Technical University of Munich

Department of Informatics

Bachelor's Thesis in Informatics: Games Engineering

Visual Augmentation To Improve Bench Pressing Form

Jonas Helms

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Visuelle Hilfestellung zur Verbesserung der Form beim Bankdrücken

Author:	Jonas Helms
Supervisor:	Prof. Dr. Gudrun Johanna Klinker
Advisor:	Sandro Weber
Submission Date:	16 December 2019

I confirm that this bachelor's thesis is my own work and I have documented all sources and material used.

Garching, 16 December 2019 Jonas Helms

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1 Introduction

In todays times the lack of vigorous exercise, a sedentary lifestyle and the health implications that are attached to these problems have become issues that are not only restricted to the developed world, but to society as a whole [7]. The World Health Organization even predicts that Cardiovascular problems like Coronary Heart Disease (**CHD**) and Strokes will be the leading cause of death in the world for the next 40 years (Table 1.1 [48]). Studies have shown that regular exercise is a contributing factor for the prevention of both Strokes [34] and CHD's [28]. As more people become aware of the negative health effects from the lack of exercise, membership in health clubs like gyms is increasing steadily [9] [45] but even though membership is rising, gym members, especially in the beginning of their subscription, have high rates of termination [8]. One notable factor may be the difficulty of learning how to use the equipment and how to perform the exercises correctly as outlined by [20]. Contributing to this diffculty of entry is the fact that the availabiltiy of fitness trainers in a gym can vary greatly, depending on the price point, location and time of day, leading to uninstructed or unskilled approaches which can be especially dangerous for beginners. This is particulary true in the category of weight training exercises which have the highest injury rates in fitness centers [14]. Applying the correct technique in an exercise plays a major role in the prevention of injuries as incorrect technique can lead to a reduced amount of applied strength during the weight training activity and thus to dropped weights or overexertion [18] [16], which are the two leading causes of injury during free weight training [14]. To combat these problems there are a plethora of tutorials on the correct execution of gym exercises available on todays video streaming platforms, but some exercises are difficult to observe for yourself and need an outside perspective to assess comprehensively. One fitness routine that is notably hard to evaluate is the bench press as you are bound to a lying position on a bench. The use of mirrors, although helpful, may not be enough as it only provides an introspection of two of the axis of movement and lacks direct visualization of the mistakes that are made. One option to help members in fitness clubs would be to automate the whole process by using 3D motion capture systems that are usually employed by sports scientists in performance labs, however these systems are not fit for use in the everyday gym setting as they are very expensive and difficult to calibrate. This would result in the need for human supervision by gym staff for the motion capture system which directly cancels out the benefit of automation (The gym staff could then give feedback on the execution directly). The only sensible way to automate feedback on the quality of execution for certain exercises would need a motion capture system that is reasonably cheap and can be used without further input once it is set up. The Kinect camera system developed by Microsoft has already been used and studied in the assessment of the injury risk for bodyparts like the Anterior cruciate ligament [39] and could therefore offer a solution to said problem [26].

Table 1.1: WHO prediction for causes of death [48]

Cause of death \ Year	2016	2030	2045	2060
Coronary Heart Disease	16.6%	17.2%	17.0%	16.3%
Stroke	10.2%	10.5%	10.8%	10.6%

1.1 Research question

Following the problem statement in the introduction, the research question that is formulated is the evaluation of a visual feedback system for the qualitative execution of the bench press fitness exercise that uses the Microsoft Kinect as its motion capture system. The program will be examined in terms of usability and also whether it is feasible to use the Kinect for this purpose.

1.2 Structure of the thesis

The first part of this thesis will portray background information on the development and technology integrated in the Kinect. Furthermore it will look at different applications the Kinect was already used and studied in, with focus on the use in sports exercises and healthcare. Following the section of the Kinect is the theoretical background of the bench pressing exercise, describing the different styles that are most commonly used today as well as the advantages and disadvantages pertaining to the styles. Afterwards it will describe the system that was developed as part of the thesis, going in-depth into the factors of the bench press that were chosen to evaluate, which algorithms and variables were implemented and finetuned to make use of the data streams the Kinect provides and which challenges proved to be difficult in the development. Finally there will be an evaluation of the usability study and the Kinect data gathered during the study that was conducted as part of this thesis. These results will be examined in the discussion in order to provide a judgement on the viability of the presented system. Further improvements in terms of technology and methology will be described in the Outlook.

1.3 Goal of this thesis

Goal of this thesis is to assess the general feasability of the Kinect as a motion capture system for the bench press exercise and the usability of the presented system. The system was developed with the goal of creating a simple to use exercise assistance with a feedback visualisation that needs no further explanation or help from a second party and that is completly independent from the body dimensions of its user.

2 The Microsoft Kinect

The Microsft Kinect was originially developed as a peripheral for the gaming console Xbox 360 and was released on November 4th 2010. The Kinect was supposed to replace the original game controller by using gestures and voice commands [46]. Although it gained traction as a completly new and affordable input method the expected success failed to materialise as it did not manage to attract investments from big budgeted video game franchises like Call of Duty or Grand Theft Auto [47]. To detect a player the Kinect uses a depth sensor to create a representation of the 3D scene which is then interpreted using motion analysis to provide a joint skeleton of the player. The algorithm for the skeleton tracking was developed by training a randomised decision forest algorithm using 100,000 depth scans of human movement such as kicking, dancing, navigating menues ect. [35]. Furthermore the Kinect features facial and voice recognition using its RGB-camera and microphone array respectively.

2.1 Kinect for Xbox 360

The original Kinect used a technique called known as "light coding" for the creation of its 3D scene. In light coding a infrared projector projects a pre-generated maps of infrared dots into the scene. The reflection of the infrared dots is then received by a second infrared camera, a monochrom CMOS sensor, which compares the received pattern to one that is hard-coded on the chip to calculate the distance of the object from the sensor[49].

2.2 Kinect for Windows

In February 2012 Microsoft released a new version of the Kinect using the same hardware specification as the Kinect for Xbox 360 but with access to support and ongoing software updates specifically for the Kinect for Windows version. Alongside this was the release of the Kinect Windows SDK allowing researchers and Kinect devotees to develop software with the Kinect for windows applications [46].

2.3 Kinect for Xbox One

On the 22nd of November 2013 Microsoft released an updated version of the Kinect for their new gaming console Xbox One. Before June 2014 all Xbox One gaming consoles included the new Kinect. This version of the Kinect included a new depth camera, had a wider angle of view and a generally higher fidelity as well as a different technique for the detection of the scene called time-of-flight [46]. In time-of-flight cameras the distance of an object is calculated by the round trip time of an laser back to its origin. The time shift which is detected in each sensor pixel at the origin is then translated into the sensor-object distance. This version of the Kinect specifically uses a periodic laser pulse which translates to a phase shift at the sensor and makes use of correlation images to counteract the deformation of the signal by nonlinear effects [32]. Although it was an upgrade in terms of technology, the Kinect for Xbox One resulted in a great deal of controversy for Microsoft [47]. This was due to a later redacted requirement that enforced the Kinect to be plugged into the console to be able to be used by the player. This limitation also had technical implications as the Kinect for Xbox One reserved processing power, even if the Kinect was not used by the game the Xbox was currently running, thus decreasing its potential performance [46]. Microsoft later removed this limitation.

2.4 Kinect for Windows V2

In June 2014 Microsoft released the standalone windows version for the Kinect for Xbox One [12]. Similiar to the Kinect for Windows, this variant of the Kinect was just a repackaging of the Xbox version, released alongside the new Windows SDK 2.0.

2.5 Joint tracking in the Kinect for Windows V2

The Kinect for Xbox One is able to the track twenty-five different joints shown in Figure 2.1. The joints referenced in the later part of this thesis are named after the convention used in Figure 2.1.

2.6 The utilization of the Kinect outside of gaming

Since the release of the first windows SDK for the Kinect developers and enthusiasts started creating software in many different areas ranging from education on anatomy [27], as an learning tool for children with autism [5], to the use of the depth sensor in robotics [21] [10] as well as healthcare, for example in the recognition of anterior cruciate ligament injury risk [13].

