Raspberry Pi from the Non Profit Raspberry Pi Foundation and the Arduino board from Arduino LLC.

3.1 Raspberry Pi

The Raspberry Pi Zero W (RPi0), the Non W (Wireless) is pictured below, is a nice fit for our endpoint controller. Its availability and its wide range of support makes it an appealing choice for the controller. The RPi0 is an excellent fit for our project as at idle it will only draw a maximum average of 100mA [Alex, 2017] with further tweaks reducing it. On a relatively low cost battery we can expect this to last a day. Many of the current SEPA stations use solar power to power the electronics inside the shed. [SEPA, 2007] Our sensors will also be battery powered leveraging a solar panel to ensure charge is maintained.

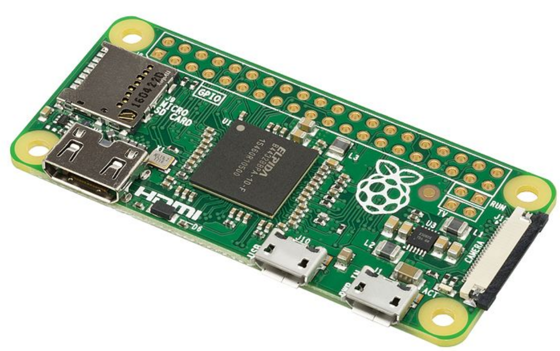

Figure 4: Raspberry Pi Zero [Amos, 2016]

The Raspberry Pi 3B+ on the other hand is a much better fit for a server/command and control device. [Leccese et al., 2014] With it's more powerful CPU increasing the power draw to an idle of 500mA [RaspberryPiFoundation, 2018a] powering this from a battery wouldn't be ideal. Instead it should be used to connecting a LTE adapter or Ethernet cable to connect the endpoints to the larger LAN or WAN for sending information back to a central server.

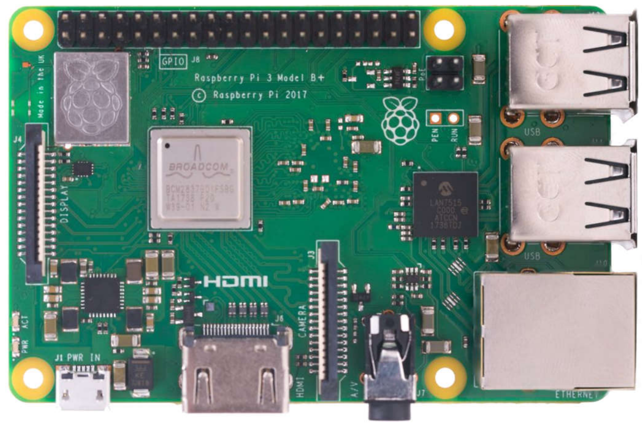

Figure 5: Raspberry Pi 3B+ [RaspberryPiFoundation, 2018b]

3.2 Arduino

The Arduino is a compelling choice as its Arduino Nano product, pictured below, uses the ATmega328 microcontroller. This is a controller with a miniscule power draw of only 19mA. [ArduinoLLC, 2010] This can be further improved to reach as low as 54 A (0.054 mA). This would enable us to run on a minimal power source such as a 9V battery cell for periods of years. [Madcoffee, 2018] Further the arduino features a smaller SoC size for both the Nano and the full-size Uno device [ArduinoLLC, 2010] making it more versatile.

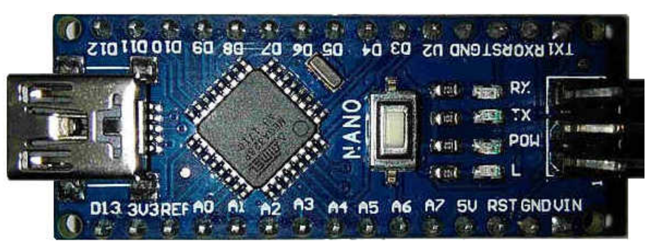

Figure 6: Arduino Nano [Mellis, 2010]

3.3 Other

Many other SoCs include the ASUS tinker board and BeagleBoard among many others. Other SoC's target features found lacking in the Raspberry Pi, namely Gigabit Ethernet and increased RAM or reducing power consumption and SoC size. These make them compelling choices in scenario's where size or bandwidth etc. are essential however these other board's are often more expensive and even more difficult to source.

3.4 Comparison

	Uno Rev 3	Nano	Pi 3B+	Pi Zero W	BeagleBone	TinkerBoard
Cost ()	15	15	35	15	50	55
Power Draw Idle	0.225 W	0.01 W	2 W	0.5 W	1.75 W	2 W
WiFI	N/A	N/A	802.11 b/g/n	802.11 b/g/n	802.11 b/g/n	802.11 b/g/n
Bluetooth	N/A	N/A	4.2	4.1	4.1	4.0
CPU Arch	AVR	AVR	ARMv8	ARMv6	ARMv8	ARMv7
Clock Speed	16 MHz	16 Mhz	1.4 GHz	1 GHz	1 GHz	1.8 GHz
Core Count	1	1	4	1	1	4
RAM	32 KB	32 KB	1 GB	512 MB	512 MB	2 GB
OS	N/A	N/A	Linux	Linux	Linux	TinkerOS

Figure 7: Comparison of devices [ArduinoLLC, 2010], [ArduinoLLC, 2008], [RaspberryPiFoundation, 2018a], [RaspberryPiFoundation, 2017], [BeagleBoard, 2017], [Asus, 2917]

The advantage afforded to the RPi0 is its availability, low cost, support but more importantly familiarity. It is important to ensure the barrier for entry, both cost and technical ability, is kept to a minimal for anyone who wishes to deploy one or more of these. Additionally by using the RPi0 we can leverage technologies already created for the device. From the graph above we can see that the pi3 and pi0 fit nicely into the middle of the graph offering good hardware and low power consumption.

