Implementation and Evaluation of Smart Training Gear

Measuring and Visualizing Muscle Data in Real Time

Samuel Svensäter
Abstract

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During weight-lifting exercises muscles are contracted and relaxed. Muscles to the left and to the right of the center of the human body are each other’s counterparts—we are symmetric in relation to the center of the body and this symmetry can be maintained if muscles are activated equally during exercises. With the help of electromyography, a technique to measure the electrical activity generated by muscles, a micro controller, bluetooth technology and a smart phone muscle activity can be measured, compared and visualized in real time. This thesis describes the development of a smart phone application to help weight lifters perform well-balanced exercises. The work is based on studies of weight lifters and experiments with electromyography sensors. Multiple sensors can be used to compare muscles' activity and the result can be a help to perform a well-balanced muscle activation. The conclusions are that the accuracy of the measurements varies mainly with two factors; muscle depth and the resistance between the sensors and the human skin—superficial muscles and low resistance provide more useful measurements than deep muscles or high resistance between the sensors and the skin. Real time muscle activity feedback can help to perform a balanced movement during an exercise, but muscle depth and the resistance between the sensors and the skin are crucial for the outcome. The visualization is represented in two ways; in real time to give direct feedback and as a ten second mean to show the activity over time.
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1 Introduction

According to a report published in 2014, Swedes’ expenses for fitness and health are approximately 50 billion Swedish kronor per year and over 60% of the Swedes exercise regularly [1]. Activity bands that track a user’s daily activity were the Christmas gift of the year in 2014 in Sweden [2] and according to a study [3] performed in March 2014 in the U.S, the three primary reasons for internet users to use mobile health and fitness apps were goal tracking, closely followed by awareness of health issues and motivation. Fitness apps can motivate and inspire people to successfully achieve their goals. This thesis will examine how real time muscle activity feedback can be used to understand how individual muscles behave during an exercise.

1.1 Background

There are products available to measure biometric data, the Nike+ Fuel activity band for example is an advanced pedometer which can measure the number of steps taken during a day or track the intensity of a workout using a 3-axis accelerometer [4]. The activity can be visualized using a smart phone or a computer and the given feedback can be a way to motivate people to exercise.

When muscles are activated they produce electrical signals, these signals can be sensed and measured using electromyography (EMG). EMG is a diagnostic technique that traditionally has been used in medicine to evaluate and record muscle activity to for example discover neuromuscular diseases [5]. However the EMG technique can be interesting for companies outside the medical sphere, to name a few companies that measure and makes use of biometric data:

Athos [6] is a company based in California, USA, who are working on a product to gather and visualize biometric data using sensors in clothing, which they call smart apparel. The idea is to measure muscle performance, heart and breathing rates in real time and send this data to a smart phone for visualization. To date they have no product available to ship.

Myontec [7] based in Finland offers shorts that measures muscle activity, heart rate and cadence among other performance data in real time. Their shorts, Mbody, uses EMG to measure electrical signals produced by the quadriceps and hamstrings.

Thalmic Labs [8], based in Kitchener, Canada, is a company who has developed a gesture control armband called Myo that can sense electrical activity in the forearm in order to identify gestures. The activity can be transmitted to a computer, a smart phone, or any other Bluetooth compatible product.
1. Introduction

These products all use EMG to sense muscle activity and the idea is, for Athos and Myontec, to show how muscles respond during exercise. The Myo armband uses the same technology but instead of showing muscle activity it can control a keynote presentation for example using the muscles of the lower arm.

1.2 Project Stark

This bachelor thesis is a description of the development of a prototype, including hardware and software, which can visualize muscle activity in real time using a smartphone. Stark is the working title for the prototype and will be used throughout the thesis to refer to it.

The thesis is made for the Swedish software company Omninova AB\(^1\). Omninova works with projects in the digitization of health and wants to look at the possibilities to gather biometric data from individuals to understand what this data can be used for as well as what opportunities and obstacles the technology offers.

Many people who exercise do so to improve their body strength, to lift heavy objects more safely, or just because they feel good when endorphins are released. Stark is developed for, but not limited to, people who want to improve their weight lifting results, or to show muscle activation for rehabilitation purposes. The idea is to introduce ways to understand how muscles activate when a particular movement is performed. The prototype will be able to visualize the activity of two muscles.

At the beginning of the project Omninova stated their idea with Stark: Stark is a product that can measure and visualize muscle activity in real time using a smartphone. The communication between sensors and a smartphone should preferably be wireless to make the product mobile. The app should feature activity visualization in real time as well as over time to show how even two muscles are activated to give the users appropriate feedback for an exercise. Further it should be possible to select muscle group to measure, these measurements should be saved as statistics. Preferably users should be able to interact with the app and start a measurement without external help or documentation.

Questions Investigated

- How sensitive is the positioning of the sensor electrodes to get useful measurement data?
- Can Stark indicate if a weight-lifting exercise is performed in a balanced way?
- How should muscle data be visualized?

This thesis will describe how two EMG sensors together with a smartphone app can be used to measure and visualize muscle activity in real time.

\(^{1}\)http://www.omninova.se, Omninova AB. [Accessed 20150322]
Since this is a thesis that involves hardware and software development the chapter division might differ from other theses that are more related to literature studies. The first chapter covers hardware related theory, how the work has been carried out and the results obtained during hardware studies. In the second chapter software development theory, user interaction related topics and the experiments performed in relation to software are presented. To summarize the results from the two chapters a common analysis and discussion will be presented at the end of the thesis. Figures used in the thesis are created by the author unless otherwise stated.
2 Hardware

To measure muscle signals EMG sensors and a micro controller will be used. Data will be sent using wireless Bluetooth technology to a smart phone, an Apple iPhone, where the data will be visualized. Apple iPhone was chosen since Ommi nova requested the prototype to run on Apple iOS.