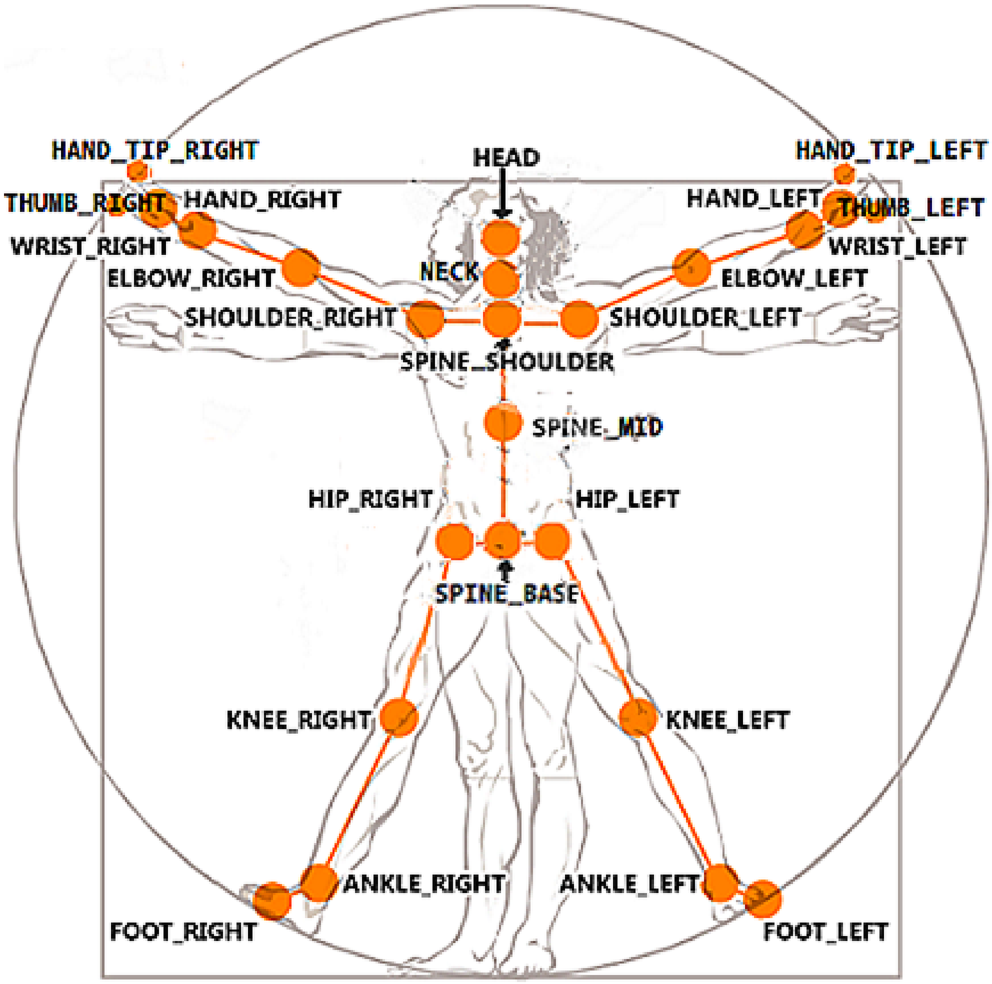

Figure 2.1: Joints the Kinect for Xbox One is tracking[17]

2.7 The use of the Kinect in exercise and sports applications

The majority of studies that have analyzed the Kinect in a sports context have done so in the context of an upright position for example in dancing [19], badminton training [40] and gait analysis [29]. The latter gait study by Pfister (2014) acknowledges the potential use for the Kinect but declares the need for advances in soft and hardware before the Kinect is feasible for clinical use. A review of twelve studies on gait posture from 2016 [37] has similar findings and assesses that spatiotemporal gait parameters have an overall good validity while variables for kinematics seem to be lacking. A study by Wang from the year 2015 [43] compared the accuracy between the first and second generation of the Kinect. This was done by selecting several different body postures, also including sitting positions, and contrasting the detected values for the joints with the values from the marker based system Impulse X2 from PhaseSpace. The data gathered in the study shows a lower standard deviation in sitting than in standing positions for the joints in the upper body [43]. However these findings could be the result of the difference in chosen activities for both positions as the goal was to compare the two different Kinect versions. The standing exercises inclduded higher frequency movement such as jogging, clapping and punching while the sitting exercises included praying, standing up from a chair and raising one knee [43]. No studies were found in the research for this thesis that determined the validity of the Kinect for horizontal or near horizontal body positions such as the bench press.

3 The Bench Press exercise

The bench press is an exercise that is usually performed by lying on a bench and pushing a barbell with added weights or a set of dumbbells upwards from your chest. Additionally it has become common to let a "spotter" stand behind the bench who is ready to catch the bar if the lifter is experiencing problems during the exercise. One of earliest known variations of the bench press in which a world record was performed was the so called "floor press" by George Hackenshmit in the year 1899 [44]. For the floor press a bar got rolled over the lifter while he was lying on the floor which the performer was then supposed to push upwards. Since then the bench press has gained increased popularity and gone through many iterations with several different styles and techniques emerging over the years.
The movement from the apex down to the chest and back up again counts as one repetition, while several successive repetitions without rest count as a set. The amount of repetitions and sets is dependent on the context of the exercise with many fitness programs recommending 2 - 4 sets of 6 - 15 repetitions, while in competetive weighlifting the goal is to push the maximum weight possible in one repetition (called 1RM). The muscles that are mainly used during this exercise are the pectoralis major (both the clavicular and sternocostal head), the anterior deltoids and the cobrachialis but other muscles such as the triceps brachii and the biceps brachii are involved in different variatons as well(Figure 3.1).

3.1 Bench press variation in bench angle

Nowadays there are 3 bench angles that are most commonly used and utilized by athletes to train differeqnt muscles [31]:

1. The flat bench press
2. The declined bench press
3. The inclined bench press

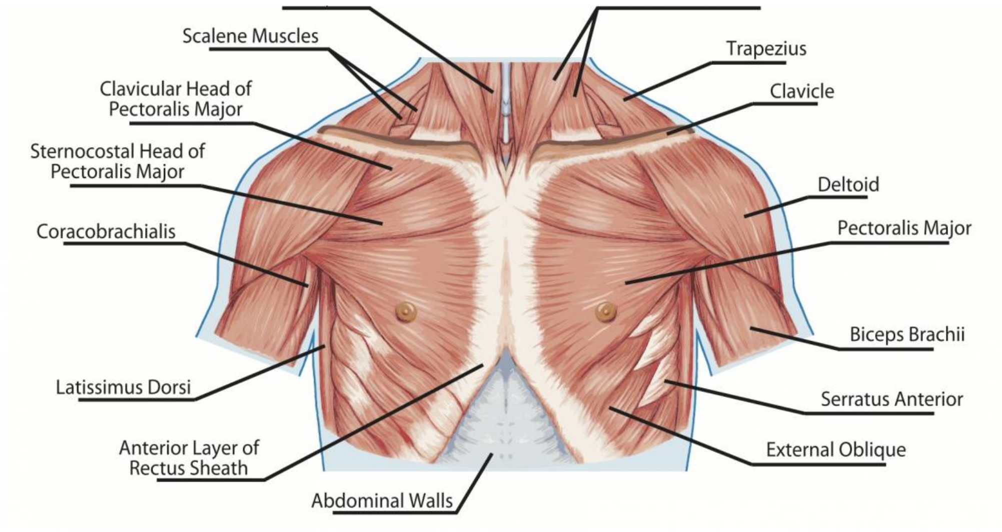

Figure 3.1: Upper body muscles in the human body [30]

3.1.1 The flat bench press

This is the variation that is usually referred to as "the bench press" in weight lifting circles if not specified further. In this form the bench is in a flat position (0° angle, Figure 3.2) which results in a higher activation of the sternocostal head of the pectoralis major (Figure 3.1) when compared to the inclined position [41].

3.1.2 The declined bench press

For the declined bench press the bench is usually angled -20° to -40° compared to the floor leading to the weightlifters knees being his highest point in this position. (Figure 3.3). Studies have shown that the declined and flat bench press have similiar effects on the muscle activation of the trainee[31].

3.1.3 The inclined bench press

In the inclined bench press exercise the bench is angled upwards between 25° and 60° as displayed in Figure 3.4. Using the inclined form of bench press results in a significantly higher activation of the clavicular head of the pectoralis major as well as the anterior deltoid ([4], [41]). Studies have also shown that the lifters doing the inclined bench press experience significantly higher biceps brachii activation but at the same time lower use of the triceps brachii [31]. Additionally, several studies indicate that the maximum amount of weight one is able to lift is lower for the inclined bench press than the other variations.

