Detection of Epileptic Seizures in a domestic environment …and turning it into a useable consumer device

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Agenda

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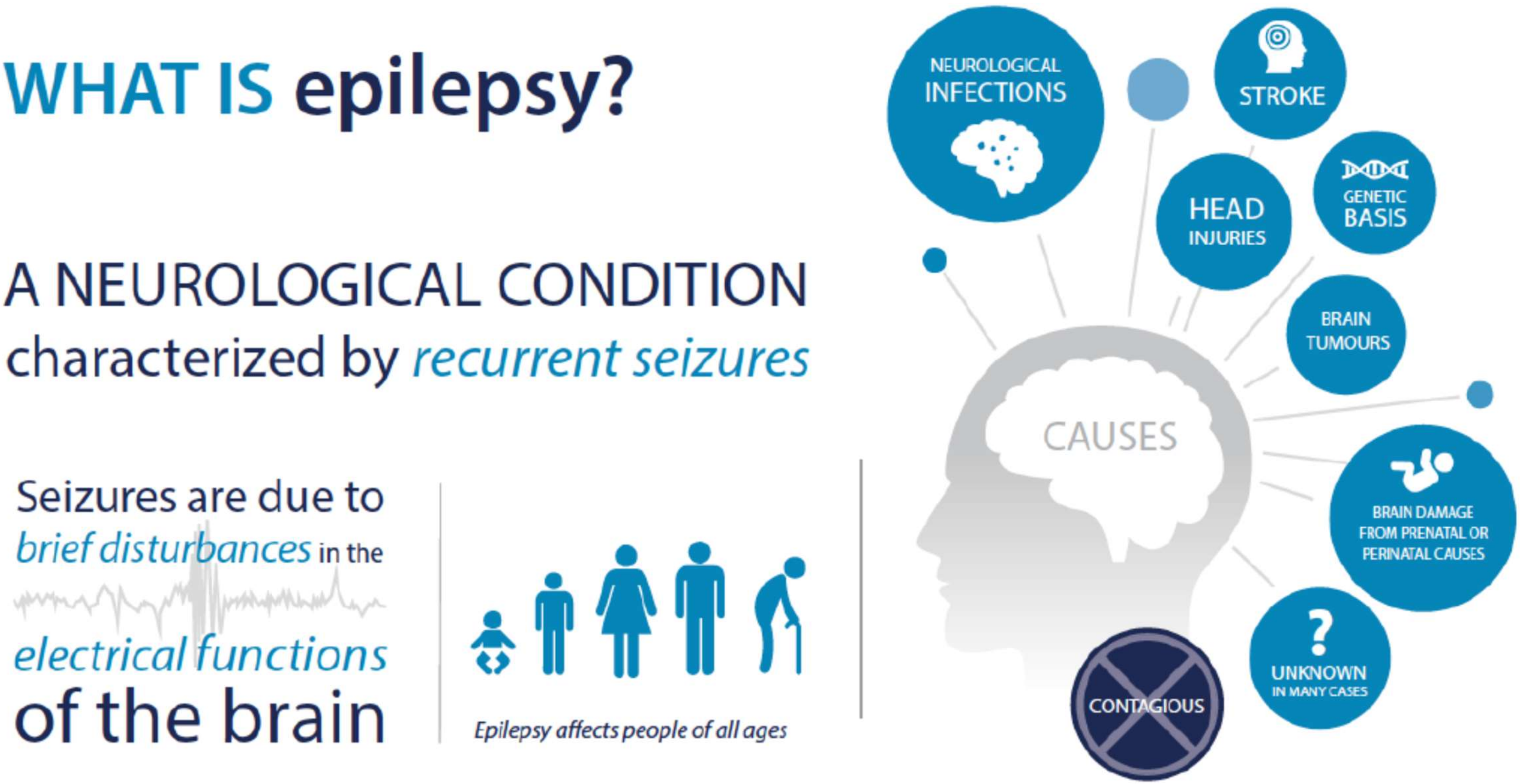
Epilepsy and Seizures (1)



- **From World Health Organisation: https://www.who.int/mental_health/mhgap/epi_slides.pdf**

Epilepsy and Seizures (2)

- **Types of Seizure**:
  - Tonic – Stiffening of muscles
  - Tonic-Clonic – Stiffening of muscles, followed by shaking.
  - Myoclonic – Sudden jerks
  - Atonic – sudden relaxation of muscles – drops to floor.
  - Absence
- **Risks associated with seizures**:
  - During some seizures, people can injure themselves, develop other medical problems, or have a life-threatening emergency.
  - The overall risk of dying for people with epilepsy is 1.6 to 3 times higher than for people without epilepsy (Epilepsy Foundation)
  - General advice is to call an ambulance if someone has a seizure that lasts for more than 5 minutes (NHS)

Project Motivation

- Our Son is severely disabled, with issues including:
  - Autism,
  - Severe Learning Difficulties
  - Epilepsy.
- We set up a video monitor to check on him:
  - One morning we noticed he looked odd on the video monitor.
  - He was having a serious seizure – we had to resuscitate him
  - Blue light trip to the hospital
- The only reason we went to check on him is that we happened to look at the video monitor.
  - <u>What we really needed was **something to go ‘beep’** to make us look up</u>….
- Commercial seizure detectors did exist at the time (2013), but they all relied on a pressure sensor in the bed….And Benjamin insisted on sleeping on the floor….
  - so I would have to make my own….

Project Objectives

- **Monitor Benjamin in his bedroom** (he is never alone anywhere else).
- **Preferably Non-contact** sensing as he is autistic and unlikely to tolerate being connected to things.
- **Raise an alarm** to prompt us to check on him.