2.1 Arduino

The Arduino is a small open source computer board equipped with a micro controller. A micro controller is an integrated circuit containing all main parts of a typical computer [9]. For this project the Arduino Uno R3 board will be used which features an ATMega328 micro controller running at 16 Mhz, equipped with 32KB flash memory, 2KB SRAM, an integrated analog-to-digital converter (ADC) and analog/digital pins for input and output. The Arduino is intended for anyone making interactive projects [10] and incorporates techniques to sense and respond to the real analog world using sensors of various kinds. See figure A.1 for the Arduino Uno R3 board layout.

Programs for the Arduino are written in the Arduino language which is similar to C. Added syntax include functions to read and write digital and analog input/output signals. External libraries can be added to any program. An Arduino program has to contain a setup function and a loop function. The setup function is executed when the board is powered or when the on board reset button is pressed. The setup function is only executed once. When the setup function is finished the loop function is executed over and over again as long as the board is powered.

2.1.1 Similar hardware

There are other hardware available that could be of interest for a project like this. BITalino [11] is a hardware and software toolkit that has been specifically designed to deal with the requirements of body signals. Various sensors are included in a kit available for purchase. The main reason why the BITalino was not chosen was that the purchase price was higher than other alternatives.

The Intel Edison [12] is a small computer with Bluetooth and WiFi chips on board. Initially the Edison was chosen to serve as the signal handler and main device for Stark because of its small size and for the reason that it had both WiFi and Bluetooth on board. It turned out, however, that the Edison lacked ADC which is needed to read the output from the sensors correctly since they only output analog
data. Even though there are external ADC boards available for the Edison the Arduino was chosen as main controller since it featured ADC and for the reason that the sensor was known to be compatible with the Arduino and that it had been tested by the manufacturer [13].

An external Bluetooth adapter will be used to transfer data wireless to a smartphone from the Arduino.

2.2 Bluetooth Low Energy

Bluetooth is a cable replacement technology operating at the unlicensed 2.4 GHz band and can transfer data over a wireless link.

Due to restrictions set by Apple on which Bluetooth technology their mobile devices support classic Bluetooth (version 2.1) cannot be used without major configurations and certificates. Bluetooth Low Energy (BLE) is optimized to consume little power and to send data at low rates. BLE is supported by the Apple’s operating system iOS, as well as by the Android operating system, version 4.3 and newer. BLE will be used for this project and is sometimes referred to as Bluetooth Smart [14].

The Adafruit nRF8001 Bluetooth LE adapter (see figure A.2) will be used since the Arduino does not have Bluetooth. The adapter can simulate a serial connection where data is being sent between two devices over a wireless link.

To set up a connection between BLE compatible devices they need to know what other devices there are available nearby, this is called the inquiry process. In the case of the BLE adapter used for Stark the phone must initiate the connection. The adapter listens for incoming inquiry packets sent by the phone and replies back. A reply contains information needed by the phone to connect to it. When a connection has been established information can be exchanged between the devices.

Technical Details

- The nRF8001 supports data transfer up to 10 meters to a BLE-compatible device.

- The nRF8001 sends out packets of data, 20 bytes at a time.

- BLE uses frequency hopping, which means that data packets are sent on different channels, to minimize interference from other technologies operating at 2.4 Ghz.

- BLE features robustness against interference with 24 bit Cyclic Redundancy Check (CRC) on all packets.

- BLE has AES-128 encryption and authentication of data packets.
2.3 Electromyography

Electromyography (EMG) is a technique to measure electrical activity generated by working muscles using electrodes. The amplitude of the EMG signal increases as the intensity of the muscular contraction increases, although there is not a linear relationship between the amplitude and muscle force. It is only in isometric contractions (see figure 2.1), that the electrical activity and the muscle force are closely associated, almost linear. Isometric means that the muscle contracts but does not change length.

![Figure 2.1: During isometric contractions muscle length does not change because the load exceeds the tension the muscle can generate [15].](image)

An EMG signal is recorded using electrodes, either indwelling or on the surface. An indwelling electrode is a needle or a fine wire placed directly in the muscle, these are mainly used for deep or small muscles.

Surface electrodes placed on the skin are mainly used for superficial muscles and will be used for Stark. These electrodes can be divided into two groups: monopolar and bipolar, see figure 2.2.

In a monopolar configuration one electrode is placed on the muscle and the second electrode on a neutral site, such as bony prominence. Monopolar electrodes are used mainly in static contractions but are poor in non isometric (non static) movements.

Bipolar uses two electrodes placed on the muscle about 2 cm apart, a third electrode is placed at electrically neutral site. A differential amplifier records the difference between the electrodes and removes any signal that is common to the two electrodes. The bipolar electrodes are most often used in biomechanics [5]. The neutral site is needed to provide a common reference to the differential input of the preamplifier in the electrode and should be placed as far away as possible from the other two electrodes [16].

