DUBLIN CITY UNIVERSITY
School of Computing

# Technical Guide for Hand Mobility Monitoring and Analysis

## Computer Applications Final Year Project

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Abstract: This project uses a Leap Motion controller to track hand movements through a series of games designed to help hand mobility. These games allow for real-time feedback on how users are progressing through an exercise and if they are archiving their goals. Analysis of the hand tracking allows for a record of progression to be recorded for care providers to create reports that can contain a mixture of both tables and graphs along with their own commentary of results.

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# Motivation

The motivation for the project originally came from a blog post about the tracking of hand tremors, from people suffering from diseases such as Parkinson's, and Wilson's using a leap motion controller. After reading the blog post I thought that not only could the leap be used for tracking tremors but also as part of an application for physical therapy. From personal experience witnessing people performing hand exercises, to gain or maintain hand mobility, when dealing with Parkinson to incidents of compressed nerves (pinched nerves), I believed that the leap motion controller could be used to guide and monitor someone doing physical therapy exercises for their hands.

While researching the idea and feasibility of the project I found a few projects relating to the idea of the application of the leap for physical therapy. The most notable of my research was one company, which is making use of the leap motion controller and the Kinect for the Xbox in the create exercise applications. However at the time, of the beginning of the project, very little information about their work was available to the general public with only social media post of conventions, for rehabilitation, they were attending and demoing at. Finding this I looked into other applications that were developed for physical therapy and which ones where been used already. I found that there was also logging applications been used to track what a patient said they were doing with little to no active tracking been done.

Finding this and seeing the amount of data that the leap motion controller could capture about a user's hand I believed that processing and storage of such data could be used by doctors and physiotherapists to better analysis a patient's progress. A system like the one developed could not only help in the analysis of a patient's progress but also the reporting of their progress.

Currently almost all progress reports are created by hand with first getting measurements manually by a physiotherapist and compiling a report based on their findings. Because of this process report may not be created as often as wanted as it may take over an hour to complete measuring before a report worked on. This process may also be difficult to complete as movements must be maintained for a longer period of time for an accurate measurement to be taken as may lead to the discomfort of a patient.

This project aims are removing this problem by capturing a patient completing their exercises in real time and collecting that data into readable results for care providers to better understand their patients progress and needs.

# Research

The research done as part of the project covered 4 main domains. These domains consisted of the feasibility of the leap motion controller as a medical device, exercises and measurements that could be carried out with the leap motion, security and graphics.

## Leap Motion Controller as a Medical Device

The first part of the project consisted of research into the feasibility of the usage of a Leap Motion controller as part of a medical application. From the years 2013 and 2015 there was research carried out on the leap motions reliability and the accuracy of its tracking of hand movements and its frequency of input.

During my research I found research papers that detailed potential issues with the leaps accuracy in tracking and infrequent input of data. The highlighted issues where "issues with continuous finger tracking and certain hand positions" ***[1]*** and in particular when "detection fails when individual elements of the hands are brought together, such as finger to finger" ***[2]***. It was also noted that there was both a limit to the leaps plane of vision and that deriving from its centre lead to in

With these finding it became apparent that the leap motion had issues with tracking the hand complete which would limit its application as a medical device. However these findings were based on the leap motions software and API from 2013 to 2014. As of 2016 there has a updates to the software and API been used by the leap motion. As a result it is unknown if all issues with the leap have been resolved or if they still persist to the same level as they were.

## Exercises and Measurements

To find exercises maintain and repair, and measurements done to examine a patient I sought after both online resources and professional references. Online I found a range of hand exercises that ranged from strengthening muscles in the hand to stretching. While researching strengthening exercises I found that all uses objects or tools as a method of adding resistance to the exercise to make it more difficult to perform. While this process is basic in practice of doing strengthening exercises it introduces a problem with the project and the leaps ability to track the hand.

Most hand strengthening exercises uses a putty like substance to add resistance to movements like as gripping and pinching. While the putty has a colour coded to the level of resistance it gives. While testing out this putty I was able to find that would cover fingers when presses this made tracking hand movements with this putty impossible was points of references would be lost.

