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Designing a platform to communicate posture and movement data to medical professionals

Christiaan Boersma

KTH ROYAL INSTITUTE OF TECHNOLOGY
ELECTRICAL ENGINEERING AND COMPUTER SCIENCE

Abstract

Healthcare expenditure has been on a steep rise in the past decade. Through preventive measures, the company Qinematic tries to assist the healthcare system through 3D scanning and assessing people with the help of a Kinect. The goal is to detect dysfunction in human movement and fix these issues, improving individual mobility, and with that lessen the burden on the healthcare system. The goal of this study is to develop a working web-based portal for physiotherapists and occupational therapists to analyze the 3D scans and derived measures. Simultaneously this portal should aid the therapists in their assessment of the person, allowing the therapists to improve and speed up the assessment. Interviews, observations, literature, and a state-of-the-art is used to explore what is necessary to assist physiotherapists and occupational therapists in their assessment. Based on these requirements, a prototype is developed to explore how these requirements might function. Finally, the prototype is tested with therapists to validate the new functionality. During the prototype evaluation, five out of the six therapists expressed that the prototype was definitely an improvement, while the other one was unsure about the overall improvement. The evaluation of the prototype also produced additional requirements and alterations to existing requirements, which can be used for future work.

Keywords

Kinesiology, posture, movement, web app

Abstract

Hälsovårdskostnaderna har ökat dramatiskt under det senaste decenniet. Genom förebyggande åtgärder försöker företaget Qinematic att förbättra hälsovårdssystemet via 3D-skanning och mätning av mänsklig rörelse med hjälp av en Kinect-sensor. Målet är att upptäcka bristande funktioner i människans rörelsemönster och förbättra och förbättra individuell mobilitet. samt därigenom minska belastningen på vårdsystemet. Målet med denna studie är att utveckla en webbaserad portal för fysioterapeuter och ergoterapeuter för att analysera 3D-skanningar och åtgärder. Samtidigt bör denna portal hjälpa terapeuterna i sin bedömning av personen, så att terapeuterna kan förbättra och påskynda bedömningen. Intervjuer, observationer, litteratur och en bedömning används för att undersöka vad som är nödvändigt för att hjälpa fysioterapeuter och arbetsterapeuter. Baserat på dessa krav utvecklas en prototyp för att undersöka hur dessa krav kan fungera. Slutligen testas prototypen av terapeuter för att validera den nya funktionaliteten. Under prototyputvärderingen uttryckte fem av de sex terapeuten att prototypen definitivt var en förbättring, medan en var osäker på den övergripande förbättringen. Utvärderingen av prototypen skapade också ytterligare kravspecifikationer och ändringar av befintliga kravspecifikationer som kan användas för framtida arbete.

Nyckelord

Kinesiologi, kroppshållning, förflyttning, webbapp

Acknowledgements

I would like to thank Glenn Bilby and Tino Krautwald from Qinematic for giving me the opportunity to work on this project. It was a great experience working with you and I learned a lot about kinesiology and human movement. I found that I am really interested in the subject and will continue to look into it, it is already showing in the focus of my gym workouts. I would also like to thank Magnus Boman for guiding me through thesis work, especially considering the amount of emails I send him the last week. He did an absolute stellar job in guiding me and helping me finish this thesis before my personal deadline. EIT Digital, the University of Twente, and KTH, also deserve a big thank you for allowing me to do the master in the first place.

Contents

1 Introduction

Qinematic is a Swedish company that has been working on automated ways to detect dysfunction in human posture and movement. Qinematic scans people with a Kinect camera and analyzes the resulting scan data. Their system currently outputs several measurements and tracking points, as well as a PDF-report for the scanned person (referred to as patient in this report). The analysis of the scan contains much information that requires specific medical training and knowledge to make sense of the information. This study aims to find ways to communicate the resulting information clearly and effectively to the healthcare professional, often a physiotherapist or occupational therapist (referred to as OT in this report).

1.1 Background

Rising costs in healthcare [1], as can be seen in Figure 1, will most likely cause healthcare to shift from cure to prevention. Preventive healthcare eventually saves on costs, while simultaneously improving people's quality of life, especially at an older age [2]. Qinematic uses the Microsoft Kinect to detect issues, or dysfunction, in the way individuals move (kinesiology). These dysfunctions could lead to pain or even immobility when people age [2], possibly forcing people into a nursing home at an earlier age than necessary, putting a heavy burden on the healthcare system [2]. Most of the dysfunctions that are detected could easily be solved with some light exercises if detected early [2].

Bad posture has several effects on the overall functioning of a person. It starts with pain in the affected area. The pain often occurs at the end of a day, and might be gone after a night of rest [3]. A possible explanation for this pain is muscle fatigue. The muscle that usually take the load and are evolved to take the load, do less of the work. Support muscles then kick in to keep the person up right, these muscles are not meant for the task and might eventually fatigue and cause pain [3]. The muscle fatigue in turn might cause the person to shift to an often even worse posture to alleviate the fatigued muscles. If this cycle continues over time, it might cause premature immobility. The immobility is not directly caused by the bad posture, but by secondary effects such as back strain or osteo-arthritis [3].

By continuously detecting dysfunction early, it might eventually be possible to reduce healthcare costs and improve and maintain a higher level of mobility for people. Lower costs, in turn, should reduce the pressure on the healthcare system [2]. The software developed by Qinematic aims to discover the dysfunction while it is still a minor issue. At an early stage major issue could be prevented by training the right muscles and correcting the posture. Preventive measures in human posture and movement are also beneficial for many businesses since it might reduce absence from the workforce. Right now, Qinematic can detect specific measures indicating dysfunctions, with a high degree of accuracy and are at a stage where they want to get their system out to a broader public. The basis for this study is an existing environment Qinematic already has in place.

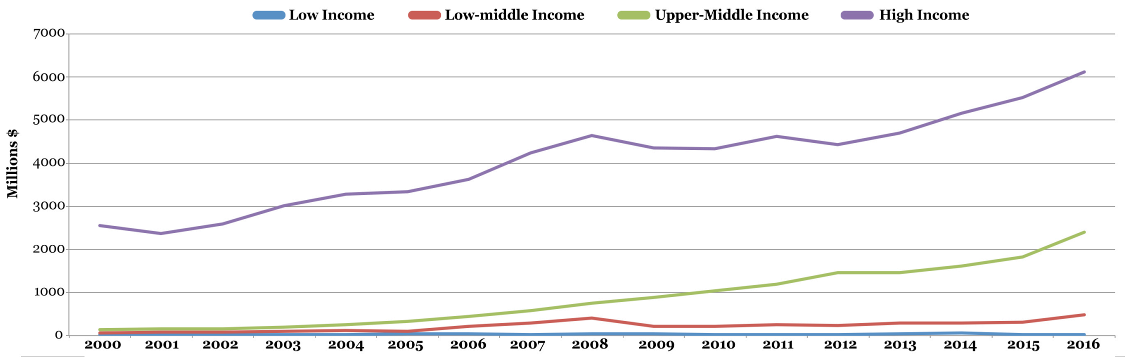


Figure 1: Capital health expenditure from 2000 to 2016, based on the income group, in millions of Us Dollars. [1]

1.1.1 Current implementation

Posture Scan is an automated scanning program running on a Windows computer with a Kinect attached. A Kinect measures distance by splitting a single laser beam into multiple beams, this creates a pattern of around 300.000 dots on the scanned objects. These dots are recorded by the infrared camera at 30 frames per second (fps). The location of the dots is compared to a saved reference plane at a known distance. The shift from the reference location is determined by an image correlation procedure [4]. This way the distance from the sensor for every dot can be calculated.

Posture Scan captures all the data needed for analysis. The program is currently able to capture six exercises in an automated way and can detect and redo failed exercises. The system is set up in a way that makes it possible to leave the patient alone, without the involvement of the OT. Movement Lab is also a Windows-based program; it allows the OT to review the scan data of a particular person. Within the Movement Lab environment, the OT can pull up many different types of metrics to analyze. Movement Lab is only meant to be for the OT, not for a patient. It is meant to be used to determine what is going wrong and possibly explaining it to the patient in a face to face session. Where Movement Lab aims at the OT, Note functions as a portal for the patient. Note is accessible through a web browser and stores a summary report of the scan produced by the system. It is also possible for the OT to send notes and drawings to the patient through Note, to further explain the assessment. In section 3.2, all the details of the current implementation are reviewed, to determine what performs well, where the improvements are, and what is missing.

1.2 Problem Statement

Qinematic has two critical requirements for the new platform they aim to develop. Firstly they want to improve on their information communication; there is a lot more data that can be extracted from the scans than is currently shown in their programs. They are, however, unsure about the approach they should take in communicating this information, what information is necessary, how to pull the attention of the OT to those problem areas, and how to assist in the assessment of their patients.

OTs are already familiar with analyzing people moving in a 3D space; during a regular appointment, OTs also use video analysis to detect dysfunction during a review of the material. The downside to using a camera is that the camera point of view static after recording. A 3D model, on the other hand, can be moved around and looked at from many different points, even after recording. It does, however, require a different way of analyzing and interpreting the data presented. The OT looking at these new types of data for the first time, will most likely not know what to do with them. The 3D scan data and information retrieved from it requires a particular way of looking at the information to be able to interpret what is going on. The issue with data interpretation is also present for the patient looking at his or her scan, although with them, the problem might be more severe. The patient, unlike OT, often does not have medical training or knowledge about kinematics and human movement.

The second requirement is that it should be accessible on multiple devices with many different operating systems and screen sizes. Thus the information and scan data should also be manageable on a mobile device instead of just a desktop. A web-based platform would be preferred by Qinematic to handle most of the tasks now done by both Note and Movement Lab. This study targets the data and information communication part of the platform in development. The focus is on finding ways to assist the OT during an assessment, with the information retrieved from scanning people. The following research question was constructed to guide the study in the right direction:

> How can the company assist OTs in the assessment of 3D posture data and information, 3D movement data and information, and problematic areas?

