**Designing and making judging aid for canoe slalom**

**CM3203 – One Semester Individual Project – 40 Credits**

**Final report**

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# Abstract

In most professional sports some form of video judge is being implemented. Cricket was one of the earliest sports to implement this technology with Hawk-eye back in 2001. With bowlers, bowling at around 90mph, it can be hard for TV spectators to follow the, but with Hawk-eye it allows the spectators and the umpires to replay these fast pasted moments to allow them to make better decisions on close calls.

Canoe slalom is no different. With athletes trying to reduce their times by seconds and cutting it as close as possible to the gates, a judge can only see so much from the bank. This project aims to design and make an accessible system for these canoe slalom judges to allow them to make better split decision calls. The project also aims to evaluate the success of the solution and verify if it could be scaled up and used in competitions at all levels.

# Acknowledgments

I would like to thank my supervisor, Dr Ian Cooper whose friendly advice and guidance throughout the whole project allowed me to work through the hurdles I encountered in the project.

I would also like to thank members of Seren Dwr Canoe club for allowing me to come down to their training sessions and collect data.

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# Introduction

As with any top level sport, canoe slalom races often come down to the finest margins, as such paddlers have been trying to find the smallest margins possible to help them win races. This has evolved over time with boat manufacturers using the lightest materials to reduce weight and allow the paddler to move faster. In more recent years, manufacturers such as PeakUK have been developing garments such as the racer ST2020[[1]](#footnote-1)which take the vital buoyancy aid on the front of the paddler and integrate it into the spray deck, this allows for the paddlers chest to be unimpeded with the traditional buoyancy aid. Although these new designs only eliminate a few millimetres from the chest, it allows the paddlers to get even closer to the poles. This new innovation meant that PeakUK athletes at the 2020 Tokyo Olympics were able to win a total of 9 out of the 12 possible medals[[2]](#footnote-2).



Figure 1 - PeakUK Racer ST2020, showing now foam on the front, to allow for tighter turns around the poles. Image Source: (PeakUK, 2020)

With the margins being as thin as mentioned above, the pressure that the judges are under to make accurate calls are huge, especially when a penalty means the difference between 3rd and 4th place, as with the Olympic games this summer[[3]](#footnote-3). That is why, my project aims to create a product that will aid judges in making these split decision calls while the race is still going, without necessarily using a video judge, which can be a lengthy process, and is also only available at the top level of racing.

Although the project is aimed for the judges use at the most competitive levels of sport, it could also be used as a training tool for all the athletes in the sport. Canoe slalom coaches have to perform two job at the same time, one as a judge making sure their paddler makes it through the gates and secondly as a coach to see what the paddler can improve on. If my project was used, the role of the judge can be taken away and the coach can focus on coaching. The coach will also be able to gain more data for quantitative feedback from the various sensors and outputs on the poles allowing them to gain tip for which poles their paddler can get even closer on without.

As of the 2018 season, the ICF (international canoe federation) has brought in a new system for video judging for only the world cups and the world championships[[4]](#footnote-4). Compared to tennis or cricket who have been using video judging since 2001. Even then in canoe slalom there is a very large team of judges, some watching the live video feed of the run and some reviewing the replay of any contested decision. Whereas in a sport such as rugby, there is only one video judge who runs it all. My proposed project would utilise the judges already on the river bank. These judges would first watch the paddler come through the gates and if they then decided there is a close call they can refer to the mobile device which will have data for them to review instantly. All of this will reduce the pressure on the judges, reduce the number of judges needed, and cut down on the time taken to the review close calls.

# Background

### A beginners guide to canoe slalom

The main focus of this project isn’t to teach the reader about the intricacies of canoe slalom, an understanding of this sport is useful to fully understand the project. A full list of canoe slalom terminology can be found in the appendix.