Through contact with both a physiotherapist and occupational therapist I was able to obtain exercise sheets given to patients as guidance for hand exercise that can be done at home. These sheets were used as a base for the exercises selected and developed as part of the project. Through this contact I was also able to identify measurements and reporting elements that would be of interest

## Security

The system developed is a medical application, and as a result carries a lot of security concerns for transferring and storage of patient data. As the system developed is a web application with both server side and client side technologies had to be secure in its handing of data and communication.

For client side communication encryption there was a selection of third party encryption libraries however each came up limitations that made them unsuitable for the project. There were two main limitations with using client side encryption was that information about the encryption process would have been public to the client, making the system less secure. The second limitation was decrypting the messages passed to the server to be processed and stored as many of the libraries did not support server side decrypting. As a result of these limitations with client side encryption, server side encryption of http connections was research and chosen.

As well as this research into database and password encryption was also undertaken as part of the project due its medical application and the storage of passwords needed for a login system. The password encryption research lead to the implementation of a combination of a one way hashed password using SHA-512 with a salt randomly assigned to each user. Database encryption was research with data at rest encryption been found as the solution to ensure encryption of data on the database.

## Graphics

For the project graphics where needed for the game elements of the exercises implemented. As the project is an implementation of a web application there was a few choices of graphics options available. These options where SVG, Canvas and WebGL, each of these where researched with limitations and advantages recognised. WebGL was chosen for the graphics of the games as it had the benefit of hardware acceleration and the opportunity to develop elements that where less resource heavy then SVG or Canvas. The choice of WebGL over the other two choices was also based on the limitations of their rendering speed and their ability for been reactive to changing elements. Out of the three WebGL provided a better design and implementation opportunity then SVG and Canvas.

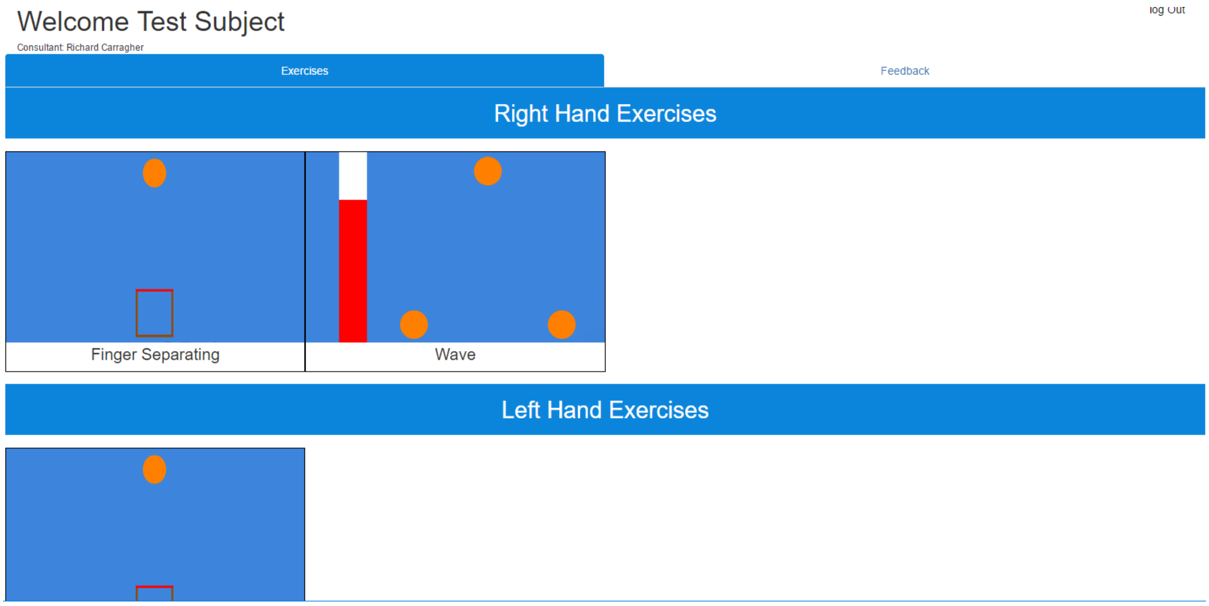
# Design

The design of the system comes in two parts the technical design of the system and the user interface for both end users of the system.