1.3 Purpose

The purpose of this study is to supply Qinematic with tested concepts, which would allow them to communicate the data they have to OTs. Qinematic will, in turn, use this information to build a platform for OTs to access the data and derived information, to help them assess patients.

1.4 Goal

The goal is to report on ways to assist in the of communicating human posture and movement information to the OT and patients. A secondary goal is to deliver a prototype that can be used to test different ways of communicating the information with the OT and simultaneously providing a base for Qinematic to build upon in the future.

1.5 Benefits, Ethics and Sustainability

Benefits include insight into the communication of health-related data to OTs. In the future this envisioned platform could be able to prevent certain types of injury and discomfort by detecting dysfunction early on and helping the patient experiencing it, to fix it before it leads to more significant issues or even immobility. This study is part of an effort to develop a sustainable healthcare solution for the prevention of mobility issues. Prevention, in turn, should lead to lower healthcare needs, lessen the burden on the healthcare system, and increase the quality of life [2]. In the future their should be more automated functionality in the system, making it also interesting for developing countries

There is also an ethical issue to take into account. This study, especially the building of the prototype, concerns medical and privacy-sensitive data. For these reasons, explicit consent was asked to the individuals in the scan to use it for development purposes. The scans stripped of all personal metadata, such as name, email, and more, are uploaded to a separate already existing development server. On the server, the scan is given a new identification number to prevent backtracking to the actual Qinematic server. Although the scans are anonymized, they are still scans of the actual individuals, and they might be identified by looking at the scan. Therefore careful handling of the data is still required, and the prototype is password protected during development.

1.6 Methodology

This study consists of empirical research, with an inductive research approach. The research leverages interviews, observations, and theory for data collection, and prototyping for evaluation. It concerns a particular user group, namely OTs, this would mean that only a limited amount of suitable and willing participants might participate within the set time frame of the study. Therefore it was chosen to perform a qualitative study, with empirical and analytical methods. Starting with determining the initial requirements necessary for effective information communication based on the expertise of Qinematic. Qinematic knows which data is available and which is probably necessary to display, combined with an evaluation of their current programs. Several OTs and other healthcare professionals within the same area are interviewed order to explore different opinions and views of the subject, apart from the ones Qinematic has. Based on this set of requirements, a web-based prototype will be developed, while being situated within the Qinematic office for a smaller feedback loop with the company. The prototype should be able to demo most of the gathered requirements for both the OTs and Qinematic. Finally, the OTs test and evaluate the prototype to determine if the set requirements live up to the expectations.

1.7 Risks and (de)limitations

This study faces several possible risks and limitations. The first risk is not being able to find OTs willing to participate in this study or OTs not willing to participate after the first interview. Limiting the study results in merely anecdotal evidence. Another risk might be the fact that most of the participants will probably be from the Stockholm region. Thus there is a high likelihood of biased results towards their preferences, limiting the generalization of the results from this study. This study is also limited by the exercises Qinematic currently tests, for instance Qinematic does not test gait exercises at this point in time. Another possible limitation is the testing of the proposed requirements and implementation of these requirements before testing. The best way to test is through a prototype or minimal viable product (MVP), but building a prototype or MVP takes a lot of time and effort. This time might not be available, or the surrounding aesthetics of the prototype might influence feedback from the participants.

1.8 Outline

Section 2 discusses the methodology of gathering, evaluating, and implementing the requirements. In Section 3.1, a literature study is done to get an idea of what is already known and applicable. Section 3.2 evaluates state of the art, and in section 4, the evaluation results get transformed into requirements. Section 5 discusses the build and evaluation of the prototype, while Section 6 discusses final the results and conclusions of the entire study.

2 Method

This study relies on qualitative empirical research methods with an inductive approach. A base is established to build upon, by taking a look at the literature and evaluating the current system in place and how they are received and operated by the OTs. Through the use of interviews and observing the OTs, the use of the current system is explored. Resulting in a full dataset containing the interviews, observations, literature research, and a state of the art analysis. The data gathered through these methods transformed into requirements for the prototype. The prototype, in turn, will be used to test newly discovered functionality with OTs. Testing new functionality is necessary for the validation of the requirement. Faulty use or interpretation of functionality and measures can have dire consequences when used with actual patients.

2.1 Situatedness

The entire study is conducted at the Qinematic office, except for stepping out to the OTs for interviews. Being situated within Qinematics office doors are opened for elicit tacit knowledge and possibly new requirements to be transferred. This knowledge is discovered by talking to coworkers at any given time, such as discussing ideas and progress during a coffee break. It also allows for asking questions about the difficult subject of kinesiology and human anatomy. These fields in itself require much studying to be understood and definitely if certain functionality needs to be correctly implemented into a prototype.

2.2 Literature Research

The medical world is different from the 'normal' world. There is specialized communication going on, and different standards might apply to the communication of specific data or information. The literature research aims to find design and communication principles within the medical world through literature, and be able to prepare for these possible differences and account for them.

2.3 State of the Art Evaluation

The idea for this web-based platform was conceived roughly two years ago and attempted to build, but faced technical difficulties. The build attempt means, there are already requirements in place for the platform, but not a working version. First, these requirements are evaluated and determined if they are grounded and within the scope of the study. Next, investigation of the current programs, which might provide insight into their vision for the communication this information.

Semi-structured interviews and observations with OTs are done to collect feedback on the current system. The interviews aim to determine how the OTs investigate scans, assess potential problems and use the system in general. The methods employed by the OTs might provide valuable insights into what is important to them to assess these problems. It might also give insights into usability-related issues. The design of the platform can then facilitate this decision making and make it a smoother process. The system walkthrough addresses every aspect of the current system while remaining flexible enough to dive deep into specific issues experienced by the OT. Due to limited access to OTs who use this system right now, it is essential to generate as much data as possible for analysis.

The interview questions are constructed using the guide by Turner [5] for the qualitative interview design. A pilot interview is held to test the constructed interview, to improve the construction of the questions, find missing questions, and remove irrelevant questions. Recordings are made of the interviews if the interviewee grants permission. They are stored on a password protected laptop within a randomly generated 22-symbol password protected folder and 128-bit encryption, due to the private and sensitive nature of the recordings. Interviews are held at a to the OT familiar location, like their clinic or office, in line with Turner's [5] recommendations. For the interviews, a laptop was used to run Movement Lab and record the conversation. This way, there is no visible physical presence of a recording device. Displaying Movement Lab on the same laptop also directs sound more or less at the recording device.

2.4 Requirements Analysis

Requirements are needed to build a platform that is suitable for the OTs to using during the diagnosis of dysfunction in the people they treat. Discovering these requirements is an iterative task since it is nearly impossible to discover all requirements at once. Based on the work of Sikkel [6], who has developed such a process to find as many requirements as possible for this study. Maximizing the number of requirements and testing them with the OTs, is necessary to find both ends of the spectrum. It will help to find useful requirements from which the OT would benefit. It will also help to find useless requirements, which would only clutter the workspace of the OT and might even be distracting.

When searching for requirements, one needs to keep in mind that merely asking OTs what they want and need, might not be enough. OTs might, for instance, believe that the functionality of the current system is the limit of what is possible. Therefore several techniques are employed to discover as many requirements as possible. For this study interviews, documents of the existing system, studying similar products, and prototyping [6] are used to gather requirements. Labeling the requirements with a level (business-, system- or design-level) and a type (constraint, functional, or quality) [6]. After labeling, the requirements are prioritized using the MoSCoW method. This way, the requirements are coded into four types:

- *Must* - Crucial, if not implemented the system is useless

- *Should* - Important, not crucial, but still an integral part of the system and great importance to the end-users.
- *Could* - Nice-to-have, if time allows, implement these requirements.
- *Will not* - Requirements that would improve the system but are outside the scope of the current study.

2.5 Prototyping and Evaluation

Based on the literature, research, and interviews, requirements emerge. These requirements form the basis of the specifications for the prototype. The prototype is used to test new communication techniques with OTs. It is crucial to test the new techniques because if the information gets interpreted in the wrong way, the OT could make the wrong decision. Qinematic would also like to see many of the requirements working for themselves, to get a good understanding of how it might look and function.

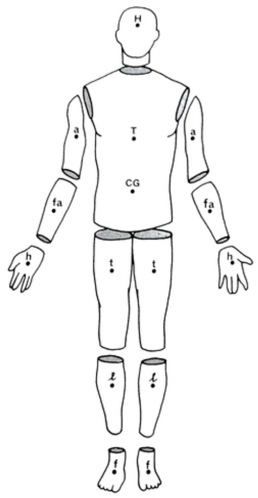
The prototype is evaluated similarly to the current platform. Semi-structured interviews, constructed according to Turner [5], are conducted with the OTs alongside with observations of them using the prototype interface. Questions specifically target the interpretation of the different aspects on the screen. By evaluating the prototype in the same manner as the current platform, results should be comparable. Allowing to see improvement, if there is any, and conclusions to be drawn about the communication of the scan information, as well as determining if the new platform might succeed in the future. Similarly to the previous interviews, the laptop running the prototype records the interview if the interviewee consents and storing the recording alongside the earlier interviews in the protected folder.