In canoe slalom athletes race down a roughly 200 meter long course consisting of a minimum of 18 and maximum of 25 different gates, of which 6 must be upstream gates. Paddlers can occur time penalties of 2 seconds for having a touch on the poles, this can be from any part of the paddlers body, or any of their equipment. The athlete can also gain a 50 second penalty for not having their complete head go in between the two poles, or for navigating the course in the wrong direction or order.

The way this is judged is with two judges having a set of 4-5 gates between the two of them. They will watch the paddler head down the course and report back to the race control what the results are. This will be in the form of numbers, for example a “zero, zero, 50, two” means that the paddler has successfully navigated the first two gates, missed the third gate, and touched the fourth gate. At the top level of the sport, if there is a disagreement between the two judges or they aren’t sure on what to give they might be able ask the video judge to review the footage they have.

### Current implementations

A picture containing text, outdoor

Description automatically generatedOn a typical canoe slalom broadcast such as the Olympics or the world cups we never get to see any of the judging or video judging taking place. The viewer might get some slow motion replays of the gates if there is time between each paddler, but there is never any formal type of judging shown. The only aid that the viewer has is a small icon showing if the paddler has hit or missed the gate.

Figure 2 – Typical canoe slalom world cup broadcast, with icon showing penalties. Image Source: (Planet Canoe, 2021)

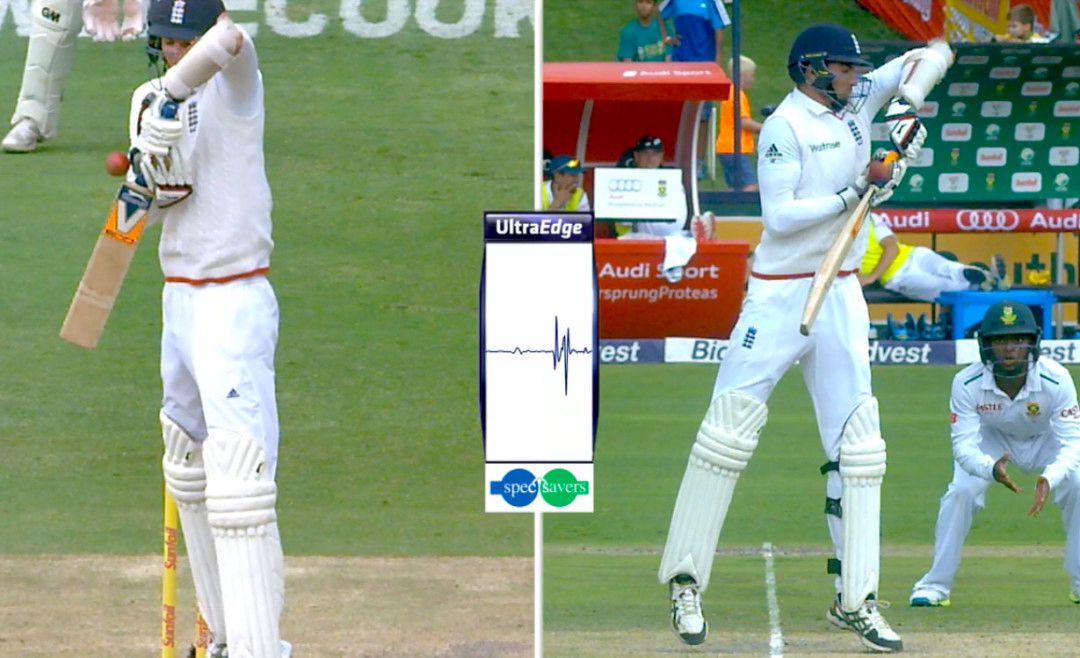
Although my project isn’t aimed towards viewers of canoe slalom, there is scope for the acceleration graphs produced by the accelerometers to be displayed alongside the replay of the gate that is under question. This would be something similar to ultra-edge in cricket where they have the sound wave produced, helping the viewers and umpires make their decision. It is reasonable to think that if the system is designed towards judges with no prior skills in canoe slalom, then the average view would be able to understand the graphs and make a decision for themselves.