## User Interface Design

The user interface is an important part of the system as it is one of the most used parts of the system and needs to be useable by people suffering from hand mobility issues. As a result of this the user interface needs to be accessible to users in a range of ways. To provide this the system provides a clean layout with large displayed elements to make it easier to select an exercise to complete.

**Patient Portal**

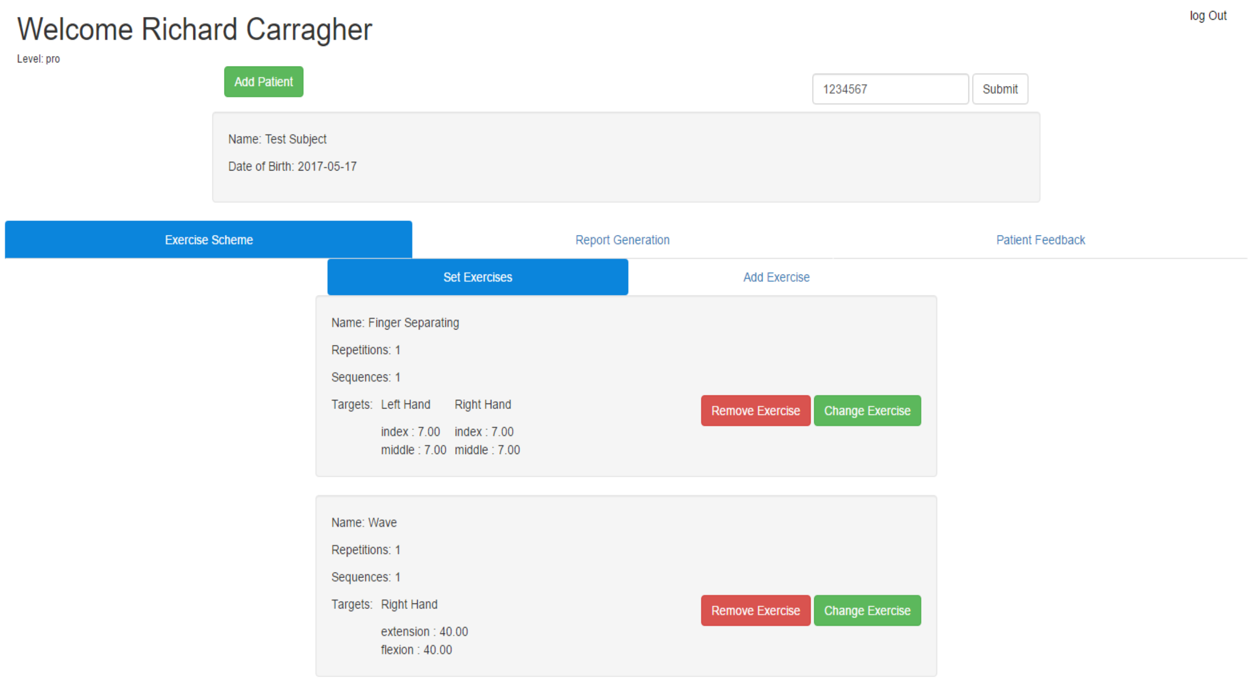



As seen above there is a large amount of blue colouring used within the design along with white. Both of these colours provide a different psychology effects, white gives a sense of space and blue gives calmness and serenity. This again is used within the exercise screens along with the colour orange to provide stimulation and enthusiasm to the exercises. This is important in the providing for exercising as it is a process that is known to be hard to complete due to been a mundane and challenging activity which can lead to frustration.

The games at are implement in this system are designed to be simple and basic to allow for the focus to the user to be on performing the exercise and to allow for any patients that have any issues with sight to be able to process the environment without any distinctions.