To get good recordings the correct placement of the electrodes is important. The electrodes must be placed so a muscle’s activity can be recorded, they should not be placed over a muscles tendinous areas or at the point where the nerves enters the muscle. The first electrode should be placed in the middle of the muscle and the second electrode at a few centimeters distance from the first one. The signal can be greatly altered when electrodes are placed perpendicular rather than parallel to the muscle fibers [5].
The resistance between the electrode and the skin should be very low to detect the electrical signals from the muscle. To achieve the best measurements the skin should be shaved and cleaned thoroughly [5].

Apart from physiological factors such as muscle fibre diameter, the distance from the skin surface to the muscle fibre, muscle blood flow etcetera, the electrode-skin resistance, signal conditioning and electrode spacing have influence on how the EMG signals are interpreted.

When it comes to concentric and eccentric contractions (see figure 2.3), the EMGs relationship with muscle force is not as when isometric contractions are performed. EMG might not indicate that the muscle length has been changed.

Studies have been performed with EMG to examine the activity of shoulder, back and leg muscles during load carrying by varying load magnitude and the duration of load carrying. EMG has also been used in the study of low-back mechanics in exercise and weight lifting, as well as in ergonomics to study the low-back musculature activity. Focus has been on proper lifting techniques and rehabilitation of industry workers with low-back problems [5].

Muscle activation is a result of signals being sent from the brain to the muscle. All contractions and relaxations of a muscle are controlled by signals from the brain [17], when a signal enters the muscle it either contracts or relaxes, this activity can be measured using EMG.

### 2.4 Muscle Sensor v3

The muscle sensor (see figure A.3) uses surface EMG technology with bipolar electrodes to measure electrical signals from a muscle. The hardware outputs an amplified, rectified and smoothed signal to a micro controller such as the Arduino. The three electrodes (see figure A.4) are attached with adhesive conductive gel to the center of the muscle (red), at a few centimeters distance (blue) and to a bony prominence (black) for reference. See figure 2.4 for correct electrode placement.

The sensor outputs analog data, 0 to max volts, depending on how much the chosen muscle is activated. The maximum value the sensor can output is the voltage of its connected power source [13]. These values are read by the Arduinos analog input. Since two sensors are used for the prototype one of the sensors can be placed
on the left side muscle and the other on the right side muscle. Sensors are used to capture real-world state, that is sense the world around us [18] and can be thought of as a device outputting data.

There are differences between analog and digital signals. The activity in a muscle is referred to as analog since it has an infinite number of possible states, the activity is continuous. The sensor used can capture this activity and output the corresponding value. Digital on the other hand constrains the measured (analog)
values within a finite set. A signal is measured at certain points in time which results in discrete values within that set. If the range of a digital signal is two the output can be one or zero, on or off for example, this would be enough to tell if a device is powered or not [18].

2.5 Wearable Technology

Wearable technology, wearables, are worn close to the body, on the body, or in the body. Among other gear wearables can be a jacket with a phone built in, a pulse sensing t-shirt sending data to a phone or computer, or a smart watch which can sense pulse and track body movements like the Apple Watch [20]. Internet of Things (IoT) devices are always connected to the Internet and wearables counts as IoT although they might not be connected directly to the Internet but via a smart phone. Stark is an IoT device in the meaning of wearables.

2.6 Results

The hardware unit consists of an Arduino, two muscle sensors, a Bluetooth adapter and two 9V batteries to supply the unit with power. See figure A.5 for the prototype. Bluetooth will be used to communicate between the hardware unit and the smart phone to make Stark as mobile as possible.

The muscle sensors measure muscle activity and outputs to the Arduino’s analog input. Even though the sensors outputs analog data the Arduino limits this data to an integer value in the range 0 to 1023 [21].

The Bluetooth adapter simulates a serial connection called Universal Asynchronous Receiver/Transmitter, UART. This is similar to a phone call between two phones. When a connection is established one device sends data and the other device listens and vice versa—data is sent back and forth between the devices. Even though BLE has the possibility to handle more complex structured data, UART will be used to communicate between the Arduino and the smart phone since this is an easy way to setup and maintain the connection. To handle UART on the Arduino an external C library [22] created by Adafruit for the nRF8001 adapter will be used. This library provides functions to setup a Bluetooth connection and to send data via Bluetooth.

When the Arduino is started its setup function is executed. This function registers the pins the muscle sensors are connected to as input pins as well as initiates the Bluetooth adapter as active. When this is done the loop function listens to the registered input pins for data and sends this data via the Bluetooth adapter if a BLE device is connected. The loop function will iterate over and over until the Arduino is turned off, or until the reset button is pressed which reboots the device and executes the setup function again. Each measured muscle has two sensors attached, left and right. At each iteration on the Arduino the data from the sensors are processed, parcelled in a string and sent to the smart phone. Data will be sent in a string formatted as MXXLLYyyyyzzzz, where XX is a one to two digit number indicating the muscle, YYYY is the left muscle value and zzzz is the right muscle value. Both YYYY
and ZZZZ has a maximum value of 1023. Take the string M1L820R890 as an example, M1 means that biceps is the muscle measured, L820 that the left sensor value is 820 and R890 that the right sensor value is 890. This results in a at most 13 byte large string, well under the 20 bytes limitation. The string is parsed in the smartphone app using regular expression.

Attempts were made to send two muscle measurements in one transfer by reducing the string to send. By changing how muscles are represented from numbers to alphabetical chars (X) and by narrowing down the measured values to a range between 0 and 999 (YYY and ZZZ) instead of 1023 the amount of data to send for each muscle can be lowered to 9 bytes. The idea was to use the string XLYYYRZZZ twice to send data from two muscles in one transmission. Major performance degradations were encountered at the receiving side when this was tried. The continuous stream of data was not as smooth as before, the measured values arrived intermittently.