Figure – 2 Ultra-edge used in cricket. Image Source: (inshorts, 2016)

### Tools used

#### Flask

The first and arguably the most important tool I used was Flask. This is a popular web app framework for python. I decide to use Flask over other frameworks such as Django as I already had some experience with using Flask in other project. Flask is also lighter weight which was important for me as everything would be running of a raspberry pi, which are notorious for struggling to run programmes.

Flask was able to provide the basic functionality to get everything the canoe slalom judge would need onto a web app. This was a vital criteria for the project, without the use of a web app the judges would need a lot more training on the programme to be able to use it effectively. Flask also has different protocols which have been very useful when building the programme. The most common request I have been using has been the GET request allowing me to get data from the flask server, this can be anything as simple as a flask route or html template.

#### SQLite

SQLite has been another backbone to the project. SQLite is a small and fast database engine. The database allowed me to easily link the data from the accelerometers to the flask server talked about above. Storing the data within the database also allowed for easy retrieval for plotting graphs to show changes in the accelerometer date. There is also spoke for being able to collect and plot old data in a competitive sense, for example if a racer has filed a objection to one of the rulings.

The reason I picked SQLite compared to other database engines such as NodeJS or MongoDB was that I already had a good understanding of SQL. SQLite is also a fully self-contained system meaning it is very simple to set up and get running quickly, and it also doesn’t take up much storage or processing power which are both key factors when dealing with a raspberry pi.

#### Matplotlib

Once I had the basic functionality of the programme down I started to work more with Matplotlib. This is a python library built upon NumPy for python, it allows the user to create all sorts of static, animated, and interactive graphs. There are a few other alternatives to matplotlib, but none based around python. I have used a charting programme based on JavaScript which I will move onto now.

#### HighCharts

HighCharts is very similar to the aforementioned Matplotlib, this time based around JavaScript. HighCharts has been used to take the accelerometer data from the Live system to the flask site. I’ve used the animation functionality of HighCharts to get a set of graphs which are atomically refreshing at a high rate to allow the judge to effectively see a live update of the accelerometer reading in a user-friendly form.

#### VNC viewer

VNC viewer has been a key productivity booster for this project. VNC viewer enables me to remotely access the pi meaning I don’t need to have a keyboard or mouse plugged in. This is a key problem as the slalom pole can often be a couple meters above the water. VNC is automatically installed on all raspberry pi meaning it is a no brainer to use. The other alternative that I could have used would have been SSH, this allows for command line execution on the pi. The only problem with this is there no graphical user interface as with VNC. This was a key downfall of SSH as I knew I would be needing to look at different graphs and different code, therefore SSH would lower my productivity as I would be needing to upload everything to git every time I made a change.

#### Hardware

The main hardware I have used during the project is a raspberry pi model B, two Adafruit ADXL345 accelerometers and one Raspberry pi camera. I decided this was this going to be the best solution after researching different microcontrollers. The main competition would have been using an Arduino. I decided to go with the raspberry pi as some of the other tools I have used weren’t available on the Arduino. Another benefit of the pi was that my supervisor Dr Ian Copper already had one spare which I could borrow for the project, allowing me to swiftly move onto the coding stage.

The Adafruit ADXL345 were used as they are readily available for a low cost, a pack of 4 only costing around £8. Although a pack of 4 was purchased, only two were needed. This was first because on one slalom gate there are two poles. Secondarily the amount of data coming from four accelerometers would have been too much to handle for one raspberry pi.

#### Ajax

Ajax has been one of the backbones for the Live system. Ajax has allowed me to retrieve data from different parts of the pi, asynchronously without having to update or refresh the page. This has been implemented in the retrieval of the sensor data, and also the retrieval of the camera live stream.