While a large percentage of users of the system would be patients of care providers there is still importance in the design of a care provider's user interface, as it needs to be usable by care providers so they may obtain accurate results from data generated from their patients. To support care providers in this an interface with clear markings of functionality is needed.

## Care Provider Portal

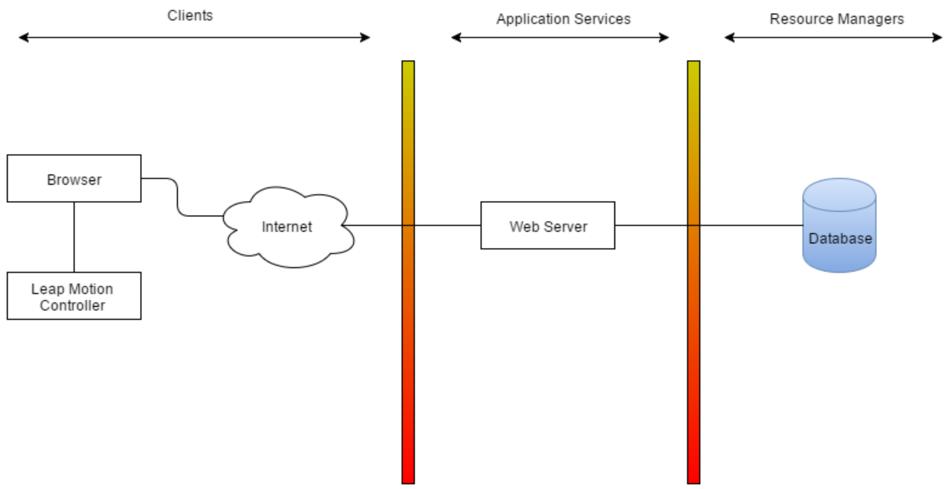



The above image shows a care provider portal screen capture. As before with the patient portal, there is a lot of usage of white to give a feeling of a sense of space. Where functionality may result is the delectation or creation of data, there are clear signs of effects through the use of red and green colouring. Functionality is grouped together to provide a structured layout of the portal with exercise selection, report creation, and patient feedback all separated to allow for faster navigation of the system.

## Technical Design

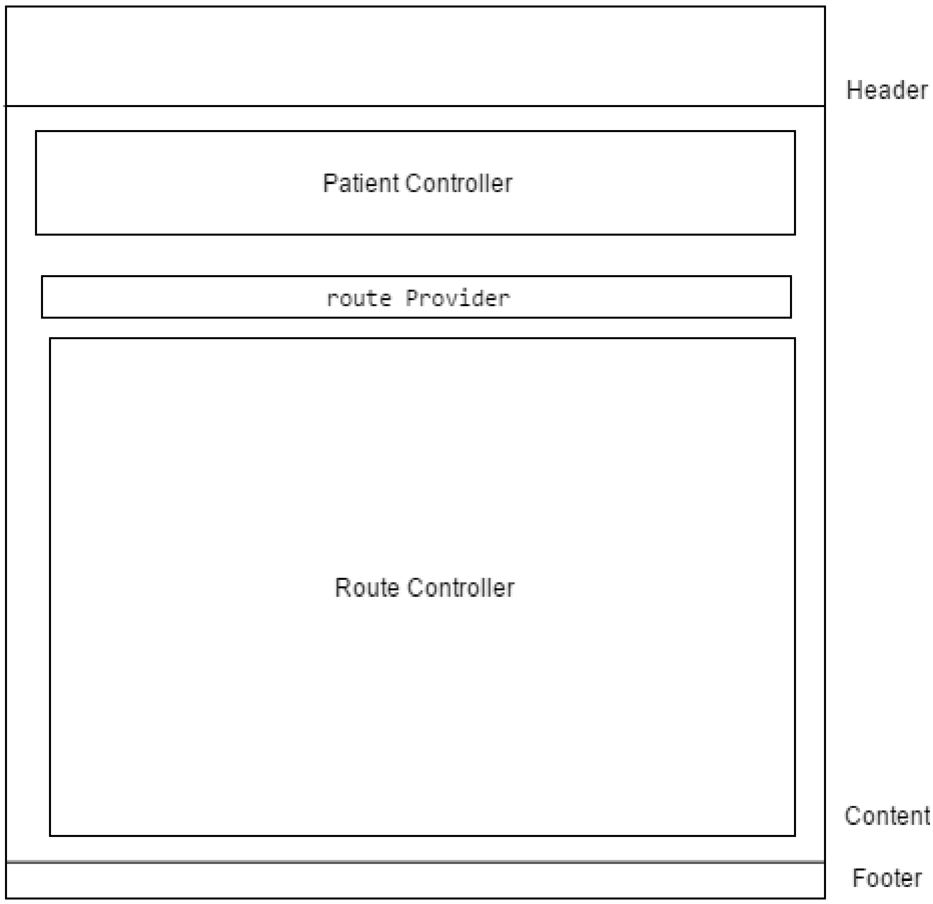
The system created is a web application as such is designed with a client, server and data layer. Each of these layers interacts with each other with clients requesting and creating data for the server to handle and maintain through the use of a data base. Below briefly outlines the basic layout of the architecture of the system.