2.6.1 Electrode Placement

The muscle sensor uses three electrode pads which are to be placed directly on the skin on any superficial muscle group. When using adhesive electrodes the electrodes are placed on the desired muscle to be able to measure that muscle’s activity. Two electrodes are attached to the muscle and one is attached to bony prominence.

The electrodes are attached with a built-in adhesive surface that loses much of its conductive properties after removal. This makes them more or less non-reusable after a workout. A commercial product is preferably easy to handle and wear. If electrodes can be sown into fitness clothes users can wear the clothes without thinking that they are wearing a measurement device.

Experiments how to place electrodes have been performed on both men and women to test how specific the placement have to be and how tight the electrodes must be to the skin. The experiments showed that the electrodes need to have good contact with the skin for the measurements to be accurate. If the resistance between the skin and the electrode is too high the sensors can output arbitrary data, there can be high values outputted even if the muscles are relaxed. If the left and right electrodes have different skin resistance there will be different results between the two measured values which will produce unreliable data.

Experiments have been performed both with and without electrodes. When no electrodes were used the cables contact areas (see figure A.4) were taped directly to the skin. If both left and right sensors are attached tight against the skin in the same way a useful measurement can be expected according to the experiments. Loose electrodes will result in incorrect measurement data.

The reference electrode is advantageously attached at the hip, to a bony prominence since this part will not rotate during exercise. Experiments were made where the reference electrode was placed on bony prominence on the arm. The measurements were the same, but since the arm flexes this electrode could be in the way to operate some exercises correctly. Several reference electrodes can be combined into one to produce a common reference point for all the sensors used.

The experiments indicate that the muscle sensing electrodes have to be tight against the skin. To make conductive fabric successful the electrodes have to stay
2. Hardware

in place. One possible solution is to use compression wear that fits tight against the body and that follows the body movement to make sure the electrode fabric stays on top of the muscle to measure.

2.6.2 Weight Lifting Related Issues

Weight-lifting related observations at a fitness center showed that incorrect technique can be a problem. Incorrect technique in combination with too much weight can put a lot of stress on wrong parts of the body, which can lead to injury. Take biceps curls for example (figure 2.5). If a person leans backwards when doing biceps curls with too heavy barbell or dumbbell weight for example injuries on the lower back can occur since it gets to much pressure. If the exercise cannot be performed without keeping the back still and straight it might mean that the weights are too heavy [23].

If Stark can measure the difference in muscle activity in the lower back while biceps are exercised then notifications could be used to indicate that incorrect technique is being used for the particular exercise.

![Figure 2.5: Leaning backwards when doing biceps curls with too much weight puts a lot of pressure on the lower back, which can lead to injury [23] [24].](image)

To examine how Stark can be a support in weight lifting, studies have been performed at a gym facility. To rule out false measurements the studies have been performed on two persons used to weight lifting. These people are referred to as the practitioners. The electrodes used have been connected to both left and right muscles in the same way during all studies. The electrodes have been attached to the biceps muscles as seen in figure 2.4.

2.6.3 Exercise Studies

A muscle can be activated in many different ways, to test the diversity in muscle activation different exercises have been performed on the same muscle. The biceps muscles were chosen since they are easy to activate and visually study, they are also easy to contract and relax both with and without muscle tension which is interesting since EMG was said to be more useful for isometric (static) contractions. A variation of biceps curl exercises have been performed, see figure 2.6.
Figure 2.6: Exercises performed; preacher curls machine with fixed rod (A), biceps curls with barbell (B), biceps curls with dumbbells (C), biceps curls with rod in cable machine (D) and hammercurls with rope in cable machine (E) [24].

When the weight-lifting exercise studies have been performed muscle data has been used in two ways; the measured data has been used in real time to indicate current activity to see how fast and how much the muscles activate as well as their activity spread out over a ten second interval to see how even they are activated over time.

When biceps curls were performed using barbell and dumbbell exercises (B and C) the studies showed a more even muscle activity than when the preacher curls exercise (A) were performed. Both the real time activity and the activity over time showed a more even activation of the muscles.

The preacher curls machine has an interlocked (meaning that the right and left arm both lift the same bar) fixed course where the upper arm movement is isolated more than in the other tested exercises. The interlocked fixed course of the machine allowed the practitioners to activate one of the muscles more than the other. The studies showed that one of the measured muscles often took more weight than the other muscle, the mean value of the activity was to the advantage of one of the muscles.

The two exercises performed in the cable machine (D and E) gave similar results to the barbell and dumbbell exercises, but the muscle activation was initially faster in the cable machine but allowed a more uneven overall muscle activation than with barbell and dumbbells.

To simulate incorrect lifting technique skew weight distribution studies were
performed in the cable machine. The practitioners had the hands placed at different distances from the center of the rod which creates unbalanced lifting, for example the right hand closer to the center than the left hand. The skewness was clearly indicated. Both the real time indicator as well as the ten second interval indicator showed that one muscle was activated more than the other.

The exercise with most even distribution in muscle activity was biceps curls with barbell where there is a free path for the arms and where the hands are fixed to the barbell.

Additional studies were performed with electrodes attached to one of the biceps muscles as well as the lower back to see if the back muscles were activated unrealistically much which could indicate wrong technique during biceps training. The results showed that the biceps electrodes indicated activity, but the electrodes attached to the back gave none or very little indication of activation.
Software development is an iterative process of user observations, design proposals and developed solutions, followed by an evaluation about how the developed system works in the intended environment. The knowledge acquired during the evaluation can help refine the design and solution, or help create new designs and solutions.