# Approach

## Fundamental system behaviour

I started off the project by defining a few basic requirements for the system, they are:

* The final product must use some form of sensor to track the movement of the pole
* Solution could use a camera to help the judges
* The solution must be presentable and easy to use for the judges
* There should be a web app as the final solution
* On the web app there should be a graph to show the changes of acceleration
* The graph could show rate of change
* The system could produce a judgement on if the pole has been hit or not

The first design decision I came to was using accelerometers as the main sensor in the solution. I came to this conclusion because after doing some research I found that the Adafruit ADXL\_345 sensor was cheap, small, and compatible with the raspberry pi, even coming with its only library. The documentation on the device was also excellent and very detailed, along with other people’s implementation of the accelerometer. All of these things combined made it a no-brainer to choose accelerometers and especially the ADXL\_345.

Ease of use was a major underlying system behaviour that I defined. This is because I started off defining my target audience and users, this made it easier to clarify exactly what my final project will be. I found that my main users would be the judges at canoe slalom races, who are often just volunteers, who possible haven’t raced canoe slalom before, nor had any deep understanding of computers, raspberry pi’s, or the accelerometers I used. This meant that I had to focus on making the user experience as simple as possible. This was challenging as it was hard to find the right balance between overcomplicating things and not showing enough detail.

A web app is essential for the final product to allow the product to be easy to set up and use for the wide variety of users. This is because 87% of people in UK own a smartphone[[5]](#footnote-5) meaning that there is a high chance all of the judges there have their own smartphone, signifying that all the judges will need to do to access the system is just enter a web address. Because the system was designed to run as a web app on portable devices, such as phones and tablets, I made sure to take this into account when developing the product.

I could have implemented a system to work out the rate of change on the accelerometers and put this on the graph, this would have also lead nicely onto the judgment call. I decided against doing this in the end as I wanted to focus more on keeping the design simple and straightforward. Having extra data, such as the rate of change would require more training for the judges and would possibly overcomplicate things. I also over ran on my expected development time meaning that I did not have the time to implement the rate of change or the judgment call even if I had wanted to.

## Live System

Originally, there wasn’t going to be the live system that I have ended up developing, but after my first proper test I found that I was not satisfied with the product I had. From here I developed my live system. This is a web app, designed for mobile devices, that is showing a live feed of both the camera and the sensors that are available. This is the main system that the judges will use to aid them in making their decisions. Therefore it is a minimalistic and simple designed, as talked about in the section above.

