Glacier Meltwater Monitoring

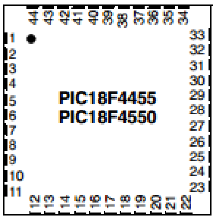
CS25710 Assignment 2011-12 - Matt Robbins

Contents

1. Components

Microcontroller

Due to my initial interest and previous knowledge of the PIC family of microcontrollers, I decided to



start off by looking at these low cost, widely used integrated circuits. I also looked at “BASIC Stamp” microcontroller modules - some of which use a PIC, but whilst also containing many ways of communication their extra functionality came at a cost of power – for example drawing 25 to 450 micro amps (depending on model) when sleeping, compared to 0.2 micro amps for the PIC.

There are many different PIC chips in the many PIC families, and I started by looking at the PIC 18F series as I had worked with them before and found them to be very capable for their tiny size.

Device	Program Memory		Data Memory		I/O	10-Bit A/D (ch)	CCP/ECCP (PWM)	SPP	MSSP		EUSART	Comparators	Timers 8/16-Bit
	Flash (bytes)	# Single-Word Instructions	SRAM (bytes)	EEPROM (bytes)					SPI	Master I²C™			
PIC18F2455	24K	12288	2048	256	24	10	2/0	No	Y	Y	1	2	1/3
PIC18F2550	32K	16384	2048	256	24	10	2/0	No	Y	Y	1	2	1/3
PIC18F4455	24K	12288	2048	256	35	13	1/1	Yes	Y	Y	1	2	1/3
PIC18F4550	32K	16384	2048	256	35	13	1/1	Yes	Y	Y	1	2	1/3

http://ww1.microchip.com/downloads/en/DeviceDoc/39632e.pdf

These 18F models use very little power and have three serial ports which may prove to be very useful to connect to the thermometer, accelerometer and pressure sensor in this project. Whilst being only £2.24 ($3.65), the 18F4550(QFN) looks to be one of the higher specification microprocessor in this family. Without further testing information, I believe the device could use a lower specification microprocessor like the 18F45K20 which only has about ¾ of the amount of RAM that the 4550 does, has a higher max CPU speed which may be useful for working on and storing data quickly, but crucially needs less voltage – 1.8 – 3.6v rather than the 2 – 5.5v needed by the 4550.

The 18F45K20 uses only 100nA whilst sleeping and 500nA when using a watchdog or oscillator timer. With a temperature range of -40 to 125°C, this low power microprocessor should be suitable for long periods of battery-powered operations in a cold environment. The MSSP (Master Synchronous Serial Port) module supports both 3 wire SPI, as well as I2C interfaces. This PIC is very cheap – just 98p per unit (if bought individually, so less if bulk bought ($1.60)).

Pressure Sensor

The pressure sensor must be able to withstand up to around 200Bar (20,000,000Pa) of pressure from the water under the ice, meaning a normal consumer £10 components were unsuitable, as they have a maximum pressure in the region of just 28 bar.

The Gems range of pressure sensors contain some much more relevant products, with max pressure readings ranging from 250 to 2200bar, the 250 bar models has an accuracy of 0.25%, can operate from -40 to 125°C, has an IP rating of 67, requires 8 to 30V dc power and costs £81.70. The minimum operating temperature of -40°C should be enough to stand the cold flowing water under the ice.

The Keller PA21SR is another industrial strength pressure sensor that can measure up to 250bar and needs 8-28 volts, but its higher minimum temperature of -20°C coupled with its lower IP rating of 65 and its non-rugged shape makes it slightly less suited to being dropped down a freezing cold glacier – and costs more than the Gems sensor, £114.86.

Thermometer

As the thermometer will be inside the device, it does not need to be as tough as the pressure sensor, which must be immersed in the surrounding environment to get a reading.

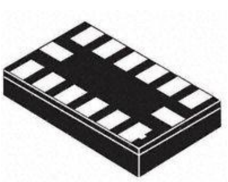
This Honeywell HEL 775-AT1 temperature probe would be appropriate for this environment, as it has an operating temperature from -55 to 150°C, which should be more than sufficient for inside the glacier.

This FCI AS-TE temperature sensor can withstand up to 345bar of pressure, operate down to -46°C, and takes just 3 seconds to register a change in the liquid temperature. This hard-wearing military grade sensor would be perfect for this device, as it could be screwed onto the end of the device. Pricing and other technical details are hard to find though.

Accelerometer

One of the only ways of learning about the motion of the device when it is under kilometres of glacier will be by recording the acceleration of the device in 3 axes by using an accelerometer. The data from the accelerometer should be able to show when the device is free-falling down waterfalls and when it is being battered around by hard ice.

