
SAARLAND UNIVERSITY

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



Interactive technology in slackline training

Christian Murlowski

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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

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Saarbrücken, 14th January, 2016

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- Mental and pushing me forward
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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

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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

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. The system has also be aware of the cognitive load and motivating aspects, which can be challenging with repetitive exercises. Several applications show where problems occur with different feedback and interaction methods. Lastly design opportunities for guiding the user through the learning process are demonstrated by various approaches.

2.1 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. [8] 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.

2.1.1 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 [43] differentiate two basic methods for the learning process on a slackline. Teaching a slackline beginner, further called slacker, without any help or with systematic external assistance. The investigation of Kroiß [23] resulted in no significant difference between both methods. But there is a trend regarding 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 [22, 23].

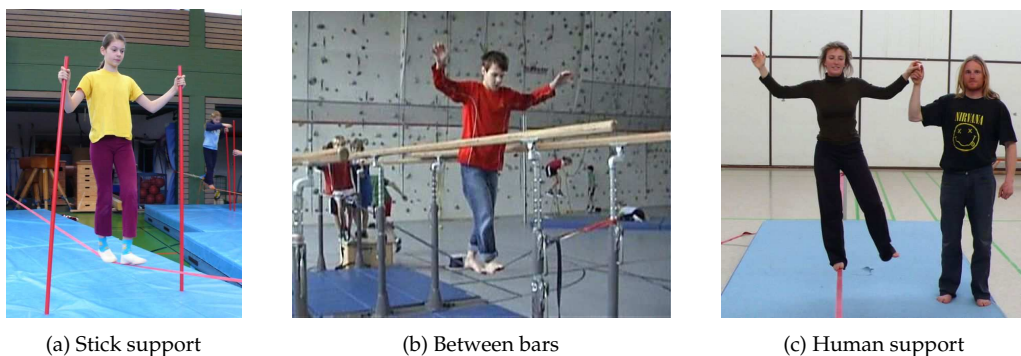


Figure 2.1: Supportive exercises [23]

With further progress, the external help, if given, 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 foot on the line, the slacker can use the other one as an additional extremity for balancing purposes.

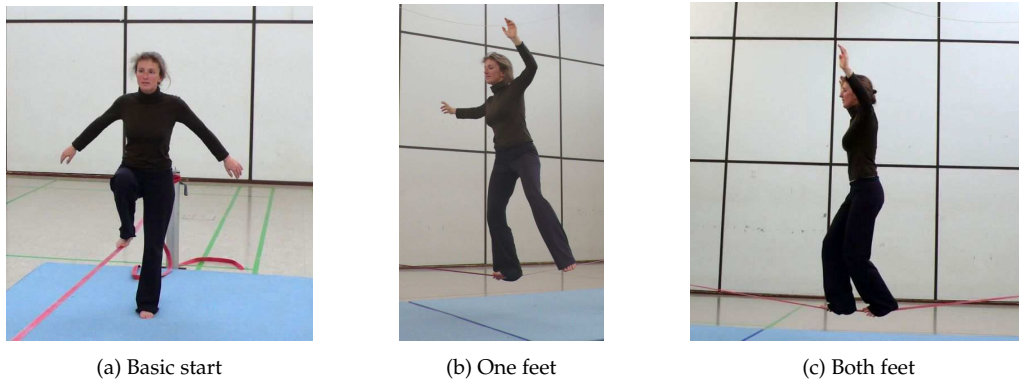


Figure 2.2: Basic exercises [23]

Advanced training should be practiced in a more dynamical way [43]. Like seen in several research works [6, 7, 13, 21, 32] this can be from crossover start (Figure 2.3a), turning on the line, hands on hips or behind the back (Figure 2.3b), walk sideways or backwards up to catch and pass a ball, kicking a football, bouncing a basketball, or a kneel down on the slackline (Figure 2.3c).