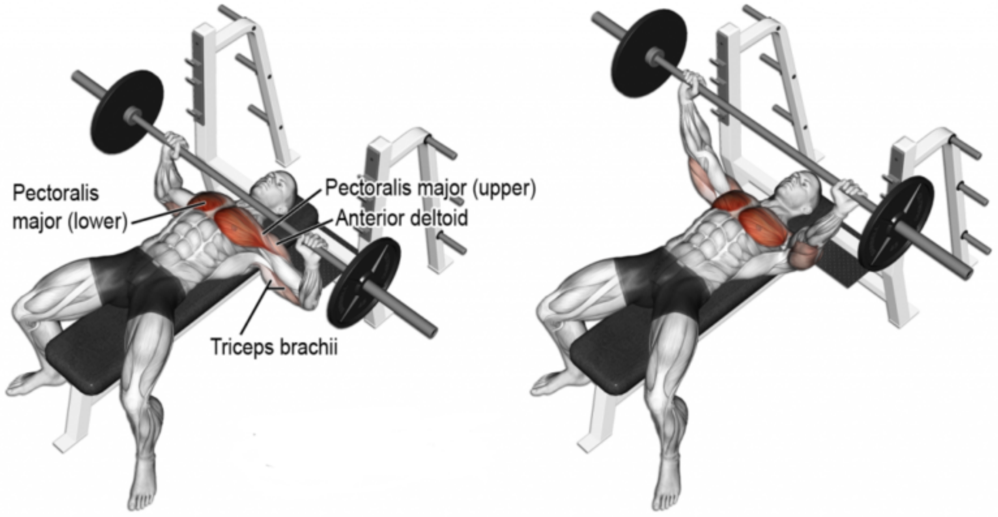

Figure 3.2: The flat bench press [25]

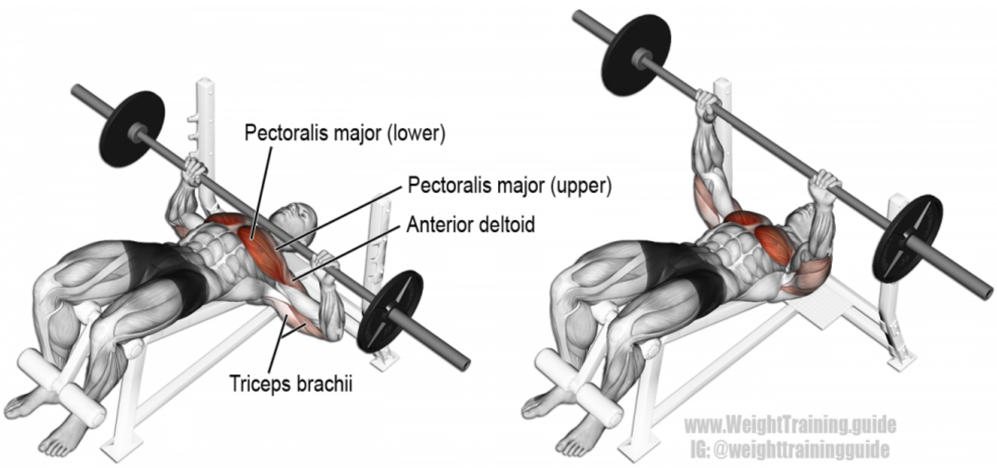

Figure 3.3: The declined bench press [24]

This was demonstrated for both competitive athletes [31] and recreational weightlifters [41]. The inclined bench press is the exercise that was used for the study.

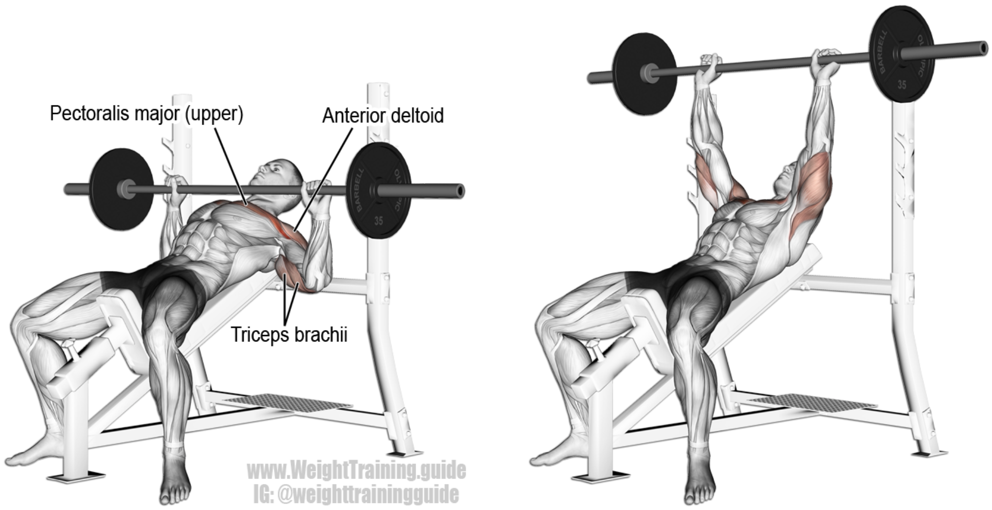

Figure 3.4: The inclined bench press [26]

3.2 Different grip widths for the bench press

The grip width for a bench press is dependent on the biacromial distance of a person which is the length between the acromial processes on each shoulder (Figure 3.5). There are generally three different grip width categories [31]:

1. The wide-grip which is classified as the biacromial distance times 1.5
2. The narrow-grip which is set at the biacromial distance itself
3. The medium-grip which the average between the wide and the narrow-grip

Studies have shown that a wide grip increases the amount of weight lifted [31]. According to research conducted by Green (2007) [15] a grip width bigger than the biacromial distance times 1.5 may increase the risk of shoulder injury, decrease the stability of the anterior deltoid and can lead to ruptures in the pectoralis major. Keeping the grip width at an amount equal or smaller than the wide grip reduces these risks. The wide grip is the grip width that was used for the exercise in this study.

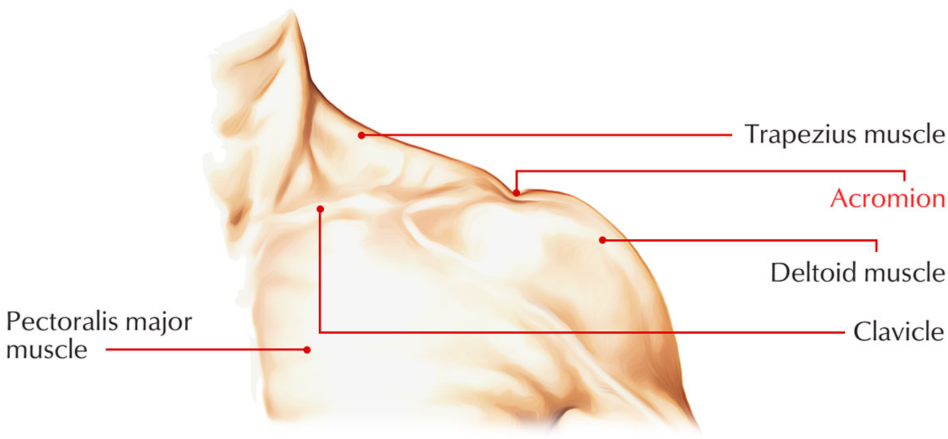

Figure 3.5: Acromion process [42]

3.3 Grip style

There are several grip styles for bench pressing but the most common ones are the standard grip, the reverse grip and the thumbless grip. In all of the mentioned grip variations the bar is placed on the low end of the palm.

3.3.1 Standard grip

The standard grip is employed by grabbing the bar such that your fingers go over the bar and point away from the lifter while the thumb is around the bar supporting it. This is the grip that was chosen to be used by the test subjects for the study as the other commonly used grip variants pose a much higher risk of injury.

3.3.2 Reverse grip

The reverse grip is applied by turning the hands by 180° from the standard grip so that the fingers now point in the direction of the lifter. The thumb has the same supporting position as in the standard grip. This grip is not very beginner friendly as it uses an unnatural position and is thus more prone to accidents. Some experienced lifter like to use it as they claim that it relieves joint pain in the wrists. This is also supported by a study which showed increased pectoralis major muscle activity when using the reverse grip which could lead to an increased force production in the biceps brachii and thus higher stabiltiy during lifting [22]. (TODO BILD)

3.3.3 Thumbless grip

The thumbless grip also known as the "suicide grip" uses a similar position to the standard grip but without the support of the thumb. In this variant the thumb is positioned on the same side as the other fingers, opening the lock of the hand around the bar. The thumbless grip is most often employed by professional bodybuilders as they claim that it alleviates pressure off the wrists due to the bar sitting lower in the palm. However using this style of grip is very dangerous as the bar can easily slip without the support of the thumb and should only be applied by very experienced lifters. People get regularly injured by falling weights or can even die in extreme cases, hence this style is named "suicide grip" in weighlifting circles.