3 Extended Background

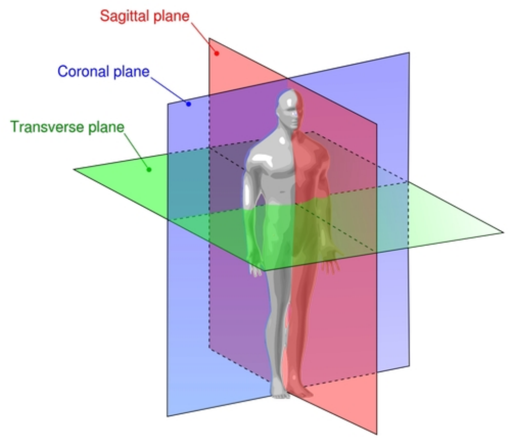
For every study, it is relevant to know what is already known and available, especially in the medical field, where standards or commonly used practices exist. First, medical imaging techniques and ways to describe kinematics and dysfunction will be discussed. After that, the state of the art is discussed and described.

3.1 Medical imaging and describing kinematics and dysfunction

This section discusses frameworks and standardized or commonly used methods to describe human movement. Since these frameworks and methods also might appear in study books, it will be familiar for OTs.



(a) The human body divided into the main body segments [7] page 22.



(b) Describing human movement is done in relation to these cardinal planes [8].

Figure 2: *Tools used to describe the human body and movement of the human body.*

3.1.1 Body Segments

Segmenting the body is a framework to describe the human body based on bone placement and joint location. This type of depiction is often used to describe the distribution of mass and the location of the center of mass (CoM) per segment (dots in each segment figure 2a) [7]. Usually, within the field of human movement, the body is divided into eight principle segments:

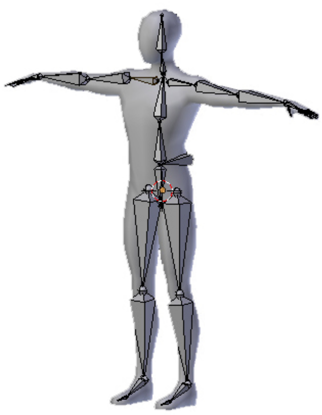
- The head and neck (Figure 2a - H)
- The trunk (Figure 2a - T)
- The arm (Figure 2a - a)
- The forearm (Figure 2a - fa)

- The hand (Figure 2a - h)
- The thigh (Figure 2a - t)
- The leg (Figure 2a - l)
- The foot (Figure 2a - f)

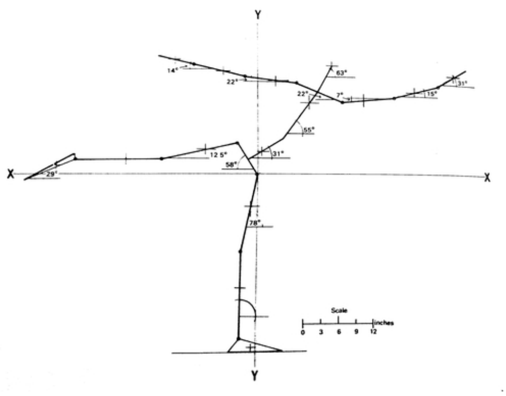
The different body segments, their mass, and CoM can be used to calculate the forces acting on the body. These forces can be used to determine which segments or joints experience a high amount of pressure in a particular position. Increased pressure on certain areas can cause pain and are an indicator of weak posture control [9].

3.1.2 Anatomical Planes

Anatomical planes, also referred to as Cardinal Planes, are used as a basis for anatomical descriptions of the human body. There are three types of anatomical planes, the sagittal plane (Figure 2b - red plane), the Coronal plane (or frontal plane, Figure 2b - blue plane) and the Transverse Plane (or horizontal plane Figure 2b - green plane). Describing the movement of the human body is often in relation to one of the three cardinal planes. For instance, movement can be described as moving away (abductive), or towards (adductive) the sagittal plane (Figure 2b - red plane) and is best viewed by looking at the Coronal plane (Figure 2b - blue plane) [7][10].



(a) A joint chain in a 3D character rigging used to animate 3D objects [11].



(b) A link diagram describes the angle of the movement arms in relation to the floor [7] page 28.

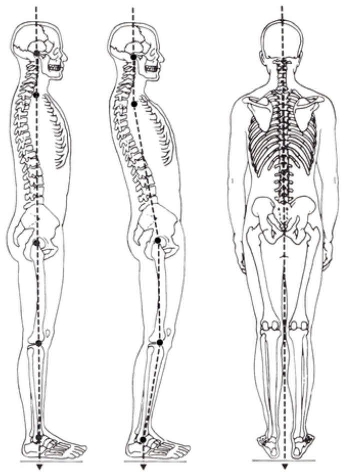
Figure 3: *Joint chains are used to position body segments, whereas link diagrams are used to describe the position of the body segments.*

3.1.3 Joint Chains

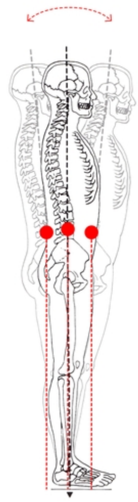
Joint chains, or body linkage system, is a simplified description of the joint and bone connections within the human body. A stick figure is a simplified example of this kind of depiction. It shows the effective points of rotation as well as the effective leverage arms. Joint chains are also used in 3D animation since they depict the main bend point and leverage arms of movement by any character (Figure 3a) [7].

3.1.4 Link diagram

The link diagram is a way to accurately describe the positions and angles of the joints and body segments within a joint chain [7]. The link diagram (Figure 3b) shows the position of the joints on the X/Y-coordinate plane. With the angles of the limbs and body segments relative to either the X-axis or Y-axis.



(a) Graphical depiction of a perfectly aligned standing posture and swayback posture (adapted from [7] page 88).



(b) Posture Sway is the movement of the center of mass over time while standing still (adapted from [7] page 88).

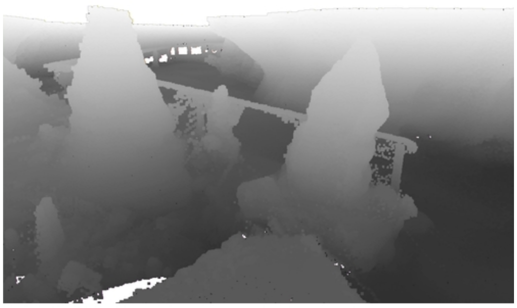
Figure 4: *Graphical depictions of standing posture alignment and swayback.*

3.1.5 Standing posture body alignment

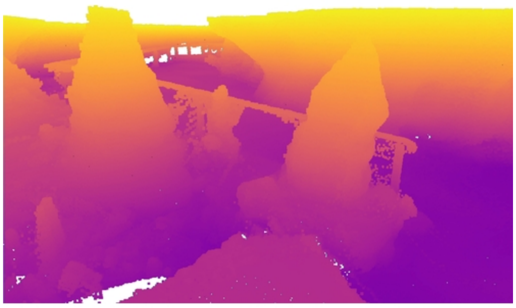
Standing posture body alignment is a way to determine whether or not a person has good posture and where it deviates from the norm [7]. Determining the body alignment is done through the alignment of the middle of the ankles, the middle of the knees, the middle of the hips, the middle of the shoulders, and in between the ears. If the posture of the person is in line with one of the conventional norms. Of which the preferred one forms a straight line (Figure 4a - left) [12]. With, for instance, a backward leaning posture (swayback posture), this line is not straight (Figure 4a - middle). Sideways posture deviations are measured using the same alignment [7].

3.1.6 Posture Sway

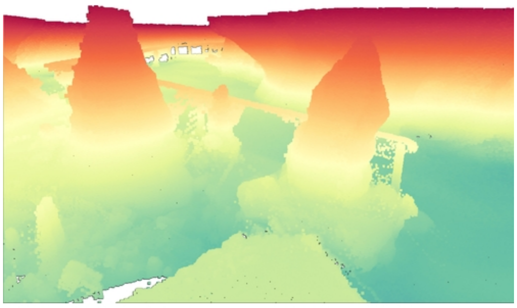
When the human body is stationary and standing upright, it is never actually standing still. There is always a little bit of movement, either back and forth, sideways, or both [7]. These movements are the results of the force acting on the body and the body, making slight corrections to correct for those forces. The sway is measured using the CoM since the aim is to keep the CoM over the feet (Figure 4b). Posture sway, or movement of the CoM in general, is usually depicted as a path seen from below the feet (Figure 6b). This path represents the location of the CoM over time.



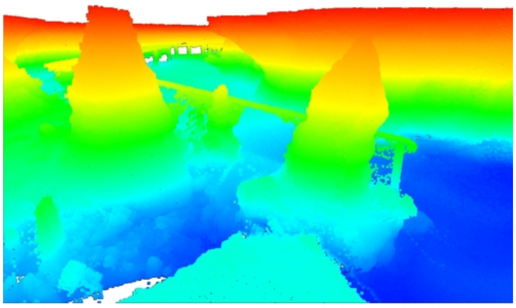
(a) This scene is rendered using a black and white color gradient.



(b) This scene is rendered using a purple and yellow pseudo chromadepth gradient.



(c) This scene is rendered using a green, yellow, and red pseudo chromadepth gradient.



(d) This scene is rendered using a full chromadepth gradient.

Figure 5: *Different gradients show different details more clearly. Scenes are part of a Potree showcase, a free open-source WebGL based point cloud renderer [13, 14].*

3.1.7 Color Gradients

Being able to perceive depth in 3D environments is very important. Therefore a reliable way is needed for the user to perceive depth when assessing the 3D scan. T. Ropinski et al. [15] tested several ways to advance depth perception in images. They found that stereoscopic depth perception was the strongest. Stereoscopic depth perception essentially, generates two images, one for the left eye, one for the right eye. The combination then produces a 3D effect. The same technique used in 3D movies and 3D screens. This technique requires special equipment and computer processing. Therefore it is not suitable for this study or Qinematic.