This ADXL345 can record up to 16g, has 3 axis of detection, and is small and low powered, drawing 40uA in measurement mode and just 0.1uA in standby. It uses SPI and I2C interfaces which will be useful as the PIC has both of those. It requires 2.0 – 3.6v DC supply to run.

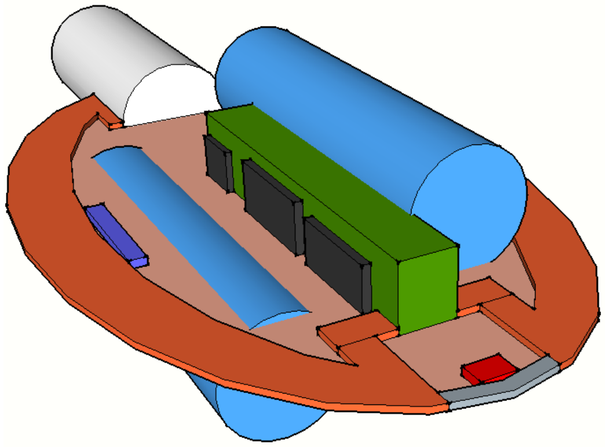


This 3 axis sensor from RS has the option of having a range of +- 2, 4 or 8g which I believe will be very useful. A prototype/old data could be used to determine what the maximum amount of force subjected to the device will be, then the best setting can be selected to give the greatest sensitivity. I imagine the 8g setting will be needed as the device is fairly light and is likely to be buffeted around (meaning sensitivity of 16 LSB/g will be used). This accelerometer is also rated down to -40°C, can be mounted to the surface of a PCB and uses an I2C interface.

Cells

My calculations have shown that for 4 days, 1263.27mAh or less will be needed to power the device. The battery will also need to provide around 8v+ as the pressure sensor requires 8-30v to operate. One option was to use 6 cells in a 3P2S (3 parallel, each with 2 series) to yield 9v and 1600mAh.

The best option I found was to use 3 x 3.7v cells to bring the voltage up to 11.1v and with 3000mAh per cell, there is 9000mAh available, meaning the device could supposedly last more than 28 days (assuming the voltage stays high enough). These cells are size 18650, so smaller than the 6 x 16340's, and more convenient to place in the pod than a 3 cell pack.



Float with the 3 size 18650 cells installed around the PCB (to scale)

Other smaller components

Amongst the other resistors, capacitors and transistors, there are a few other special components that will be needed.

Micro SD

A microSD card will be the perfect way to store data because:

- They can store masses of data (cards sized 32 and 64gb are common).
- They are rugged – with no moving parts, they can be thrown around and survive.
- It is very easy to retrieve data and reuse – just unplug it from the device and attach to a computer.
- They are cost effective – testing will show how much data the device is likely to obtain, but even a 32gb card is only around £22.
- They are lightweight and tiny – 15mm x 11mm x 1.0mm.
- They can plug straight into a little holder (right).

The microSD holder can be mounted to the circuit board to keep it out of the way, and, for example, an 8gb Duracell microSDHC could be inserted. The holder costs around 78p, and the card, around £8.20.

Magnetic Switch

As the device must be watertight and able to withstand a lot of pressure, it has been built to be rugged and resistant to damage rather than full of holes to allow components on the outside. One way to turn the device on without having to have physical access to the internal circuitry would be to use a magnetic switch mounted inside on one end. This would be save having to use power hungry wireless technologies like Bluetooth, and just means to activate the device, it would have to be placed next to a strong magnet before starting its journey down the glacier. This Rhodium Plated Reed Switch from Maplin would be suitable, as long as the devices could be placed in a controlled environment until needed for use, as otherwise the switches may be accidently activated, and the data logging processes started early, resulting in wasted battery power. The miniature version of this component is just 19mm long, 2.6mm wide and costs just £1.59, with prices dropping below £1 when over 100 are bought.

2. Interfaces and interconnections

To enable the components in the device to be useful, they will need to be connected to the PIC via the use of buses or other connections.

I²C Bus

Components such as the accelerometer will need an I²C bus to communicate with the microcontroller. The I²C interface only requires 2 lines - a serial data line and serial clock line that can carry 8 bit sets of data in either direction at a speed of 10kbit/s in Standard mode. The data line will have to be connected to the SDA (I²C data I/O) pin 12.

SPI Bus

The Honeywell thermistor uses a serial interface, and will need to connected to an SPI data in (SDI) pin 12. The micro SD card in its holder must also be connected to the SPI bus, but an SPI out pin (SPO).

Analogue

Devices like the pressure sensor produce an analogue output which must be connected to one of the "Analog in" pins such as AN0 (pin 19).

3. Power requirements

In this section, I will look at the power required by each major component when running and sleeping.