- Later, as the project matured I extended it to being **Open Source** and freely available to other people who might benefit from it, with the intention of making the lowest cost seizure detector possible (http://openseizuredetector.org.uk)

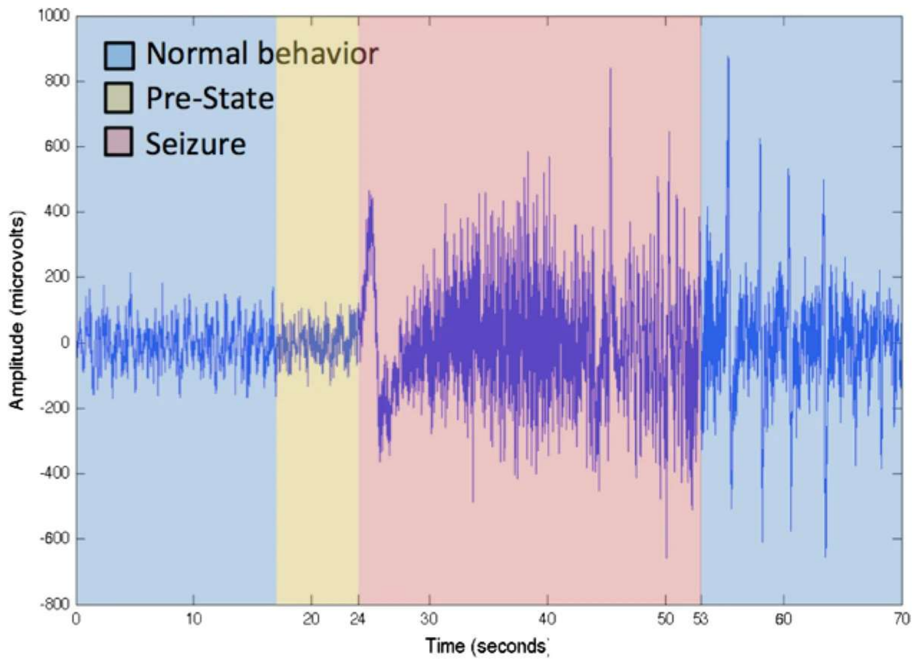
Seizure Detection Techniques

Seizure Symptoms

- Unusual brain activity
- Movement of Limbs (3-8 Hz)
- Falls
- Breathing Rate
- Heart Rate (?)
- Skin Conductivity
- ‘Odd’ Behaviour
- …..maybe more

Methods Available at the Time (2013)

- Electroencephalogram (EEG) – measurement of electrical activity in the brain (from Alotaiby et. al. 2014)



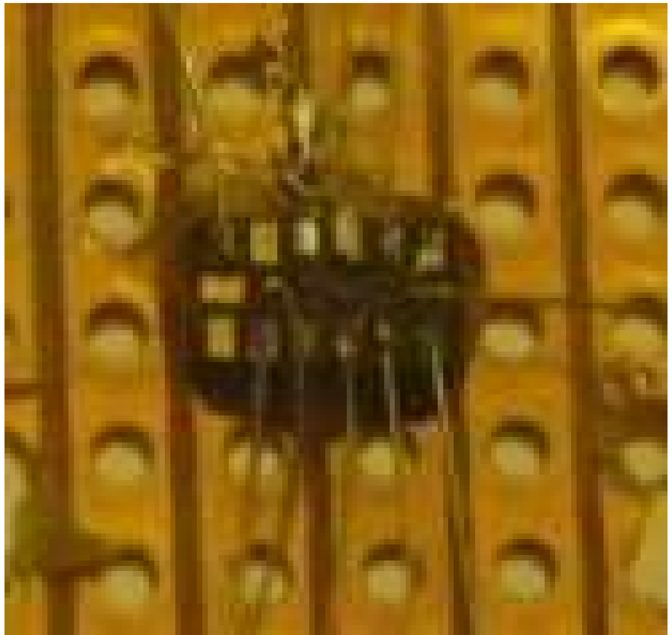
  — 19 electrodes attached to the head, so not practical in the home.

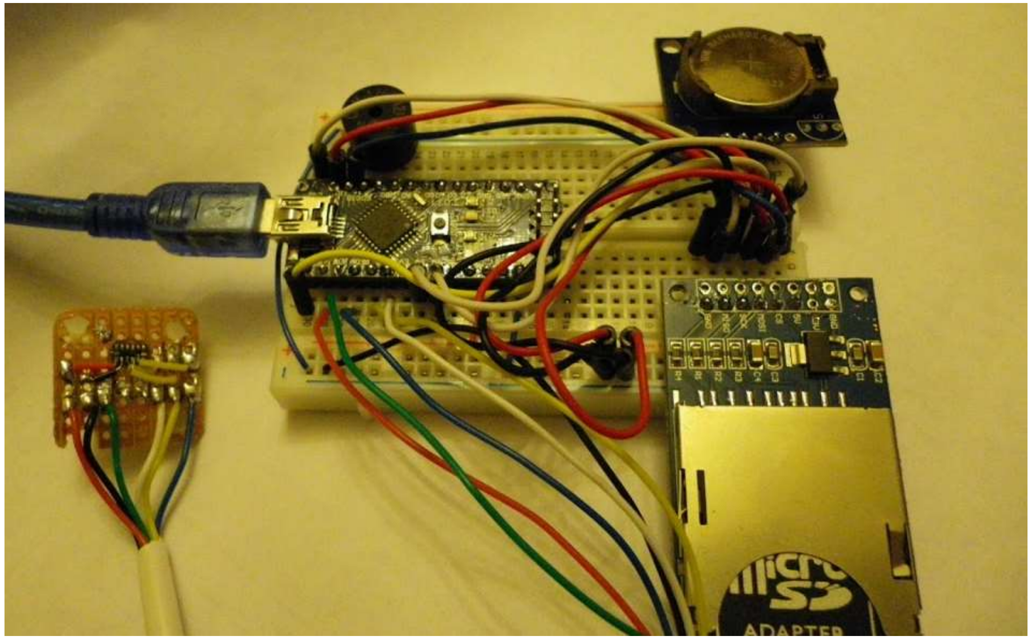
- Bed monitor – detects vibration and possibly moisture.
  — But Benjamin slept on the floor, so no use.