The second most reliable technique Ropinski et al. [15] found was, pseudo chromadepth. Chromadepth uses the color spectrum to color code depth (Figure 5d); for instance, far away objects are green, while objects closeby would be yellow. Although they expected full chromadepth to be more reliable, pseudo chromadepth, which uses only a few colors (Figure 5a, 5b and 5c) scored higher. Through interviews, they found that full chromadepth is more confusing when the meaning of the colors was not explained or known, pseudo chromadepth is more intuitive in use.

3.1.8 Limb and Joint Position

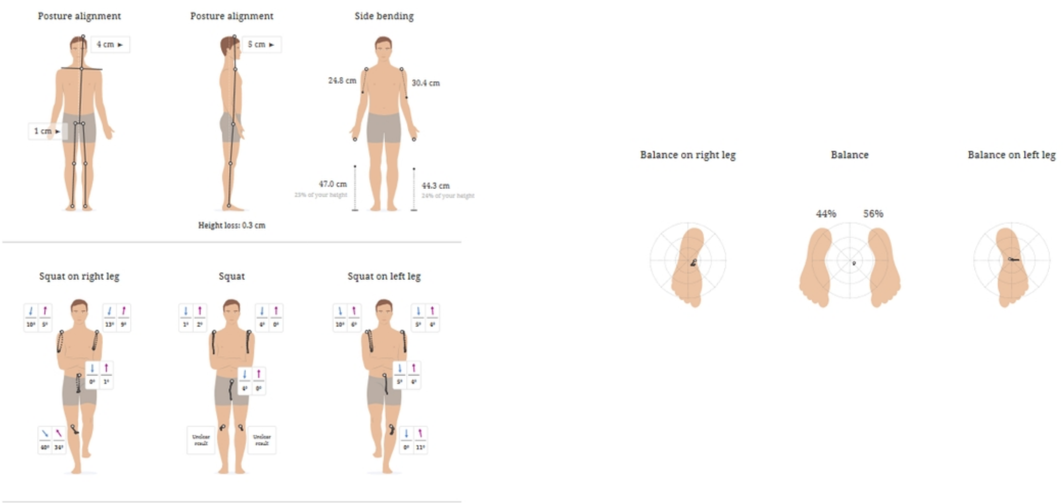
Limb and joint position are often described using the angels in relation to the ground (reffig:link-diagram) or between bones. To provide a useful and accurate representation of the body position [7], one needs to take into account the body linkage system 3.1.3. Combining this representation with the Degrees of Freedom of the joints, it is also possible to describe limb motion.

3.1.9 Curves

The primary way of describing motion and movement is through a velocity curve or displacement curve. These curves display velocity or displacement of individual points within the body over time. These curves always describe in relation to one of the anatomical planes described above 3.1.2. In Figure 8, for instance, the displacement of various upper body tracking points are described as seen in the coronal plane.

3.2 State of the art

Since there already is a system in place, it is wise to evaluate that system first. Trying to discover what is good or bad about the current system and what might be working poorly or missing, serving as the starting point for the development of the prototype. Interviews were held with current users of the system and its different components to get feedback and discover usability problems with the current implementation. There are a total of three separate programs in place at this time. Data collection is handled by Posture Scan, while and information communication is done through Note and Movement Lab.



(a) Note communicating up and down movement statically.

(b) Note displaying posture sway in a single and double legged stance.

Figure 6: *The different types of dynamic data, statically displayed by Note.*

3.2.1 Posture Scan

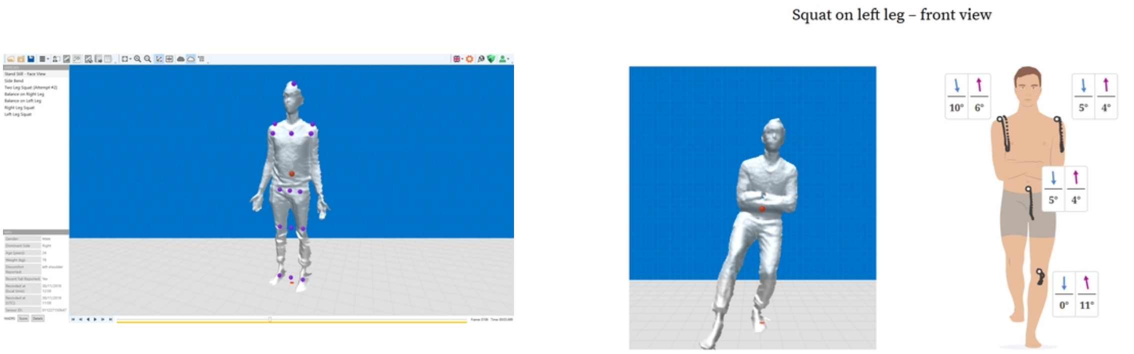
Posture Scan handles the data collection. It is an automated system where the user only has to input some personal details and follow the instructions. Posture Scan currently captures seven exercises:

- Stand Still
- Balance left leg
- Balance right leg
- Squat
- Left legged squad
- Right legged squad
- Side bend

Posture Scan is also able to detect faulty exercises and prompt the patient for a redo. This program in itself is not very interesting for this study since it is only used for the data collection, not for the data or information communication of the scan results. Therefore it was not analyzed any further during this study.

3.2.2 Note

Note is an online environment of Qinematic. Within the online Note environment, the scanned person can request their data whenever he or she wants to. The Note environment is a simplified version of Movement Lab. It is only possible to view static measures overlayed on a generic human body. These measures intend to be as self-explanatory a possible. Within Note, there is also an option for the OT to leave written comments or draw directly onto the summary report to further explain the case to the patient.



(a) Movement Lab's 3D scan viewer with tracking points enabled.

(b) Animated feedback displayed next to the static measures within Movement Lab.

Figure 7: *The two screens in which Movement Lab shows dynamic scan data.*

3.2.3 Movement Lab

Movement Lab is a program developed for the OTs to review the scans. Movement Lab consists of three major components, the scan viewer, the animated feedback, and the bio-mechanics report. The scan viewer can display the scanned image in 3D at the recorded rate of about 30 fps, with the tracking points, derived from the captured point cloud data (Figure 7a). These tracking points are intended to display the joints, and the trajectories the joints are traveling during the exercises. With the scan viewer, an OT can look at a person's movement pattern from every angle, without the limitations he or she would have in the real world, such as a floor through which an OT cannot physically move.

Movement Lab also provides something called animated feedback. With animated feedback, the 3D environment is shown next to a static image with simplified measures (Figure 7b). Which types of measures the static image show depends on the exercise and either contains absolute deviations from a baseline (Figure 6a - top), trajectories (Figure 6a - bottom), or weight distribution (Figure 6b).

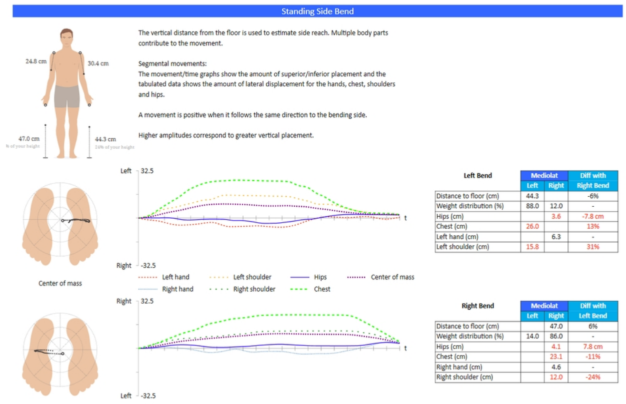


Figure 8: *Part of the static report generated by Movement Lab, showing balance, flexibility, and displacement during the side bend exercise.*

Next, to the 3D view and simplified measures, Movement Lab is also able to provide the OT with a full biomechanics report (Figure 8). This report provides detailed information about the movement of the patient, often displayed in either a graph or in tabular format. To interpret this data correctly, one needs either a background in biomechanics or kinesiology. Included in this report are:

- Trajectory angles - Average trajectory angles of during the different movement sections of the exercise
- velocity and displacement curves, these are static graphs displaying the velocity and displacement of tracked joint over time.
- Sway patterns - The path of the center of mass is projected on the floor and compared to the feet, displaying the balance correction done by the patient.
- Standing posture alignment - Describing the posture deviation in relation to the plumb line.
- Side bending flexibility - Numerical values describing the flexibility of the patient when bending to the left or right
- Axial rotation - rotation of both the pelvis and shoulders compared to the ankles

4 Requirements Engineering

Requirements for the new prototype system were gathered from multiple sources, increasing the discoverability of requirements. After discussions with Qinematic, it was decided that every function deduced from evaluating the current system would be labeled as *Must* for the final system, since Qinematic does not want the system to lose functionality. However, newly discovered requirements will have for implementation into the prototype. Doing so increases the change of new requirements being implemented in the prototype and available for validation by the OTs.

4.1 Gathering Requirements

The first requirements were gathered through analyzing the current system (Section 3.2), noting every scan or measure related functionality and transforming them into requirements (Appendix B). The other requirements supplied by Qinematic came from an earlier attempt to develop this platform. Several requirements were elicited during that development attempt, based on expertise and knowledge about the information they can display (Appendix B). The second source was the background literature (Section 3.1), supplying several techniques to describe human posture and movement. Requirements were stated in the *traditional style*, describing system behavior [6]. Apart from the requirements gathered for this study, there is one major constraint to which the prototype has to adhere. Qinematic wants the system to be accessible through a web browser; it is the reason this study started.

The user evaluation of the current environment was done by interviewing OTs. The participants of the user evaluation consisted of seven OTs; of these OTs, one was from the Netherlands and had his practice in Wageningen. The other OTs practice in the Stockholm area. All the interviews were recorded, except for the one in the Netherlands where only notes were taken. There was also a failed recording with one of the Stockholm based OTs. Notes of this interview were written down about an hour after the interview. Of the seven interviewees, two had minimal experience with the system and were therefore unable to provide much feedback on it. All the interviews took place in the practice of the OT who got interviewed. Appendix A contains an overview of the discovered requirements.