Running

Component	Voltage /Volts		Current /mA	
	Min	Max	Min	Max
Accelerometer(2)	2.4	2.8	0.40	0.49
Thermometer			1	1
Pressure Sensor1	8	30	4	20
Pressure Sensor2	10	28	2	25
PIC 18F45K20	1.8	3.0	0.011@31kHz	0.016@31kHz
PIC 18F45K20	1.8	3.0	0.6@1mHz	0.8@1mHz
Store data to SD	?	?	?	?
Total				21.506mA

Sleeping

	Voltage /Volts		Current /uA	
	Min	Max	Min	Max
Accelerometer(2) Sleeping	2.4	2.8	2.5	10
Accelerometer(2) running	2.4	2.8	400	490
PIC 18F45K20 PRI_IDLE	1.8	3.0	3.5	8
Total	4.2	5.8	403.5uA	498uA

Timings

Time /ms	Turn On	Turn Off	Self-Test
Accelerometer(2)	20	20	20

+1ms wait time for I2C/SPI to be ready

After looking through all the component's data sheets, I found the accelerometer needs time to turn on its higher powered components when waking from sleep mode. Due to this lengthy process and the frequency of the readings needed per second, I am going to leave it switched on at the cost of around 400-480uA.

The accelerometer also seems to be the only component that takes a significant and adjustable time to output a reading. The PIC should not take too much time to warm up, as the designated primary oscillator continues to run in PRI_IDLE mode. I estimate no more than 40ms would be needed for the device to warm up, obtain the readings and store them. I would have to discuss this with an expert to be sure as the data sheets don't give exact answers on timings. It is also worth noting that some devices may run slightly faster due to the cold temperatures.

Every cycle [worst case]:

1 read cycle: 21.506mA for 40ms = 2.39x10-4 mAh

15 read cycles: 3.60x10-3 mAh

Time remaining to sleep per second: 1s – (15 x 40ms = 600ms) = 400 ms.

Power needed for sleep time: 498uA for 400ms = 5.53x10-5 mAh

Total power needed for 1 second: 3.66x10-3 mAh

Total power needed for 1 day: 315.2mAh

Total power needed for 4 days: 1263.27mAh

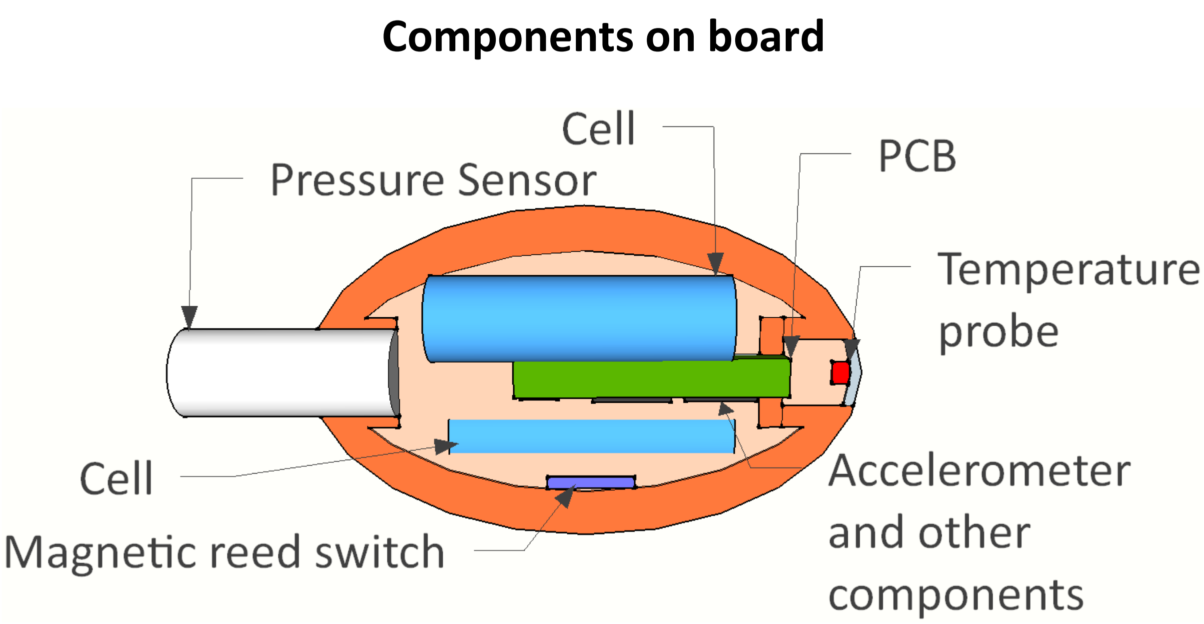
4. Dimensions and weight

	Dimensions /mm			
Component	Height	Length	Width	Weight /g
Pressure Sensor	20	48	20	35
Temp Probe	5.08	3.81	2.54	<1
Accelerometer	1	5	3	<2
PIC on PCB*	~5	~60	~20	~4
micro SD card	15	11	1.0	0.5
micro SD holder	17	13	2.0	<1
Magnetic Switch	19	2.6	2.6	<1
Size 18650 Cell	18.6	65.2	18.6	~46.5
Size 18650 Cell	18.6	65.2	18.6	~46.5
Size 18650 Cell	18.6	65.2	18.6	~46.5
Other components and the pod itself	-	-	-	-
Total per device				184g

*PIC+PCB weight and size estimated using average dimensions of a gumstix board.