4 The Visual Augmentation for Bench Pressing System

The goal for the Visual Augmentation for Bench pressing system is to provide helpful information for the user while performing the bench press. This section will cover the general approach to this problem, the software and hardware that was used, which aspects of the bench press were chosen to be analysed and how the visual feedback was displayed. Afterwards it will describe the physical setup that was found to be ideal and the issues that arose during the development of the system.

4.1 General approach to the problem

The general idea for this program was to analyse the positional data of the joints provided by the kinect depth sensor and skeleton tracking. This data is first used to measure and save the body dimensions of the user. The saved, precalculated lengths, are then compared to the joint positions provided on runtime in the later part of the program. The feedback is a visualization of the resulting delta of these values. The joints (Figure 2.1) that need to be tracked to analyse the bench pressing exercise are the following:

1. WRIST LEFT and WRIST RIGHT
2. ELBOW LEFT and ELBOW RIGHT
3. SHOULDER LEFT and SHOULDER RIGHT
4. The Kinect joint called SPINE SHOULDER which is located central between the shoulder joints
5. The kinect joint called SPINE MID that can be found in the center of the spine

4.1.1 Visualisation

The calculated feedback was displayed using a screen that was set up next to the bench as shown in Figure 4.5. Other options for the representation for the user, such as a Virtual

Reality headset, were considered but ultimately discarded. The two main reasons for not using a head mounted display (**HMD**) were safety concerns and viability of using an HMD in a near horizontal position. The safety concerns are in regard to visually blocking the bar and the bar getting in contact with the HMD of the user when he is moving his head.

4.1.2 Software used

The system was developed with the Unity Engine version 2019.1.9f1 and the Unity Pro Package "KinectForWindows-UnityPro" version 2.0.1410.

4.1.3 Hardware used

The hardware used for the majority of the development as well as the study was GamesLab-PC1, equipped with an i5-8600K CPU, a NVIDIA GeForce GTX 1080Ti and 32GB Ram running the Windows 10 OS. The motion capture system used was the Kinect V2.

4.2 The FileWrite class

Early on in the development it became clear that the systems ability to work correctly was dependent on several variables that had to be manually adjusted. In order of streamlining this process a class "FileWrite" was written that automatically writes a line into a selected file by invoking the method WriteString(String line, String FileName). The files can be found in the TestData folder of the Unity project. This class was also used for the data collection during the study.

4.3 Factors of bench pressing that were analysed

There are a multitude of different factors that the execution of a bench press repetition can be judged on. The present system focused on the following:

1. Correct grip width: wide-grip
2. Counting the number of repetitions performed
3. Reaching a sufficent height, for the maximum and the minimum of a repetition
4. Keeping the bar on an even level while lifting
5. Landing the bar above the pectoralis major

4.4 Joint position calculations

Each of the joints mentioned beforehand is used in the detection of different factors. In this section it is described which joint is involved in which aspect of detection.

Figure 4.1: Kinect V2 and the positioning of the camera space coordinate system [17]

4.4.1 Wrist Joints

The wrist joints are the most important joints that have to be tracked as they are used to determine the height of the bar. This means that they are involved in the detection of most of the selected factors as the height of the bar usually represents the most significant information. They are furthermore used in the calculation of the maximum arm length in the precalculation section of the program and the adjustment of the correct grip width.

4.4.2 Elbow Joints

In this implementation the elbow joints are only used for the calculation of the arm length. The calculation of the arm length is implemented by calculating the vector length from shoulder to elbow and from elbow to the wrist respectively. Both vector lengths are then added together resulting in the total arm length.

4.4.3 Shoulder Joints

The shoulder joints are used in the calculation of the biacromial distance, the minimal point for a repetition as well as the arm length as explained in the subsection 4.4.2. The biacromial distance is derived as the vector length between the left and right shoulder joint. This was verified by comparing the values of distance the Kinect detected and measuring the distance between the two acromian processes using a measuring tape.

4.4.4 Spine Shoulder and Spine Mid

The joints SPINE MID and SPINE SHOULDER are used in the approximation of the chest muscle. For this purpose an ideal point of impact on the vector between the two joints is calculated. This is done by first calculating the point between SPINE MID and SPINE SHOULDER and then shifting it along the vector along the Y-Z plane of the Kinect camera. The orientation of the coordinate system is displayed in Figure 4.1. Pictures of the study setup in the section section 4.6 may give a better overview. The SPINE SHOULDER is additionally used as the center of the body for the adjustment of the grip width of the test subject.

4.5 Program runthrough:

4.5.1 Fixed variables

The following variables determine important factors such as timings, data recording and accuracy of the study and can be found at the beginning of the class BodySourceView. They are hardcoded on purpose and should not be changed on runtime:

String FileName is the name of the file the recorded data will be written into.

int avgFrameCons determines the amount of frames the position of all joints are averaged over.

float preCalcTime is the amount of time in seconds the program has to calculate the body dimensions of the test subject.

float biaDistSetupTime the duration of the grip width adjustment period in seconds.

float gripWidth The factor that is mulitplied with the biacromial distance to determine the ideal grip width.

4.5.2 BodySourceView.JointClass

The data on the position of the joints that is provided by the Unity Pro Package for the Kinect are stored in the wrapper class called JointClass. The JointClass is used to average the position for each joint for a predetermined number of frames to filter out small changes in position. The variable to change the number of frames the position is averaged over is BodySourceView.avgFrameCons. The higher the number of averaged frames the lower is the accuracy as the position is blurred. Testing found the best results to be at a value of four. The JointClass is additionally rotating all coordinate positions by 20° around the x-axis to counteract the -20° tilt employed in the setup. This is further explained in section 4.7.

4.5.3 Precalculation / Phase One

After startup the program is in phase one also known as the precalculation phase. In this phase the measurements for the body dimension of the test subject are recorded. These measurements are the biacromial distance and the arm length for both arms. Each avgFrameCons number of frames the current length is calculated and stored in a list. At the end of phase one the values of the list are averaged and stored in IbpTest.biaDist and IbpTest.armVal. During phase one the user is instructed to hold a T-position as displayed in Figure 4.2. This position was selected so that the Kinect can get the most accurate measurements for the biacromial distance and the arm length. When the test subject was hunched forward, the Kinect could not detect the posture correctly and thus not distuingish between joints which resulted incorrect joint positions. An example of this can be seen in Figure 4.9. The length of this phase can be adjusted by changing BodySourceView.preCalcTime.

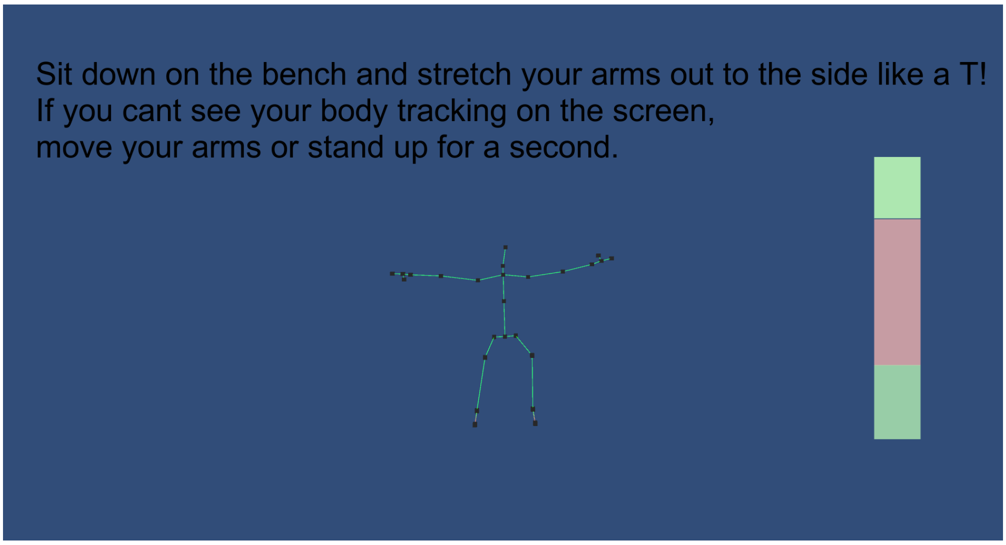

Figure 4.2: Instructions to the user in phase one of the study

4.5.4 Grip width adjustment / Phase Two

In this phase the test subject is supposed to select the grip width using the value for the biacromial distance calculated in phase one. The correct grip width is determined by using the center point of the body (in this implementation the SPINE SHOULDER joint) and adding or subtracting half of the predetermined biacromial distance in direction of the x-axis (Figure 4.1) to either side. The user gets a visual representation of his hands along with two green boxes that represent the correct grip width as shown in Figure 4.3. The position of the displayed hands is X-position of the respective wrist. The grip width can be adjusted by changing BodySourceView.gripWidth. For this study the wide grip was selected and the variable therefore set to one-point-five. The wide grip was chosen as it allows for the heaviest lifting [31] and hence decreases risk of injury [18] [16]. Entering phase two also starts a countdown (top of the screen in Figure 4.3) after which the exercise stage of the program is started. The length of this phase can be adjusted by changing BodySourceView.biaDistSetupTime.