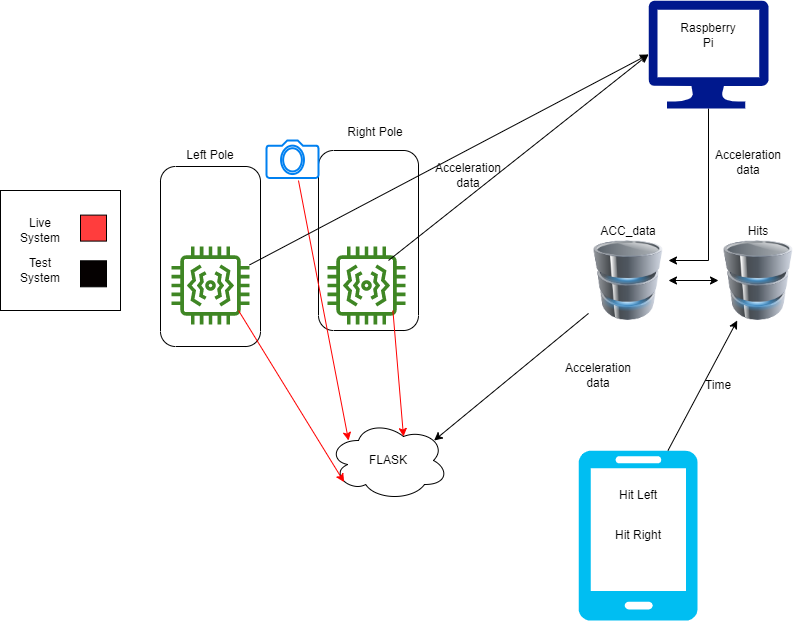
Photo of the app

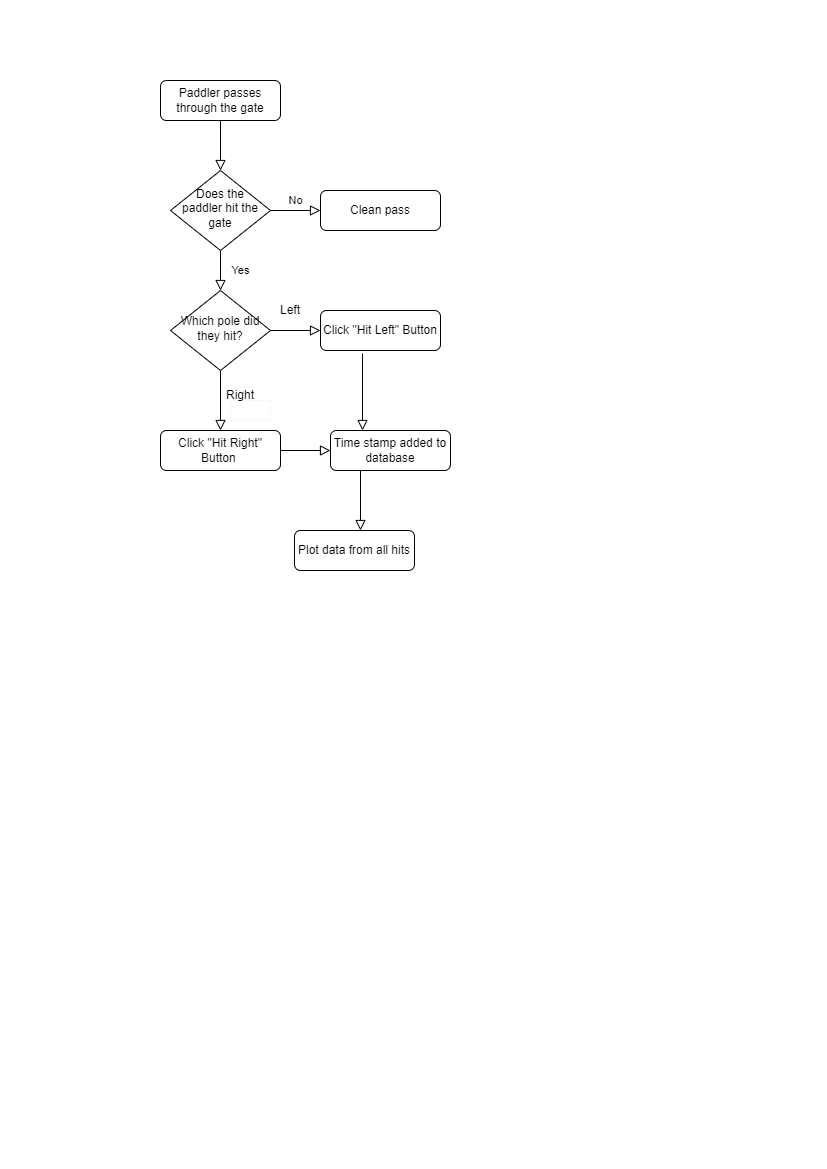
## Test System

The test system is less based around the judging in real time and more aimed towards a canoe slalom coach, or a large competition. Once again the interface for this system is very simple with only two buttons, and a table showing the last data entry. The two buttons allow the user to store the time of when they believe there was a hit. After the race is done, or the training session is over the user can then collate all the times they believe there is a hit onto a PDF document showing a graph of the last 500 data entries from the time of hit. This would work well in a race if there was a dispute as all the data entries from the sensors have been logged and can be queried at any time. A combination of both systems should lead to a better judging experience for everyone

Photo of the results?

## System Flow

With everything discussed above here is the network diagram for both systems and information flowchart for the test system.