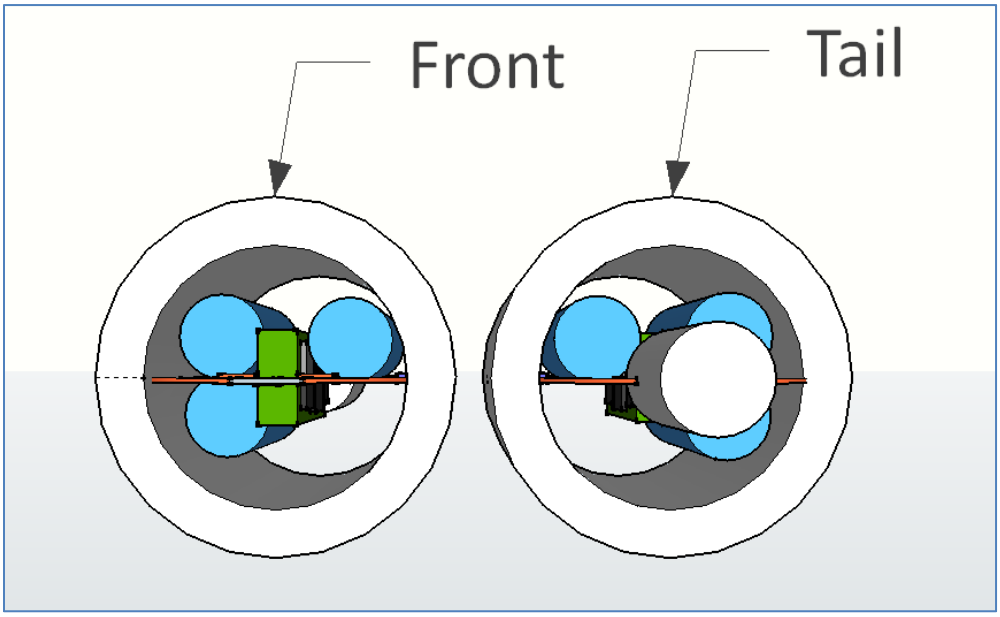
This table shows all of the major components that I have selected for the device and their attributes. To ensure as best as possible that all of the components will fit in when a prototype is built, I made a scale model of the device in the computer aided design program Google Sketchup. When placing the components inside the pod, I had to move the PCB from the centre to the side to allow the 3 large batteries to fit in (see the pictures below).