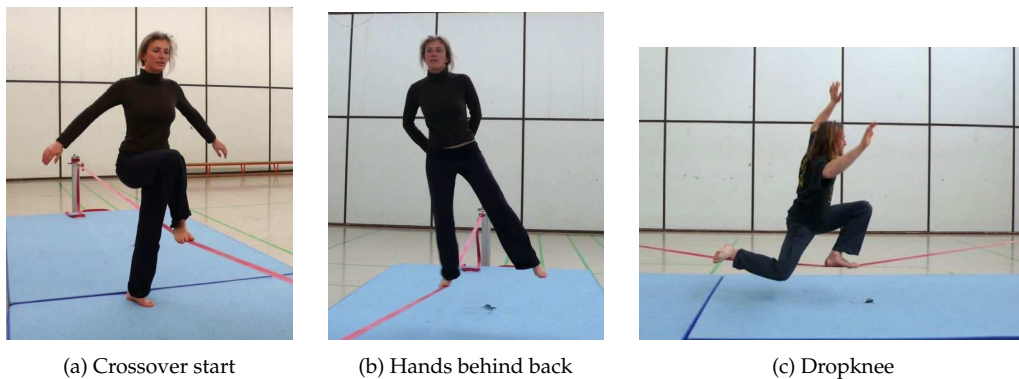


Figure 2.3: Advanced techniques [23]

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 [21, 32, 33]. 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 [23].

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 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.

2.1.2 Slackline specific training effects and application scenarios

Donath et al. [6] 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. [7] 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. [21] 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. [32] 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. [33] 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. [13] 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 [32]. 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.

2.2 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 motion capture systems, 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.

2.2.1 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 [3, 41]. Gesture recognition is an essential aspect of the slacklining assistance system for giving appropriate feedback regarding the executed exercise. Schlömer et al. [39] 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 [3, 41].

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, like *Xsens MVN* [27] or *OptiTrack* [30], 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 [3, 4, 29]. 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 [19, 42]. To the user they can be hidden, e.g. by only showing the output of the depth cam [17]. 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.

2.2.2 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. [25] 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.

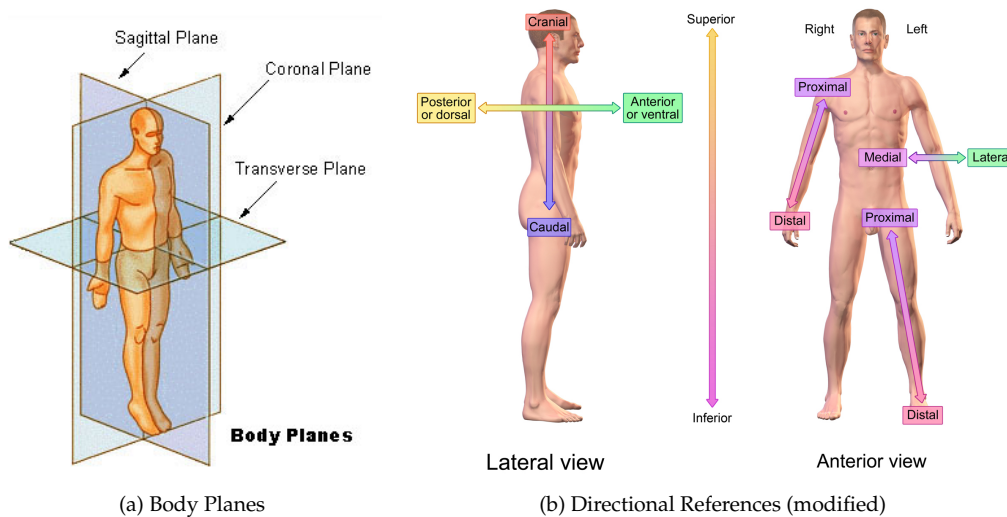


Figure 2.4: Anatomical terms of location [47]

Chang et al. [4] 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 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 perfor-

mance comparison shows that the OptiTrack system is negligible faster than the Kinect.

Woolford [55] 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.