Accelerometer

Wrist Worn Accelerometer (1)

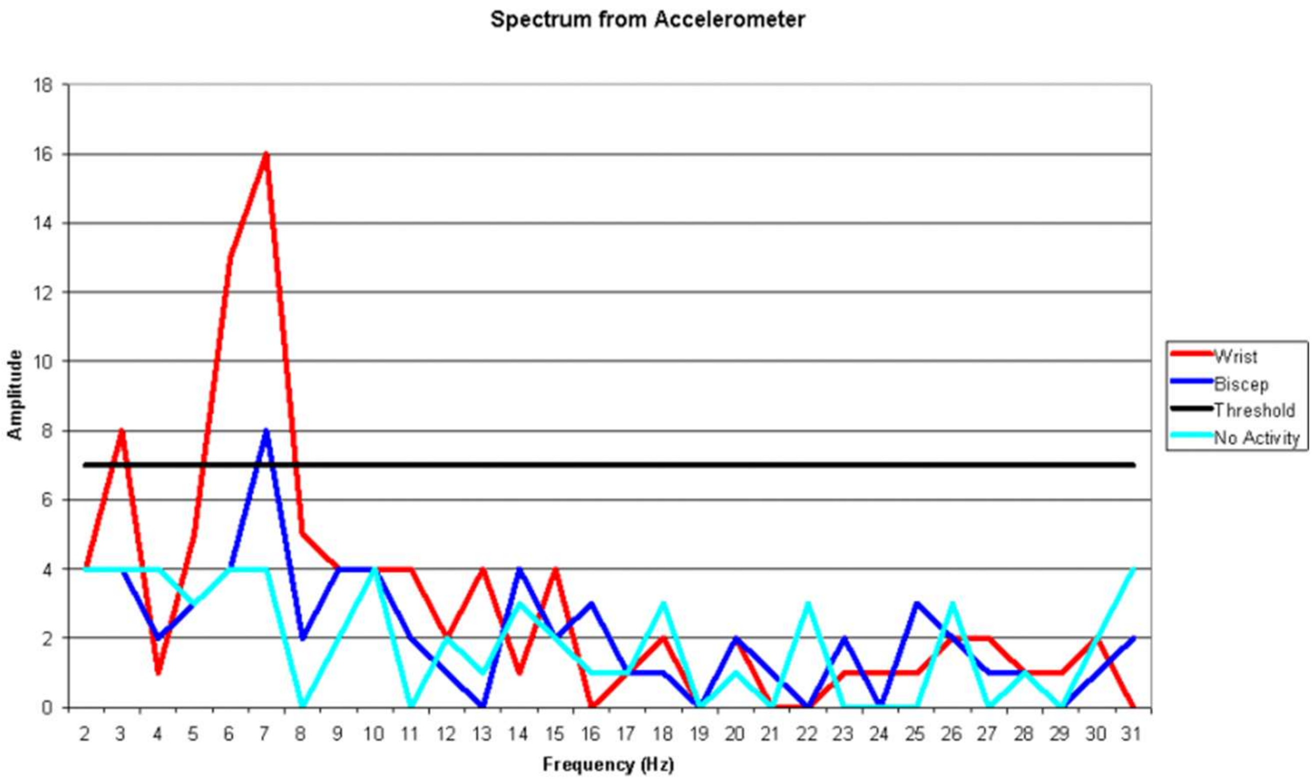
- You can buy tiny accelerometers on a chip (e.g ADXL345 – 4mg/LSB, over 100Hz sample frequency, data buffer with interrupt driven output)
  - but it is a SMD so a pain to connect!
- We expect the seizure movement to be in the 3-8Hz range.
- Sample at 25Hz or greater means we can detect up to 12.5Hz
- Shoehorn an integer based FFT library onto a well known microcontroller
- Look for an excess of movement in the 3-8Hz range compared to the rest of the spectrum.
- Add a buzzer, clock and memory card for logging….Very first prototype shown below.





Wrist Worn Accelerometer (2)

- Surprisingly, it worked pretty well – can clearly detect ‘seizure like’ movements when worn on the wrist.   Could also work on a bicep, but signal less distinct.



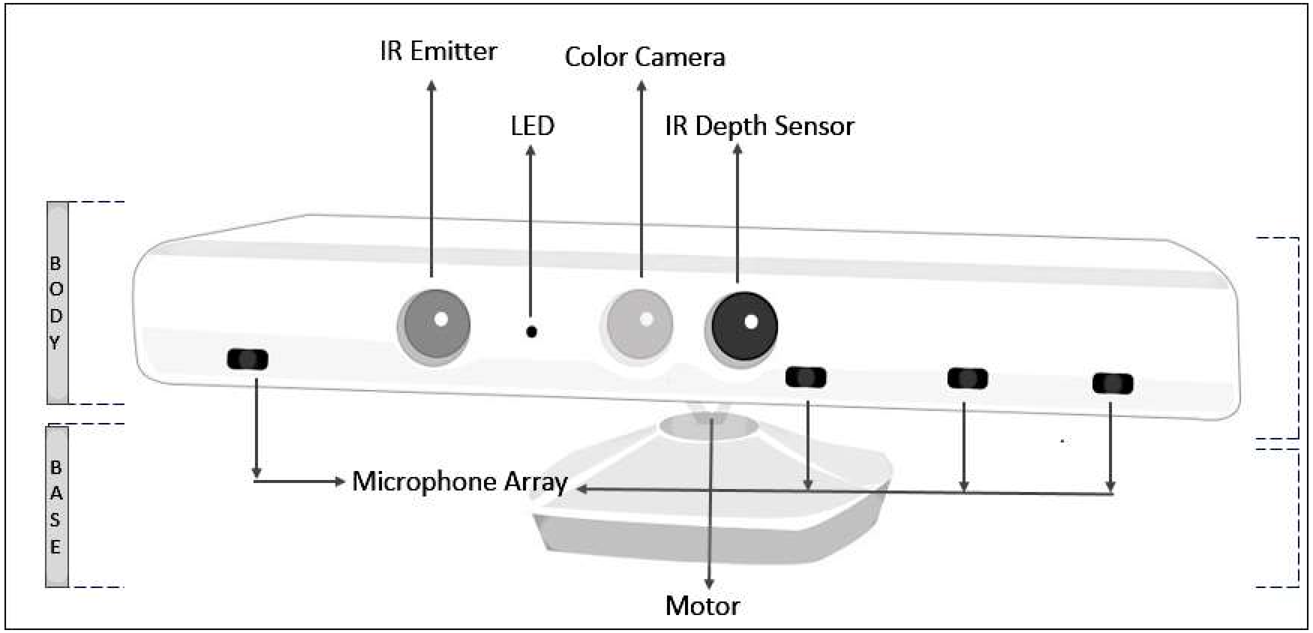
- But very bulky and flattened a 9V battery in a few hours, so not practical.
- Tried attaching an accelerometer to a floor board, but it was an abysmal failure!
- We did go back to the wrist worn accelerometer in the end though – more later…..

