SAARLAND UNIVERSITY

Faculty of Natural Sciences and Technology I
Department of Computer Science
Related Work Summary

Interactive technology in slackline training

Christian Murlowski

October 2017

Main advisors:
Prof. Dr. Antinio Krüger
German Research Center for Artificial Intelligence
Saarland Informatics Campus
Saarbrücken, Germany

Advisors:
Felix Kosmalla
German Research Center for Artificial Intelligence
Saarland Informatics Campus
Saarbrücken, Germany

Dr. Florian Daiber
German Research Center for Artificial Intelligence
Saarland Informatics Campus
Saarbrücken, Germany

Handed in on 23/03/2017

Saarland University
Faculty of Natural Sciences and Technology I
Department of Computer Science
Campus - Building E1.1
66123 Saarbrücken
Germany

Eidesstattliche Erklärung

Ich erkläre hiermit an Eides Statt, dass ich die vorliegende Arbeit selbständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel verwendet habe.

Statement in Lieu of an Oath

I hereby confirm that I have written this thesis on my own and that I have not used any other media or materials than the ones referred to in this thesis.

October 2017

Einverständniserklärung

Ich bin damit einverstanden, dass meine (bestandene) Arbeit in beiden Versionen in die Bibliothek der Informatik aufgenommen und damit veröffentlicht wird.

Declaration of Consent

I agree to make both versions of my thesis (with a passing grade) accessible to the public by having them added to the library of the Computer Science Department.

Saarbrücken, 14th January, 2016

Acknowledgements

Thanks to:

- Prof
- Advisors
- Tobias Walter
- Family
- Everyone else
- Maybe avarteq

Thank for:

- Help regarding research
- Be able to write the thesis in here
- Organizing and getting hardware and stuff for thesis
- Supporting me in all things regarding conceptual, design related, technical and reviewing stuff
- Mental and pushing me forward
- Avarteq for letting me have time to write the thesis

Abstract

TEXTTEXT

- Kinect v2
- Slackline
- No interactive system
- Just learning by doing
- No real-time feedback to clarify if something is wrong
- System gives this feedback
- Measure learn progress
- In here user will be guided through exercises
- If such an interactive system can be used to learn user to go on a slackline
- If such a system is at least comparable with a human trainer (maybe also video training) or even better
- Feasibility study with experts
- User study with beginners in 2-3 groups and 2 sessions
- In 2. session all will train with the system
- -
- Problem
- Current approaches to solve the problem
- Problems with solutions, what would be better, what can't you do with these
- Solution approach of thesis to make everything better, What will be better
- Developed prototype, Used techniques, prototype design to motivate user
- Pre-study / Feasibility study –> Why doing this? What evaluate?
- Solve occurring problems, which exercises can be implemented + good trackable
- Main study –> what will be tested?, number of exercises and tiers/stages and exercise levels
- Final results, What was good, What was bad, Usability of system
- Assumed hypothesis true or false

Contents

While the following examples, arguments, and descriptions apply equally to both genders, for the sake of ease of reading, only the female pronouns are used in this thesis.

Chapter 1
Introduction

1.1 Motivation

- Interactive real time feedback system in other sports
- more exergames realeasing in past decades
- Exergames in general
- No comparable work regarding slacklining
- Support slackline beginners with such a system

1.2 Research Goals

- Investigate related system
- Requirement analysis
- Conceptual design of an interactive feedback system for slacklining
- User interface design
- Integration
- Investigation of the system

1.2.1 Hypothesis

- Provide supportive feedback
- Show if an interactive real time feedback system is usable for this kind of sport

- If the learning progress is comparable with other training methods like human trainer

- If such a system motivates user for slackline exercises

1.3 Outline

The thesis is structured as follows: As a groundwork the **Related Work** chapter involves basics of **Slackline specific training and effects to the human body**, a number of possible interactive tracking devices that will be compared in the section **Interactive technology**, and **Feedback and interaction methods**.

- Further chapters

A List of **??**, **??**, **??** and the **??** can be found at the end of the thesis.

Chapter 2
Related Work

2.1 Introduction

This section presents related work to a slacklining assistance system with an interactive technology approach. It provides exercises and feedback for beginners on a slackline with the Microsoft Kinect v2 as a tracking device. Hence it is necessary to provide instructive teaching methods for beginners. Therefore existing approaches and studies have been elaborated to build an appropriate foundation and point out several application scenarios. Also the user interface should motivate the slacker for the training scenario and lead to a proper user experience.

First related concepts regarding slacklining show how to build learning techniques for beginners, the efficacy of it in balance training, and areas of application. Next current tracking technologies have to be compared for tracking the human body on the slackline and why the Microsoft Kinect v2 seems like the appropriate tracking device. Lastly the system has to be aware of cognitive load and motivating aspects, which can be challenging with repetitive exercises. Several applications show where problems occur with different feedback and interaction methods. Also design opportunities for guiding the user through the learning process are demonstrated by various approaches.

2.2 Slackline specific training and effects to the human body

As in other sport activities it is important to have a concrete baseline about what exercises and tips are useful for very beginners. Mainly to have a good knowledge of the basics, which results in a faster learning process, but also to prevent injuries from the beginning. In the following several slackline learning techniques will be discussed, which can then be implemented in the assistance system. Prior research indicates the applicability of slackline training for areas like sport medicine and rehabilitation training. It shows why slacklining could be used as an alternative to classical balance training and how the body swift affect these. Donath et al. [6] found in his meta-analysis significant improvements in the postural control after slackline training, which indicates the efficacy of this training method. This subsection shows several application scenarios in which a slackline can be implemented and improve the training effect.

2.2.1 Exercises during slackline training

For beginners it is difficult to walk or even stay on a slackline. The uncontrollable swift of the narrow line result in unfamiliar movements that cannot be handled at the very beginning. Therefore they should learn to concentrate, build up motoric basics and trust into the line, as well as manage their body behaviour.

Thoman [34] differentiate two basic methods for the learning process on a slackline. Teaching a slackline beginner, further called slacker, without any help or with external assistance. The investigation of Kroiß [19] shows that providing methodological aid, like human support or physical objects as nordic walking sticks or a bar, can help to improve the learning effect (Figure 2.1). Therefore it is a good advise for beginners to learn the fundamentals of standing and walking on the slackline to build up a groundwork. Several basic techniques and tips are useful to support her in this way. For example focusing on a specific point, stretching out the arm, raising the hands over the shoulder level, turning the palms to the top, going slightly in the knees, have the feet straight with the line, and so on [18, 19].

With further progress, the external help should be reduced. The slacker can now try to stay and walk on the line on her own. It is recommended to begin with the practice of a basic start, to stay with both feet, and one feet on the slackline since these are basic techniques (Figure 2.2). Staying with both feet seems easier in the beginning but only the hips and hands can be used for balancing. With just one feet on the line, the slacker can use the other one as an additional extremity for balancing purposes.

Advanced training should be practiced in a more dynamical way [34]. Like seen in several research works [4, 5, 10, 17, 24] this can be from crossover start (Figure 2.3a), turning on the line, hands on hips or behind the back (Figure 2.3b), walk

(a) Stick support

(b) Between bars

(c) Human support

Figure 2.1: Supportive exercises [19]

(a) Basic start

(b) One feet

(c) Both feet

Figure 2.2: Basic exercises [19]

sidewards or backwards up to catch and pass a pall, kicking a football, bouncing a basketball, or a kneel down on the slackline (Figure 2.3c).

Additional cognitive load is caused by unfamiliar exercises and simultaneous balancing on the line. This conjunction can lead to impairments. Even more difficult exercises can be carried out in further sessions like standing up from a sitting position, juggling, two people on the same line, reading a newspaper, closing eyes while balancing, vertical jumps, or rope skipping. Due to the higher difficulty of constraints, it results in a more unstable movement of the line.

Changes directly on the slackline itself, like varying the tension and length, have also an influence on the stability of the human body on the line [17, 24, 25]. A short and tight line results in a relatively small vibrating area, where the slacker has to outbalance short unpredictable movements on point. Given a longer and loose line, it results in a more swinging behaviour that she has to counteract [19].

The slacklining assistance system should mainly train and support slacker to walk on the slackline. With those approaches in mind a foundation is set to build helpful exercises for the system. Because the focus relies especially on beginners, this information serves as an inspiration for supporting them with effective and

(a) Crossover start

(b) Hands behind back

(c) Dropknee

Figure 2.3: Advanced techniques [19]

efficient methods. Now is the question, what effect has slackline on the human body and where can it be applied? This is part of the next subsection.

2.2.2 Slackline specific training effects and application scenarios

Donath et al. [4] elaborated the effects of slackline training on regular balancing, jump performance, and muscle activity with young children in school sport. The slackline specific balance has improved. Also the dynamic sway and muscle activity for the lower limb is reduced. But there were no effects regarding jump performance. The children enjoyed the slackline training. In comparison to classical balance training it can be more fun for the children and at the same time an effective training method.