## Expected limitations of the system

As with any project there will always be some limitations, but due to the nature of this project being a proof of concept there are some major limitations we have had to overlook. For example, in the real world of canoe slalom courses are a minimum of 200m[[6]](#footnote-6) with many being longer and often in a straight line. If we take a look at the river Teifi in Llandysul, a popular natural Welsh slalom course, we can see that it is 200m long in almost a straight line and , based on my personal experience, the internet signal at the course is not very strong. This would produce problems for my solution as a good internet connection is required to run the web application and live stream the sensor data quickly. One possible solution to this would be to set up a mesh network between the different pi’s that would be needed.

The next limitation is I have developed the system for one pole running off one raspberry pi, in a real world with 18—25 different gates6 having a pi for each individual pole would be very expensive, but then you would run into problems wiring the sensors from each different pole to the different raspberry pi.

Increasing the scale brings along other challenges with the amount of data that is being processed. Currently the pi doesn’t struggle too much with reading the data from sensors, but if we were to increase this by 3, 4 or 5 times then the pi might start to slow down and struggle to output the data we need. The same problem occurs with the test system, but this time the bottle neck will be the database, currently adding one more sensor would mean that the current SQLite database won’t be able to handle the volume of data and will lock itself. If we then reduced the number of times a second that the sensors were writing to the database the graphs wouldn’t be as accurate and could possible end up missing hits. The solution to this would be to move to a heavier database that could handle the amount of data coming in, and the amount of data needing to be stored.

My final limitation of the system is the design. Although this is not taken into account when developing the system, for the final product to be produced for a real customer the design would need to be thoroughly thought threw. At the moment I have the pi taped to the wire overhanging the Whitewater with the cables from the sensors coming up through the pole. This means that the pi can only be a short distance away from the pole. In an ideal world I would need to find a wireless accelerometer, with range that would cover 4 or 5 slalom poles, which would be a total of around 50m.

Photo of set up

# Implementation

## Live System

## Overview

Having a live, up to date, system was possible the most important part of the whole project. Originally the two systems I will talk about were meant to be combined into one. But after testing and thinking more in-depth about the flow of data through the network I realised it was easier to separate the two.

After realising I needed to separate the two systems I conducted some research into the best way to livestream the data from the sensors to a web app. I decided to use HighCharts and Ajax as discussed above in section 2.3.

ADD ANOTHER BIT

## Camera

The first functionality to be implemented was the camera. I decided on this first as I had already seen many popular implementations for similar products during my primary research. One such implementation was a camera live stream using flask by user EbenKouao[[7]](#footnote-7). This GitHub repository was the foundation on which I based my camera solution. Using existing python modules such as OpenCV, an open source computer vision library, and imutils, a set of functions to make image processing more convenient, the repository makes livestreaming the camera to a flask site very easy and convenient.

Overall the repository saved me a lot of time and effort, allowing me to have the camera set up and working since the first day of development.

## Live Data and charts

The live streaming of the data to the charts was slightly harder and required my own solution. When doing my research I had already ruled out matplotlib from earlier tests at livestreaming the data, this lead me to search for JavaScript based alternatives such as HighCharts. In an ideal world I would have kept using matplotlib due to it being more simplistic and easier for me to understand. But HighCharts would ultimately allow me to do what I had planned. More on this can be found above in section 2.3.

The solution that I came up with was using ajax. I would read the data coming off the accelerometers onto it’s own route in the flask server. This was done using the Adafruit python library that supports my specific accelerometer.

One major challenge I had to overcome with this was using two accelerometers at a time. This is because as standard the raspberry pi only comes with 1 i2c bus enabled. This meant that wiring one accelerometer to the pi was simple and very easy, but two was a new challenge. To overcome this, I had to go into the configuration file of the raspberry pi and add lines of code to enable the new i2c buses. I had to make sure when I was doing this to never use bus 0 or 2 as they are used more other things such as pi hats. These new i2c buses also meant that I needed to change the standard Adafruit python script to read the data and tell the new script which buses to read from.