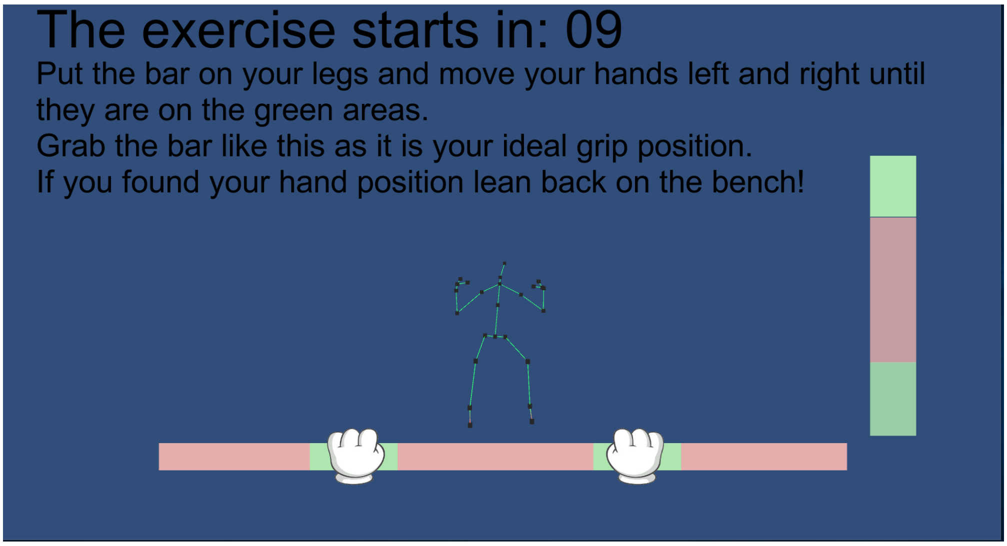

Figure 4.3: Instructions and interface for the adjustment of the grip width in phase two

4.5.5 Exercise / Phase Three

In the exercise phase of the program Y-position of the wrist joints is used to determine whether the bar is currently at the maximum or minimum elongation. The minimum is hereby the Y-position of the shoulder joints and the maximum the same height with the length of the arm from the precalculation added on top. A repetition is counted as correct when the user has reached the maximum, then the minimum and then the maximum again. The first repetition can be counted as correct even if the test subject did not start out at a maximum as the state at the start of phase three is already set to a detected maximum. This was done to supress frustration of the user that could occur when not realising why the first repetition did not register. The minimum and maximum is visualised by the weighted bar icon that can be seen in Figure 4.4. When either extreme is reached the icon switches to a green colour from the default red colour. The graphic behind the bar that displays the extreme areas is not connected to the positions calculated by the program and is just a background. Nevertheless should these designated areas correspond to the change in colour of the bar when using the setup specifications described in section 4.6. In this phase there is also a repetition counter displayed at the top of the screen as shown in Figure 4.4. Furthermore there is a continous comparison between the Y-position of the left and right wrist to determine if the bar is kept on an even level. When the discrepancy of y-values is too big a message is rendered which is also shown in Figure 4.4. Finally there is a calculation performed that compares the Z-position of a point on the center of the bar to the Z-position of the approximated chest position of the user. This is done to determine whether the bar is between the chest and neck of the lifter. This calculation is implemented but did not work correctly until the study was finished.

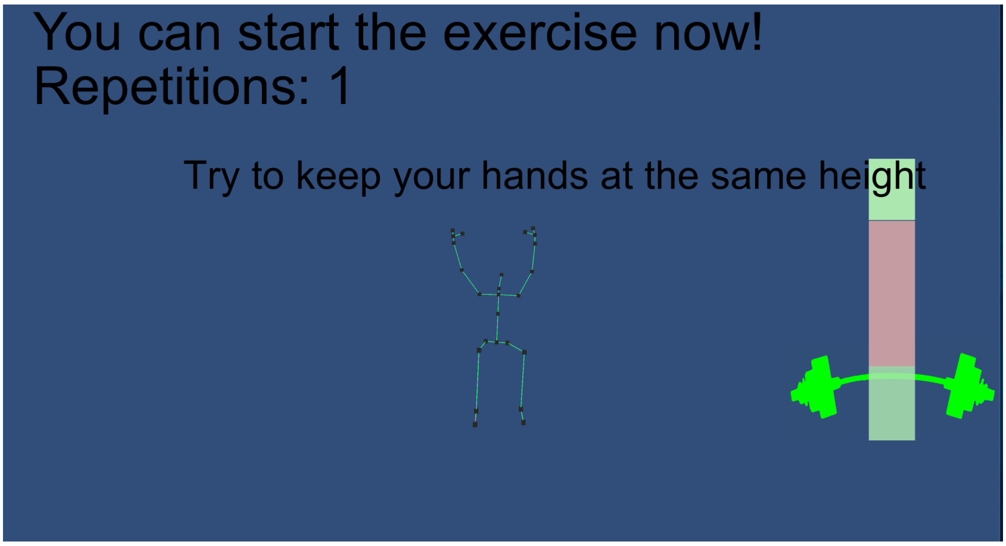

Figure 4.4: Interface for the bar height and repetition counter in phase three

4.6 Setup of the Kinect, Bench and Screen

The Visual Augmentation for Bench Pressing system requires a very specific setup to work correctly. Although once it was set up it did not have adjusted for new test subjects. The most important factor to consider during the setup is the fact that the coordinate system of the Kinect camera shifts with the position and angle of the sensor. The setup that was used in the study is displayed in Figure 4.5.

4.6.1 Kinect Configuration

The ideal Kinect configuration that was found during testing was with a height of 135 cm and a angle of -20° to the plane of the floor. These measurements are in reference

Figure 4.5: Setup for the study

to the sensor of the Kinect. How the angle of the Kinect was set up is explained in subsection 4.6.4.

4.6.2 Setup of the Bench

The study used a distance of 153cm from the Kinect sensor to the foot of the bench. It is possible to set the bench farther away than the distance used in the study but it is recommended to setup the bench not closer than 150cm. It is important to angle the bench completly central and parallel to the kinect sensor as the coordinate system is otherwise shifted. An unaccounted shift in the coordinate system invalidates the use of direct coordinate comparisons and limits the calculations to the use of vector lengths as they are independent of the coordinates. The angle of the bench was set to 45° which is further explained in subsection 4.7.1.

4.6.3 Positioning of the Screen

The screen was positioned in such a way that it was adequatly close enough to be readable. When placing the screen it is essential to turn it in such a way that the test subject does not have to turn its head. Turning the head results in the rotation of the upper body resulting in an incorrect bench pressing position. Ideally the screen would be placed above the lifter, removing any need to turn the head. Such a setup was not available for the study.

4.6.4 Determining the angle of the Kinect

To correctly set up the Kinect with a -20° angle a laser pointer was fixed in parallel to the sensor on top of the Kinect case (Figure 4.6). Then a point on the floor, parallel to the Kinect sensor, was marked. The distance of the point is thereby dependant on the current height of the Kinect sensor. The distance can be calculated using basic trigonometric functions: $distance = \frac{height}{tan(20)}$ (Figure 4.7). One can then use the laser pointer and adjust the angle of the kinect by aiming at the designated point on the floor. This will result in a 20° angle of the Kinect sensor.

4.7 Issues

There were several issues to overcome when designing the Visual Augmentation for Bench Pressing system. This section will describe the problems that had the most significant impact on the development and setup of the system.