Another study of Donath et al. [5] investigated slackline training with seniors from an age between 59 to 69 to measure effects on slackline specific balance and neuromuscular performance. They found significant differences between pre- and posttests during all slackline stance conditions. In addition the trunk and limb muscle activity were reduced after the training phase. With this in mind slacklining can be provided as an alternative balance training method for seniors. Regular balance training can help to reduce the fall risk, which can be an useful therapy for seniors when keeping in mind that 30% of seniors suffer from fall injuries once a year.

Keller et al. [17] examined the improvement of the postural control regarding the Hoffmann-Reflex after slackline training and whether adaptations can be found regarding classical balance training. The H-Reflex (Hoffmann-Reflex) is used to assess and quantify stretch-reflex responses due to electrical stimulation. The measurements show that these were significantly reduced as well as slackline specific balance were improved. Therefore slackline training and classical balance training have at least similar effects on the postural control.

Pfusterschmied et al. [24] found significant effects regarding stable stance after slackline training and even more effects were found for perturbed leg stance.

This is because slacklining is a high dynamic movement activity and there is more need of regaining equilibrium as in perturbed stance than for maintaining balance as in a stable leg stance condition. The velocity in medio-lateral and anterior-posterior center of gravity, knee and hip joint is reduced as well as the range motion in knee and hip joint. No changes in medio lateral direction for the stable surface or joint kinematics for both have been found.

Another study of Pfusterschmied et al. [25] shows effects on lower limb joint motion and muscle activation. They found a decrease in platform velocity and improvements in corrective action in the knee joint. Also enhanced activation of the muscle activity in rectus femoris (upper leg) was measured.

Granacher et al. [10] investigated the impact of slackline training for balance and strength promotion and found contradictory results compared with the studies described above. Static and dynamic postural control were analysed as well as the isometric and dynamic muscle strength. There were no effects regarding the postural control, maximal torque, and jumping height. The results can be explained due to the assessment of other recorded variables, usage of different methods for analysing the data, and the relatively short slackline training time than in other studies [24]. Therefore this study can be seen as an exceptional case.

Those investigations show that slacklining is indeed an effective method for improving the postural control. Hence many application scenarios can be thought of to implement a slacklining assistance system. For example it can be used as a training approach in school sport, preventative activity for seniors, and rehabilitation alternative. Furthermore it can be used as a supportive training method for athletes in sport activities like skiing or skating, that require a good body balance. Interactive technologies can be used to support training in such scenarios. The next section provides an overview about state of the art technologies, compares them, and show several implementations in balance scenarios.

2.3 Interactive technology

To build a real time feedback assistance system, a tracking device is needed that supports the slacker in an appropriate way and won't interrupt her. The Microsoft Kinect v2 seems like a suitable tracking system in this context, because the user don't need any further devices to be tracked. But it should be compared with other tracking technologies like the Nintendo Wii, Playstation Move, and a motion control suit, to justify its usage. In the following advantages and drawbacks of these systems will be discussed. Further several studies show how accurate and precise the Microsoft Kinect v2 is, if it can be applied for balancing purposes, give the user appropriate feedback, or useful analysis data for specialist like therapist.

2.3.1 Comparison of tracking technologies

The Nintendo Wii consists of a sensor bar with infrared sensors that estimates the position of the Wiimote controller in 3D. Further an accelerometer is integrated in the Wiimote to detect its motion. Thus the user can interact with the console, based on predefined gestures [1, 32]. Gesture recognition is an essential aspect of the slacklining assistance system for giving appropriate feedback regarding the executed exercise. Schlömer et al. [31] analysed the gesture recognition of the Wii and found an error rate between 5% and 15%.

A similar approach with a handheld controller is followed by the PlayStation Move. It contains an RGB camera called Move Eye that is used for tracking the 3D position of a lighting sphere attached on the handheld device named Move wand. The controller contains an accelerometer, gyro sensor and geomagnetic sensor to track the rotation and also support position tracking. In this way more accurate tracking is possible than with the Nintendo Wii [1, 32].

Both systems are good devices if the controller itself can be replicated as a virtual device like for example in golf or tennis. But they do not track the body movement and the user is bound to her handheld devices to interact with the system. In the slacklining system they could disturb user standing on the slackline. Moreover accurate feedback from the whole body is wanted and thus it should be the actual controlling device. Therefore they seem not to be appropriate devices for the slacklining system.

With a motion capture suit markers have to be attached on the user's body for tracking her body motion and rotational data. This makes it the best device for high accuracy and precision body tracking. Problems with the suite are that it is very expensive and the setup takes relatively long time because of the marker attachment and the positioning of the tracking cameras. The biggest drawback is the uncomfortable bulky equipment that could interfere the user during the performance [1, 2, 22]. This makes it an inappropriate device for user tracking on a slackline.

The Microsoft Kinect is a static device that includes a RGB camera and depth sensor. Because the body joints and player position are recognised by these, the user is free in her movement without any further controller. Another advantage is the low price in comparison to the motion control suite, and the low setup time because only the device itself is needed. Problems occur with occlusion of body parts that results in glitches and flawed tracking [15, 33]. To the user they can be hidden, e.g. by only showing the output of the depth cam [13]. This problem can also occur in the slacklining case because of overlaying feet. Therefore a feasibility study should be realised to show if this is a bigger problem or can be neglected.

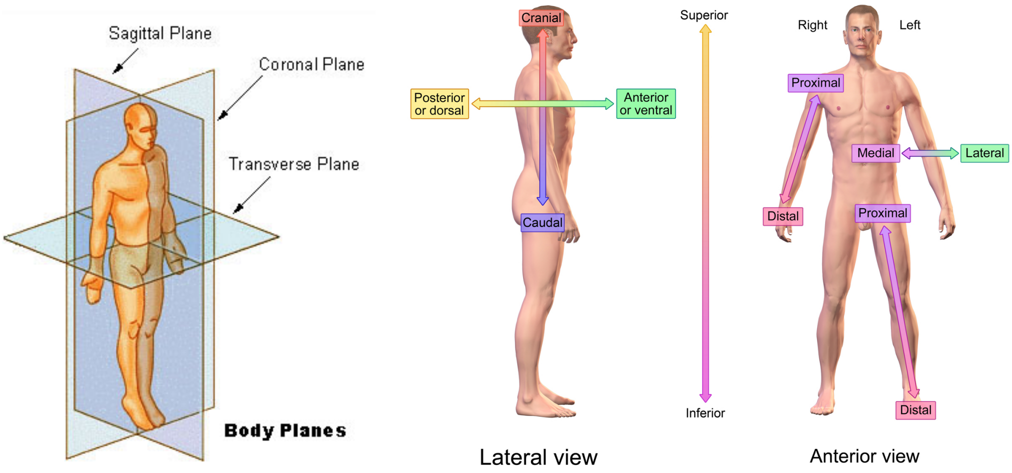
With this in mind, the Microsoft Kinect v2 seems like the most suitable device. The recognition of the whole body, freedom of movement, short setup time, and relatively low cost makes it the best system out of the stated devices.

2.3.2 Accuracy of the Microsoft Kinect

In the field of balance training it is necessary to give appropriate feedback for the patient that reveals errors in the performance and support a proper execution. With this in mind user tracking should be good enough to fulfil this criteria. Since Microsoft Kinect is used as the tracking device the accuracy and precision should be assessed.

Lim et al. [21] assessed the accuracy of the Kinect with a 3D motion capture system as a reference system. For further understanding please review Figure 2.4 regarding expressions to body planes and anatomical directional references. The participants had to execute balance training with complex aperiodic movements in the body planes (Figure 2.4a). Similar characterization of movements are provided by the Kinect in comparison to the 3D motion capture system. The correlation analysis showed that the Kinect and the 3D motion capture system are highly correlated for the flexion and extensions in the medio-lateral-axis (x-axis) but not on the anterior-posterior-axis (y-axis) and the cranial-caudal-axis (z-axis) (Figure 2.4b). This is because the Kinect determine joint locations based on the depth image data and the data input is limited to the depth camera view. Therefore recognition of joint angles in the sagittal and transverse plane is not optimal (Figure 2.4a). Also the primary goal of the Kinect is to measure the dynamic movements in the coronal (frontal) plane for gaming reasons. It is indeed an effective system to characterize changes in center of mass and movements in the frontal plane during balance training. But it would not be suitable in balance training that require in-depth analyses of joint motions, which is not needed with the slackline assistance.

Chang et al. [2] focuses mainly on the tracking performance of the Microsoft Kinect as a rehabilitation device in comparison with a high fidelity motion capture system called OptiTrack. In their application the user has to move objects from one side of the screen to the other. Five correct and incorrect movements



(a) Body Planes (b) Directional References (modified)

Figure 2.4: Anatomical terms of location [37]

have been realised and both systems successfully identified them. In trajectory comparison the results of the hand and elbow by the Kinect are very close to the OptiTrack system. Tracking of the shoulder movements are moderate because it involves rotation that the device does not recognizes well. The timing performance comparison shows that the OptiTrack system is negligible faster than the Kinect.