4.1 Device design

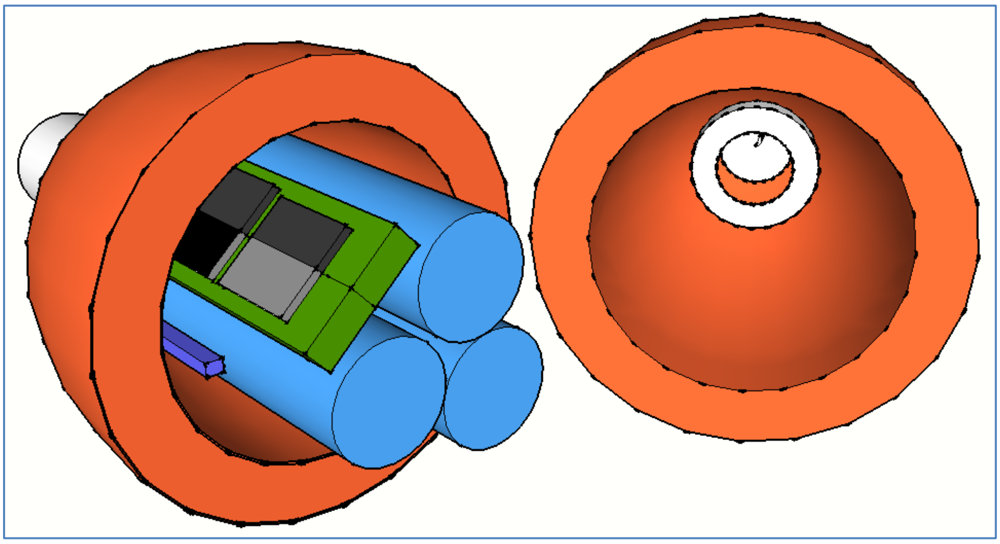


Device design continued

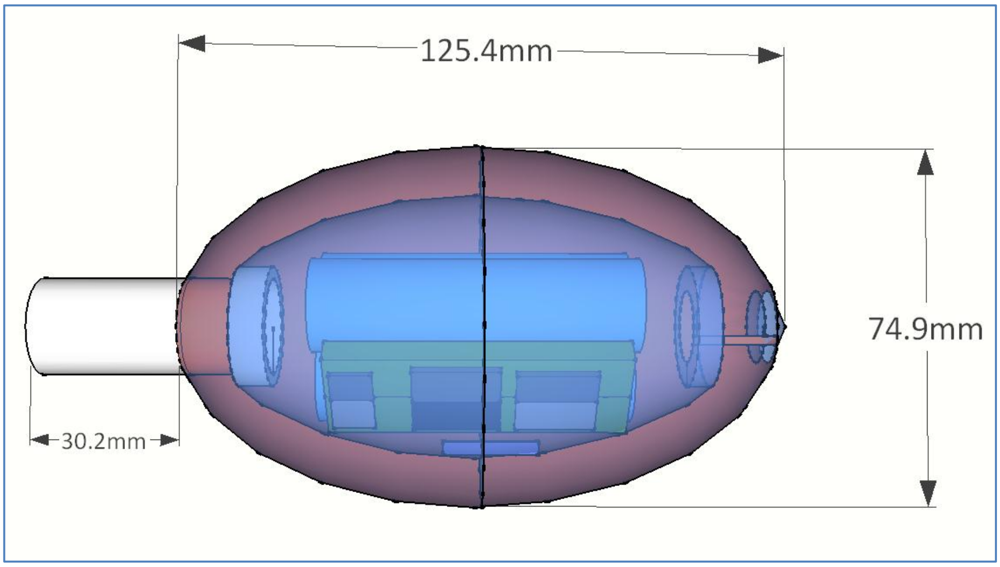
End view



Open view



Sealed view



5. Estimated cost

To get the best results, many of these devices are going to be deployed into the meltwater lakes when the water starts escaping through to the base of the glacier. As some may get lost on their journey, and some may never be recovered, it was important to keep the cost per unit as low as possible.

Bill of Materials

Component	Price per unit /£	Price each if ~100 bulk bought /£
PIC 18F45K20	1.37	1.25
Pressure Sensor	81.70	81.70
Temp Probe	14.99	13.49
Accelerometer	2.74	1.42
micro SD card – 8gb	6.99	6.99
micro SD holder	0.782	0.76
Magnetic Switch	1.59	0.99
3 x Size 18650 Cell	4.99	4.11
Other components, PCB, wires, solder, pod itself etc	-	-
Total per device	£115.152	£110.71

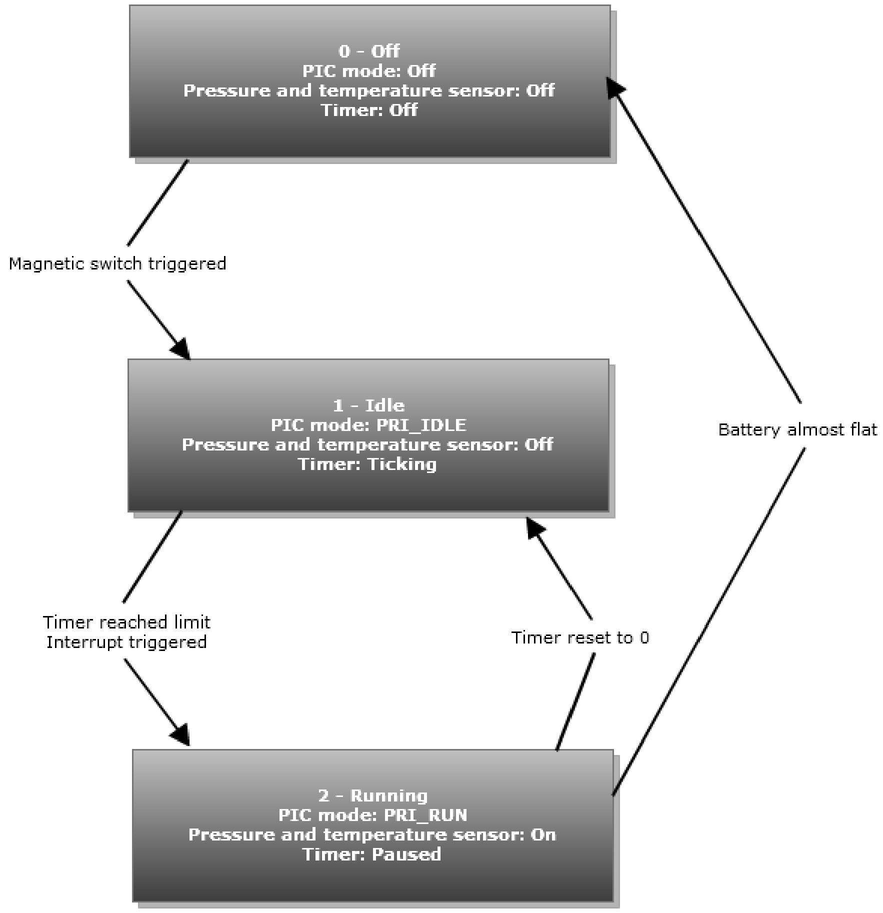
If the components are bought in bulk, the price per device will be around £110, mainly due to the £81 pressure sensor. If this device was going to be mass produced, I would look at alternative industrial strength pressure sensors that may be cheaper.