3.1 User Experience

The main goal of interaction design is to develop usable interactive products, meaning they should be easy to learn, effective to use and provide a pleasant user experience. Further it is important and interesting to keep in mind what activities people are doing when they use the product and what environment surrounds them. This might affect how the user interface is designed.

Even though the product is developed with a certain group of people in mind they are a wide spread group, therefore it is not possible to know in advance exactly who they are and why they are using the product. Löwgren calls this mass-market projects. This means that usability goals are not set by a specific customer, instead the goals for the product are based on the analysis of competing products or by looking at how people perform their daily work today - in this case how they perform an exercise [25]. Löwgren writes that the "best" definition of usability is that a system is usable if it is in fact used in practice. The problem is that this cannot be measured until the system is ready to be interacted with.

Löwgren introduces usability as the result of REAL; Relevance, Efficiency, Attitude and Learnability [25]:

- **Relevance** is how well the system serves the users’ needs.
- **Efficiency** states how efficient the users can carry out their tasks in the system.
- **Attitude** is the users’ subjective feelings towards the system.
- **Learnability** of a system is how easy it is to learn for new users and how well the users remember the skills over time.

3.2 A Process of Interaction Design

1. Identify needs and establish requirements
For a design to help people, the target users have to be known, as well as how an interactive product could support them.

2. **Develop alternative designs**

Make a design that meets the requirements agreed upon in the step above. This activity can be broken up into two sub-activities: conceptual design and physical design. What should the product do, behave and look like is conceptual design and physical design puts emphasis on colors, sounds, what images to use, menu design and icon design. Alternatives are considered at every point.

3. **Evaluate the design**

This process determines the usability and acceptability of the design in terms of a variety of criteria including the number of errors users make using it, how appealing it is, how well it matches the requirements etcetera. A high level of user involvement is required throughout the development, this enhances the chances that an acceptable product is delivered.

4. **Refine the design**

With the knowledge from the evaluation process in the step above the design is elaborated to create a more acceptable design.

The common denominator of these principles is to evaluate what has been created and to re-evaluate after each major modification to make sure the items above are iterated through. The main focus has to be to make the product usable. One solution often used to ensure the usability of a product is to involve the intended users early in the process and to keep them in the development until the end to verify that the product still is usable even after major changes. At the beginning of a project the users’ expectations and goals have to be identified, documented and agreed upon for the project to have better chances to get the expected results [26]. The different iterations and all design decisions will not be covered in detail, only choices interesting for the reader will be covered.

User observations can give valuable insight how to think when creating software to the users likings and needs. Early design ideas should be quick sketches, 5-15 minutes, which can be used to explore alternative designs and to learn about desirability and feasibility in a cheap and easy way. Sketch prototyping is an exploratory tool, where time should not be spent on refining details [27].

### 3.3 Hybrid Mobile Applications and Frameworks

Hybrid mobile apps, web apps, are developed with the web technologies HyperText Markup Language (HTML), Cascading Style Sheets (CSS) and JavaScript. Web apps can with the help of technologies like Cordova PhoneGap be deployed to multiple platforms. PhoneGap allows web apps to run locally on most smart phone operating systems, including Apple iOS, Android, Blackberry OS and Windows Phone 8 [28], with little or no code modification.
For computation intensive apps native languages, Objective-C or Swift for iOS development for example, will give better performance since these languages often are optimized for the device chosen. In other cases PhoneGap can be a great way to develop an app without the need to learn the programming language specific for the device. Development time can be saved in projects where the software are supposed to run on multiple platforms since PhoneGap can deploy the same code to different platforms.

To give the application the look and feel of iOS, Framework 7 by iDangero.us [29] can be used which provides an HTML framework to build iOS apps using the web technologies mentioned. Ionic [30] is a similar framework to create web apps for iOS and Android. Because of its ease of use Framework 7 was chosen for this project and for the reason that it is especially developed to create iOS apps.

### 3.4 Procedure and Results

The Bluetooth data sent from the hardware is read using a Bluetooth plugin for PhoneGap created by Don Coleman [31]. JavaScript provides functionality to setup a Bluetooth connection as well as handling data to and from a connected device. The connection has to be initiated and managed by the smart phone.

To be able to test the app on an Apple iPhone an Apple Developer account has to be registered [32]. The app can be tested on an iOS simulator in Mac OSX, but it is not possible to access Bluetooth related features in the simulator. To be able to test the Bluetooth communication and to access other hardware related features, the app has to be sent to the phone from Apple Xcode. The app is developed using HTML, CSS and JavaScript, built using Cordova PhoneGap and sent to an iPhone using Xcode.

#### 3.4.1 Observations

As a software developer it is important to know the users expectations. Observations of the users’ environment can be of great help to understand what features the software should have to support their daily work, in this case to support them during an exercise.

A handful of observations were performed at a gym facility before and during the software development phase to understand a users needs and requirements for the software. Observations showed that many people bring their smart phone and use them at the gym—as music players, for exercise logging, to share photos to social media, etcetera. People tend to have their smart phones in their hands or in a small pocket on one of their upper arms. In the case they do not have a pocket attached to their bodies the phone is normally placed on a bench or on the floor at some distance during an exercise since their hands might be occupied.

A personal trainer studies and instructs their clients during exercises to help them acquire correct weight-lifting technique.