Woolford [39] compared the accuracy and precision of the Kinect v2 with the Qualisys motion capture system for the usage in healthcare applications. He describes that accuracy is the amount of how close a measured quantity to the actual value is. Precision is the similarity of repeated measurements (Figure 2.5). For example the Kinect skeleton tracking methods are accurate because the average joint position data is very close to the actual physical position. Regarding his definition of precision, the joint position data is not always precise because the data spreads in its position of the frame. The results show that the Kinect V2 is accurate but imprecise for body parts whose center of mass cannot be easily identified like the shoulder. For smaller body parts as well as between two body parts such as elbow or wrist the accuracy and precision is very high.

The Microsoft Kinect v2 can indeed be compared with high performance tracking devices. If no detailed analysis is needed, it provides reliable and appropriate data. For the assistance system it should provide sufficient data to track the user and give useful feedback

2.3.3 Implementation in balance training scenarios

Like already stated Chang et al. [2] not only assessed the accuracy of the Microsoft Kinect but also if it could fit as an alternative training device in rehabilitation

(a) Inaccurate and imprecise system generates random-like measurements

(b) Inaccurate but precise system, where measurements are close to each other but have systematic error

(c) Accurate and precise system generates measurements that are close to the real world

(d) Accurate and suffice precise system generates measurements that are close to each other and are not systematically biased

Figure 2.5: Definition of accuracy and precision [39]

training. The results show that it provides enough usable feedback to the therapists to be an appropriate device for medical uses. Woolford [39] state that the Microsoft kinect is a useful device for monitoring such exercises. The set-up is relatively easy and the tracking is appropriate for exercises in a healthcare environment. Lim et al. [21] investigated the usage of Microsoft Kinect in the field of falling risk. They tracked characterizing movements and found that it is an useful device for balance training. Ustinova et al. [35] used the Kinect to improve the postural control as well as coordination deficits from chronic traumatic brain injury patients. It resulted in improvements of postural stability, movement performance and motoric coordination. The participants were also very satisfied whereas normal exercises have been stated as boring. Pisan et al. [26] used the device to investigate the prediction of the loss of balance for elderly users with a step training program. The user preferred doing exercises with the system and the tests matched also the expectation of the researcher. An integration in promoting the postural control for parkinson disease with

Kinect games were elaborated by Pompeu et al. [27, 28]. The results affirm that the patients improve in balance purposes and motoric movements with this help.

Furthermore Estapa et al. [7] and Freitas et al. [8] collected data of execution from patients for medical reviews. Both developed a motor rehabilitation game. It is used to support therapeutic exercises and evaluate biomechanics of the patients. This allows subsequent analysis of the performance data for the therapist.

This approach of data analysis was also integrated by Garrido Navarro et al. [9] but in addition they elaborate if the Kinect can serve as a rehabilitation home assistance. Many patients are thrown out of their daily life environment for accessing traditional rehabilitation training in a medical center. Here the patient incorporate the system into their daily life and avoid such trips. The medical stuff gets all relevant parameters due to the transmission of the recordings from the exercises to the medical center. Beside this they get more time because nobody has to observe the training.

Keeping the stated results in mind shows that the Microsoft Kinect is a promising system for balance exercises that provides sufficient accurate and usable feedback. It can be embedded in a variation of fields as rehabilitation system, home assistance, or preventative technique. The aspect to motivate patients with an exergame approach and enjoyable user interface can also lead to successful exercise execution, which is part of the next section.

2.4 Feedback and interaction methods

Cognitive load plays an important role if skill acquisition is a major factor. In slacklining the user has to focus on multiple things simultaneously that increases the mental pressure. Several studies show why and how the cognitive load should be restricted. Another important fact is that repetitive exercises can lead to a boring and demotivating user experience. For that reason several methods, systems and game approaches can be used as an inspiration to build a system with a motivating and joyful environment. At last the integration and visualisation of feedback and interaction methods should be well thought out. Various techniques have been elaborated on how to provide this appropriately.

2.4.1 Restricting cognitive load

As a baseline Paas et al. [23] describes that the acquisition of new skills is in conjunction with cognitive load. By adjusting this the learning effect can be easened or hardened. Three types of cognitive loads exists that handle the working memory of a person regarding the learning process. Intrinsic load is the inherent complexity that is caused by the topic itself. It is also important in which manner information is given to the user. If this is unnecessary, repetitive, or interferes her it is called an extraneous cognitive load and increases the burden of the user. The last type is germane cognitive load, which describes also how information is given to the user but by supporting the him in that way. This is brought by activating and automating already existing patterns or generating new ones in the working memory to enhance a learning process. Regarding this several applications have been evaluated that are also relevant to the slacklining supporting system.

Van der Spek [36] evaluated how to deal with the right complexity in serious games. He describes in his mental model construction (Figure 2.6) that interference can be avoided by information regulation and focus attention. Improving is encouraged by predictability and reflection of the tasks. The attention of the user should be focused to relevant material by regulating the information given to him. Since a serious game like approach should be developed this is an important reference for building an effective learning process to the user.

Pisan et al. [26] evaluates the user risk of falling with cognitive loading exercises. They executed two stroop tests, where the participant had to name the correct color of the word. High and low cognitive load can be measured by differentiating the meaning and color of a word. In the next challenge she has to answer different maths problems provided by the system. The results show that the reaction time due to cognitive load is much larger with users that have a higher risk of falling than for users that have a lower risk. This could be explainable due to the fact that user with higher falling risk are not that good in terms of switching the cognitive focus from the balancing action into other actions.

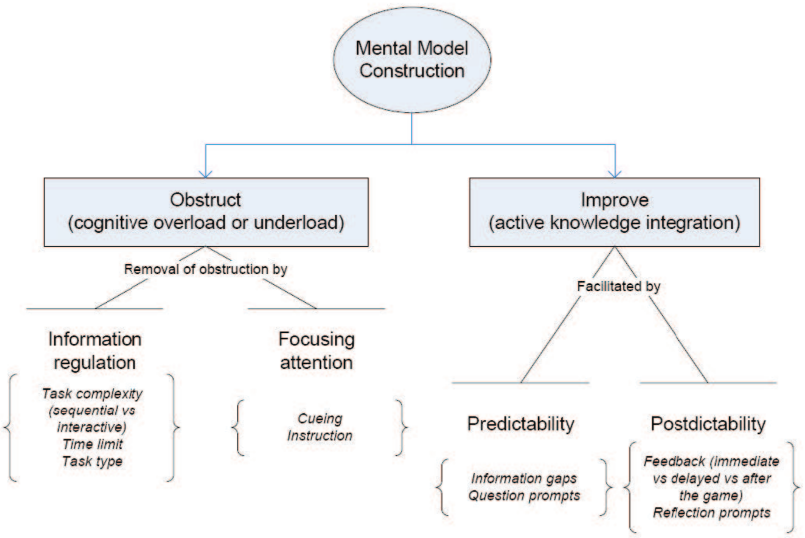


Figure 2.6: Guideline for enhancing the cognitive load [36]

Training on a slackline provides cognitive load to the user because of several simultaneously things she has to be aware of. Hence feedback given on how to behave in a situation should be provided in an appropriate manner to support the slacker. The system has to be aware of this and restrict the cognitive capability in the right way. Next to cognitive load the system has to ensure that the user stays motivated for the training, which is part of the following subsection.

2.4.2 Motivating factors for skill acquisition

Several rehabilitation and sport training programs can be elaborated for motivating facotrs because the skill acquisition in slacklining resemble with them. The training procedure is a process of repetitive exercise execution. For mastering new skills and extend himself a user must have the willingness and commitment for practicing, which can be described as motivation. The self-determination theory by Ryan et al. [29, 30] describes several types of motivational factors. First the intrinsic motivation, which is caused by interest to an action and satisfies the own psychological needs for self-determined behaviour. This is the fundamental stimulus for high valuable learning and practicing. Second the extrinsic motivation that is performing an activity because of an external output. The user can hereby feel externally propelled due to compliance with external regulations or she can be self-endorsed due to willingness and acceptance by the value of the practice.

Johnson et al. [14] stated regarding rehabilitation training that if exercises and the user himself provide negative factors like boredom, repetition or long execution time it results in a discouragement. Enhancing the interaction with this trainings can lead to effective training. Pisan et al. [26] says that video games can help to motivate the patients through their physical training. The participants in his user tests found the games that he developed engaging. They preferred doing the exercises with the system.

Several researchers involved the motivational aspect of video games in their system. Ustinova et al. [35] developed four custom virtual video games to elaborate the efficacy for postural deficits. First a virtual teacher where the subject has to copy its movements strictly. Second a virtual challenger that is divided into a skateboard, courtyard and an octopus game with specific exercises in which the movements of the user are more flexible. Successfully completed performance will be rewarded with a number of points. Overall the user were strongly satisfied with the gaming part of the therapy and moderate with the virtual teacher part.

Freitas et al. [8] focused on user centred development of a physiotherapeutic game that supports motor rehabilitation exercises. A plane represented the user and she has to fly through rings in the air and avoid obstacles. The patients were strongly satisfied with the game. An important factor here is the good user interface that affects the user motivation, visually presented scenario and playing technique in a positive way.