1. Major program operating modes

My software uses an interrupt to run the data collection and storage program 15 times a second (or 26.67ms after the last time the data was collected. This gives the device 3 main operating modes:

1. Off – Where the device has not yet been started, the processor and all other components are turned off and are waiting for the magnetic switch to be triggered to start them, sending the device into the idle mode after starting up.
   This mode is also used when the battery has reached a critical level to try and avoid discharging it completely and damaging it, and to leave the components and data storage in a known, consistent state. Without this battery check, the device may run out of power half way through a data storage operation and risks corrupting the entire set of data. The limit of when the device is told to turn itself off could be changed depending on whether it was feasible to re-use the inexpensive, on-board rechargeable batteries.
2. Idle – Where the device is effectively asleep and waiting for the interrupt to change it to the running mode. When in idle mode, the PIC mode is set to PRI_IDLE, and the pressure and temperature sensors are switched off to save power. Currently I have left the accelerometer on rather than exploit its sleep mode, as it took 20ms to power on and power off from sleep move to active and back. With more investigation, it may be possible to use this mode, especially if the run time is set to be longer than around 40ms.
   When the ticking timer has reached 827 cycles (26.67ms), it causes an interrupt to change to the running state.
3. Running – This is where the device is switched on completely and capturing then storing data. The PIC mode is set to PRI_RUN, and all sensors are switched on too. Firstly, the device starts turning on the temperature and pressure sensors, and takes the (already switched on) accelerometer reading. It then takes the temperature sensor reading as it should be ready first, and then the pressure sensor reading when it is ready.
   Once all data has been collected, the sensors are told to switch off whilst the PIC stores the data to the microSD card along with the time and date.
   When the data has finished being written, all of the sensors are turned off, and there is still at least enough current in the battery to do another few readings, it sends itself back to the idle state.

1.1 State diagram



This is a state diagram showing the major operating states of the software, explained above.

2. Program function explanations

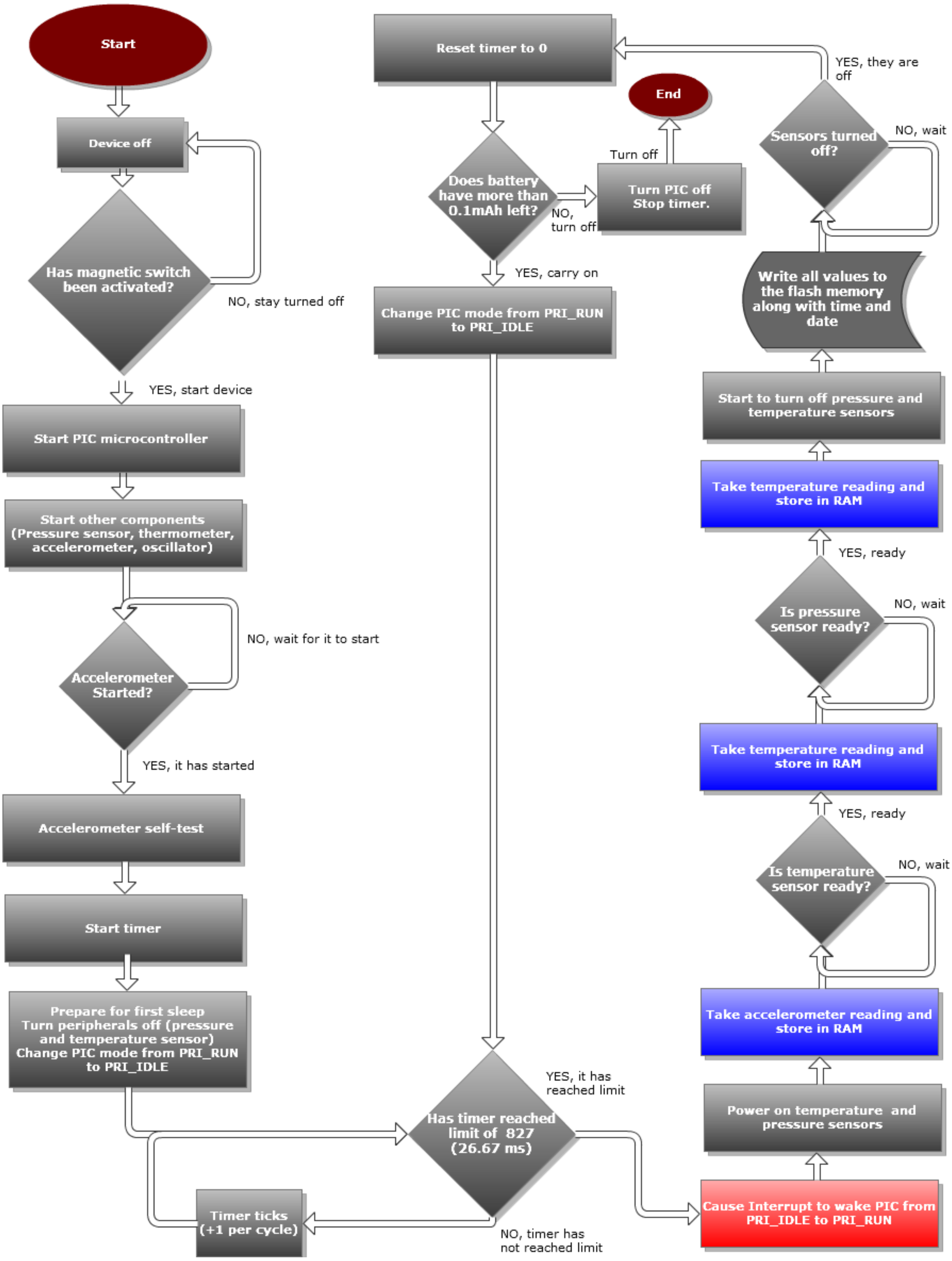
The major functions of my program will be:

1. The "onStart" function
   Once the PIC is started, some of the components such as the accelerometer have "self-test" features which will need to be run so each sensor is calibrated and ready to start reading useful data. Once the sensors are ready, the software will take a reading from each of them and store an error log if there are any abnormalities. As there is no way to check for errors until after the device has been recovered at the end of its journey, it will continue logging all sensor data, even if one is useless – as the other data from the inexpensive device may still prove valuable. An LED in the wall of the device may be a good upgrade to show if the device is switched on and working correctly.
2. The "sleep" function
   This will be where the timer is set to tick once per cycle to keep track of when data had been read in last. A watchdog timer could also be set up here to reset the program if for some reason the program stopped doing the sensor reading cycles. In this function, the PIC will have been told to move to its idle (PRI_IDLE) state, and the pressure and temperature

sensors told to turn off to conserve power. The PIC's idle state allows perpherals like the accelerometer to keep running whilst it sleeps using a maximum of 8 micro amps.

3. The "wake" interrupt
   When the timer has hit/passed its limit, the wake interrupt would be triggered to move the PIC out of its idle mode to the primary running mode (PRI_RUN) which will start the CPU. This interrupt will also have to start supplying power to the pressure and temperature sensors too, as previously they were switched off with no power being wasted on them. Once all sensors are ready to read data, the main function will be executed.
4. The "main" function
   When the main function is running, all readings are taken from the sensors in a time-saving way. As the accelerometer is already running, the data is taken from that first whilst the other sensors are still powering up. Next the temperature sensor sensor is checked to ensure it is ready, and then a reading is taken. The same then takes place with the pressure sensor before they are both told to turn off. As the sensors are turning off, the PIC is free to store the data from its RAM to the safe microSD flash memory, along with the date and time when the data was read. Now finished, the PIC is told to go back to its idle mode, and the "sleep" function is called.
5. The "packUp" function
   When the device no longer has sufficient power available to continue running safely, the "packUp" function is called at the end of a read/write cycle to enable the device to shut down correctly. The pressure and temperature sensor have already been turned off, but the accelerometer is still on, and will need to be turned off here, before the PIC is turned off completely too to leave the cells with a little charge in them, prolonging their life.

2.1 Program flowchart



3. Software and hardware tools

To get a good idea of whether this device will work when took to the glaciers, it will need to be tested first in a number of different ways. The first few tests will ensure the software written is working correctly and the device is logging data 15 times a second. This is an important test to show whether the processor clocked at 31kHz is able to manage, or whether it needs to be clocked slightly higher. Data can be easily obtained from the microSD card to allow the outputted data to be verified against other sensor and measuring devices to ensure the sensors are reading and writing data correctly. :