## Architecture Overview



**Client**

The client is made up of a web browser that may be connected locally to a leap motion controller. The interactions with the client and web server are made through http request from web pages created using HTML and CSS. The client side is generated through the use of AngularJS, Bootstrap, and HTML templates allowing for a module design to both patient and care provider portals. The design is both modular in how components are created and how functionality is assigned to each separate component, allowing for a Model View Controller (MVC) approach to the development of the user interface.




The design above is for the care provider portal, it is the basic view of the portal in respect to the AngularJS controllers. The patient controller at the top is responsible for adding a new patient and accessing patients already in the system a registered to the care provider either directly or indirectly if assigned to teams. The route provider that is part of the AngularJS application for the portal page provides linkage to three main controllers each with their own HTML template for display. These controllers are displayed within the route controller box after been selected by the route provider. This is similar to the design of the patient portal where there is only the route provider and route controller to go between exercises to selecte and feedback.

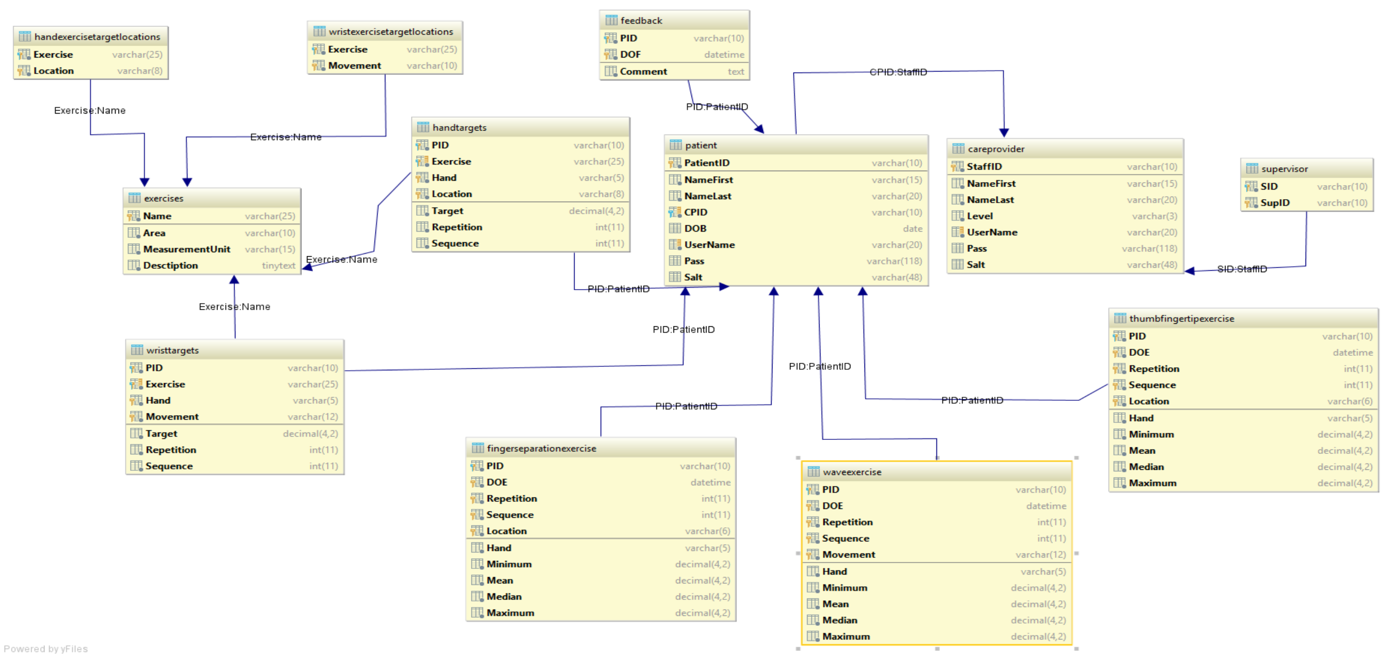
## Server

The server is designed to be act as a gateway to the data source, and as such needs to have security methods in place to only allow access to the correct users. To achieve this, an Apache server using PHP to communicate between the client and database (SQL) is used. On each HTTP POST request there is a check done to ensure that each request comes from a client that is activity logged into the system. As well as this there are sanitized queries created to be performed on the database.

# Database

The database used in this project is SQL based. The design of the database is as follows

**Database Scheme**




The database contains the following tables:

- CareProvider: holds information about a care provider, such as name, id, user name, hashed password and salt.
- Supervisor: holds the relationships between care providers and their supervisor.
- Patient: holds information about a patient, name date of birth, patient id, user name, hashed password and salt.
- Exercises: holds the name of the exercise and the area it is performed with.