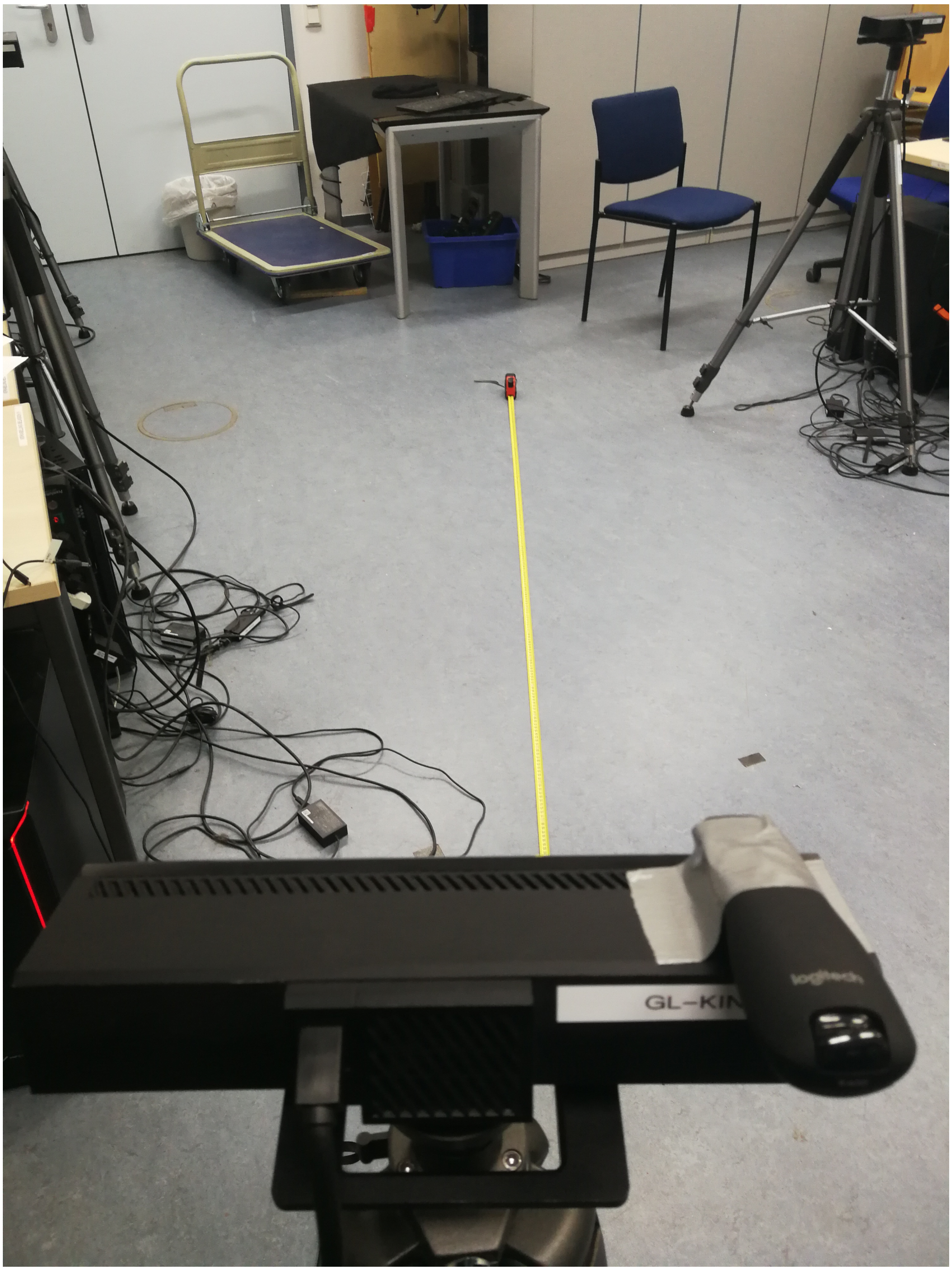

Figure 4.6: Measuring the angle of the Kinect

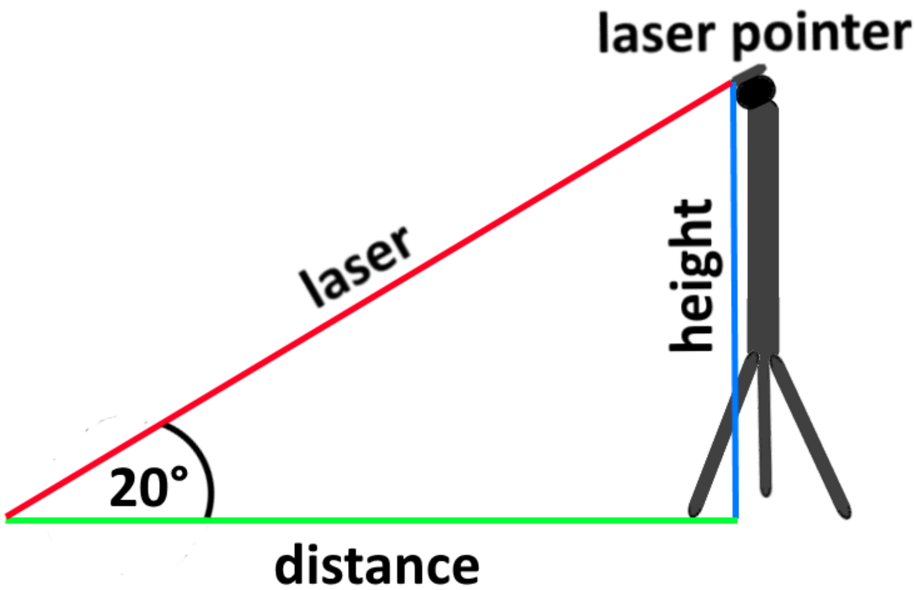

Figure 4.7: Calculation of the distance in determination of the angle

4.7.1 Horizontal Posture

The Kinect posture recognition can not correctly determine the skeleton when the test subject is in a horizontal position compared to the angle of the Kinect. The encountered problem is a severe version of the issue displayed in Figure 4.9. This had a crucial impact in the construction of the system as it directly eliminated the option of using the flat bench press as an exercise when using the equipment available in the GamesLab. Instead of switching to a fitness exercise that is better suited for the use with the kinect it was decided to use the incline bench press. The problem with the detection persisted further but was able to be alleviated by rotating the Kinect as far down as possible. In the end it was decided to stick with an -20° angle.

4.7.2 Detection of the Barbell

During testing and the study it was noted that the bar sometimes gets detected as part of the body in the pose recognition of the kinect. This results in the warping of the position of the hand and wrist as displayed in Figure 4.8 which turned out to be one of the biggest issues especially in the recognition of bar height. At extensions of the arm closer to its maximum length this problem occured less frequently. Conversely, this problem was encountered much more often while weights were attached to the bar. One possible solution could be to use the raw data stream of the Kinect and try to ignore values that fit in a certain margin around the vector between both hands.

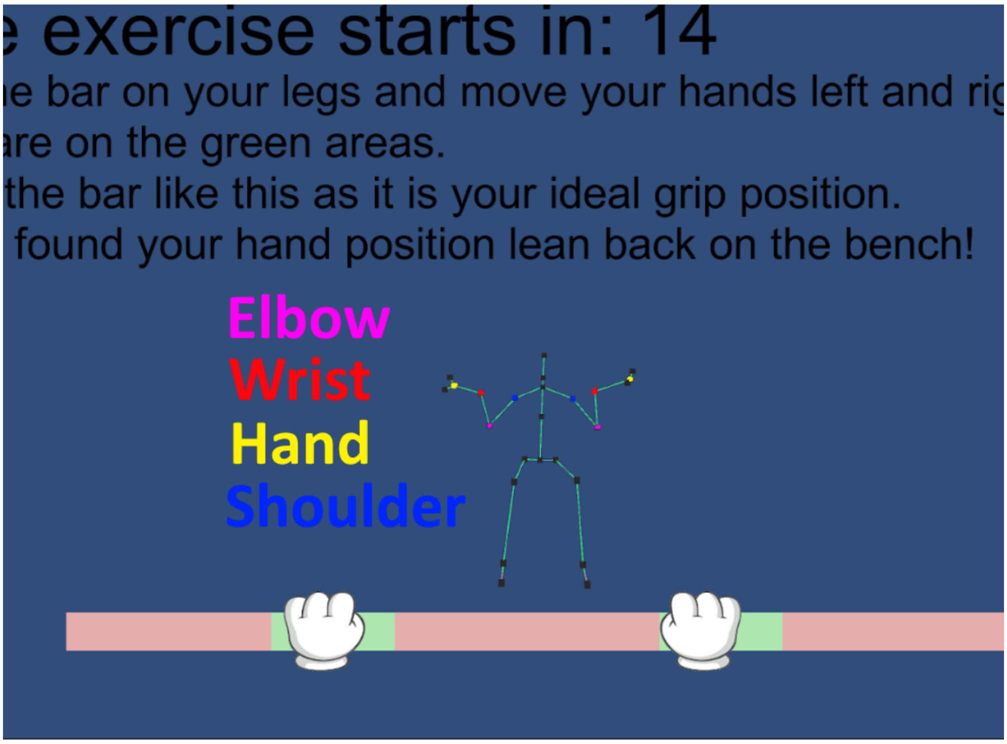

Figure 4.8: The Kinect warps the jonts when a bar is interrupting the line of sight