Estepa et al. [7] evaluates three developed exergames involving different psychophysical rehabilitation exercises. A virtual avatar represents the patient and orders are giving via an auditive or visual stimuli. The first two games are a series of coming balls placed at desired angles that the patient has to avoid with her trunk or, in the second game, with her feet. In the third exercise she has to step forward to a colored line between starting and goal position. All games were easy to understand and provide necessary feedback. The patients had a considerable interest to use the system.

Kajastila and Hämäläinen [15] encourages monotonous parts of climbing training by adding goals and supporting the social collaboration of the participants. Hence they are making it overall more enjoyable. Six prototypes were developed. Prototypes that rely more on a training part are an easy route builder, automatic route generator and instant video feedback. For the user those were the most useful ones. The exercises that consists of a more playful part, such as a chasing animated saw that the climber has to avoid, shifted the focus away from the training part.

With this in mind an useful training device should be considered that includes an enjoyable virtual environment. A good balance between these both is the key for successful and motivating skill acquisition. Another part of the system should also provide useful feedback to the slacker. Which methods can be used for this will be discussed in the following.

2.4.3 Approaches and techniques for providing feedback

Several technological advances like video feedback, virtual environments and auditive information can be applied for providing feedback in sport activities. Liebermann et al. [20] evaluated those regarding their field of application. With video information costs are relatively low, it is easy accessible, and portable. It can be repetitively replayed in real-time or superposition of two video. Training in 3D virtual environments can help to improve or to familiarize with a real world skill acquisition. The user can pre-practice a skill in simulated unknown conditions like pilots in a simulated airplane. Providing appropriate auditive information can also have a relatively high impact on performance enhancement. Also the Microsoft HCI-Guidelines state that implementing audio is a good way if the user need to be notified, and to indicate states of changing behaviour [3]. For example in balance training a warning signal can indicate that the current pose is not the desired one. If the user corrects his posture in the right way, the signal should then transform into an more comfortable signal. All of these allow qualitative and meaningful feedback in their application context. The user can review the execution, pre practice in a virtual environment, or be supported by audio warning signals. WIth this she can discover failure in her performance.

Feedback has to be provided in an appropriate manner for improving new motor skill acquisition. Especially for starting to learn a new technique it is important to have immediate feedback sources on which the user can rely on [12, 38]. Therefore it should be easy to understand for enhancing the learning process.

Hämäläinen [11] developed applications for a camera output in front of the user. An automated motion controlled approach starts and stops the recording if the motion exceeds a certain threshold. Second a speech and last a gesture control prototype. Both consists of four commands to record, play, stop and delay the recording. The user test ranked the automatisation the worst because it reacted to unintentional motions, which ends in unwanted command recognition. The speech system ranked the best but only worked well if the participant speaks near the microphone. Some mentioned that the gesture approach were more intuitive and natural, which could be a good compromise out of the three approaches.

Holsti et al. [13] investigated delayed video feedback and a platform jumping game in trampoline sport. The former records the performance execution and shows it repetitive to the user. In the second the player has to jump back- and forwards on virtual platforms. They tested it with athletes and beginner. The delayed video feedback was ranked useful for nearly all athletes. Overall the platform jumping game was ranked the best.

Kajastila and Hämäläinen [15] project graphics on an artificial climbing wall. A feasibility study showed that graphic information is best located near holds where the focus of the climber goes naturally. This can be adapted to slacklining since the slacker has to focus usually a specific point in front of her.It would be useful to provide information in the peripheral view. Next to other prototypes he has implemented an instant delayed video feedback. This is rated as one of the most useful ones because the user can immediately analyse her performance. Also a gaming approach is developed as an animated saw that chases the climber and has to be avoided. User state that it moves the focus away from the training, but it could be an enjoyable alternative to kids for getting them used to the sport.

Based on the results of the last paper Kajastila et al. [16] developed two games and a route creation application. User emphasize the versatility and excitement of the games. They also forget the fear of heights due to time limits and forcing them to focus and achieve a goal. User stated that playing and spectating is also more fun due to implemented sound and visual effects.

Like seen a delayed video feedback is a good approach to learn new skills. Combining this with a gaming approach can simultaneously lead to a joyful experience with training aspects. Also adding audio signals can further improve this experience for the user as well as for spectators. A well suited interaction mechanism and a good looking environment can help to create an effective system and motivate the user for training purposes.

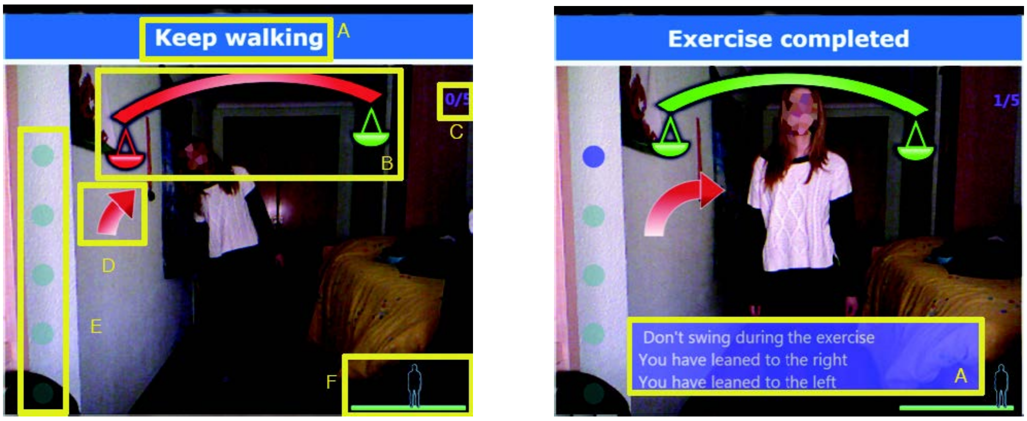
2.4.4 User interface

Important feedback information during the exercise should be placed surrounding the focus point in the peripheral view of the user. Directing the user for correcting her movement can be done in several ways. Basic information about the execution should be given prior to the user for exercise preparation. Surrounding objects can be displayed as arrows, flashing notifications or weighting scale like seen by Garrido Navarro et al. [9] in Figure 2.7a. Additional informations like current exercise and the state can be displayed outside of the focus space. But they should be designed to not distract the user. If they do so it should be able to just show the feedback visualisations. A feedback summary after the execution can give an useful resume about the exercise as an reflection like in Figure 2.7b.

Another method is to show the user itself or an avatar that demonstrates the correct performance of the current exercises like in Figure 2.8 and 2.9. Holsti et al. [13] implemented such a user integration and in user testing they endorse to see themself performing in real time.

The task about the execution has to be clarified. Chang et al. [2] provides real time feedback on the performance quality due to a visualised path. If the performance is correct the path will turn green. But if she moves outside the range the path turns red and an arrows guides him into the correct position. Instructions and highlighting objects can help to complete an exercise successfully (Figure 2.10). If she performs something wrong during the performance e.g. in the slacklining case corresponding body parts could be highlighted.

Microsoft itself offers human interface guidelines for the Kinect v2 [3]. In this document is describes how to design and develop for the user. It provides a quick



(a) Surrounding objects in the UI

(b) Completed exercise feedback summary

Figure 2.7: Interface of a rehabilitation training application [9]

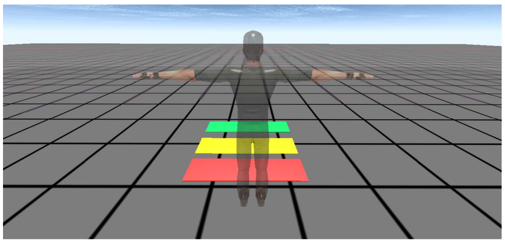


Figure 2.8: 3D Model as avatar [7]

Figure 2.9: Rail-time user representation [13]

introduction into the Kinect itself, design principles for interactions regarding gesture and voice, and how to visualize appropriate feedback. Also which interactions should be used for a specific action. Overall design principles are that the application should be context-aware, make the user confident, choosing the right input method and to conduct user tests. A gesture that relies on the real world can help the user to be more familiar with the product, than learning unknown gestures (Figure 2.11a).

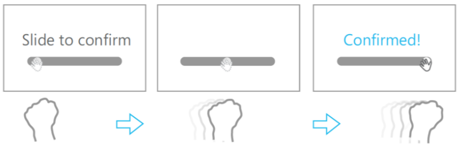
Teaching gestures is a core functionality in the slacklining assistance system. The HCI-Guidelines state that new gestures should be teached with a quick

(a) Instruction to the game

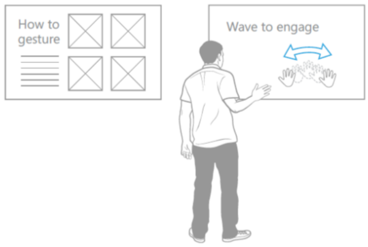
(b) Green indicator for correct performance

Figure 2.10: User interface of a rehabilitational application [2]

tutorial. Further a visual hint, animation, or notification can also help for first the engagement (Figure 2.11b).