- HandExerciseTargetLocations: holds exercise name and the locations that can be targeted.
- WristExerciseTargetLocations: holds exercise name and the movements that can be targeted.
- HandTargets: holds the name, location, hand and repetitions and sequences to be done for a hand exercise
- WristTargets: holds the name, location, hand and repetitions and sequences to be done for a wrist exercise.
- ThumbFingerTipExercise: holds the records for Tip To Tip exercise.

- FingerSeparationExercise: holds the records for Finger Separation exercise.
- WaveExercise: holds the records for Wave exercise.
- Feedback: holds feedback messages from patients to care providers.

# Implementation

Any file with in a lib folder in the source code is a third party library used as part of the project. It is not my own work.

## Exercises

To implement the exercises in the project I used WebGL as a result of this there were seven main scripts that had to be used within each of the exercises. Four of these scripts are common to all exercises as they prepare global variables for the generation of graphics. The four main scripts are main.js, program.js, shaders.js, and shapes.js.

Main.js is responsible for setting up the global variable main.gl, which is the WebGL program used to display object on to the canvas on the exercise pages. The script gains the WebGL context of the canvas and compiles both a vertex and fragment shader code onto the WebGL object gl. This compiling and linkage of shader code is done through the use of the projramUtil.js and shader.js scripts. The projramUtil script is responsible for the creation of the gl objects used to render out shapes. It functions by taking shader code stored in shader.js and compiling it and applying it to a gl program that is created from the gl variable. There are three programs created in the main.js script these are glPolygonProgram which is used by basic shapes such as rectangles and squares, as well as glFilledCircleProgram and glCircleProgram which are both used to create two different types of circles circles.

Shapes.js is a script file containing all shapes needed for the exercises. It contains basic shapes such as squares, rectangles and circles, as well as more advanced shapes such as the bucket in the finger separating exercise, that has both set elements and ones that change to users input. The script file contains a module pattern for the creation of the shape objects to ensure encapsulation of information and for structured modular growth of the file without any risk of naming collisions.