Further observations showed that people aims to exercise left and right muscles evenly to become equally strong in both muscles. This observation led to the idea that if an imaginary line is drawn from the top of the head and vertically downwards...
the muscles of the body to the right and to the left of this line are mirror images of each other. It might be interesting to see how evenly two mirrored muscles are activated, since we are symmetric in relation to this line.

3.4.2 Prototyping and Application Design

Stark is supposed to motivate and help people to achieve their goals, therefore the software has to be created with its users in mind. There have to be some sort of recognition factor, the users have to be able to relate to the app.

The conceptual design started with design prototyping. To be able to evaluate a design there has to be a design to evaluate. This is an iterative process where user observations should be mapped if possible. Early prototypes were made as sketches on paper, influences from other user interfaces were tested, combined and tweaked; the process is to design, evaluate and redesign until a working prototype has been produced. Further refinements of the prototype were made in image processing software on a computer.

As with prototyping, which lays the foundation for the final design, the design and development part is an iterative process. Solutions that were produced during the prototyping phase are implemented and later tested together with users to see if there is a match between the software and the users expectations. When a particular design is created this is compared and evaluated in relation to earlier designs and solutions. Löwgren argues that there is no such thing as a universally best design. Every decent proposal has its benefits and shortcomings [25].

To personalize the app and to give the users a recognition factor they will be asked to enter their name and to select their preferred body type. The name will be used to give a personal welcoming message when the app is started and the body is used to visualize muscles when an exercise is performed.

The observation that people at a gym place their phone some distance away during an exercise shows that the displayed information have to be readable from one to two meters away. If it is important for the users to see a particular object from a distance they should have the possibility to interact with its size, they should be able to enhance it to make it more readable from a distance.

The physical design of the app focuses on images and colors among other things. To make the different app elements easy to distinguish, colors are being used sparsely. Clickable elements have colors and the background is dark so it does not draw unnecessary attention. Muscle colors are set to orange and teal to be easy to read and distinguishable for people with colour vision deficiency. See figure 3.1 for a comparison between different colour vision deficiency for the colors orange and teal.

3.4.3 Muscle Activity Visualization

Raw sensor data can be hard to understand without knowing its meaning, or in what range it is for example. It might not be interesting to see numbers only. Graphics can bring data to life and make it more understandable and easy to read.

Each sensor outputs data in the range 0 to 1023, where 0 is minimum exertion and 1023 is the maximum exertion possible. To visualize individual muscle exertion
the idea of an equalizer, or a graph with two bars, has been used. The left and right bar indicates left vs. right muscle activity and the height indicates muscle effort, the higher bar graph the greater muscle effort.

The observation that people tries to activate the corresponding left and right muscles evenly can be illustrated using the idea of a circular spirit-level, see the outer circle in figure 3.2. Evenly activated muscles results in the level being horizontal, if either the left or the right muscle is activated more than the other then the level tilts to that muscles favor. The level indicates the measured difference between the left and right muscle over time as a moving average with a window of approximately ten seconds. The graph and the level are merged together to one unit. This level-equalizer unit is referred to as a visualization element and can be enlarged when the user wishes to, to make it more readable from a distance. Figure 3.2 depicts the visualization element.

As a complement to the visualization elements and to understand where muscles are located on the body the muscles are indicated on the body figure. The left and right muscles have the same colors as the bar diagrams left and right. The muscles opacity are changed, between 0% and 100%, in relation to muscle activity.

Muscles in the body are connected to each other, if one muscle is activated other muscles can be activated as well, these can be referred to as secondary muscles. To show this activity during an exercise several visualization elements can be used. Forearms and shoulders for example might be activated at the same time as biceps and this can be visualized using additional visualization elements.

There can be a problem when a body’s front and back muscles are referred to. A body facing the user will muscle-wise be rotated 180 degrees—the figures right muscles are to the left and the figures left muscles are to the right, seen from the users point of view. Further when the figure are turned away from the user this will be the opposite, the users right muscle is the figures right muscle. To make this uniform the figure shown in the app will always have the same orientation muscle-wise as the user.
3. Software

Figure 3.2: A visualization element. Spirit-level with equalizer inside to show muscle activity. Left element shows even muscle activation with max intensity and the right element shows that the right muscle (teal) is being activated more than the left muscle (orange) and therefore the level tilts.

3.4.4 Application Flow

When the app is started and the configuration is completed the users have two options, either to start a workout, or to see recent workouts statistics. If workout is selected a full body figure facing the user is displayed. This is the figure that was selected during the configuration step when the app was started the first time.

The muscles available to exercise in the workout section are categorized in relation to their placement on the body, either front or back, see figure 3.3. The user swipes the body horizontally to switch between front and back view. By tapping the body different muscle groups are selected and the corresponding visualization elements are updated. Visualization elements are faded when there are no measurement going on and the users cannot interact with them.

There is also an option to make a full body measurement where all sensors are activated and they all have corresponding visualization elements. Since the prototype only features two sensors the several muscles related features will not work, but support is added for this feature.

A workout is started by tapping the red record button at the bottom of the screen, which transforms to a stop button when the measurement has started. The visualization elements becomes visible and they can be enlarged by tapping at them. The measurement is stopped by tapping the stop button and can be resumed once tapped again. Buttons to save the workout for statistics and to reset the workout are shown when the stop button has been tapped. If the reset button is pressed the view is changed back to what it looked like when the user selected workout from the start menu.