Once I had overcome the problem of using two accelerometers at once I moved onto getting the data to the flask site. I already had working static graphs using matplotlib, so went straight onto producing the live graphs. Researching ways to do this, I found a couple solutions which were similar to what I was aiming for and as such helped influence my decision making, such as identifying ajax as a good way to get the data from the sensors, this is done by using the GET method within HTML.

Once data was being livestreamed to the flask site I was finally able to get the charts worked out. There is a lot of documentation on the HighCharts website as to how to set up the graphs with lots of different examples. I found that the chart type “area” produced the best looking graphs, but this was only for one axis of the accelerometers. To make it even more user friendly, as talked about in sections above, I tried to implement the three axis onto one graph but found it too time consuming to get to the right answer. I carried on with each axis of the sensor on its own graph. This still produced a satisfactory result with an easy to read graph. I have set the ajax function to call every 0.2 seconds, meaning that the graph adds 5 new points every second, which could be increased to get an even more accurate reading of the sensors, but I have balanced the call time with the limitations of the raspberry pi’s computing power, as talked about above in section 3.5. I also found that if I used the line chart type when producing the graph it wouldn’t be as accurate and produced some weird results compared to the area type.

Chart photos

## Test System

## Overview

The ‘test system’ is the first system I developed, before re-evaluating the network. This system takes the accelerometer data and stores it in a MySQL database. There are many advantages and disadvantages to this system with many already being discussed in the sections above. Although there are many disadvantages, I still found it more important to keep this section in the final product, as it shows the history of the product and the many decisions I had to make to get here.

During development, there were many hard decisions to make, to do with the way the product should go. This can be seen with having the two systems. For example you could see how the test system could be used by a judge as a judging system, where it would produce the graph after the user presses the button. I found this to be too time consuming, compared to having the live system, as well as it being impractical for the judge to use, as there would be a 30 second or more delay to render the graph. This would make the system unusable if I were to expand the product to include more poles and having racers coming down in quick succession. Although this idea failed, it grew into what I have developed now as a system to test the product and save results, with more scope for the system to be used in a real world race if the product were to ever expand.

## Database management

The key component of the test system is the database and its connectivity with the flask sever. As discussed above I have used SQLite as my database, you can find my reasoning in section 2.3. To start with I created my database with two tables, ACC\_data and Hits. The ‘Hits’ table is populated with a timestamp, which pole has been hit, and the Row\_ID. The Row\_ID is the foreign key linking the two tables together. ACC\_data table has the x, y, z from each sensor, with the right sensor being x2, y2, z2. There is also a timestamp which corresponds to when the reading was taken and the ROWID built-in function of SQLite. This system works well to allow me to store all the data that I would be needed to identify a hit.

A picture containing chart

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Figure X: shows how the database is setup

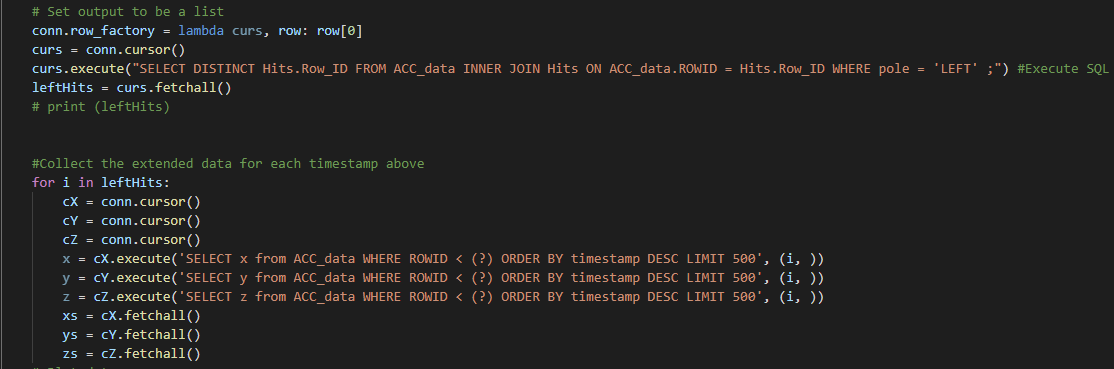
One slight limitation of this system is there isn’t a way distinguish between what each hit is. For example there is no way in the database to see what a hit with a paddle is, or a helmet. I decide that this would not be needed for the way I was using it. This is because I was able to note down what each type of hit was as I was testing it in my back garden.