Each exercise has to implement the following script files exercise.js, game.js and dataProcessing.js. The exercise.js script contains the logic of the exercise in terms of the measuring of targets and the processing of the game, in terms of when to pause and resume when a hand is in view of the leap motion controller. As each exercise is focused on different targets and measurements each exercise as a result has to implement its own exercise script.

The game.js script contains the game logic of the exercise, that is when the exercise script inputs data to the game script, the game script alters the display of the canvas to reflect the passing of time with the motion of object and elements that are controlled by the user and their hands. The dataProcessing.js script is unlike the other scripts as it is used as a web worker to process the collection of data, each script runs through the collection of data for each sequence and each repetition and calculates maximum, median, minimum and a rolling average of the data collected, as to make the results more readable by care providers.

## Login Sessions

To create a portal system for patients and care providers as well as to allow for security login sessions had to be implemented as part of the system. To does this both client and server side sessions where looked into, and server side sessions were chosen due to increase of security of hiding information on a server then client machines which can be more actable to attacks.

When a user logs into the system they must enter a username and password, once entered both are sanitized to pervert SQL injections. After the username is checked to see if it is on the system and then if the password hashed with a salt is the same as the stored hash password. Once this process is completed a server side session is created, for the client, and information about the user is stored such as their staff id or patient id which is used to access resources that they can only access. The client only stores a session cookie for a session id, that is passed to the apache sever on every http request from the client. This is used to renter a session with the server to gain access to their information.

## Report Generation

The report generation feature of the project allows for care providers to access current exercises applied to a selected patient and applied there data to both line charts and tables of results. To do this a mixture of generated html and third party libraries were used. For the generation of graph report elements a third party library called HighCharts.js is used, and for the generated tables a process of creating a table and appending it to the webpage is used.

Both the graphs and tables both have a similar process of getting requested data from the database through the server by making use of an http post call through AngularJS's $http function. The process is done in JavaScript and starts with creating a new report element div and appending either a graph element or an html table to another div created to store the data and appending it the parent div. This process allows for the generation of a report through the continuous addition and expansion of the report stage available to care providers.

# Problems Solved

## PDF Creation

There were two main problems in the creation of PDFs exports of care provider reports of patient's data. These problems were that that HighCharts did not support valid output methods that jsPDF could use as input, the second was that css from tables was not supported by jsPDF.

To solve the problem with the incompatibility of HighCharts and jsPDF the creation of a new function in HighCharts was created as a prototype. This enabled the access to the data within the HighChart object itself. Using a third party library called canvg it was possible to convert the graph to a SVG and render it to a canvas and then returned an image. As a result of this process the grahp can be changed to an image and then added to the PDF as a simple image.

The code below shows this process.

```
Highcharts.Chart.prototype.createCanvas = function(width, height) {
    let svg = this.getSVG();
    let canvas = document.createElement('canvas');

    canvas.setAttribute('width', width);
    canvas.setAttribute('height', height);

    if (canvas.getContext && canvas.getContext('2d')) {
        canvg(canvas, svg);
        return canvas.toDataURL("image/jpeg");
    }
    else {
        alert("Your browser doesn't support this feature, please use a
modern browser");
        return false;
    }

};
```

In the case of the tables another third party plugin to jsPDF had to be used to create tables in the PDF. To do this the table had to be converted into header columns and rows and then into columns and rows for the rest of the data contained in the table in the report.

## Processing of Exercise Results

JavaScript been a asynchronous language introduced a problem with calculating results of exercises after a sequence or repetition was completed. There were two options available to resolve this problem one was to store all data gathered throughout the exercise and process it all at the end or to process it during the exercise while the data is been created.

The first process was not suitable as it had to main disadvantages the first was that storing all the data generated would take up space of varying size depending on the requirements set by a care provider, this meant that the space taken up could be large and could affect the performance of the exercise and the users interaction with it. The second problem was that the wait time for the processing to complete would be longer than doing the processing in stages throughout the exercise, this could mean that after an exercise was completed the user would have to wait a longer period of time and so could exit out of the page and cause for the data to be lost before been sent to the server for storage.