In general, the interviews did not produce a lot of new ideas. Possibly since the OTs are not always aware of what is technically possible. The most often mentioned improvements were all based on information and measures that were already available in the current system. One of the often mentioned improvements was highlighting a measure when it went over a literature-based threshold. A second one was a continuation of the threshold, which was marking the affected part on the 3D model. Where most interviewees generated one or two of the total 13 ideas mentioned in the interviews, there was one interviewee who mentioned almost every idea. Compared to the ideas and requirements from other sources, the interviews managed to discover just one additional idea.

One OT said he got confused with what was the left- and right side in the scan, he suggested to put the medical notation for left (Sin) and right (Dx) in the 3D environment. This way, confusion between left and right should be limited. As a requirement (B.24), this idea was extended to include front (anterior) and back (posterior) as well. Another often mentioned requirement was a side by side view (B.19 & B.18); OTs would like to be able to compare scans over time. A side by side view would especially be useful for them when checking the progress over time. It also makes it easier for the OT to explain to their patients where the progress is visible.

One OT was very keen on having some visual aid specifically for the side bend. He mentioned that he had a hard time comparing the flexibility when bending to the right and left. Although Movement Lab reports the numbers, he thought a visual aid would make it even easier and quicker. The other requirements generated through the interviews are in Appendix A, they are more thoroughly discussed in the next section.

4.2 Requirement Implementation

Appendix B contains all the gathered requirements, but redundant requirements were taken out. After which they were labeled for implementation into the prototype. Not every requirement was planned for implemented. Requirements that are already in Movement Lab can be tested and evaluated through Movement Lab. By skipping these for the prototype, there is more time to build and test new functionality. Appendix B shows an overview of the requirements and if they are planned for implementation.

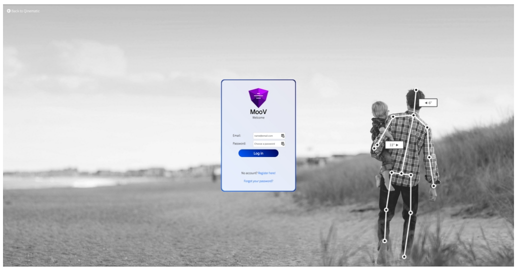
First, the constraints by Qinematic and the requirements necessary for the functioning of a 3D environment are marked for implementation; these include things as:

- Accessibility through multiple web browsers (B.1)
- Mobile or smaller screens support (B.2)
- The scan should be visible as a 3D object (B.3)
- The user should be able to rotate and zoom (B.5 & B.6)
- Basic playback controls (play, pause) (B.7)

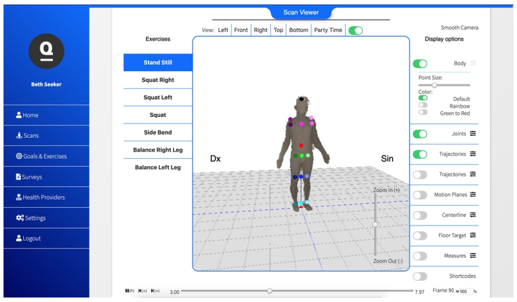
As mentioned before, requirements opted by the OTs and found through literature will receive a higher priority. Therefore, the 13 requirements mentioned by the OTs are up for implementation. Finally, the requirements only found in the literature are marked for implementation. Resulting in 21 requirements marked for implementation and seven not marked for implementation. Of these seven requirements, viewpoints (B.4), shoulder rotation (B.16), and pelvic rotation (B.17) only have Movement Lab as a source, and were therefore set to a lower priority. The other four remaining requirements had multiple sources, but were also very well testable through Movement Lab and therefore not marked for implementation.

5 Prototyping

A prototype (Figure 9b) was built to test the newly found requirements, functionality, and ways to communicate human movement and posture data. The prototype was tested with the same OTs who test Movement Lab, except for the OT from Wageningen, due to logistical issues.



(a) The login screen of the prototype



(b) The full scan interface of the prototype with the stand still exercise loaded.

Figure 9: *Screenshots from the prototype user interface.*

5.1 Development and Technical Specifications

The prototype was developed at the Qinematic office to get direct feedback from the people working at Qinematic if necessary. It allowed for quick answers to questions about human movement and posture and accurately program the guides and measures into the prototype. Development was stared with the authentication of the user since the prototype handles sensitive data, authentication is required from the start. The database and corresponding API (application programming interface) used for the prototype is hosted by SICS research institute in Stockholm. They build it as part of the previously mentioned attempt for this project. Since that project is over, SICS seized development of the database and API. The prototype is limited by this back-end, this resulted in a lot of workarounds and the prototype being slower than it could be. Apart from the displaying the scans, which will be discussed in section 5.3, the prototype also includes a more extensive user interface (UI) to give the OTs a better idea of the overall idea Qinematic has and to allow Qinematic to use it for demo purposes in the future.

The prototype includes two major open source software components and a preexisting API. The platform is built on NodeJS, an asynchronous event-driven JavaScript-based runtime. NodeJs was chosen because it is open source software and suitable for scalable (web-)applications. ThreeJS handles the 3D visualizations, ThreeJS is also an open source project, utilizing WebGL and Javascript to render 3D environments within the browser. The test data, available for this study, is stored on a separate server. A pre-configured API allows access to the data after log in. The various pre-existing API calls were determined based on the previous attempt and not eligible for change during this study. Due to the inefficiency of these calls, the scans took several seconds to load, severely diminishing the user experience. These limitations in data retrieval, impaired the build of the prototype and the loading of the 3D data takes several seconds because of it. Next, to these major components, there are several smaller components, handling various small tasks, such as PassportJS for authentication, PugJS for page rendering, and ExpressJS to handle sessions.

5.2 Requirements Implemented

The biggest constraint Qinematic set on the development of this prototype was accessibility. Qinematic wants their data and information to be accessible from as many devices as possible, preferably through the browser. The prototype was tested in multiple web-browsers, including Chrome, Firefox, Safari, Opera, Microsoft Edge, and Internet Explorer 11. Apart from some minor visual differences between browsers, the prototype runs on all off them without issues. These browsers together were good for 94,74% [16] of the internet browser market share in 2018. The platform was made responsive to guarantee access on both mobile and large screen devices. Responsiveness and widespread browser compatibility make the prototype effectively run on any modern device, satisfying Qinematics most significant requirement. Appendix C shows an overview of all the implemented requirements.

Of a total of 28 requirements, 21 were scheduled for implementation into the prototype before user testing. In the end, three of those did not get implemented due to technical difficulties. We failed to show two models side by side (C.18 & C.19) and converting the point cloud data into body segments (B.28) within the time available. However, three others not marked for implementation did make it into the prototype. These requirements were posture alignment (C.14), the average angle for the up and down movements (C.13), displaying scan details (C.9), and the different standard viewpoints (C.4). The reason that these requirements are in the prototype is that they could use the same function as other requirements, allowing implementation with only small adjustments.

5.3 Prototype Description

The first page shown when the prototype is opened is the login page (Figure 9a). After entering the correct credentials the OT is able to navigated his or her patient and their scans. Here the OT can view all the scans he or she made over time, including the reported areas of discomfort. After choosing a scan, the empty scan viewer is shown with the available exercises. The OT is then able to load and view the exercises one at a time. With a loaded scan the OT is able to zoom in and out and rotate around the scan. This allows the OT to look at the scan from every possible angle and level of detail. The OT also has the ability to use some of the preset viewpoints, which includes a front, top, bottom, left, and right view. Next to this the OT is able the manipulate the playback of the scan. The OT is able to play, pause, and manually navigate through the timeline of the scan. It is also possible to increase and decrease the playback speed of the scan.

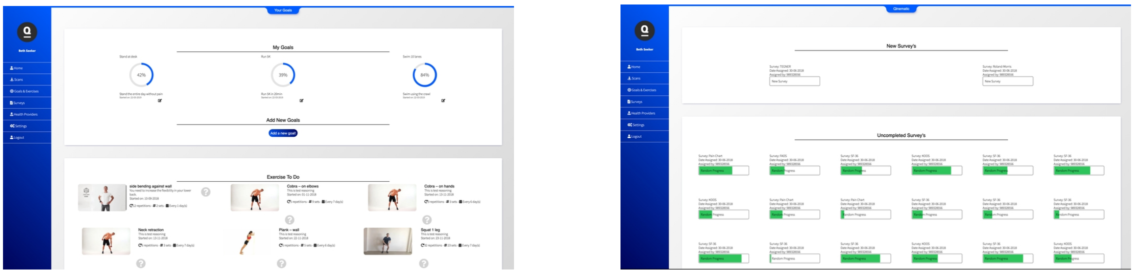
With the prototype the OT is also able to add and remove measures, guides, and the raw scan data which was not available with Movement Lab. The OT is also able to manipulate some of the guides and measures themselves. The OT is able to manipulate the body image of the scan. The body is rendered as a point cloud, the OT is able to adjust the size of these points, this way he or she is able to mimic low and high opacity of the body. The OT is also able to change the color of the points based on distance from the center, these gradients allow the OT to better distinguish depth in the scan. The OT is able to choose three different gradients, all are shown in Figure 11a. It is also possible to adjust the size of the tracking points and the size of the trajectories in the same way as the body point cloud.

The prototype is also able to mark areas of interest (AoI) based on the Qinematic data analysis, these AoI's stand out according to the Qinematic system and might need extra attention from the OTs. These AoI's are marked in red on the body point cloud (Figure 11a). It is the same for the numerical measures, the OT is able to display numerical depending on the exercise currently loaded. If these measures deviate from the literature based norm, they are marked in red (Figure 12a).