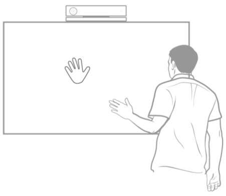
(a) Slider as dynamic gesture



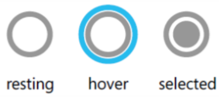
(b) Teaching new gestures

Figure 2.11: Gesture interaction [3]

Appropriate feedback should visualise if the sensor is ready, the user is visible to the Kinect, she is engaging right now, etc. For example if the user can control something with his hand can be visualised in form of a cursor and the state of a UI control element should also be clear (Figure 2.12).



(a) Hand cursor



(b) UI controls

Figure 2.12: Feedback methods [3]

The most important part is the progress indicator described in this guideline. It says that an indicator should be given if the user has to hold a position, as well as the frequency of gesture repetition. Clear and prominent visuals should be used to show the entire progression (Figure 2.13). If a user should copy a specific movement an avatar or animation can be shown, before or during the movement.

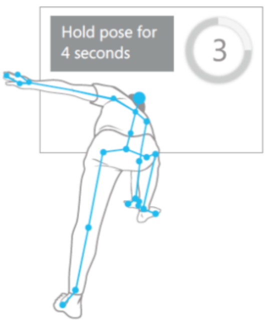


Figure 2.13: Repetition and time length indicators [3]

Summarizing the user interface should not distract the slacker but support him. Only necessary and useful information have to be displayed during the exercise. Providing an introduction and useful tips can help to give an understanding of the exercise. An avatar or animation is a good alternative to make clear how to perform an exercise. The system should also rely on Microsoft human interface guidelines, which provides design tips and serves as a reference to build user friendly applications.

2.5 Conclusion

With the stated related work a foundation is given to build a slacklining assistance system. For teaching beginners on a slackline it is important get familiar with it. The assistance system should provide the given exercises and tips for beginners which build a foundation for further training. Several application scenarios show that slacklining can replace balance training in rehabilitation environment, as prevention system, in school sport or as an home assistance. This can be combined with interactive technology, which helps patients to fulfil their exercises and provide the medical stuff with sufficient analysis data.

As interaction device the Microsoft Kinect v2 seems like the best choice out of the available technologies. It provides sufficient useful and accurate data analysis, if no in-depth analysis is needed. More advantages are the low cost, short setup time and the freedom of the movements for the user. Several studies indicate also that the Kinect can be embedded in balance training scenarios and increases the training efficacy while motivate patients.

A problem that occurs with more complexity in the exercises is the raising cognitive load. The system should therefore provide appropriate feedback and be aware of the cognitive load of the slacker. Motivating the slacker for further exercise execution can be done with a well defined interaction mechanism, an enjoyable but challenging virtual training environment, and an user friendly interface. This can be realised especially with the help of human interface guidelines provided by Microsoft, which include several design tips for developing a Kinect application.

With the help of this foundation a concept for the slacklining assistance system has been created, which can be seen in the next chapter.

Chapter 3
Slacklining and learning techniques

3.1 Introduction into slacklining

- What is it actually
- „The fascination behind it" —> Optional?
- Different ways to slackline **figures**
  - Normal
  - Highline
  - Waterline
  - Longline
- Approach scenarios
  - Hobby
  - Competition
  - Tricklining
  - Walking
- Tension
  - Strong
  - Loose

3.2 Learning techniques

3.2.1 Methods for learning slacklining

Static

Methodical / Dynamic

3.2.2 Stages and exercise of learning slacklining

Preliminary

First contact

Static exercises

Dynamic exercises

3.3 Proof Of Concept

A few questions have to be clarified before starting with a concept of the assistance system. First if it is possible to track a human body on the slackline with the Kinect v2. Is the answer positive than the second question should be how good is the tracking behaviour of the device and can it therefore be used to track a human body on a slackline.

3.3.1 Introduction

As seen in several movement scenarios, in the area of balance training, the user were successfully trackable by the appropriate device **[CITE]**. Hence the expectation is that the Microsoft Kinect v2 should be able to track the human body on a slackline with an appropriate accuracy and precision. But the range of the slackline, the movement of the line itself, unpredictable movements of the user, and his balancing actions could also possibly disturb the tracking ability. This can then lead to imprecise and inaccurate tracking data that negate the stated findings of other tracking balancing scenarios.

With this in mind multiple angles, positions of the camera, as well as the slackline have been tested. This Chapter will therefore describe a feasibility study, which gives clarification about the named questions.

3.3.2 General setup of the study

One essential part that is needed for the experiment is the slackline. But it exists in many different forms and variations as seen in the **Introduction into slacklining**.

Also all lines have to use a fixing mechanism and are normally attached on a tree, pole, pillar, or with anchors on the ground or on a wall. In the case of this study, it would result in a constraint of variability. The choice felt therefore on a mobile slackline device variation, which is the most suited alternative. It consists of a slackline itself that is tensed around brackets at both ends. For feasibility reasons and because the focus of this scenario lies mainly on beginners, the device is comparatively short. A variable middle rail can be telescoped and vary the length of the device from **1 m up to 3.5 m**. With this it is possible to test it indoors and in different positions with a minimum of effort **figure x**. Another advantage of this is the independence and variability of the device. This makes it easy to test it for the best position regarding the tracking camera, which is another essential part of the experiment.

In slacklining the user should be free in his movement and match predefined gestures. Therefore the low-cost tracking camera Kinect v2 is used as tracking device. As discussed in **Interactive technology** this is the most appropriate one out of the available user tracking devices. A mentionable role plays the detection range of Kinect's depth sensor regarding the length of the slackline. The sensors range lies between **0.5 up to 4.5 meters [CITE]**. Since a mobile slackline is used with a length up to 3.5 meters, it would fit entirely in the tracking range. To track user for further training on a longer slackline, the depth range is not sufficient. This could be solved by using more than one Kinect device to have a larger the range.

Generally a major point for tracking the user is the interplay between positioning the tracking device and slackline The coherence of angle and height of the Kinect v2 is essential for the depth range, which varies by changing these parameters. This will be discussed in the following.

3.3.3 Testing scenario

The study took place in the laboratory of the research group in the ***german reasearch center for artificial intelligence***. A big advantage of this is the large space to place the slackline in different variations. The slackline can therefore be easily moved and is faced in three positions to the Kinect - frontal (0 Degree), diagonal (45 Degree) and sideways (90 Degree) **(Figure X)**. Each of this positions is tested regarding three different height level of the Kinect v2. Therefore it is attached on a tripod like seen in **Figure X**. At the end nine different combinations are covered to track a user on a slackline, which gives a good coherence of the camera height position to the slackline direction. In the following the results discuss the feasibility of the coherence. With this a good overview is given to find appropriate tracking positions.

Slackline positioning

Sideways

Here is the slackline positioned sideways, in 90 Degree rotated to the Kinect v2. The advantage of this is that the whole body on the slackline is in a constant line within the tracking area of the Kinect v2. With this no interference regarding the tracking distance can happen **(Figure X)**. But the result show that regardless of the Kinect height the user tracking is very bad. This is because many body parts overlay and the Kinect v2 has problems to detect the body joints with appropriate accuracy and precision, which can be seen in **Figure X**. Therefore this seems not like the appropriate slackline position.

Diagonal

The slackline stays diagonal in 45 Degrees to the camera view. Because of this there is now a distance between front and end point of the slackline. This is not a problem because it fits well in the tracking range **(Table X and Figure X)**. This could even result in a better trackability in matter of the depth field range, since the distance in the front shrinked and is therefore closer to the Kinect depth view. Another advantage is that many body party doesn't occlude entirely here because of the angle to the camera. Therefore a better tracking ability is given than positioning the slackline sideways.

But this problem is not entirely solved. It occurs with occluding joints of the slacker at the end of the line due to the angle the arms and the body **occlude/interfere** with each other. Also the whole leg occludes the other one while stepping forwards **(Figure X)**. This results in a not entirely perfect joint tracking and can lead to detection problems, depending on the executed exercise.

Frontal

In the last positioning the slackline stays frontal in line with the user facing towards to the Kinect camera. The distance takes almost the whole range from the Kinect's depth field up to the edge of it **(Table X)**. The advantage is the user tracking ability which is here the best out of the three positioning. The camera can see the full body and have nearly no problems with occlusions.
One problem could occur with overlaying feets if the slacker stay with both feet on the line, which is in this case independent to the Kinect height **(Figure X)**. But testings regarding this problem have not shown any critical detection problems. The Kinect can calculate the location of an occluded joint with a certain tolerance due to its own algorithms **[CITE]**.

Kinect height

Three main height levels were used to show the main differences of the tracking behaviour from the Kinect. It is mounted on a tripod and covers the heights seen in **Table X**, within the range of 0.80 meters up to 2.40 meters from the ground.