Microsoft Kinect Video Game Controller

Video Game Depth Camera (1)

- Because of Benjamin's Autism, and refusal to sleep in a bed, we really wanted a **non-contact way of monitoring** him.
- The Microsoft Kinect sensor is rather clever in that it contains a **Depth Camera** where the pixel values are the distance of the object at that position from the camera.
  - — It works by projecting an **array of NIR dots** into the room, which are detected by a CMOS camera that is offset from the light source.
  - — Some knowledge of the geometry and shape of the array of dots means you can calculate distance.
  - — Fortunately the Kinect Sensor did all the geometry, and there is an open source driver for it, so I just received a series of images where the pixel values are distance from the camera.

http://openseizuredetector.org.uk



Video Game Depth Camera (2)

- Compare Depth Camera frames to measure velocity of features in the room
- Image Processing Approach is to collect a series of images and process them to extract a measure of the amount of movement of the test subject:

Background Image

With Test Subject

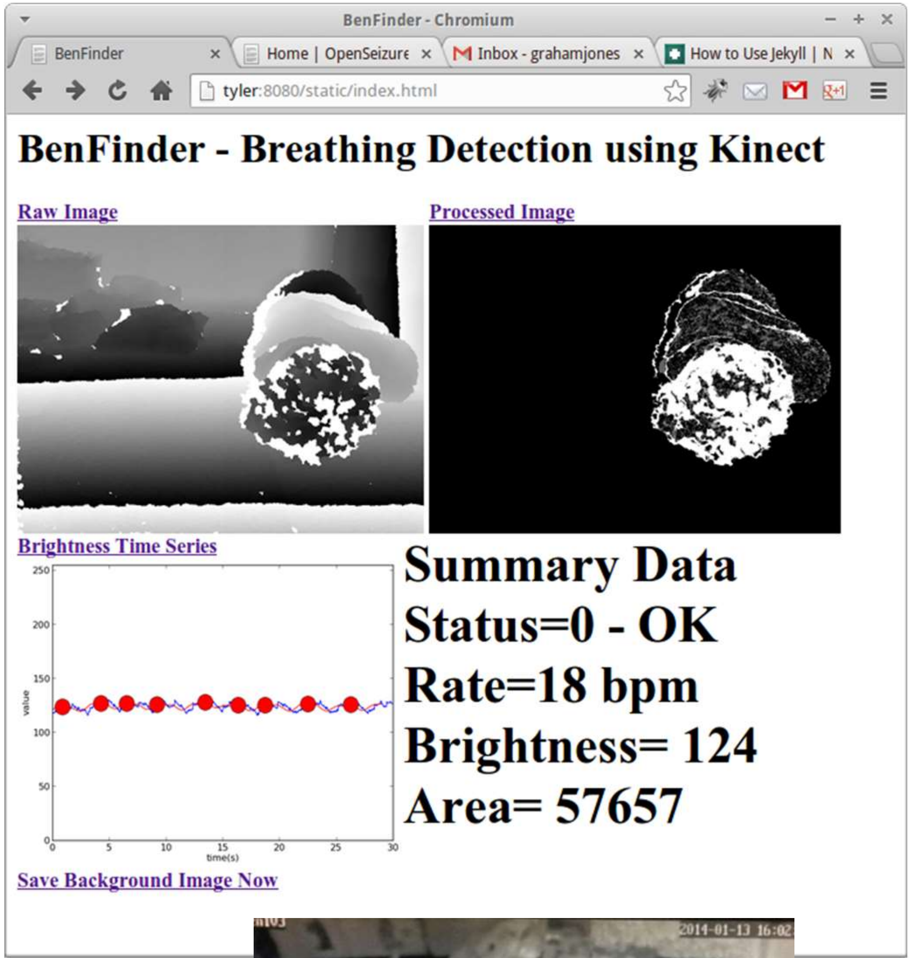
Subtract Background to give ‘current’ image of subject.

For each frame, subtract rolling average of ‘current’ images, and amplify the differences – small movements show up clearly.

Pick out the largest bright area, which we assume is Benjamin, and calculate its intensity – this is a measure of how much he is moving. Record this into a time series for analysis.

Video Game Depth Camera (3)

- Develop the image analysis calculation route to
  - Record the total brightness of the resulting image for each frame.
  - Look for peaks in the brightness time series.
  - Interpret peaks as breaths to give us a breathing rate in breaths per minute.
- Use a raspberry Pi to display the images and analysis results in our bedroom.
- It is not a seizure detector – frame rate is too slow to detect 3-8Hz movement , but it is an apnoea ‘lack of breathing’ detector which provided us with some peace of mind.
- **First working detection system ☺.**
- We used this for a couple of years, but it was too temperamental to suggest other people installed it.



Video Image Processing

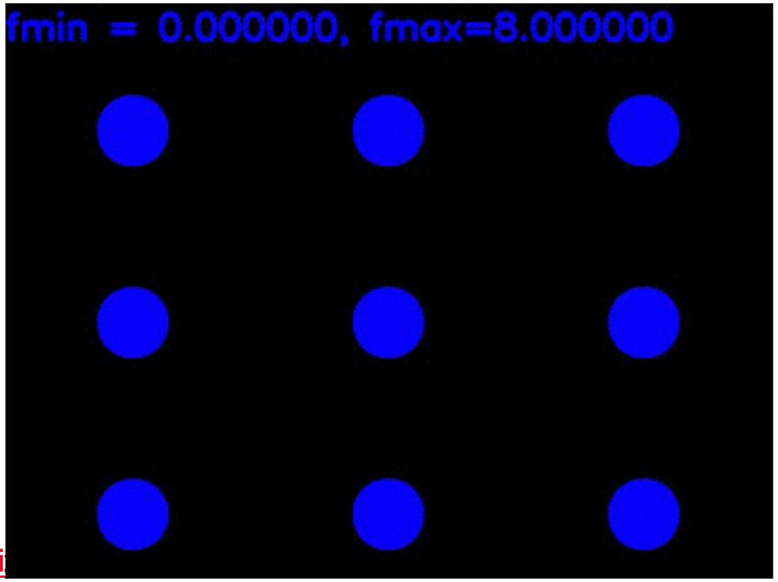
Video Image Processing

- The Kinect based system was nice in that it confirmed Benjamin was breathing (comforting to know!), but it would not detect a seizure, and was quite power hungry (>30W).
- We have a digital video camera in his bedroom, so can we process the images from that to identify seizure-like movement?
- Tried two different approaches at different times:
  - "Deterministic" image analysis of video frames to track features and deduce movement.
  - A machine learning (neural network) approach to train a model to recognise 'normal' and 'odd' postures, where 'odd' ones could be seizure-like behaviour.

The next slide has some flashing images – you may want to look away….