Another guide in the prototype are the anatomical planes (Figure 12b). The OT is able to switch these planes on and off, all at once or every plane separately. It is also possible for the OT to make the separate planes transparent or opaque. If these anatomical planes are to obtrusive, the OT can choose to use the plumb line instead (Figure 13a). This line runs from the base of support, which is the mid ankle with double-legged exercises and the ankle with one-legged exercises, straight up to cover the height of the scanned person. There is also an option for a small grid below the feet, this is called the floor target within the prototype (Figure 13b). The floor target aims to assist the OT discovering dysfunction from below. In addition to the plump line and floor target; the prototype displays a floor grid and background grid, different from the other measures these grids can not be turned off.

The final guides implemented in the prototype are the linkage system (Figure 14a) and standing posture (Figure 13a). The linkage system is a stick figure like depiction of the exercise, it simplifies the body of the person and puts the emphasis on the movement. Standing posture as described in Section 3.1.5, is meant to determine posture when standing upright and still. It is however available for every double legged exercise.

Apart from these measures and guides, the prototype has some added functionality. These were added either on request from Qinematic, who would like to use it for demo's in the future, or to speed up development and testing. Qinematic requested some rudimentary functionality for goal setting (Figure 10a), exercises and survey assignment (Figure 10b), and user profiles. To decrease development time and testing time the prototype has the ability to use hotkeys to toggle camera view points, playback, and measures or guides.



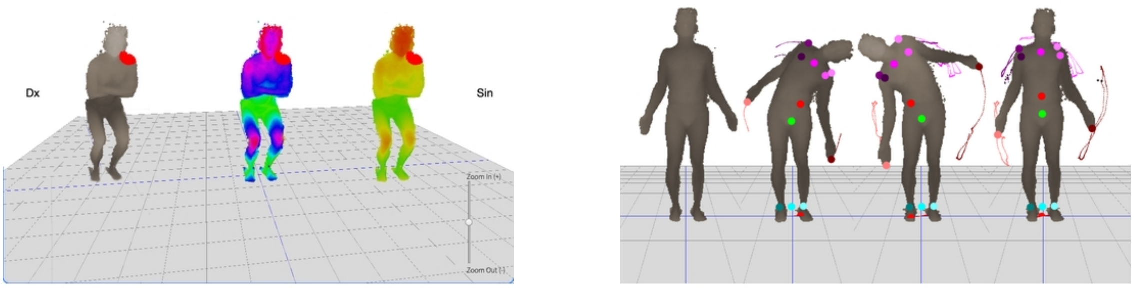
(a) Screenshot of the goals and assigned exercises overview

(b) Screenshot of the survey overview

Figure 10: *Screenshots from the prototype user interface for Qinematic future demo's.*

5.4 Requirement Evaluation

Evaluating the prototype was, similar to the current system evaluation, a semi-structured interview with slightly different questions (appendix D). The same interviewees as in the first round participated, except the OT from the Netherlands due to logistical issues. All interviews were recorded and stored in the same location as the others. In general, the OTs were very enthusiastic and initially surprised by the progress made with the prototype. During these interviews, the OTs got a better idea of what was possible for the project and were able to generate more ideas to improve the prototype. Although the background grid was implemented before testing, it failed to show during the interviews. Therefore it was decided to leave the background grid out of the figures, to better represent the interview conditions. All OTs did however mention the missing background grid, meaning the background grid is an important feature to have.



(a) Different color gradients combined with the area of interest (adapted from screenshots).

(b) Movement of tracking points builds trajectories (adapted from screenshots).

Figure 11: *Adapted screenshots from the prototype to better compare differences.*

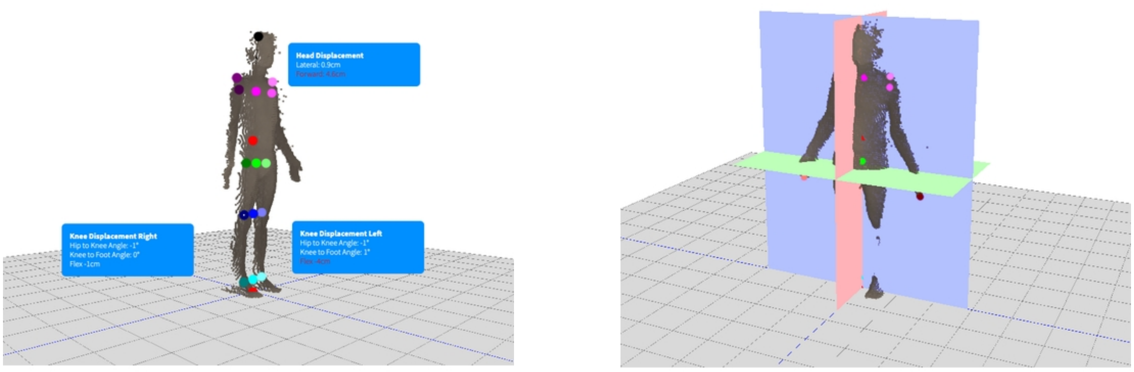
5.4.1 Color & Highlighting

The color gradient got received very well, all but one OTs liked it and saw value in using it for better depth perception. It was noted that the colors for the gradient should carefully be chosen. Since the highlighting function in the prototype using red for problem areas, two OTs expressed second thoughts about using red in the gradients as well (Figure 11a). The two uses for the color red could easily get mixed up. There was one OT unsure about the color gradient for depth perception; he thought it would be easier to see this from the side view.

Highlighting and measures that are higher or lower than thresholds from the medical literature was perceived as a potentially time-saving feature by all OTs. The area of interest is marked in red on the 3D scan, this, as discussed, is an issue and needs adjustments. The red highlighting of the values that are reported did not have this issue (Figure 12a) and was well received by the OTs.

5.4.2 Tracking Points & Trajectories

Although the tracking points are also available in the current system, they were considered essential enough and too closely related to displaying of trajectories to be left out of the prototype. The tracking points, in combination with the trajectories, were considered beneficial and helped solve several issues mentioned during the evaluation. They allow the OTs to better asses the movements of particular joints over time. They also help in assessing flexibility in the side bend through visual aids, as mentioned in section 3.2. Through the use of trajectories, the flexibility of a patient is fairly easily spotted now (Figure 11b).



(a) Annotations and measures displayed next to the 3D model in the prototype.

(b) The anatomical planes with the 3D model used to describe movement.

Figure 12: *Screenshots from the prototype.*

One of the OTs did raise an issue with the colors used for the tracking points and trajectories. The tracking points were given different colors to distinguish them in the top and bottom views better. Light blue for the feet, dark blue for the knees, green for the hips, pink for the shoulders. With a slightly lighter shade of the color on the left side compared to the right side. The slight difference in shading is where the issue lays; the OT felt it distorted the image since the lighter shade felt higher in 3D space than the darker shade, while they were actually on the same level.

Another issue was raised with a specific tracking point, the Center of Mass (CoM). The CoM is effectively depicted twice in the scan viewer, once at its actual location, and once as a projection on the floor, for the posture sway (The two red dots in Figure 11b). The suggestion arose to link them with a dotted line for more clarity and also make them look more different than the other tracking points. It is not always clear it concerns the CoM.

5.4.3 Anatomical planes, reference lines, and grid lines

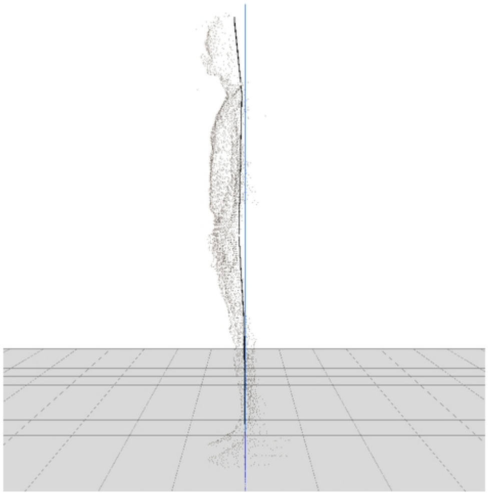
When assessing movement, OTs use a lot of reference lines and points. These references provide a stable base to compare movement patterns. Within the prototype, there are several references available for use. Anatomical planes are one of them (Figure 12b). Anatomical planes are a reference for describing the motion of the body or body parts, especially in textbooks. The planes were considered useful by four out of six OTs; one found it interesting but did not how it would be useful, while the last one did not like it at all.

Other references made a better impression, one of them being the plumb line. The plumb line is a straight line to which the standing posture aligns if it is textbook perfect (Figure 13a). The reference allows the OT to spot posture deviations easily, which was the main reason they liked it so much. Although the plumbline is well received by all six OTs, it does need more research. In the prototype, the plumbline originates from the mid ankles of the first frame of the scan. After consulting Qinematic, on where the origin of the plumbline should be, this was the decision. It was in line with the plumbline location where the data of the bio-mechanics report is based on. One OT questioned its origin. Unfortunately, he was not able to provide an alternative at that moment.

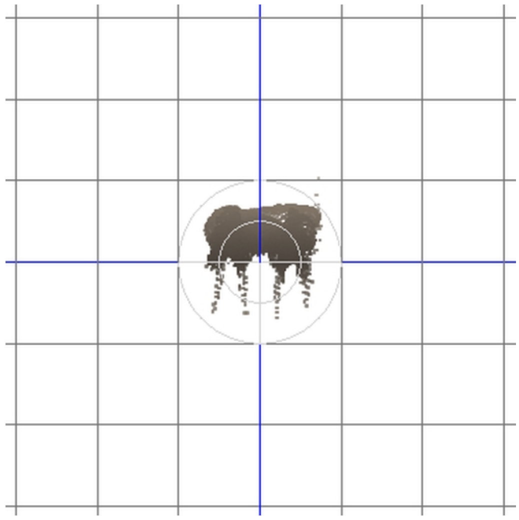
Every OT noticed the missing background grid before being asked about it, implying that the background grid in the current system was a welcome feature for the OTs. Although it could have been a little more present according to some OTs, and it needs to be in the new system. The floor grid and floor target were working during the interviews (Figure 13b) and were considered valuable by the OTs, although they were unsure about the floor target when the grid is already present.