Beginning with a height of 2.40 meters the Kinect has a very steep angle to track the slackers body on the full range of the slackline. Because of this the depth range shifts into the front like seen in **Figure X**. Therefore if the slacker begins at the starting position on the slackline, he immediately reaches the end of the tracking area which can cause tracking problems. Because of this steep angle the joints will occlude other, the further he walks to the end of the line.

A step lower with a height of 1.60 meters the entire body is fully visible in almost all ranges. The Kinect is now on a level with the users shoulder and has therefore a relatively flat angle. Because of this the slackline has to be positioned a little bit further away as former to be fully visible for the Kinect view. This results in a more homogeneous depth range view like seen in **Figure X**.

Problems can occur at the very end of the slackline depending on the slacker's height. It could be the case that his head or more will be cropped. Therefore the slackline has to be slightly further away from the Kinect camera than on other heights. But for beginner training purposes this is not relevant.

A height of 0.8 m results in an even more flat ground perspective. The Kinect is now a little above the level as the slackline. Like in the last one the whole body is in the entire line good visible, but here also at the very start of the line. Problems can occur here with the tracking ability at the starting point. This is because the full tracking range is used **(Figure X)**. Therefore at the very end

Overall a range of 0.80 m up to 1.60 m seems like the best height for the Kinect for tracking a slacker. The tracking and view is more homogeneous and the angle is flatter with which the full depth range can be used.

3.3.4 Best positioning for beginner learning purposes

The frontal positioning has the only big problem with the depth range at the starting position of the slackline. Since only beginners are the main focus of this study, the starting position of the slackline plays an important role. Therefore for tracking purposes it is better to move the slackline closer to the camera. With this the last quarter of the slackline is cropped out of the view but the slacker can be tracked with a higher confidence **(Figure X)**. The Kinect height should be between 0.8 and 1.8 meters. With a higher attachment the angle will be too steep and the available space is cropped, or occlusion of body parts can occur.

table

Chapter 4
Concept

With the help of the previous **Related Work** chapter, and the **Slacklining and learning techniques** chapter, a concept can be built for the interactive system. Therefore this chapter elaborates a conceptual analysis. It involves **Key elements of a kinect application** where general features of a Kinect application will be discussed regarding the Kinect Human-Interface-Guidelines. Section **General** describes basic requirements of the entire system. This is followed by the more specific sections **Interaction**, **Stages** and **Exercises** as well as **Feedback system**, which describes how feedback is properly given to the user. Lastly the section **Scenario** gives a better overview about the worflow of the particular components.

4.1 Key elements of a kinect application

Microsoft created Kinect Human-Interface-Guidelines (HIG) for developer and designer that covers the design of basic and further interactions, gestures, voice, and feedback for an approriate kinect application [3]. Therefore developer may follow this general standard to support their end-user. In the following key features of the guideline will be discussed on which the interactive slackline system will rely on to enhance the user experience.

Context-awareness

Controls should be placed where user would expect them to be. Also it is important that the user feel confident. Interactions should be designed simple and easy to learn.

Visual and audio feedback

Giving the user constant feedback helps people to know what is happening. Regarding this a combination of visual as well as audio feedback results in a better experience, e.g. clicking a button changes its visual state and provides an audio signal. More specific feedback regarding the system can be found in **Feedback system**.

Clarification

The user may interpret interactions with the system differently from others. Therefore the system should explain clearly what the user has to do, e.g. *"Raise one hand above your head"* instead of just *"Raise your hand"*. The cognitive load of the user should be kept low and not exceed a number of six gestures, such that she easily remembers the actions. The system has a set of three basic interaction techniques, which fits in this range.

User viewer

A small scene viewer shows the range in which the user can move and is recognized by the Kinect. It displays a mirror like view in which the user can see a silhouette of herself and the constraints of the Kinect device, like in figure 4.1.

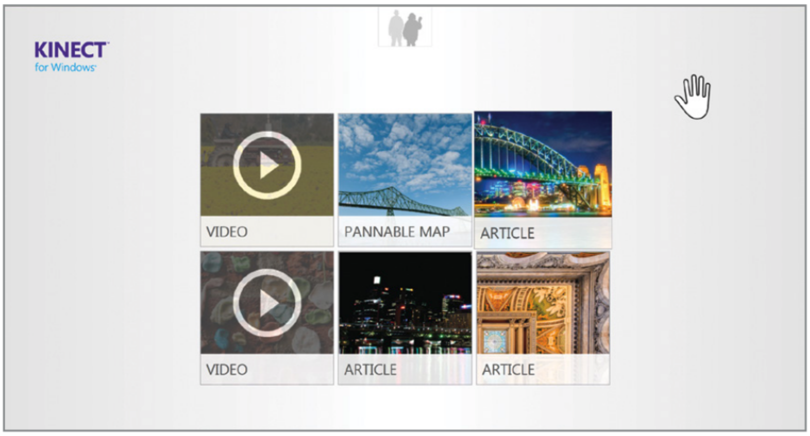


Figure 4.1: User Viewer on top [3]

Learning interaction methods

The system teach the user how to proper interact with it right from the beginning with an introduction tutorial. It provides also support to interact with both hands for left- and right-handed people. More about interaction methods can be seen in **Interaction**.

Teaching complex gestures / exercises

For more complex gestures (exercises) the system provides a tutorial on how to accomplish this gesture successfully. An indicator should thereby show if the gesture is executed. More can be found in **Exercises**.

Element sizing

The system will rely on the guidelines and match the button sizing regarding the screen resolution to keep reliability on interaction. This is a size of 208 by 208px in a resolution of 1920x1080 pixel. As recommended a tile button style will be used which are a good baseline where the user can hit them accurately and read the button text.

Physical interaction zone

This zone ensures that the user is able to reach anything in a comfortable range. In the application it is constrained by the joints of the shoulders to the hips of the opposite site of the interaction hand. It is designed like seen in figure 4.2 to have a better understanding.

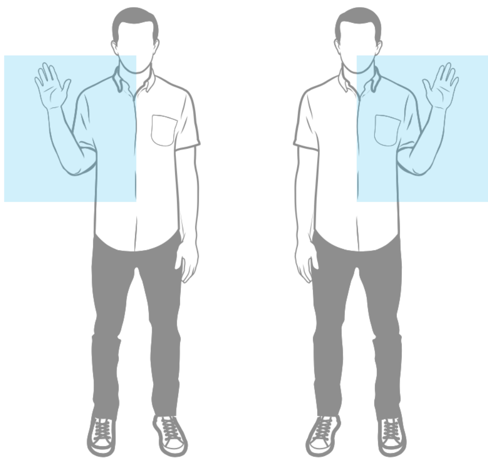


Figure 4.2: Physical interaction zone [3]

4.2 General

Since the user should get feedback about her performance during exercise execution, the system must be able to track her in an appropriate manner. Further all relevant data should be immediately saved when it is needed, for example when successfully accomplishing an exercise and so on. In each screen there should be a title, which informs the user were she currently is. Also a back button gives her the possibility to go to the last screen if she misclicks. One can system that the system is available on one device but several persons should be able to interact with the system. Therefore it should provide a user selection screen, in which each user can select her own profile. This can also be seen in many others applications like **[CITE]**

4.3 Interaction

Since the user can and should be able to navigate through the system by herself the interaction can be seen as one of the bigger parts of the system. The user can control a cursor with her own hand, which is also visualized in the screen. When initially starting the system the user should raise one hand over the head to convey that the system initially recognises and responds to a user action.

Further a small tutorial is given in which the user is instructed in how to click by pushing his hand towards the Kinect or doing a point gesture and how to scroll through a menu. These actions have to be directly applied by the user. The state of the current interaction is visualized properly by providing a circle around the hand cursor that represents the progress like seen in figure 4.3. Besides this she is instructed on how to stay in the right starting position. This is required by some actions like just before starting the exercise execution to ensure the user is ready.

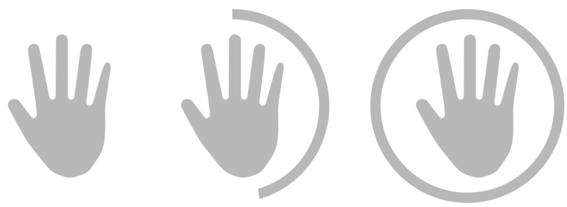


Figure 4.3: Progress of handcursor (Left: Default, Middle: In progress, Right: Finished)

Another big role of this plays in the exercise execution. Here the user interacts with the system to match a predefined gesture for accomplishing the exercise. Therefore real time feedback is provided which gives her hints about the right interaction and how good it is performed. More information about the feedback methods can be found in **Feedback system**.

4.4 Stages

The system contains predefined gestures, which are subdivided in stages, which can be seen in **Stages and exercise of learning slacklining**. A stage menu should be provided to give the user an overview and in which each one consists of several exercises. Every stage is locked except the first one, which is the users starting point. The next stage can be unlocked, by successfully executing all exercise in the current one. Hence it can be assured that the user is able to encounter with the more difficult exercises. The user should be introduced to the stage. In here the purpose, goal, and helpful techniques should be given, such that the user becomes an overview about the exercises. At last a summary scene shows several performance parameter for the exercises in this stage.