Deterministic Image Analysis

- Collect a video frame
- Identify ‘interesting’ features in the frame.
- Track those features in subsequent frames to determine their speed
- Feed the calculated speeds into a Fourier Transform to get frequency of movement – and see if that is ‘seizure like’
- Videos below use different thickness circles to highlight areas of movement at different frequencies. The computer generated ‘test card’ one looks like a promising start – it is detecting higher frequencies near the faster moving blobs, but the real video is just measuring noise…..
- Also tried attaching reflective markers onto Benjamin’s clothes, but not much more successful…And it was very CPU intensive…
- **Abandoned! ☹**



Machine Learning Video Analysis (1)

- Sandie noticed that when Benjamin is about to have a seizure, he will adopt an unusual pose – kneeling up looking to one side, getting up onto his hands and knees, waving arms...
  - — If we could detect these ‘odd’ poses we might be able to detect some of his less serious seizures that do not result in sustained regular shaking.
    - …and I had just read a book about using neural networks to do image processing.
- The idea was:
  - — Collect lots of ‘normal’ pose images.
  - — Collect as many ‘odd’ pose images as possible, and categorise them manually.
  - — Train a neural network to look at an image from Benjamin’s camera and classify it as ‘Benjamin not Present’, ‘Normal’ or ‘Odd’.

Machine Learning Video Analysis (2)

- Collecting images from the video camera was easy, but classifying manually to find enough ‘odd’ ones to train a model was difficult and tedious.
- So I dressed in Benjamin’s favourite Pudsey Bear sleepsuit and demonstrated a lot of ‘odd’ poses for the camera…..
- There were a few problems:
  - The neural network was not detailed enough – I successfully taught it that Benjamin is ‘Normal’ and Graham is ‘Odd’!
  - Benjamin started to do the ‘odd’ behaviours when there was nothing wrong with him.
  - It would be very Benjamin specific, so not much use for anyone else.
- **Abandoned!** ☹

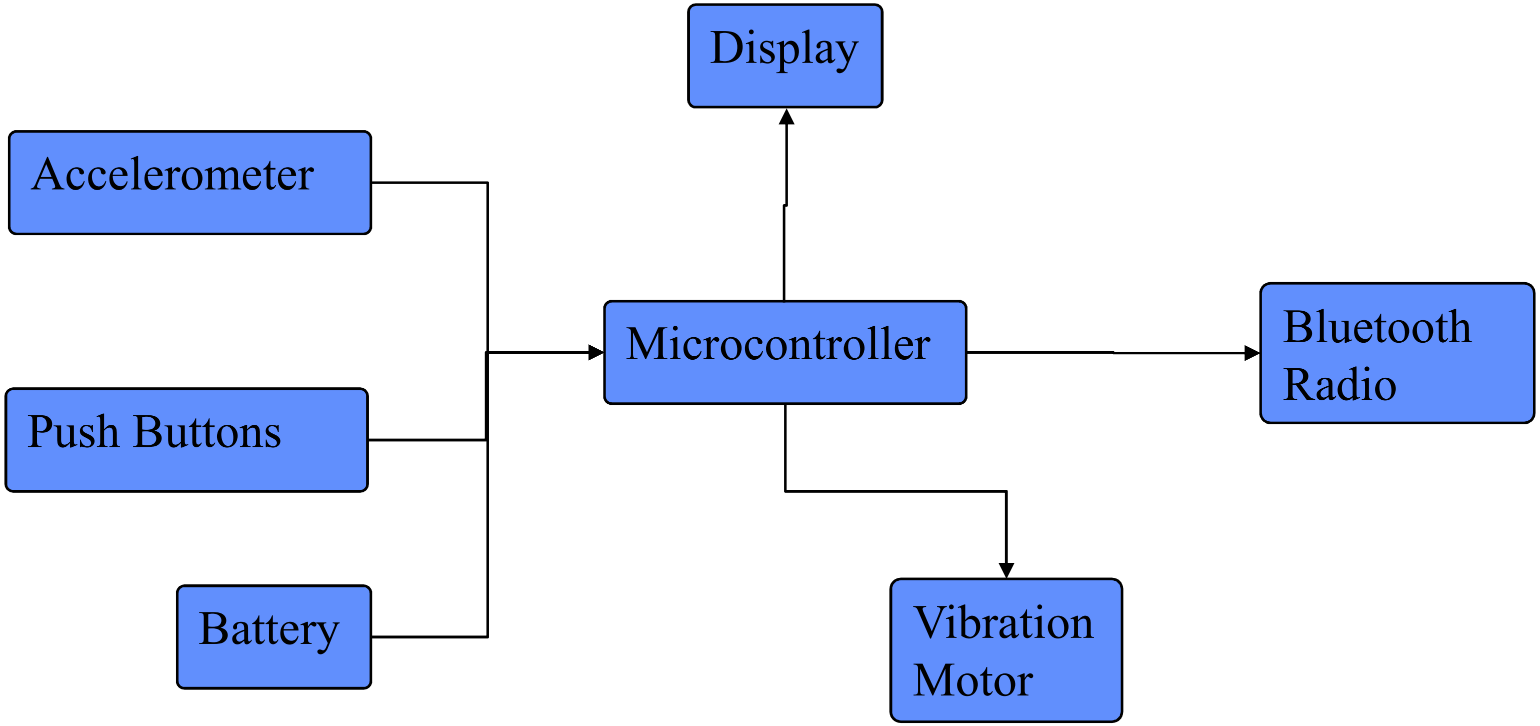
Genuine ‘odd’ image

Simulated ‘odd’ images

Smart Watches

SmartWatches (1)