5.5 New Requirements

The OTs seem to have gotten a better grasp of what is technically possible and how it could help them during their work. During the second round of interviews, they suggested new ideas



(a) Standing posture alignment (black) compared to the plumb line (blue).



(b) An exercise viewed from the bottom, in most of the offices OTs work in, an unobtainable perspective.

Figure 13: *Screenshots from the prototype.*

(Appendix E) to try out for the next iteration, and in general, seemed more enthusiastic about the project.

5.5.1 Optional and Simplification

Although the OTs liked most of the new functionality, they were a little overwhelmed initially. All though it was possible to switch off features and options, be it through a button or through coding. Most of the OTs still wanted to make sure all the options would be made optional. Each guide, option, or visual should be optional, meaning the OTs want to be able to turn off everything. Preferably they want the system to start with just the point cloud, nothing else. Some OTs also suggested limiting some functionality for other OTs, since some might not have the training required to use it. Limiting it and first letting OTs go through a (video)tutorial, before opening the functionality was suggested multiple times.

The same issue arose regarding the patient view for the scan. The OTs were very concerned that the complexity would distract from the actual message. They suggested to take out functionality. One OT suggested to exchange the 3D point cloud for an avatar and keep it the same for every user without the proper knowledge, while another OT suggested showing pre-rendered animations or videos to the patient, without the interaction aspect.

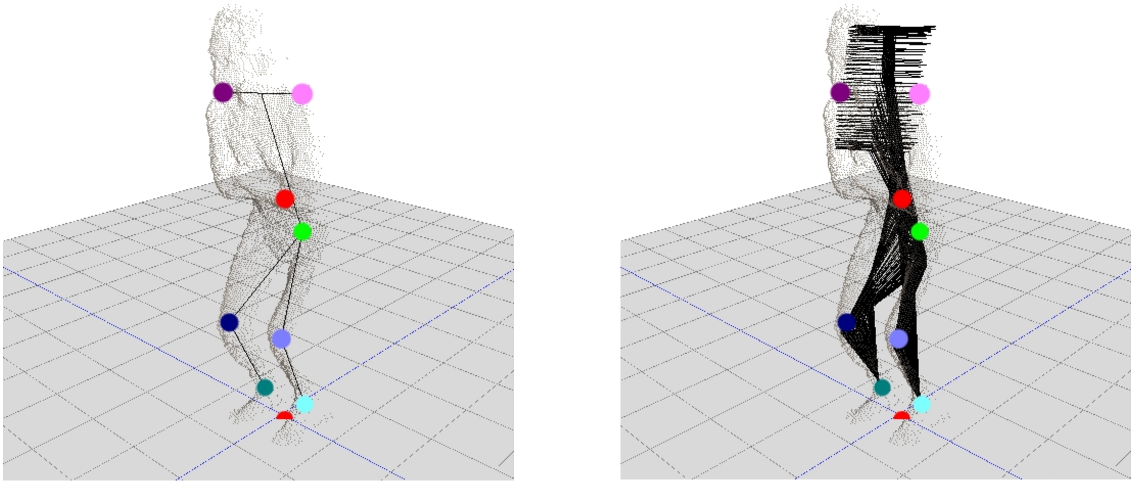
5.5.2 Calculations

Another suggestion was to calculate basic biomechanical forces to estimate the force exerted on joints. These forces might give insight into the extra stress acting on joints due to a suboptimal posture. It could be combined with highlighting if the forces exceed a certain threshold. Another

OT relies heavily on the use of grids and lines during his assessments, not only with this system but also other systems. The let to the idea of drawing lines in the prototype and calculate angle with them. This OT also suggested using the system in combination with a pressure plate, the combination between the movement and foot pressure seemed very interesting to him.

5.5.3 The Spine

One OT is currently looking into spine shapes. He suggested adding a scan of the back to evaluate the spine shape of a person. His work is based on a study into Roussouly classifications of the spin [17]. In this study, they investigated spine types based on pelvic incidence (PI) and pelvic tilt (PT). These measures might be detectable through the Qinematic system as well.



(a) The linkage system in the prototype, shown without the bug.

(b) The linkage system in the prototype, shown with the bug.

Figure 14: *Screenshots from the prototype.*

5.6 Miscellaneous results

Not all functionality in the new platform is the result of interviews or research. Some functionality come to be through discussions about the progress of the prototype in the Qinematic office. These situated requirements are often small changes, options or ideas. One of the bigger ones being the ability to increase or decrease the playback speed of the point cloud. Another, which for some reason all the OTs mentioned was better accessibility of the preset camera views. Within the current system, they are hidden underneath a button, requiring an extra click. Playback controls do not differ much from the current system, apart from the ability to adjust the playback speed, which was a welcome addition.

The linkage system is, in essence, a stick figure representation of the movement. It allows the OT to remove the body to get a clear and simplified representation of their patient (Figure 14a). The linkage system on its own was considered useful by only half of the interviewed OTs. However, during one of the interviews, there was a bug, where it stopped removing the linkage system from the previous frame (Figure 14b). The OT was intrigued and thought something like it could also be useful.

6 Conclusion

The goal of this study was to find ways that would assist the OT in the assessment of dysfunction in the posture and movement data of a patient. After studying the current system of Qinematic, doing literature research into medical imaging, and interviewing OTs, 28 initial requirements were established for the prototype system. The prototype eventually contained 21 of the requirements for testing with OTs. The OTs thought the newly found ideas were beneficial and improvement for the assessment of their patients. The suggested improvements and additions to the prototype, supply Qinematic with great potential in supporting the OTs in their assessment. The interviews showed that the OTs were confident about the new functionality introduced by the prototype. Especially the color gradients and trajectories seem to be of great value to OTs in their assessment work, liked by five out of six and all six OTs respectively. The same goes for the reference lines and anatomical planes added to the prototype. A majority of the OTs liked the anatomical planes and plumb line introduced through the prototype, liked by four out of six and all six OTs respectively.

Also, the secondary goal, a working web-based prototype, of the study was met. The prototype was well received by Qinematic and development will continue. Through the evaluation of the prototype, new ideas were generated and some issues with the implementation of the requirements were raised. For instance the starting point of the plumb line is up for discussion. This leaves plenty of room for improvement in the development of the platform. Next to edits for the requirements currently in the prototype, new requirements were found. In total 13 new requirements and ideas were found through prototype evaluation (Appendix E).

6.1 Discussion

A potential drawback to this study is the fact that the study is part of a global effort to analyze human movement and posture. However, the prototype was only tested in the Stockholm area, this may cause biased results. Another drawback might be the number of people interviewed for this study. Only seven people were assessing the current system, of which some had minimal experience, even for this niche project that is a small sample size. A few more in interviews were planned in the Netherlands, but were canceled due to scheduling issues. By the time this problem emerged, the time frame for this study was coming to an end. To counter the lack of experience with the system it might have been better to focus the questions more on the workflow they had before the introduction of the system, that way more insights could have been generated from those participants. A contingency for the lack of interviewees could have been a brainstorming or co-creation with multiple OTs. The prototype was evaluated with six OTs, it might have been possible to extent it to testing with OTs who have not used the Qinematic system before.

6.2 Future Work

This study showed that there are multiple techniques and visuals out there that increase the effectiveness of the system in assisting the OT in the assessment of the patient. The next step for Qinematic would be to improve the functionality in the prototype and test the new requirements generated during the prototype evaluation (Appendix E). The prototype is still very rough and might perform significantly better when given more attention. For example the CoM, the suggestion to link the actual CoM with the one projected on the floor is one of those improvements that might be very beneficial, but also the previously mentioned plumb line needs further testing. Another example would be the missing background grid. The missing grid was noticed by every OT, therefor it seems that it is an important feature for the prototype to have. Also the newly found requirements need to be implemented and tested with the OTs. Currently there are 41 requirements found of which 20 are implemented in the prototype (Appendix E). All in all, the prototype performs well; there is a lot to gain in fine tuning the functions introduced and improving user-friendliness.

References

[1] WHO. *Global Health Expenditure Database*. URL: http://apps.who.int/nha/database/Select/Indicators/en. (accessed: 04.04.2019).

[2] Cohen, Joshua T, Neumann, Peter J, and Weinstein, Milton C. “Does preventive care save money? Health economics and the presidential candidates”. In: *New England Journal of Medicine* 358.7 (2008), pp. 661–663.

[3] Burt, HA. *Effects of Faulty Posture: President's Address*. 1950.

[4] Khoshelham, Kourosh. “Accuracy analysis of kinect depth data”. In: *ISPRS workshop laser scanning*. Vol. 38. 1. 2011.

[5] Turner III, Daniel W. “Qualitative interview design: A practical guide for novice investigators”. In: *The qualitative report* 15.3 (2010), pp. 754–760.

[6] Sikkel, Klaas and Daneva, Maya. “A primer on Requirements Analysis”. In: (2014).

[7] Galley, PM and Forster, AL. *Human movement: An introductory text for physiotherapy students*. Churchill Livingstone, 1987.

[8] Commons, Wikimedia. *File:Human anatomy planes.svg — Wikimedia Commons, the free media repository*. [Online; accessed 1-May-2019]. 2017. URL: https://commons.wikimedia.org/w/index.php?title=File:Human_anatomy_planes.svg&oldid=258490882.