If I were to use this in a faster paced environment, where the judge wouldn’t have the time to note down the different types of each hit, I could add a field into the Hits table to identify the type. This could then be queried and added onto the header of the plot. An example of this would be figure X.

Once the user has clicked the button that corresponds to what side the paddler hit the pole on the system enters the last timestamp and last ROWID from the ACC\_data table, saves it in the Hits table. Once the testing session is over the user will run the file ‘PlotfromHits.py’. This is where the user is able to plot all the hits they have just logged and get an output of PDF files for the left and right poles.

To achieve this plotting, the system must first select a wider range of results from the time of the hit. This is done by joining the two tables on Row\_ID and ROWID and selecting the Row\_ID’s where the pole is either left or right. A for loop then selects 500 x, y, z entries where the ROWID is less than the selected Row\_ID from the last query. These coordinates are then plotted on three subplots and saved to a PDF file. This is then repeated for the right sensor, meaning that the two different sides are outputted to their own PDF document.

Snippet of code showing the SQL queries needed to plot the data.



Once major problem I found when first starting this section was the format that SQL queries output. This was a major problem for me because as you can see from the code I need to query the output from the first query. SQL outputs all the results from the first query in a tuple usually. This will not work when trying to iterate through for the next for loop. To combat this I found the row\_factory feature in the documentation of SQLite. Row\_factory allows the user to set the output of their query to a list making it much easier to use in the for loop. This was a major hurdle I overcame by using the documentation.

To log the data needed to run all of this the user must run the file “logADXL.py” this is a very simple file that reads the x, y, z data from the accelerometer using the already mentioned python module. It then uses the ‘INSERT’ feature of SQL to add all of the data to the ACC\_data table.

## Network Overview

The network has already been briefly discussed above in section 3.4, but here I will go into more detail.

First of all, everything is running off the pi, as such I aimed to keep everything as lightweight as possible due to the lack of computation power the pi has. The next major part of the network is the flask severs, one for each system (live and test). On boot, the pi automatically runs the Live system flask sever, to reduce the set up team needed when using the system. According to the network diagram, we can see that the information from the sensors flows to the pi, then to the flask sever, this is done via the GET method in html, along with some ajax and jQuery in index.html template that is loaded by the flask sever.

# Results and evaluation

## Evaluation of Live system

## Analysis of results

## Conclusion of evaluation

## Discussion of Results

# Future work

# Conclusions

# Reflection on learning

# Appendix

## Code

## Glossary of Canoe Slalom terms

**Downstream –** The direction the water is flowing

**Upstream** – the opposite direction that the water is flowing

**River left –** The left hand side of the river, if you are looking at it downstream

**River right –** The right hand side of the river, if you are looking at it downstream

**Spray Deck –** the piece of neoprene that covers the cockpit of the kayak to stop the paddler falling out

# References

1. https://peakuk.com/index.php?route=blog/blog&blog\_id=283 [↑](#footnote-ref-1)
2. https://peakuk.com/index.php?route=blog/blog&blog\_id=340 [↑](#footnote-ref-2)
3. https://www.canoeicf.com/sites/default/files/tokyo\_2020\_olympic\_games\_canoe\_slalom\_results\_book\_v1-3\_og2020-\_csl\_b99\_csl.pdf [↑](#footnote-ref-3)
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