4 Server

A server is defined as a device that can serve one or more ”client” devices. This will usually be a powerful device that clients can send raw data to and have the server do any computation required before returning a result. [Raymond, 2003]

A number of operating systems exist to target the server. This is achieved by first stripping the system of as many superfluous systems as possible, such as a graphics stack. [Canonical, 2013] The configuration is therefore handled primarily though the shell, under Linux this is usually Bash (Bourne Again Shell). Windows Server’s do not abide by this however and usually a graphical stack is used to perform most configuration [Microsoft Corporation, 2017a]. Due to this, a Linux server is best placed due to its far lower system requirements to run.

	Raspbian Lite	**Ubuntu Server**	**Microsoft Server**
CPU	1 GHz	1 GHz	1.4 GHz
RAM	128 MB	384 MB	512 MB
Storage	2 GB	1.5 GB	32 GB

Figure 8: Comparison of operating systems [Debian, 2018], [Canonical, 2013], [Windows IT Pro Center, 2017]

To ensure that costs are kept low small SD Cards are ideal which somewhat rules out the Windows option. In addition hardware support for Windows on Raspberry Pi is limited to Windows S [Microsoft Corporation, 2017c] which would require any software to be written as a UWP [Microsoft Corporation, 2017b] which would hinder performance.

5 Sensors

5.1 Water Level

The collection of the river data will be the trickiest part of the project. Currently, to collect water level data, a wire is laid across the river and a buoy attached to the middle. The sag in the wire can then be used to calculate depth [SEPA, 2016]. An alternative solution involves using an ultrasonic sensor to judge the distance between the sensor and the water [Aravind Jayan, 2016]. An example of this sensor is shown in Figure 9. This method has the advantage of being a low physical footprint solution to monitoring.

Figure 9: HC SR04 Ultrasonic Sensor [Mouser Electronics and OSEPP Electronics, 2016]

5.2 pH Sensor

The sensing of the pH level is somewhat more difficult and requires a specialist tool. The EZO-pH Embedded pH Circuit [Atlas Scientific, 2018] which allows a digital signal to be read through i2c or UART by a connected device. Dey [2018] One issue with this sensor is that is an analogue device and thus if a Raspberry Pi is used we will require an ADC (Analogue to Digital Converter) to hook it up, if however a Arduino is used this will not be an issue.

5.3 Temperature Sensor

To collect the temperature a wide range of sensors can be used with the only requirement being they are waterproof. The most accessible of these is the DS18B20 [Adafruit] which communicates over the 1-Wire protocol. This is particularly useful to us as it is a digital sensor meaning we will not need the additional ADC if a Raspberry Pi (Zero) is used. Once connected this can be polled for the current temperature at the sensor. [Monk, 2013]

6 Networks

	ZigBee	Pi 3B+ WiFi	Pi 0 W	Bluetooth
IEEE	802.15.04	802.11 b/g/n	802.11 b/g/n	802.15.1*
Frequency (GHz)	2.4	2.4/5	2.4	2.4
Main Application	Smart Devices	WLAN	WLAN	Low Bitrate Streams
Bit Rate	250kbps	600 Mbps	54 Mbps	24 Mbps
Range	100m	100m	30m	15m

Figure 10: ZigBee vs. some other wireless network.[RaspberryPiFoundation, 2018a], [RaspberryPiFoundation, 2017]

The communication methods listen above all have there advantages and disadvantages. ZigBee has a significant advantage in this area as in addition to the above metrics it has a significantly lower battery usage than the other two protocols [Leccese et al., 2014]. However this comes at a cost, both financially and to accessibility, as the ZigBee protocol requires an additional module to be attached to the device used to allow it to communicate. Further complicating things is these modules are an additional cost on top of the controller (SoC) and sensors required. [Digi International, 2015] This additional complexity serves to increases the desirability of Wifi and Bluetooth as options.

To connect these devices together, especially if Bluetooth is used, a method of daisy chaining them together is almost essential to keep costs to a minimum. This introduces many issues however as one of the main issues facing SEPA with it's current solution is vadalism [SEPA, 2018] and these sensors could be an attractive target. The removal of a device near the start of a chain either through a fault, theft etc. could affect many more sensors further along having a cascading effect. This is not ideal and makes Bluetooth a very unattractive option. Further, the Bluetooth 4.1 and Bluetooth LE suffer from major range limitations of a meagre 10 to 15 metres [?], again ZigBee provides a excellent replacement to this with a majorly increased range over Bluetooth. [Pocero et al., 2017]

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