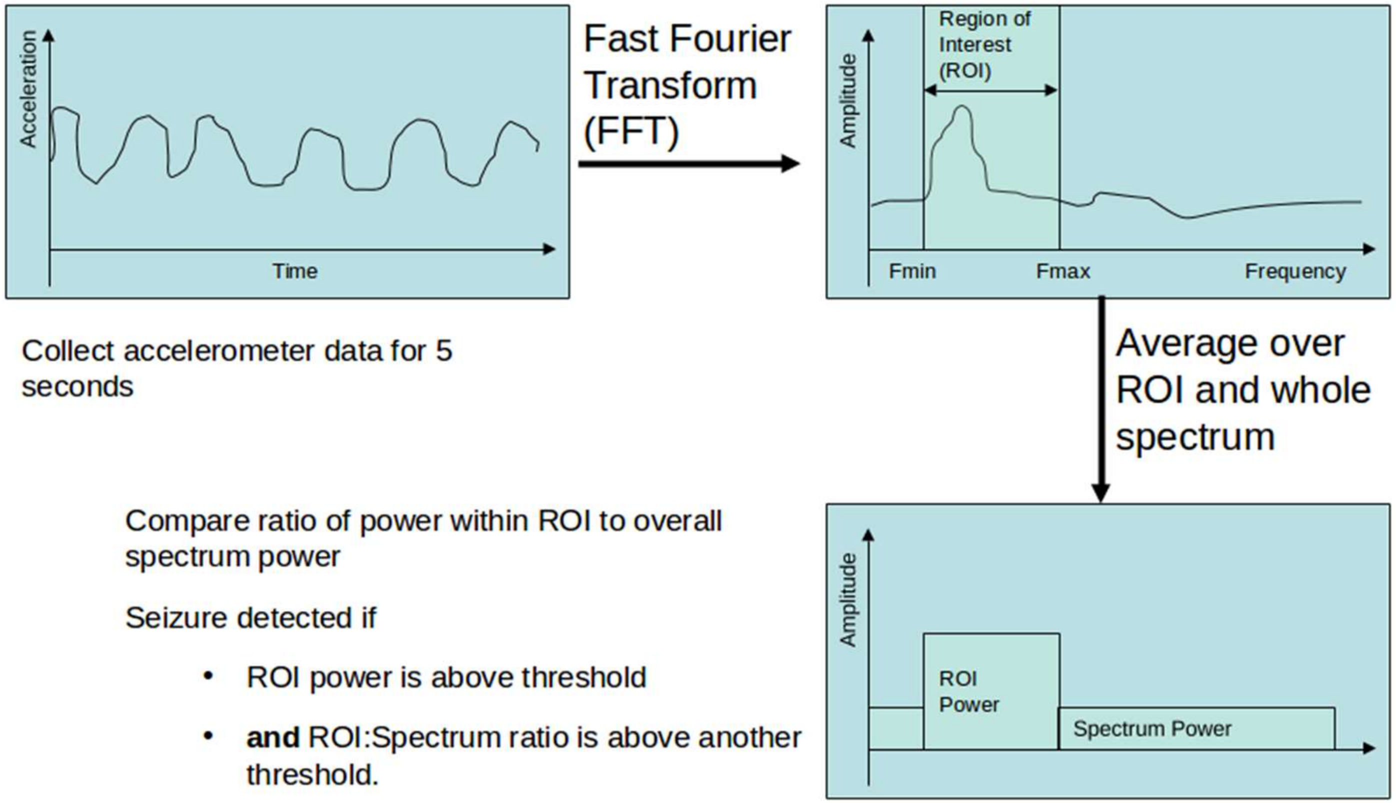
- The Invention of the Pebble Smart Watch changed things.
- It had the required **hardware** (accelerometer, microcontroller, Bluetooth radio, battery).
- And most importantly the manufacturer gave away the **Software Development Kit** so you can write your own software for it….and you programme it in C ☺.
- So set about implementing the **accelerometer based seizure detection** algorithm on it, in the hope we can train Benjamin to wear it.



Seizure Detection Algorithm

- Collect accelerometer data (at 25 Hz) for 5 seconds.
  - 25Hz sample rate means we can detect up to 12.5 Hz, which seems to be high enough for human movement.

Detection Algorithm



Collect accelerometer data for 5 seconds

Compare ratio of power within ROI to overall spectrum power

Seizure detected if

- ROI power is above threshold
- **and** ROI:Spectrum ratio is above another threshold.

Warning raised if seizure detected for ~5 seconds

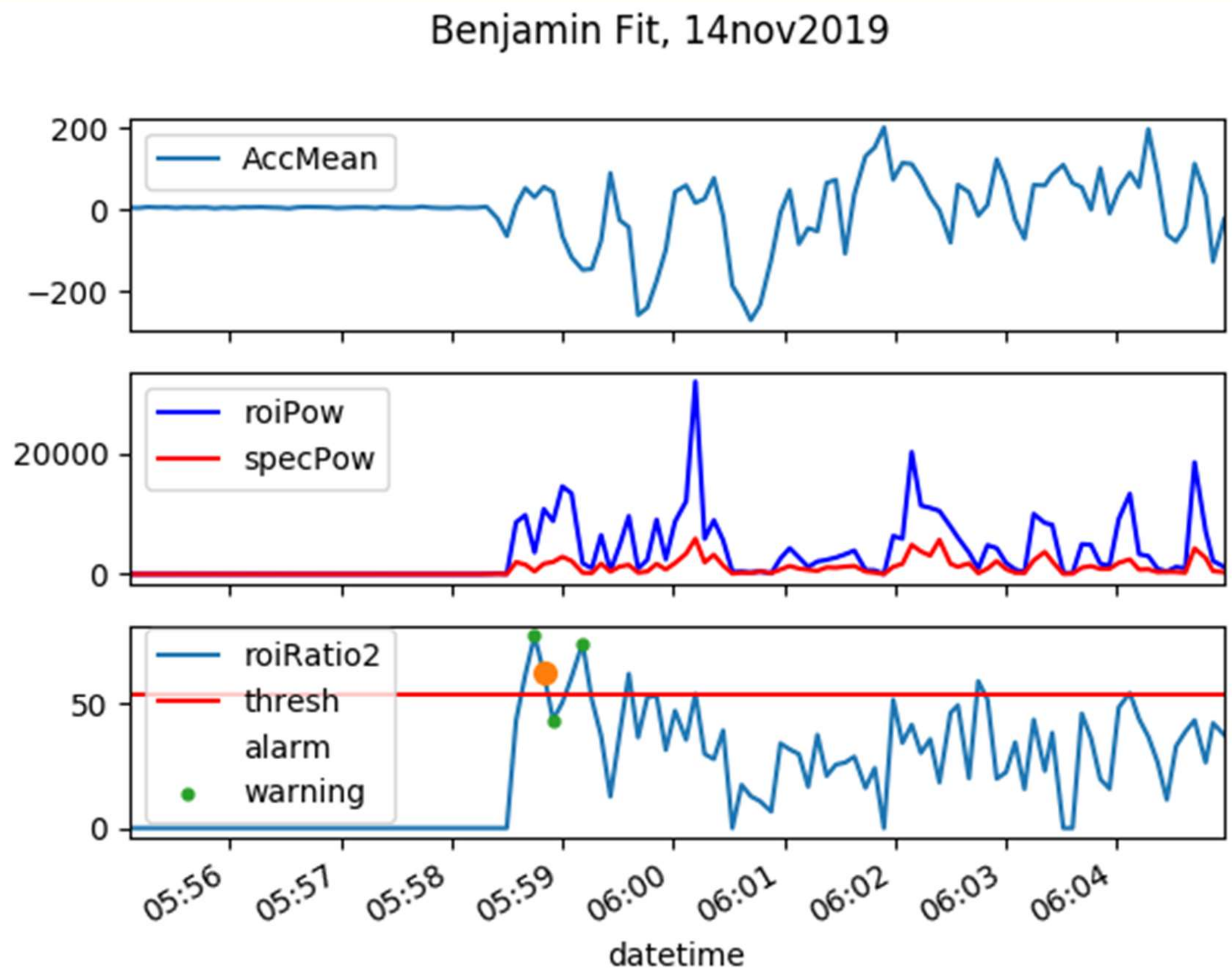
Alarm raised if seizure detected for another ~5 seconds