4.5 Exercises

Each exercise is part of one stage. An exercise itself is divided into two body sides, which are further divided into several repetitions, see figure 4.4. Each exercise is locked except the first one to provide a starting point. The next exercise can be unlocked by accomplishing both sides of the current exercise. Similarly a side is completed if all repetitions have been finished. Like for the stage, each exercise should be instructed for the user, such that she can successfully perform it. She should stand in a starting position to start the exercise. This is to ensure that no exercise is starting to track if the user would make a random gesture which could lead to confusion of the user. During the execution she should get real time feedback about her current performance, which is further discussed in **Feedback system**. After the execution a summary should show the performance of the execution with several parameters like execution time, amount of attempts needed, and the confidence regarding the given gesture.

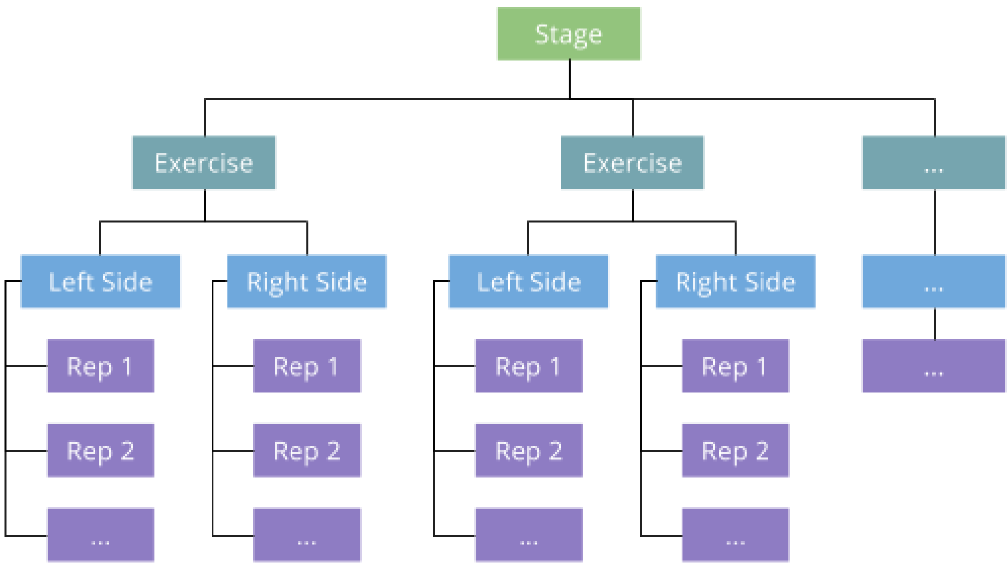


Figure 4.4: Exercise structure

4.6 Feedback system

Feedback is the main and most powerful component of the interactive learning system. Since the user should interact on her own with the system one has to assume that no other person interfere with her and the system. With this in mind the feedback of the system should designed in a way, that the user knows at anytime what she has to do or has done. In general audio and visual feedback is provided to the user. Regarding the **Interaction** with the system, e.g. clicking a button, the system should respond with an audio signal and change the elements visual state accordingly.

For the accomplishment of the exercise execution the system provides essential responses like seen in other applications **[cite, maybe Related Work]**. In the slackline system the following feedback indicators are integrated for the exercise execution:

- Staying in the right position before starting an exercise
- When an exercise is currently correctly performed
- How good the exercise is currently performed, namely the confidence
- The elapsed time the user is performing the exercise
- When the repetition is successfully accomplished, i.e. the minimum time has been reached
- When an repetition attempt was not successful
- How many repetitions in general, finished and left
- Checklist about key elements in an execution (like hands up, foot stretched, etc.)
- A summary that shows the user parameters about the performance (execution time, overall attempts, confidence) for each repetition and an average value of these
- A similar summary can also be found for the entire stage, where the same parameters for each exercise are listed in average

With this a baseline is built for appropriate real time feedback to the user.

4.7 Scenario

To have a better understanding regarding the interplay of the several components a generic scenario workflow will be given from the point of view of the user:

The user raises the hands over her head to start the application. She is now instructed on how to interact with elements on the screen, e.g. clicking and scrolling. After being confident with this, she selects her user profile to load the appropriate exercises and leads her to the stage selection. She selects the first stage since all others are currently locked. Now she is in the exercise menu. In here she clicks on the *stage information* button, which gives her an introduction into the stage. After confirming that she has read the introduction the first exercise becomes unlocked and she selects it. After that she decides to train her left leg first in the side selection. An exercise introduction screen is following, which shows specific information about the execution. After reading the introduction she feels ready to counter the exercise. Therefore she goes into the starting position and starts the exercise by clicking the start button. The screen changes and all relevant elements are shown for the exercise execution. She performs every repetition of the exercise successfully. After finishing these the system leads her to the exercise summary screen, which shows her the performance of the just executed exercise. In here she can now decide to return to the main menu or go on and start the training for the other body side. This procedure is also visualized in Figure 4.5 below.

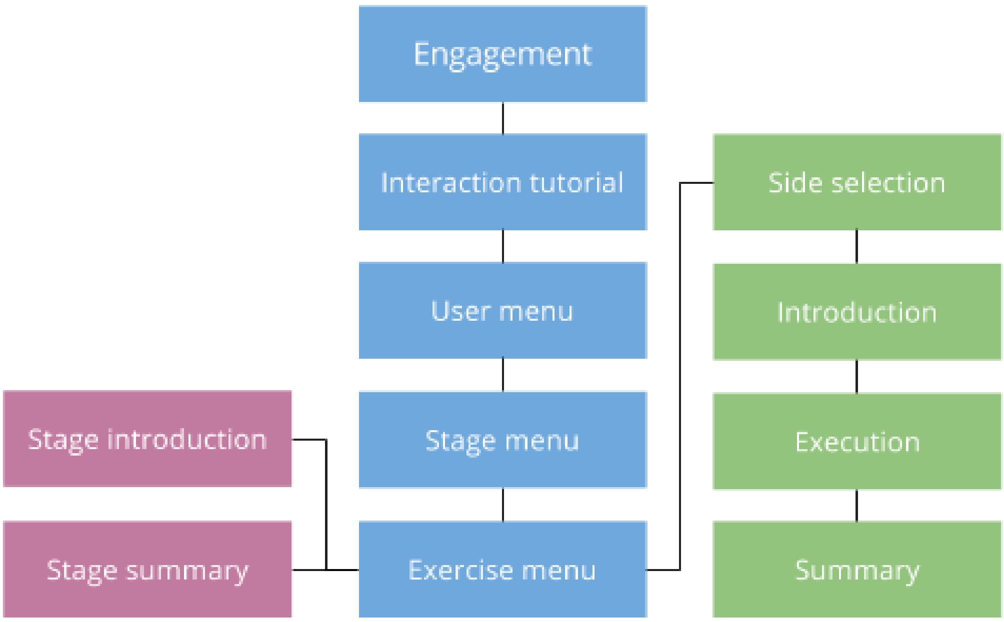


Figure 4.5: Scenario workflow

Chapter 5
System integration

Cursor

Specifically for the cursor, with which the user can interact with elements on the system by pushing the hand towards the kinect, the state will be clarified by a circle like seen in figure insert figure below.

Bibliography

[1] Bogdanovych, Anton and Stanton, Christopher. A Novel Approach to Sports Oriented Video Games with Real-time Motion Streaming. In *Proceedings of the 7th ACM SIGCHI Symposium on Engineering Interactive Computing Systems* (2015), EICS '15, ACM, pp. 64–73.

[2] Chang, Chien-Yen; Lange, B.; Zhang, Mi; Koenig, S.; Requejo, P.; Somboon, N.; Sawchuk, A. A. and Rizzo, A. A. Towards pervasive physical rehabilitation using Microsoft Kinect. In *6th International Conference on Pervasive Computing Technologies for Healthcare (PervasiveHealth) and Workshops* (2012), pp. 159–162.

[3] Corporation, Microsoft. Kinect for Windows | Human Interace Guidelines v2.0, 2014. [Online; accessed 13-March-2017].

[4] Donath, L.; Roth, R.; Rueegge, A.; Groppa, M.; Zahner, L. and Faude, O. Effects of Slackline Training on Balance, Jump Performance & Muscle Activity in Young Children. *International Journal of Sports Medicine 34*, 12 (2013), pp. 1093–1098.

[5] Donath, L.; Roth, R.; Zahner, L. and Faude, O. Slackline training and neuromuscular performance in seniors: A randomized controlled trial. *Scandinavian Journal of Medicine & Science in Sports 26*, 3 (2016), pp. 275–283.

[6] Donath, Lars; Roth, Ralf; Zahner, Lukas and Faude, Oliver. Slackline Training (Balancing Over Narrow Nylon Ribbons) and Balance Performance: A Meta-Analytical Review. *Sports Medicine* (2016), pp. 1–12.

[7] Estepa, A.; Piriz, S. Sponton; Albornoz, E. and Martínez, C. Development of a Kinect-based exergaming system for motor rehabilitation in neurological disorders. *Journal of Physics: Conference Series 705*, 1 (2016), p. 012060.