- Water resistivity over a long period – The device should lowered down to the bottom of a pond or pool and then retrieved after a couple of weeks to ensure that no water has managed to leak into the device and obstruct its operation.
- Low temperature durability – To test for any abnormalities at low temperatures, the device should be placed in a freezer of around the same temperature or just lower than the temperature of the glacial meltwater. After a couple of weeks, the device should be taken out and checked to ensure that the device has functioned properly, the temperature and pressure readings match those of a separate thermometer and pressure sensor in the freezer, and that the accelerometer has reported no movement for the time it has been in there.
- Ruggedness test – The device will be knocked around and bouncing off solid ice when deployed for real, so rolling the device down the side of a rocky, moderately steep cliff should show whether the components inside have been properly secured so they don't rattle around and cause damage and severed connections.
- Battery test – The device should be ran normally, and then the battery measured at regular intervals to see how close the estimated power consumption comes to the actual power consumed. Hopefully, the actual power consumed should be less than expected, as I calculated how long the device would last in the worst case, with each component drawing the maximum current it could in its current state.

These endurance tests will assess the device in environments similar to which the device may encounter when deployed for real. These tests will also show how much data is actually stored over long periods, and whether the 8gb microSD card needs to be upgraded, or should be downgraded to a smaller size.

4. Set up and deployment of the device

1. Software and hardware tools
2. Set up and deployment of the device

1. Block diagram (state chart) – major operating modes of software
   Power mode
   Sleep mode
   Interrupts if needed? From clock?

2. Description of each part of program, what it does and why. Major functions, parameters required and operations performed in each.
   Flow charts
   Activity diagrams
   Document the operation of the main algorithm(s) or tasks of your applications
   Think about:
   How are you exploiting the power saving features of the hardware selected
   Exploiting the input and output abilities of hardware
   How will ensure the operating modes inherent to application are addressed in implementation?
   Why I have broken the problem up the way I have and how the various components/functions are synchronized and triggered.
3. How you will develop your implementation in terms of software and hardware tools required
   How would you test, debug and refine the implementation
   Do you require any library code for app
   What would the libraries be used for
   Remember to consider how much program and data memory your software will require
4. What is the procedure for using the device in the field?
   Are there any user configurations required for software? Describe and how they will be stored and changed if needed.

SLIDESET 4 + 10

Timer → interrupt

OpenTimer

WriteTimer

Checks..

Analogue to digital conversion functions

OpenADC

CloseADC

ConvertADC..

Configure how you need things

Set stuff going, wait for it to happen

Get the results

Serial communications too

OpenUSART(..) …

Can use printf(..) – output can be displayed on a simple terminal on a PC connected with a serial cable → DEBUGGING. TESTING.

Further Research

To get a better understanding of the route the meltwater takes, compass modules could be added to the device that would allow the device's heading to be recorded. Fins would also have to be fitted to keep it "driving" forwards, and the ballast added to the bottom of the device to keep it upright. The headings would then be able to be plotted on a map to get an idea of which way the device was facing and for how long, indicating it was travelling in that direction. The accuracy of this method would be very limited as the device is so small and will constantly be moving and changing direction, and may start sailing backwards (which could be countered by modifying the design of the pod).

References and sources

PIC 18F45K20

http://www.microchip.com/wwwproducts/Devices.aspx?dDocName=en026337

Gems Pressure Sensore

http://uk.rs-online.com/web/p/pressure-sensors/4554781/

Keller PA21SR

http://uk.farnell.com/keller/pa21sr-80395-3-250-4-20ma/pressure-transmitter-0-250bar-g/dp/7100760

Honeywell HEL 775-AT1

http://uk.rs-online.com/web/p/temperature-sensor/3683923/

FCI AS-TE temperature sensor

http://www.fluidcomponents.com/Aerospace/Products/TemperatureSensors/A_ProdTemp_ASTE.asp

ADXL345 Accelerometer

http://www.coolcomponents.co.uk/catalog/triple-axis-accelerometer-breakout-adxl345-p-427.html

3 axis accelerometer from RS

http://uk.rs-online.com/web/p/accelerometer/7191002/

Size 18650 cell

http://www.aliexpress.com/product-fm/471755557-10pcs-lot-Durable-3000mAh-Rechargeable-Cell-3-7v-18650-Strong-Light-Torch-Flashlight-Ultrafire-Li-ion-wholesalers.html

Size 17335 cell

http://www.aliexpress.com/fm-store/908974/211263302-532538650/Ultrafire-3V-Rechargeable-Battery-CR123A-17335-3-0v-800-mah-Battery-x-2-Festival-3V-Rechargeable.html

MicroSD card holder

http://uk.rs-online.com/web/p/memory-card/7388809/

MicroSD card

http://www.7dayshop.com/catalog/product_info.php?cPath=777_6&products_id=107983

Magnetic reed switch

http://www.maplin.co.uk/rhodium-plated-reed-switches-34157

I2C Specification

http://www.nxp.com/documents/user_manual/UM10204.pdf

PIC 18F family

http://www.microchip.com/paramchartsearch/chart.aspx?mid=10&lang=en&branchID=1004