http:/

Does it Work?

- The results were surprisingly good – had expected to have to develop the algorithm to maybe look at shape of spectrum, but the crude bandpass approach in previous slide seems to work ok.
- Issues are:
  - It only detects **tonic-clonic** seizures that result in shaking of the arm – if the arm does not shake (because it is a partial seizure) or because it is trapped under the body, there will be no alarm.
  - It will generate **false alarms** – brushing teeth, touch typing, touching moving car bodywork all generates vibration in the 'seizure like' range. We get of the order 1 false alarm per day, depending on what Benjamin is doing.
  - The Pebble watch only does **integer arithmetic**, so everything is fixed point.
  - Battery usage is a challenge, so minimising CPU use by **using simplifying assumptions** which are not exactly correct mathematically..
  - Fitbit bought out Pebble, and promptly shut down manufacture ☹.
  - So now use Garmin watches which also allow **abnormal heart rate alarms** to be generated – and we can get raw data off them because of use of BLE.

Example Data from a Real Seizure



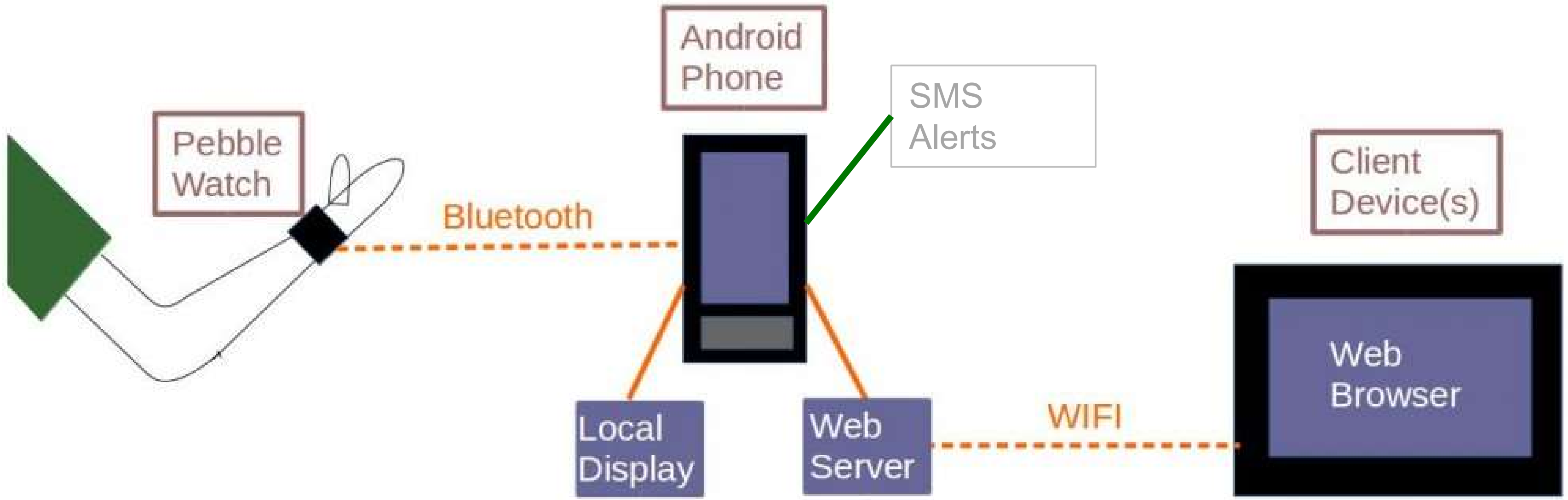
From Proof-of-Concept to Deployable System

System Requirements

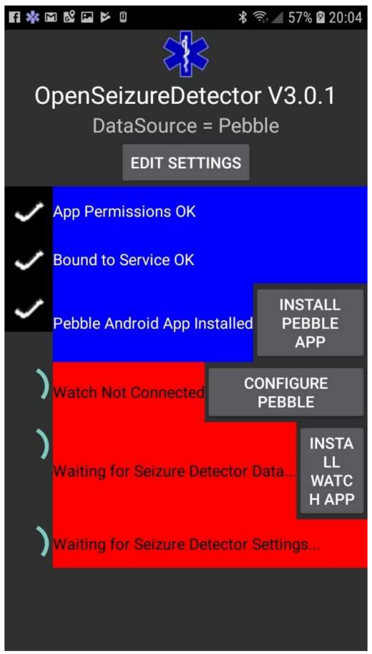
- Demonstrated detection reliability.
- Acceptable false alarm rate.
- Battery Life > 12 hours.
- Self-Diagnosis of Faults, and warn user of fault conditions.
- Reliable method of notifying carers
- Ability to mute alarms if doing an activity that will generate false alarms.
- Log data for future analysis if necessary.
- Easy (enough) to get software onto device.
- Ability for users to adjust settings to suit their use-case.

This “Boring Software Infrastructure” was the most time consuming part of the project, by a considerable margin.