To resolve this problem the only choice was to process the data as the exercise was been performed without taking the user out of the exercise or impacting there interaction with it. To do this web workers were used as they provide a way to execute large sums of calculations without taking up JavaScript's execution queue or main run time.

## Large Data Passing to Processor

WebGL provides a way of creating graphics through the use of fragment and vertex shaders, each object created using WebGL typically consists of many triangles, such as a square which is made up of two triangles. And a circle made up of many triangles all stemming from its centre and around to form a circle. Doing this process would involve doing the following process.

```
vertices = [centre[0], centre[1]];
for(var i = 2; i < 32; i++){
   vertices[i]= centre[0] + cos(θ) * radius;
   vertices[++i] = centre[1] + sin(θ) * radius;
}
```

This results in 272 bytes per circle been sent to a CPU per cycle of a rendering. This process can however be cut down to only creating one triangle large enough to create a circle within it. This can be done by first outlining the size of the circle to be created and creating a triangle around it. To complete this process the fragment shader below would have to be used instead of the fragment shader used to create squares or the original circle. The following fragment shader would have to be used instead.

```
void main(){
  vec4 backgroundColor = vec4(0.24, 0.522, 0.863, 1);
  float x = gl_FragCoord.x;
  float y = gl_FragCoord.y;
  float dx = center[0] - x;
  float dy = center[1] - y;
  float distance = sqrt(dx*dx + dy*dy);
  float diff = distance - radius +0.5 ;
  if(diff < 0.0 ||  diff >= 0.0 && diff <= 1.0)
    gl_FragColor = vec4(1.0, 0.5, 0.0, 1.0);
  else
    gl_FragColor = backgroundColor;
}
```

This fragment shader works by getting the size of the WebGL context and using it as a base to where the circle should be placed based the x and y coordinates been passed in. If the distance between the coordinates of the canvas was with in the distance of the circle it was rendered with the colour of the circle and if not it would be render the background colour

# Results

## End User Testing

A large part of this project has to deal with the usability of the system by both care providers and patients suffering from hand mobility issues. As a result of this end user testing was an important factor of finding out the usability of the system and where faults in the designed layer in order for them to be fixed.

To gather this information end user testing was performed near the end of the project completion to find the usability. There was both good and bad feedback from the end user testing from both potential end users of the system.

Care providers while using the system found that over all the controls were simple to figure out and use without many instructions needed in order to gain access to patient data and to change the exercises as needed. However there was confusion over the measurements units used within the exercises, and that there should be a unit of measurement indicated with in the exercise to make it clearer as to what is been used, i.e. cm, mm etc.

The export to PDF functionality was seen to be a good overall feature with the main feedback been the formatting of the patient data at the header been smaller or removed to be instead a place to include a hospital identification sticker used already in charting systems. As well as this the inclusion of space for the hospital header if needed for out going report.

The feedback form potential patient's users of the system were also overall positive. Many found the system to be usable with little help need to navigate the exercises the first time been used. This was manly do to the many of them never seen or using the leap motion controller before their involvement with the testing of the system.

The main feedback that was given was the leaps inconstant readings in the Tip to Tip exercise where they would be at the tip of on finger and another node would be highlighted instead, and moving your hand to a different position would resolve this issue. However maintaining and finding this position took time.

## Future work

For future work on this project the feedback from end user testing would have to be considered with any improvements been made done so to improve the quality of the system in terms of front end design and possible corrective measures that could be taken to improve the leaps readings and the systems response to them.

There would also be the opportunity to develop a learning algorithm for the system based on information once enough data could be generated to create a method of indication to a patients process without the need for manually review first. For example a notification system if a patient's measurements are seen continues decline.

# Appendix

1. Ondrej K, František J, Approach to Hand Tracking and Gesture Recognition Based on Depth-Sensing Cameras and EMG Monitoring Acta Informatica Pragensia 3(1), 2014, 104–112, DOI: 10.18267/j.aip.38
2. Potter E L, Araullo J, Carter L, The Leap Motion controller: A view on sign language, ISBN: 978-1-4503-2525-7