[9] Massion, Jean. “Postural control system”. In: *Current opinion in neurobiology* 4.6 (1994), pp. 877–887.

[10] Moore, Keith L, Dalley, Arthur F, and Agur, Anne MR. *Clinically oriented anatomy*. Lippincott Williams & Wilkins, 2013.

[11] Shah, Karan. *Building A Basic Low Poly Character Rig In Blender - Step 30*. [Online; accessed 1-May-2019]. 2012. URL: https://cgi.tutsplus.com/tutorials/building-a-basic-low-poly-character-rig-in-blender--cg-16955.

[12] Woodhull, AM, Maltrud, K, and Mello, BL. “Alignment of the human body in standing”. In: *European journal of applied physiology and occupational physiology* 54.1 (1985), pp. 109–115.

[13] University, Heidelberg. *Demo of a Dechen Cave scan showcasing the Potree open-source WebGL based point cloud renderer*. [Online; accessed 1-May-2019]. 2012. URL: http://potree.org/potree/examples/showcase/dechen_cave.html.

[14] Schuetz, Markus. *Potree*. URL: http://potree.org/.

[15] Ropinski, Timo, Steinicke, Frank, and Hinrichs, Klaus. “Visually supporting depth perception in angiography imaging”. In: *International Symposium on Smart Graphics*. Springer. 2006, pp. 93–104.

[16] NetApplications.com. *Browser Market Share*. URL: https://netmarketshare.com/browser-market-share.aspx. (accessed: 27.05.2019).

[17] Laouissat, Féthi et al. "Classification of normal sagittal spine alignment: refounding the Roussouly classification". In: *European Spine Journal* 27.8 (2018), pp. 2002–2011.

Appendices

Appendix - Contents

A Interview Questions for the Current System

1. How would you describe your experience in the system so far?
   - What do you like about the current system?
   - What do you dislike about the current system?
2. How has the system helped or limited you in diagnosing dysfunction?
3. Which parts of the system do you use for your diagnosis?
   - What is useful about part X?
   - Why do you not use unused part Y?
4. Are you missing functionality, guides or measures within the system?
5. Do you use tools or measures from outside of the system for your diagnosis's?
6. Is there anything else you would like to see differently?
7. Is there anything else you would like to add?

B Initial requirements

#	SOURCES	DESCRIPTION	PLANNED
B.1	Q	The platform should be accessible through multiple web browsers	✓
B.2	Q	The scan should also work on mobile or smaller screens	✓
B.3	Q, ML, I	The scan should be visible as a 3D object	✓
B.4	ML	The user should be able to view the scan from different viewpoints (front, left, right, back) by clicking a button	✗
B.5	Q, ML	The user should be able to rotate around the scan	✓
B.6	Q, ML	The user should be able to zoom in and out	✓
B.7	Q, ML, I	The user should be able to influence playback (play, pauze, next & previous frame)	✓
B.8	Q	The user should be able to increase and decrease the playback of the scan.	✓
B.9	Q, ML	Scan details should be accessible (Date, Time, Personal details)	✗
B.10	Q, ML, I, L	Scan measures derived from the scan, such as angles and displacement should be visible from within the scan environment	✓
B.11	Q, ML, I	Tracking points should be displayed	✓
B.12	Q, I	Trajectories of the tracking point should be displayed	✓
B.13	Q, ML	Average angles of joint trajectory in the up and down movements	✗
B.14	Q, ML, L	Display posture alignment compared to the plumbline	✗
B.15	Q, ML, I, L	Display movement of center of mass, including a projection on the floor for posture sway	✓
B.16	ML	Display shoulder axial Rotation	✗
B.17	ML	Display pelvic axial Rotation	✗
B.18	ML, I	Display the single leg exercises left and right side by side	✓
B.19	I	View two scans, an older one and a new one, side by side	✓
B.20	ML, Q, I	Display a grid on floor and wall	✓
B.21	ML, L	Report movement velocity	✗

#	SOURCES	DESCRIPTION	PLANNED
B.22	ML, L	Report movement curves	✗
B.23	Q, I	Highlight areas of interest	✓
B.24	I	Display Dx, Sin, Antirior and Posterior to help with the orientation of the 3D model	✓
B.25	I, L	Color the 3D scan with a color gradient to better interpret depth	✓
B.26	L	Display the anatomical planes	✓
B.27	L	Display the linkage system to better illustrate joint connections	✓
B.28	L	Display the body segments	✓

Table 1: Generated Requirement in no particular order, their source, priority and if they are planned for implementation
Source explanation: Q = Qinematic, ML = Movement Lab, L = Literature, I = Interview

C Updated Requirements

#2	DESCRIPTION	PLANNED	IMPLEMENTED
C.1	The platform should be accessible through multiple web browsers	✓	✓
C.2	The scan should also work on mobile or smaller screens	✓	✓
C.3	The scan should be visible as a 3D object	✓	✓
C.4	The user should be able to view the scan from different viewpoints (front, left, right, back) by clicking a button	✗	✓
C.5	The user should be able to rotate around the scan	✓	✓
C.6	The user should be able to zoom in and out	✓	✓
C.7	The user should be able to influence playback (play, pauze, next & previous frame)	✓	✓
C.8	The user should be able to increase and decrease the playback of the scan.	✓	✓
C.9	Scan details should be accessible (Date, Time, Personal details)	✗	✓
C.10	Scan measures derived from the scan, such as angles and displacement should be visible from within the scan environment	✓	✓
C.11	Tracking points should be displayed	✓	✓
C.12	Trajectories of the tracking point should be displayed	✓	✓
C.13	Average angles of joint trajectory in the up and down movements	✗	✓
C.14	Display posture alignment compared to the plumbline	✗	✓
C.15	Display movement of center of mass, including a projection on the floor for posture sway	✓	✓
C.16	Display shoulder axial Rotation	✗	✗
C.17	Display pelvic axial Rotation	✗	✗
C.18	Display the single leg exercises left and right side by side	✓	✗
C.19	View two scans, an older one and a new one, side by side	✓	✗
C.20	Display a grid on floor and wall	✓	✓

#2	DESCRIPTION	PLANNED	IMPLEMENTED
C.21	Report movement velocity	✗	✗
C.22	Report movement curves	✗	✗
C.23	Highlight areas of interest	✓	✓
C.24	Display Dx, Sin, Antirior and Posterior to help with the orientation of the 3D model	✓	✓
C.25	Color the 3D scan with a color gradient to better interpret depth	✓	✓
C.26	Display the anatomical planes	✓	✓
C.27	Display the linkage system to better illustrate joint connections	✓	✓
C.28	Display the body segments	✓	✗

Table 2: Updated Requirements in no particular order, if they are planned for implementation, and if they were actually implemented

D Interview Questions Prototype System

1. What are your first thoughts seeing this prototype?
   - What do you like about it?
   - What do you dislike about it?
2. This is part X, what are your first thoughts?
3. Does part X seem useful to you?
4. Would you use it during your work?
5. Are you missing functionality, guides or measures within the prototype?
6. Is there anything else you would like to see?
7. Do you have other suggestions to improve the prototype?

E All Requirements

#	DESCRIPTION	STATUS
E.1	The platform should be accessible through multiple web browsers	Implemented
E.2	The scan should also work on mobile or smaller screens	Implemented
E.3	The scan should be visible as a 3D object	Implemented
E.4	The user should be able to view the scan from different viewpoints (front, left, right, back) by clicking a button	Implemented
E.5	The user should be able to rotate around the scan	Implemented
E.6	The user should be able to zoom in and out	Implemented
E.7	The user should be able to influence playback (play, pauze, next & previous frame)	Implemented
E.8	The user should be able to increase and decrease the playback of the scan.	Implemented
E.9	Scan details should be accessible (Date, Time, Personal details)	Implemented
E.10	Scan measures derived from the scan, such as angles and displacement should be visible from within the scan environment	Implemented
E.11	Tracking points should be displayed	Needs improvement
E.12	Trajectories of the tracking point should be displayed	Implemented
E.13	Average angles of joint trajectory in the up and down movements	Implemented
E.14	Display posture alignment compared to the plumbline	Implemented
E.15	Display movement of center of mass, including a projection on the floor for posture sway	Needs improvement
E.16	Display shoulder axial Rotation	Implemented
E.17	Display pelvic axial Rotation	Implemented
E.18	Display the single leg exercises left and right side by side	New
E.19	View two scans, an older one and a new one, side by side	New
E.20	Display a grid on floor and wall	Needs improvement
E.21	Report movement velocity	Needs improvement
E.22	Report movement curves	Needs improvement

#	DESCRIPTION	STATUS
E.23	Highlight areas of interest	Needs improvement
E.24	Display Dx, Sin, Antirior and Posterior to help with the orientation of the 3D model	Implemented
E.25	Color the 3D scan with a color gradient to better interpret depth	Implemented
E.26	Display the anatomical planes	Implemented
E.27	Display the linkage system to better illustrate joint connections	Needs improvement
E.28	Display the body segments	New
E.29	The user is able to manually draw lines and measure angles with them	New
E.30	The user is able to connect with pressure plates used during the scan	New
E.31	Show classified spine shapes	New
E.32	Show bio mechanical stress areas	New
E.33	The user is able to turn off every measure and visual	Needs improvement
E.34	Differentiation between measures over a threshold and measures with in range	New
E.35	Show in the playback timeline when the exercise changes direction	New
E.36	The user is able to switch between avatar and point cloud as a 3D model	New
E.37	Show a pre-rendered movie for patient	New
E.38	Display scores for the exercises	New
E.39	The user is able to view a back side scan	New
E.40	The user is able to unlock measures and visuals through tutorials	New
E.41	The user is able to resize the points in the point cloud	implemented

Table 3: An overview of all the requirements generated during this study.