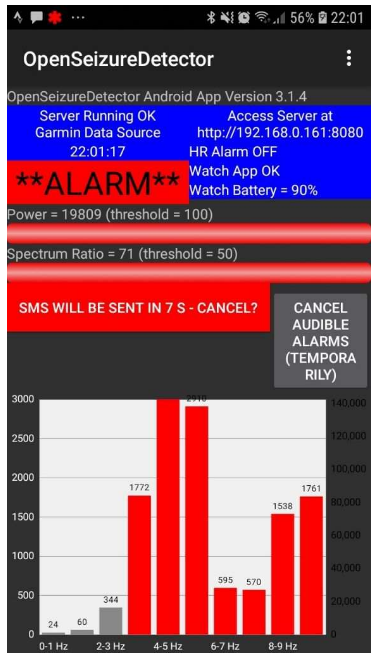
Android Based Alarm System



Self-Checking on Start-Up

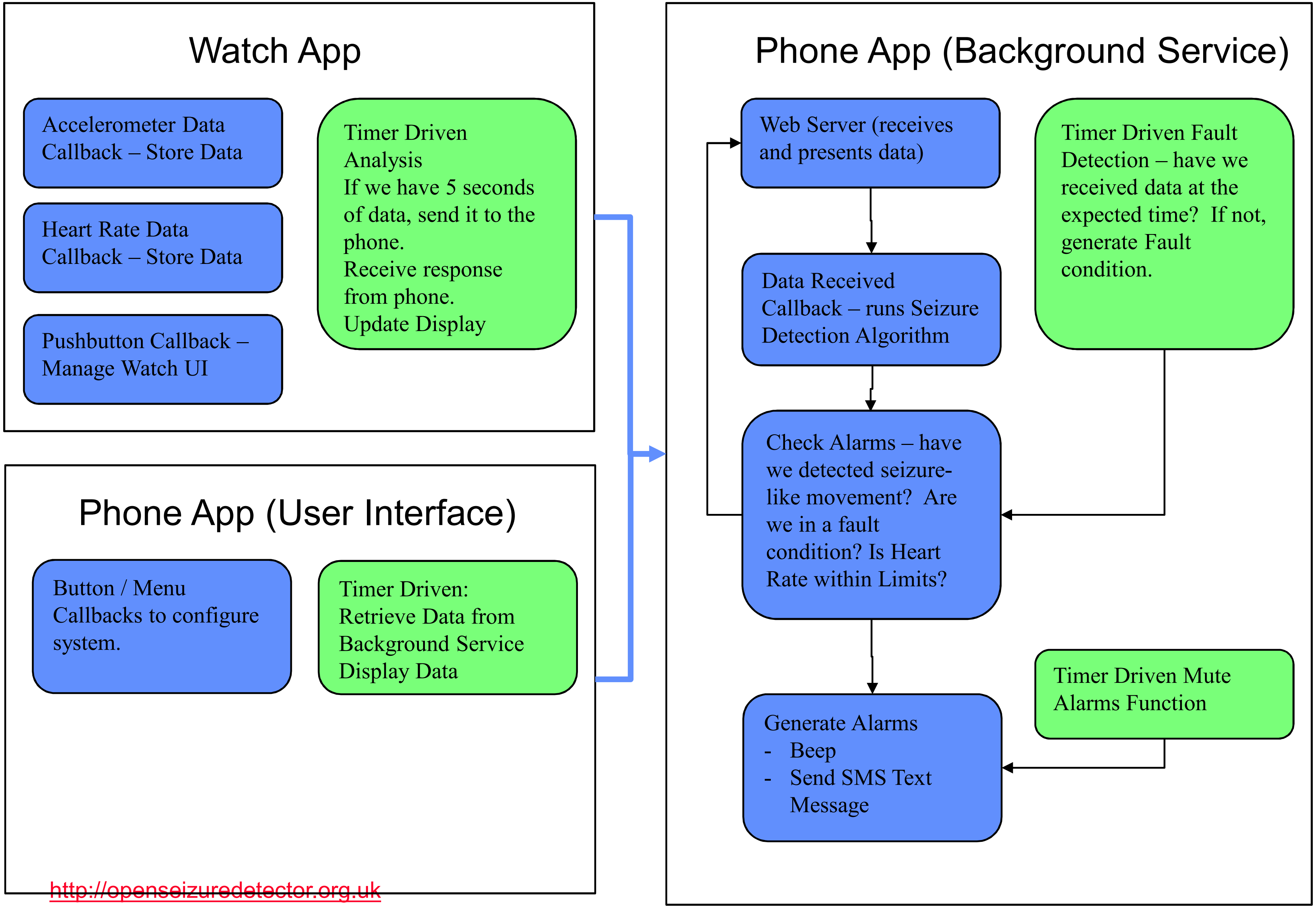


Main Display in Alarm Condition



http://openseizuredetector.org.uk

Software Architecture



Deployment Challenges

- It is licenced under GPL3, so has a ‘**no guarantees**’ clause in the licence, but do users read that?
- To make it easy for users to install, publish app on **Google Play Store**.
  - The app needs some ‘Dangerous’ permissions – to send SMS messages or make phone calls without user intervention.
  - It took a lot of effort to persuade Google that this was a reasonable use case so it could stay on Play Store.
- The Watch app is installed manually (by copying the executable file onto the watch on a PC) because Garmin were concerned that this might be a ‘Medical Device’ so **need FDA approval**. I don’t have the time or energy to seek FDA approval….
  - Quite a few users struggle with the manual installation.

End User Experience

- Take-up has been relatively slow
  - — Do not ‘advertise’
  - — But if it was too popular I would struggle to provide support.
- Most people who install the app uninstall it quickly, but do not leave any comments about why.
- Those that do leave reviews tend to be positive (better feedback than the commercial equivalent).
- Writing documentation for a non-technical user is difficult (for me at least!).
  - — It is all in English
  - — But some users are now providing translations for the app text which is good – now supports several languages.

What Next?

- Since we started on this, commercial seizure detectors have become available (e.g. Empatica Embrace, SAMi video based detector.).
  - I was planning on Scrapping mine when the Embrace finally arrived, but I am not keen on its approach to the alarm system infrastructure - it relies on distant servers and internet connection to generate an alarm sound at the other side of our house.
- Very Low Cost Seizure Detector
  - There are some very cheap smart watches available now – I would like to make the lowest cost seizure detector using one of those (about £20 each) – it looks like it is possible because someone has worked out how to get software onto them – job for the winter.
- Machine Learning Algorithm
  - Ask users to log data to my server and make a machine learning algorithm to try to improve detection reliability and reduce false alarm rate – server software about ready, but I'm concerned about holding personal information.

Questions or Suggestions?

References

- https://openseizuredetector.org.uk
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