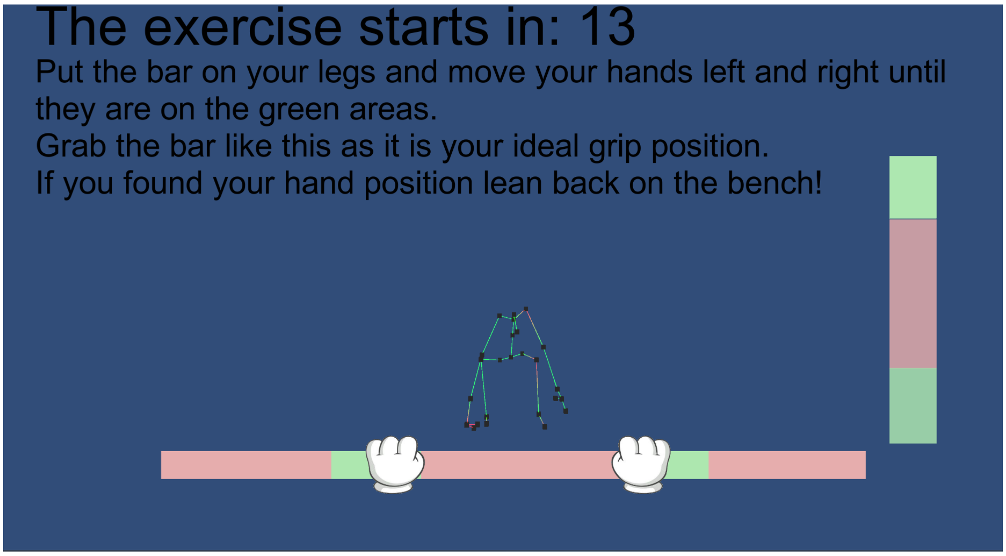

Figure 4.9: The Kinect issues in the detection of the posture when the subject is hunched forward

5 User study for the Visual Augmentation for Bench Pressing System:

The following chapter describes the methods and practices used in the user study for the Visual Augmentation for Bench Pressing System. The study was conducted between the 9.12.2019 and the 13.12.2019 in the Games Lab (Room 00.13.037). On average it took a participant about 20 minutes to complete the study.
The Study was divided into the following four parts:

1. Introductionary Text
2. Consent Form
3. A Demographic questionnaire and additional questions on sports activity
4. The bench press exercise
5. The System Usability Scale questionnaire

5.1 Introductionary Text

The introductionary text described the procedure of the study, a short description of bench pressing and which task they have to perform in the exercise. The task description was formulated as follows:

> The task you have to perform during the exercise section is the completion of 10 bench press repetitions using my assistance system. The system will provide instructions on the screen throughout the exercise and displays other useful information for example the number of already completed repetitions. The visualisation of the bar will turn green when you reach the sufficient maximum or minimum height requirement. If possible I want to repeat the

exercise three times but if you want to abort the experiment for any reason inform me immediately. If you have any further questions feel free to ask me at any time.

5.2 Consent Form

A standardized consent form was provided by the Research group for Augmented Reality.

5.3 Demographic questionnaire and additional questions on pursued sports activities

On top of the standard demographic questions, the study population was asked to supply information on their sporting behaviors. Test subjects that go or used to go regularly to the gym were given additional questions, for example on the average hours spent in the gym per week, the preferred fitness exercises or the self-attributed skill level. These questions were specifically designed to judge the test subjects experience with fitness exercises and could later be used to isolate the feedback of people familiar with the gym settings and fitness exercises. Furthermore it was asked whether the participant had already used the Kinect before, as it could provide an advantage in handling the system. The questionnaire was conducted online on a prepared laptop next to the study setup using the soscisurvey.com platform [36].

5.4 Study exercise:

The workout chosen for this study was three sets of ten repetitions each, with no weight requirement except for the 10kg heavy barbell as the focus of this study was not about the amount lifted but the handling of the visual support system. The participants were entrusted with choosing a weight they were most comfortable with and were allowed to test differently loaded bars before and during the exercise. As is good practice in weightlifting circles all subjects, but especially those without prior experience in weightlifting, were urged to do a warmup set of at least five repetitions, that were not counted for the study, in order to get a feeling for the barbell. Between each set a minimum rest time of 1 minute was enforced to reduce the risk of overexertion and therefore injury [18] [16]. The weights available to the lifters were two 10 kg plates and two 5kg plates.

5.5 Usability questionnaire

For a fully automated system, designed to facilitate the learning of unfamiliar movements and exercises with heavy weights, it is especially important to get a good usability rating. It is possible that unclear instructions or non-intuitive behavior in an automated system can not only lead to a rejection of the system by the user but in severe cases even injuries. Avoiding and counteracting the mentioned issues is also known as the "harm of use" in the human-centered quality of a system. In order to measure these aspects in the present system the System Usability questionnaire was used. The questionnaire was conducted online on a prepared notebook next to the study setup using the soscisurvey.com platform [36].

5.5.1 Usability

The International Organization for Standardization (ISO), defines usability as the extent to which a system, product or service can be used by specific users to achieve specified goals with effectiveness, efficiency and satisfaction in a specific context of use [38].

5.5.2 Human-centered quality & harm of use

The human centered quality is defined by the ISO as the extent to which requirements for usability, accessibility, user experience and avoidance of harm from use are met. Harm of use encompasses all negative consequences regarding health, safety, finances or the environment that result from use of a system [38].

5.5.3 System Usability Scale

The System Usability Scale (**SUS**) is one of the most used questionnaires for measuring the usability of a system and was created in 1986 by John Brooke as part of of the usability engineering programme at Digital Equipment Co. Ltd, Reading, UK [6]. It was developed because Brooke saw the need for a quick subjective measure in order to evaluate the usability of a system, without the need for a context analysis and selection of suitable metrics. The SUS questionnaire is made up of ten items which are judged on a five-point Likert scale from "Strongly Disagree" to "Strongly Agree" and is recommended to be answered directly after use of the system to judge the immediate reaction of the user [6]. The items on the SUS are alternating between a positive and a negative statement e.g. "1. I think that I would like to use this system frequently." and "2. I found the system unnecessarily complex.". This means that the negative statements have to be converted to the scale of the positive statements by subtracting them from the maximum score. The result of the addition, now a number between 0 and 40 is scaled onto the range of 0 to 100 by multiplying it by 2.5. The final count of the SUS is not a percentage, but is judged by their percentile ranking. A statistical evaluation of over 500 SUS questionnaires

[33] determines the average SUS rank (50th percentile) to be at a score 68 as shown in Figure 5.1.

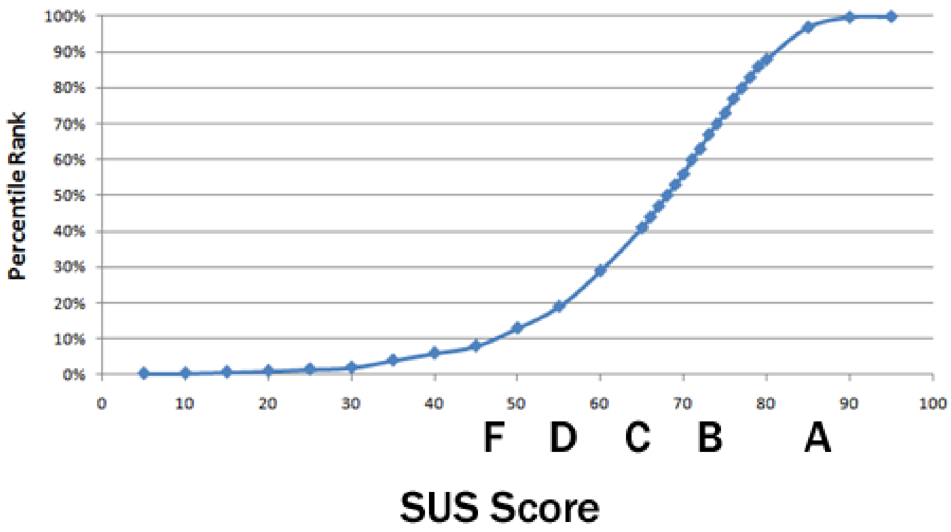

Figure 5.1: Statistical analysis of over 500 SUS evaluations [33]

5.6 Equipment

The bench pressing equipment used for the study was as follows:

Movit Profi Langhantelstange, verchromt mit Sternverschluss as the barbell [3]

ISE Hantelbank Multifunktion Tranings Fitness Bank as the bench [2]

Hop-Sport 30kg Hantelscheiben Sets 30 mm Gewichte for the weights [1]

6 Results of the study

6.1 Study population

There were ten subjects that took part in this study, all of them students at either the Technical University of Munich or the Ludwig Maximilian University of Munich. All of the participants were male and were on average 24 years old. 70 percent of the test subjects had no prior experience in a fitness center. Of the remaining study population 57 percent were regularly active in a sports activity resulting in seventy percent of the participants being physically active. The average amount of time spent on sports of the regularly active part of the participants was 2.6 hours per week. 70 percent of the participants had prior experience using the Kinect. Only one subject chose to use additional weights for all three sets while one increased the weight for his last set of repetitions. All examinees were able to finish the proposed number of three sets.