When a measurement is started the phone is trying to connect to the hardware unit via Bluetooth. If the connection is successful the measurement will start and if there are any problems during the connection phase a modal pop-up will be shown with an appropriate feedback message.

The first time the app is started the users need to go through a few steps to configure the app. In addition for the users to enter their name and select preferred
Figure 3.3: Main workout view; before, during and after a measurement.

body type the device is paired with a smart phone. A short tutorial is shown how to use the device, see figure 3.4. This step is shown only once and the settings are remembered the next time the app is started. A new configuration can be done in the settings menu inside the app.

Figure 3.4: Tutorial view in the app.
3. Software

3.4.5 Evaluation

To maintain the usability of the application according to REAL [25], user evaluations during the development process have provided input for the next redesign iteration. Löwgren calls this formative evaluation [25]. This evaluation technique has two purposes; to find usability problems in the system and to get ideas how these could be addressed in the redesign and secondly to see if the stated usability goals are fulfilled.

Studies, where users were asked to interact with the product, have been performed at a location where the prototype could be used, in this case at a gym. Early tests were performed using development versions of the software to get users feedback. They were asked to do a weight-lifting exercise and to think out loud [34] to understand their actions. Even though the app lacked a few features the users could tell what they thought should happen. Later in the process tests were performed when the hardware and software could communicate and field studies [25] were performed. The users were given the task to exercise biceps and were asked to reveal their thoughts how well they could perform the task, how efficient they could work, what they thought about the system and how easy it was to interact with. Except to test usability in relation to REAL these tests were performed to see how the visualization worked, as well as how the use of an enlarged visualization element could help to make the visualization easier to read from a distance.
Studies with electrode placement show that it is important that the electrode and skin resistance is low since too high resistance can result in incorrect measurement data. However, the output from the sensors, both with and without electrodes deliver comparable quality, as long as the contact with the skin is good. Electrodes attached with adhesive helps to achieve good contact. The knowledge that cables taped to the skin can work as well is an interesting result since it shows that correct measurement can be obtained even without adhesive and electrodes. This is a prerequisite for successful development of compression wear with conductive fabric since adhesives in clothes otherwise would cause problems for the person wearing them.

When the electrodes were attached to different muscles the experience was that different muscles produce different strong signals, at least according to what the sensors can measure. This can depend on how deep the muscles are, but also that the sensors might need to be calibrated for that particular muscle to be able to do a more sensitive measurement.

The studies performed during weight-lifting show that Stark can be used to indicate individual muscle activity in real time as well as how even two muscles are activated over time with the help of the visualization elements. When exercises were performed standing up the phone was placed on the floor with an enlarged visualization element to be able to read the measurements without leaning forward. An enlarged visualization element was needed for the practitioners to fully be able to read the measurements from a distance. The visualization of the muscles on the body figure was harder to read than the visualization elements, both since they might be smaller in size, but also because it was harder to register the changes in opacity, especially from a distance. Skew weight distribution could be detected both by looking at the real time muscle activation feedback as well as at the ten seconds interval which tilted to one side if the muscles had been activated uneven. Skew weight distribution is closely related to unbalanced lifting where one of the practitioners measured muscles is activated more than the other. This information could be used to indicate incorrect lifting technique when comparing right and left of a muscle (right and left biceps for example). However, Stark could not detect incorrect lifting technique during biceps curls in relation to the lower back muscles since the electrodes attached to the back gave none or very little output. To sum this result up, Stark might detect incorrect technique. Different exercises activate muscles in different ways and muscles are at different depth in the body. Even though the tests indicated similar results for the test persons peoples bodies are different. To detect incorrect technique for a particular exercise more thorough and intensive tests needs to be performed for that exercise to be able to guarantee detection of correct
or incorrect technique. The studies with the cable machine gave a more uneven result in relation to left-right muscle activity than with barbell. One possible reason is that the rod and rope connected to the cable machine does not hold any weight itself but is connected to the weight via cable. The weight is centered in relation to the position of the hands in a way that differs from that of the barbell and this allows the practitioners to make a more unbalanced lift initially before the hands are stabilized. With the hands in level and when the right and the left hand held on to the same bar the measurements were most even—the visualization elements indicated both a horizontal level as well as a reasonably even bar graph during the exercise.

The user opinions and thoughts through formative evaluations have been a great help to strive in the right direction during development. The responses from the final evaluation were that the application was straightforward how to start a measurement, especially after the tutorial and that it was interesting to understand how muscles respond. It might not be a product to use during every workout but it could be useful to be able to see how even two muscles are activated. The project time might have been to short to be able to say anything about how well users remembered how to interact with the system over time, therefore it is hard to say anything about learnability over time. The think aloud technique used can be argued if it is useful since people tend to stop talking when they are stuck on a problem. Although this has been used since they could get help during the study. This was not performed to get an approximation how much time a users spent on particular tasks, more to understand how they thought they should interact with the system.

Some test persons initially felt that the spirit-level should tilt upwards to a muscles favor if that muscle was activated more—this since it should relate better to the bar graphs orientation. Another response was that the app lacked options to do a full body measurement. If the practitioner did not know exactly what muscles a machine at the gym should exercise they wanted Stark to tell them what muscles were activated - something that could be achieved by adding more sensors. An option to see a playback of the measurements afterwards was requested to get a visual summary of the workout.