[8] Freitas, Daniel Q.; Da Gama, Alana E. F.; Figueiredo, Lucas; Chaves, Thiago M.; Marques-Oliveira, Déborah; Teichrieb, Veronica and Araújo, Cristiano. Development and Evaluation of a Kinect Based Motor Rehabilitation Game. In *Proceedings of SBGames 2012* (2012), vol. 2012, pp. 144–153.

[9] Garrido, Juan Enrique; Marset, Irma; Penichet, Víctor M. R. and Lozano, María D. Balance Disorder Rehabilitation Through Movement

Interaction. In *7th International Conference on Pervasive Computing Technologies for Healthcare and Workshops* (2013), PervasiveHealth '13, ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering), pp. 319–322.

[10] GRANACHER, U.; ITEN, N.; ROTH, R. AND GOLLHOFER, A. Slackline training for balance and strength promotion. *International Journal of Sports Medicine 31* (2010), pp. 717–723.

[11] HÄMÄLÄINEN, PERTTU. Interactive Video Mirrors for Sports Training. In *Proceedings of the 3rd Nordic Conference on Human-computer Interaction* (2004), NordiCHI '04, ACM, pp. 199–202.

[12] HODGES, NICOLA J. AND FRANKS, IAN M. Modelling coaching practice: the role of instruction and demonstration. *Journal of Sports Sciences 20*, 10 (2002), pp. 793–811.

[13] HOLSTI, LEO; TAKALA, TUUKKA; MARTIKAINEN, AKI; KAJASTILA, RAINE AND HÄMÄLÄINEN, PERTTU. Body-controlled Trampoline Training Games Based on Computer Vision. In *CHI '13 Extended Abstracts on Human Factors in Computing Systems* (2013), CHI EA '13, ACM, pp. 1143–1148.

[14] JOHNSON, D.A.; ROSE, ED; RUSHTON, S.; PENTLAND, B. AND ATTREE, E.A. Virtual Reality: A New Prosthesis for Brain Injury Rehabilitation. *Scottish Medical Journal 43*, 3 (1998), pp. 81–83.

[15] KAJASTILA, RAINE AND HÄMÄLÄINEN, PERTTU. Augmented Climbing: Interacting with Projected Graphics on a Climbing Wall. In *Proceedings of the Extended Abstracts of the 32Nd Annual ACM Conference on Human Factors in Computing Systems* (2014), CHI EA '14, ACM, pp. 1279–1284.

[16] KAJASTILA, RAINE; HOLSTI, LEO AND HÄMÄLÄINEN, PERTTU. The Augmented Climbing Wall: High-Exertion Proximity Interaction on a Wall-Sized Interactive Surface. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (2016), CHI '16, ACM, pp. 758–769.

[17] KELLER, M.; PFUSTERSCHMIED, J.; BUCHECKER, M.; MÜLLER, E. AND TAUBE, W. Improved postural control after slackline training is accompanied by reduced H-reflexes. *Scandinavian Journal of Medicine & Science in Sports 22*, 4 (2012), pp. 471–477.

[18] KLEINDL, REINHARD. *Slackline: Die Kunst des modernen Seiltanzens*. Meyer & Meyer, 2011.

[19] KROISS, ANDREAS. Der Trendsport Slackline und seine Anwendungsmöglichkeiten im Schulsport. Master's thesis, TU München, 2007.

[20] LIEBERMANN, DARIO G.; KATZ, LARRY; HUGHES, MIKE D.; BARTLETT, ROGER M.; MCCLEMENTS, JIM AND FRANKS, IAN M. Advances in the

application of information technology to sport performance. *Journal of Sports Sciences 20*, 10 (2002), pp. 755–769.

[21] LIM, DOHYUNG; KIM, CHOONGYEON; JUNG, HOHYUN; JUNG, DUKYOUNG AND CHUN, KEYOUNG JIN. Use of the Microsoft Kinect system to characterize balance ability during balance training. *Clinical Interventions in Aging 10* (2015), pp. 1077–1083.

[22] NUSMAN, DAAN. Real-time full-body motion capture in virtual worlds. Master's thesis, June 2006.

[23] PAAS, FRED; RENKL, ALEXANDER AND SWELLER, JOHN. Cognitive Load Theory and Instructional Design: Recent Developments. *Educational Psychologist 38* (2003), pp. 1–4.

[24] PFUSTERSCHMIED, JÜRGEN; BUCHECKER, MICHAEL; KELLER, MARTIN; WAGNER, HERBERT; TAUBE, WOLFGANG AND MÜLLER, ERICH. Supervised slackline training improves postural stability. *European Journal of Sport Science 13*, 1 (2013), pp. 49–57.

[25] PFUSTERSCHMIED, JÜRGEN; STÖGGL, THOMAS; BUCHECKER, MICHAEL; LINDINGER, STEFAN; WAGNER, HERBERT AND MÜLLER, ERICH. Effects of 4-week slackline training on lower limb joint motion and muscle activation. *Journal of Science and Medicine in Sport 16*, 6 (2013), pp. 562 – 566.

[26] PISAN, YUSUF; MARIN, JAIME GARCIA AND NAVARRO, KARLA FELIX. Improving Lives: Using Microsoft Kinect to Predict the Loss of Balance for Elderly Users Under Cognitive Load. In *Proceedings of the 9th Australasian Conference on Interactive Entertainment: Matters of Life and Death* (2013), IE '13, ACM, pp. 29:1–29:4.

[27] POMPEU, J.E.; ARDUINI, L.A.; BOTELHO, A.R.; FONSECA, M.B.F.; POMPEU, S.M.A.A.; TORRIANI-PASIN, C. AND DEUTSCH, J.E. Feasibility, safety and outcomes of playing Kinect Adventures!™ for people with Parkinson's disease: a pilot study. *Physiotherapy 100*, 2 (2014), pp. 162 – 168.

[28] POMPEU, JOSÉ EDUARDO; TORRIANI-PASIN, CAMILA; DONÁ, FLÁVIA; GANANÇA, FERNANDO FREITAS; DA SILVA, KEYTE GUEDES AND FERRAZ, HENRIQUE BALLALAI. Effect of Kinect Games on Postural Control of Patients with Parkinson's Disease. In *Proceedings of the 3rd 2015 Workshop on ICTs for Improving Patients Rehabilitation Research Techniques* (2015), REHAB '15, ACM, pp. 54–57.

[29] RYAN, R. AND DECI, E. Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist 55*, 1 (2000), pp. 68–78.

[30] RYAN, RICHARD M. AND DECI, EDWARD L. Intrinsic and Extrinsic Motivations: Classic Definitions and New Directions. *Contemporary Educational Psychology 25*, 1 (2000), pp. 54 – 67.

[31] SCHLÖMER, THOMAS; POPPINGA, BENJAMIN; HENZE, NIELS AND BOLL, SUSANNE. Gesture Recognition with a Wii Controller. In *Proceedings of the 2nd International Conference on Tangible and Embedded Interaction* (2008), TEI '08, ACM, pp. 11–14.

[32] TANAKA, KAZUMOTO; PARKER, JIM; BARADOY, GRAHAM; SHEEHAN, DWAYNE; HOLASH, JOHN R AND KATZ, LARRY. A comparison of exergaming interfaces for use in rehabilitation programs and research. *Loading 6*, 9 (2012), pp. 69–81.

[33] TANG, RICHARD; YANG, XING-DONG; BATEMAN, SCOTT; JORGE, JOAQUIM AND TANG, ANTHONY. Physio@Home: Exploring Visual Guidance and Feedback Techniques for Physiotherapy Exercises. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (2015), CHI '15, ACM, pp. 4123–4132.

[34] THOMANN, ANDREAS. Methodik im Slacklinesport - Wie geht guter Slacklineunterricht?, 2013.

[35] USTINOVA, K. I.; PERKINS, J.; LEONARD, W. A. AND HAUSBECK, C. J. Virtual reality game-based therapy for treatment of postural and co-ordination abnormalities secondary to TBI: A pilot study. *Brain Injury 28*, 4 (2014), pp. 486–495.

[36] VAN DER SPEK, ERIK D. COgnition-based DEsign Rules Enhancing Decisionmaking TRaining In A Game Environment (Code Red Triage): Doctoral Consortium Paper. In *Proceedings of the 28th Annual European Conference on Cognitive Ergonomics* (2010), ECCE '10, ACM, pp. 319–322.

[37] WIKIPEDIA. Anatomical terms of location — Wikipedia, The Free Encyclopedia, 2017. [Online; accessed 12-March-2017].

[38] WINSTEIN, CAROLEE J. AND SCHMIDT, RICHARD A. Reduced frequency of knowledge of results enhances motor skill learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition 16*, 4 (1990), pp. 677–691.

[39] WOOLFORD, KIRK. Defining Accuracy in the Use of Kinect V2 for Exercise Monitoring. In *Proceedings of the 2nd International Workshop on Movement and Computing* (2015), MOCO '15, ACM, pp. 112–119.