6.2 Data consistency of the Kinect

One part of the study is the examination of the feasability of using the Kinect to analyse the bench pressing exercise. A crucial aspect of the system is the dependence on consistent values gathered by the Kinect in the precalculation phase. In the precalculation phase the body dimensions for the arm length and the biacromial distance are determine and stored for the rest of the exercise.

6.2.1 Biacromial Distance

The data gathered on the biacromial distance is displayed in Table 6.1.
Although there are some cases in which the difference in detected biacromial distance between two sets was considerably small (less than one millimeter), it was generally not consistent for all three sets. The calculation of the standard deviation was not performed because the detected difference of more than a few centimeters was due to the subject not following the instructinos to sit in a T-Pose in the precalculation phase. Sitting in a pose which the Kinect was not able to detect resulted in impossible joint positions. These incorrect positions would still be considered for the averaging and create values

Table 6.1: Biacromial distance in cm

Test Subject	Set 1	Set 2	Set 3
1	39.291	36.162	37.627
2	35.441	33.277	37.874
3	31.227	35.065	37.172
4	32.530	36.140	36.127
5	36.283	37.441	36.278
6	38.228	36.903	37.524
7	35.891	30.142	34.368
8	35.723	38.102	37.556
9	34.435	37.573	39.009
10	38.959	38.941	37.407

that were in the worst case more than 5 centimetres off the other values. Even when using the correct posture small differences, such as a more upright position, had a direct effect on the shoulder position. This change in shoulder position between sets resulted in most values having a delta of at least one centimetre when compared to the other sets.

6.2.2 Maximum Arm Length

The second gathered body dimension is the maximum arm length displayed in Table 6.2.

Table 6.2: Maximum arm length in cm

Test Subject	Set 1	Set 2	Set 3
1	50.769	50.549	51.291
2	49.495	51.392	51.093
3	44.528	50.008	51.791
4	44.650	48.713	48.031
5	50.499	49.835	50.432
6	50.064	50.009	49.514
7	48.562	45.219	47.892
8	50.321	50.152	50.218
9	51.291	51.338	51.049
10	53.534	50.803	43.606

The detection of the maximum armlength suffers from similar problems as the biacromial distance in terms of the Kinect not being able to detect the posture when the test subject is hunched forward. Not sitting correctly in the precalculation phase created differences in arm length of almost ten centimetres. However when the testee is doing the T-pose correctly, the data seems much more accurate. This is explained by the type of calculation that is performed. The implemented biacromial distance changes when the subject moves the shoulders in the shoulderjoint while the arm length calculation is using the shoulder as the starting point. This means that moving the shoulder also moves the rest of the arm thus resulting in the relative movement of all joints in the arm.

6.3 Usability evaluation of the Visual Augmentation for Bench Pressing System

The Visual Augmentation for Bench Pressing system scored a 80.25 on the System Usability Scale (Table 6.3). As shown in Figure 5.1 a value of 80.25 corresponds to the 90th percentile and is just on the edge of an excellent usability [33]. The study population of ten participants is also sufficient enough to detect more than 94% of the usability problems according to Faulkner [11]. Although it used to be considered not meaningful to judge singular items on the SUS, a factor analysis of the SUS by Lewis (2009) [23] showed convergence into two different factors. Lewis split the items into groups of eight and two with the items "4.I think that I would need the support of a technical person to be able to use this system." and "10.I needed to learn a lot of things before I could get going with this system." comprising one group and the rest of the items making up the other group. Lewis postulated the name "Learnability" for the new item group of size two and argues that the factors can be measured seperatly [23]. The group of the other eight items is still considered the usability. In the seperate factor of "Learnability" the Visual Augmentation for Bench Pressing system scored 87.5 points which is in line with one of the postulated goals of creating a system that does not need any prior knowledge before its use.

Table 6.3: Results of the System Usability Scale questionnaire, N = 10

Item	Score
1. I think that I would like to use this system frequently.	26
2. I found the system unnecessarily complex.	29
3. I thought the system was easy to use.	30
4. I think that I would need the support of a technical person to be able to use this system.	32
5. I found the various functions in this system were well integrated.	33
6. I thought there was too much inconsistency in this system.	30
7. I would imagine that most people would learn to use this system very quickly.	34
8. I found the system very cumbersome to use.	36
9. I felt very confident using the system.	33
10. I needed to learn a lot of things before I could get going with this system.	38
Average Score	32.1

7 Discussion

The goal of this thesis was to assess the general feasability of the Kinect as a motion capture system for the bench press exercise and the usability of the presented system.

7.1 Feasibility of the Kinect for the bench pressing exercise

Using the Kinect posed several challenges and the system was only able to be developed by limiting parametres such as the type of bench press detected in the exercise. Even when limiting the applications of the system, the data gathered for the biacromial distance and arm length shows that it is far from an ideal system. In the case of the biacromial distance, the errors in consistency may not present much of an issuef as a slightly closer than recommended grip width is still a viable position and may even reduce the risk of injury [15]. The difference in arm lengths, although generally smaller than the disparity of the calculated biacromial distance had a noticable effect on the participants of the study. In the open text box after the Usability questionnaire three examinees noted issues reaching the maximum height that was dictated by the system. This corresponded to the sets of the same participants where the precalculation resulted in a much lower arm length than the other sets. Although this could be contributed to inconsistencies in the detection of the Kinect it was most likely due to a design fail in the system. The precalculation phase starts right after starting the program with no time for the test subject to read the instructions and get their arms into the T-position. This results in the blurring of the recorded data as it is just the average of all values calculated during the precalculation phase. This issues was not only found in the first time use of the system, but also in the later sets for some users as it was not correctly communicated that the system is calulating the body dimensions for every set.

> I had to stretch my hands a lot in the first round to complete a repetetion. But the next two rounds it [w]as much easier. - Test Subject 4

Although the study population was sufficient to detect the majority of usability problems it limited the confidence of results in terms of the gathered body measurements. An increased number of sets, and a bigger and more diverse study population would be needed to confirm the results of this study. Furthermore it should be examined whether it is possible to alleviate the problems of the Kinect in detecting bodies that are horizontal to its coordinate system by constructing a cage that mounts the Kinect over the bench or directly attaching it to the ceiling.

7.2 Usability of the system

The results of the usability evaluation are in accordance with the postulated goal of creating a simple to use exercise assistance that needs no further explanation or support. Especially the scores regarding the learnability aspect of the system is seen as proof that the type of visualisation used in the user interface should be continued. One area the usability evaluation needs further confirmation in is the goal of being usable by everyone. Further studies need to show that the system can achieve similar rankings in a more diverse group of test subjects regarding age, sex and technological proficiency.

8 Outlook

Future work on this system should include the overhaul of the precalculation phase, creating a temporal buffer after the start of the program so the user can adjust his position for the calculation of the body dimensions. Additionally only a few factors for the correct form of the bench press were tracked and displayed. In future work more aspects of the correct bench press form could be implemented building on the already established framework of the JointClass and other calculations. Furthermore it should be assessed whether the Kinect can produce better results in terms of body tracking while being attached to a mount or the ceiling above the weightlifting bench. Conformation of this could lead to a expansion of the possible weight lifting exercises that could be tracked with this kind of system. In future studies the system should be evaluated by an increased and more diverse study population to confirm the assumptions made in this study. One additional improvement may be the use of the Azure Kinect, the newest version of the Kinect, that includes new hardware and a new development kit. The new kinect has an upgraded RGB and depth camera now recording at 12 megapixel and 1 megapixel respectively. The Azure Kinect SDK is also connected to the Microsoft Azure cloud which provides computing, data storage, data management services for its supported products. Using these new resources, especially the depth camera of the Azure Kinect could provide significantly better and more exact data as input for the system.

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