When combining frameworks, like Framework7 and PhoneGap used in this project, with ones own code the time needed for debugging might increase. Errors might be caused by problems in the framework itself, that the framework operates in a way not expected. Development projects with graphical user interfaces of some sort can be difficult to troubleshoot, especially when several frameworks are added to the project. The different frameworks might interfere with each other, and they might interfere with the code developed. During the project there have not been too much difficulties using the frameworks mentioned but instantiation of some Framework7 elements in JavaScript were proven to be difficult, especially difficult to debug. The process when developing an app with HTML, CSS and JavaScript is very similar to the process of producing a web page. The app can be interacted with and debugged using a web browser.
5 Discussion

As with Stark, both Athos and Myontec offer visual real time feedback using EMG, Bluetooth technology and a smart phone. The idea with this project has not been to develop a product better than their products but to discover possible limitations with the technology as well as how a smart phone can be used to visualize muscle activity. Even though the products by Athos and Myontec have not been tested their intended functionality can be discussed briefly.

Both Athos and Myontec compares the activity of two muscles to give the user knowledge if muscles are activated in a balanced way—as far as this Stark has the same functionality. The studies showed that it was harder to measure some muscles than others since they are located at different depth in the body and that the electrical signals thereof might be difficult to measure. Even though the tests to measure biceps muscles with Stark provided useful results the same sensors attached to lower back muscles gave less useful data. An assumption is that the sensors used by Athos and Myontec are either more sensitive or calibrated to measure a particular muscle to provide useful data. This is as far Stark goes. One way to solve this for Stark could be to have an initial calibration phase before an exercise to activate the muscles in a predefined way to provide the app with "known" data. Athos and Myontec offers heart rate monitoring as a complement to muscle activity. Additional to this Myontec features cadence speed and distance measurements to provide the user with even more data during exercise. These features can be added to Stark with additional hardware. It has been hard to find user reviews for the products by Athos and Myontec, reviews found on the Internet have been written before they claim they have a product to be shipped to customers.

Humans have a built in spirit-level, meaning; we tend to see if something is more or less horizontal. The idea with a level as a metaphor for horizontal was borrowed from digital cameras. Many of today’s professional digital cameras have a built in level that can be shown on the display of the camera to indicate if the camera is in level or not. The level was chosen to illustrate the balance in muscle activation between left and right muscles, and I think people more or less can relate to and understand its meaning.

Stark is in no way secure today. Anyone with the app can connect to the same unit as everybody else without problems, allowing them to interfere and disturb. There is no password to connect to the device, but since this is a prototype this has been considered acceptable. An article related to security risks handling user health data was published in the Swedish newspaper Dagens Nyheter [35]. The article addresses security risks with activity bands that gather biometric data. Many products have security breaches and personal information can end up in the wrong hands.
5. Discussion

The article mentions that according to the IT security company Kaspersky Lab, a third party can without too much difficulty connect to many of the most common activity bands on the market today without the owner’s knowledge. Furthermore, the article says that information about a person’s health can be very interesting for insurance companies among others. If Stark becomes available for purchase it is of utmost importance that the security issues related to user health data are taken seriously.

I believe that wearables like Stark can be useful. An individual can with the help of real-time feedback understand how a particular muscle is activated, but it can also be a complementary tool for a personal trainer to really supervise how the muscles of a client activate during an exercise. Stark can be of great help for a user to achieve weight-lifting goals since visual feedback, especially over time, can show how evenly two muscles are activated. I think this direct feedback can motivate people to exercise since they get a relation between weight-lifting and their muscles activity. I think that the willingness to use a product like Stark depends how easy it is to wear.

5.1 Future Work

Since the device broadcasts that it is available and ready to be connected to, the hardware unit needs to be secured against untrusted users. One possible way is to use a PIN code in the connection establishment process. Classic Bluetooth uses a solution similar to this, but Bluetooth LE has removed a few features to make the standard easier to use and deploy. However, this puts more responsibility on the developer if a secure product are to be developed.

Data is being transferred from the hardware unit to the phone in a string. It is time consuming to create this string and there are better solutions. If the left and right measurement data can be concatenated to one integer value at the hardware unit and then divided again in the app using integer division and modulo arithmetic then a lot of time now used to create the string can be saved. Unfortunately these alternatives have not been tested properly and is therefore not implemented.

Additional hardware: accelerometers and gyro meters for example can be used to count the number of steps taken or to track the speed of a particular movement, among other things.

The app does not feature playback of a performed exercise. However, since the data has been captured within the app this problem is mainly related to the need for additional development time.

5.2 A Final Word

Even though Stark still is a prototype people who have been introduced to the project have expressed that they could find such a product useful to use and interesting to try. Given more development time and additional sensors Stark can become an interesting product in the fitness app jungle.
Appendix: Hardware

Figure A.1: The Arduino Uno is a microcontroller board based on the ATmega328. It has 14 digital input/output pins, 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header and a reset button [36].

Figure A.2: The Adafruit Bluefruit LE nRF8001 Breakout can be used to setup a wireless link between an Arduino board and any compatible iOS or Android (4.3+) device [37].
A. Appendix: Hardware

Figure A.3: Three-lead Differential Muscle/Electromyography Sensor for Microcontroller Applications [38].

Figure A.4: Electrode cable and electrodes with blue conductive gel in the center.

Figure A.5: Hardware unit, consists of an Arduino, two muscle sensors, a Bluetooth adapter and a battery pack.
References


[28] PhoneGap. PhoneGap / Supported Features. PhoneGap. URL: http://www.webcitation.org/6Yfa8hmYy (visited on 05/01/2015).