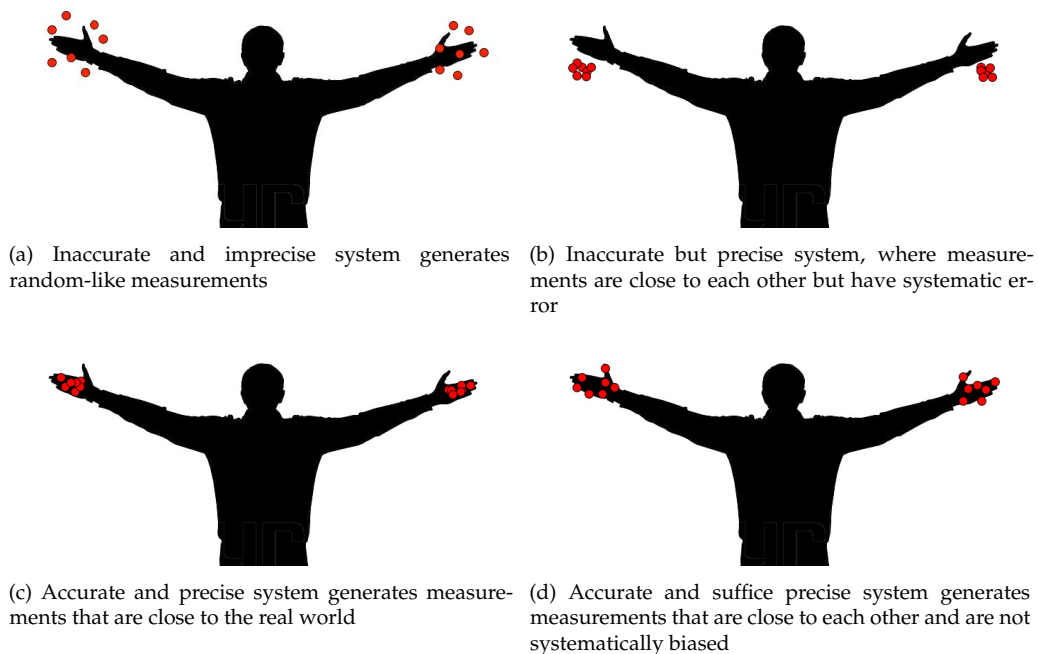


Figure 2.5: Definition of accuracy and precision [55]

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

2.2.3 Implementation in balance training scenarios

Like already stated Chang et al. [4] not only assessed the accuracy of the Microsoft Kinect but also if it could fit as an alternative training device in rehabilitation

training. The results show that it provides enough usable feedback to the therapists to be an appropriate device for medical uses. Woolford [55] 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. [25] 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. [45] 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. [34] 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. [35, 36]. The results affirm that the patients improve in balance purposes and motoric movements with this help.

Furthermore Estapa et al. [9] and Freitas et al. [11] 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 et al. [12] 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.

2.3 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.

2.3.1 Restricting cognitive load

As a baseline Paas et al. [31] describes that the acquisition of new skills is in conjunction with cognitive load. By adjusting this the learning effect can be eased 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 [46] 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.

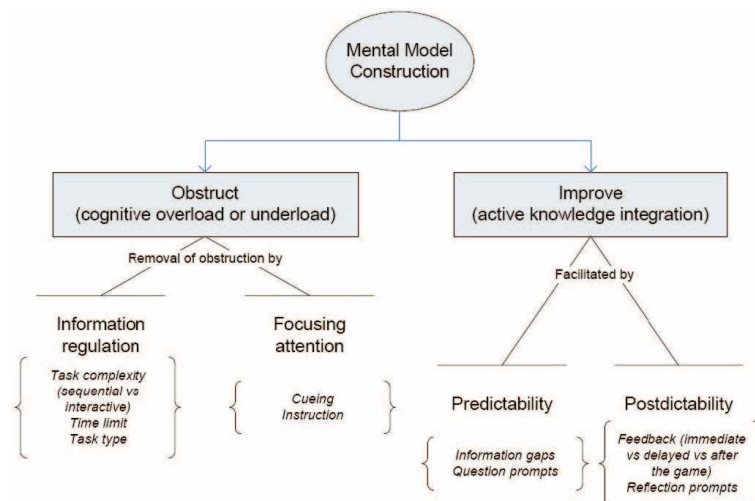


Figure 2.6: Guideline for enhancing the cognitive load [46]

Pisan et al. [34] 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.

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.

2.3.2 Motivating factors for skill acquisition

Several rehabilitation and sport training programs can be elaborated for motivating factors 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. [37, 38] 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. [18] 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. [34] 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. [45] 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. [11] 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. [9] 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 [19] 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 a 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. What methods can be used for this will be discussed in the following.

2.3.3 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. [24] 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 [5]. 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 [16, 54]. Therefore it should be easy to understand for enhancing the learning process.

Hämäläinen [15] 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 automatisisation 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. [17] 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 [19] 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. [20] 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 User interface design

The user interacts with the system through the provided interface. This should contain all relevant information, which are necessary to achieve a specific goal and support her on the way to reach this goal. General user interface approaches from exergame like related work approaches should be compared. Therefore the subsection *User interface design for appropriate feedback* gives an overview on which elements can be used for guiding the user through the system and how feedback can be visualized properly. After that in subsection *Kinect for Windows - Human Interface Guidelines* shows how to enhance the user experience on a kinect application with guidelines provided by Microsoft.

2.4.1 User interface design for appropriate feedback

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 et al. [12] in Figure 2.7a. Additional informations like

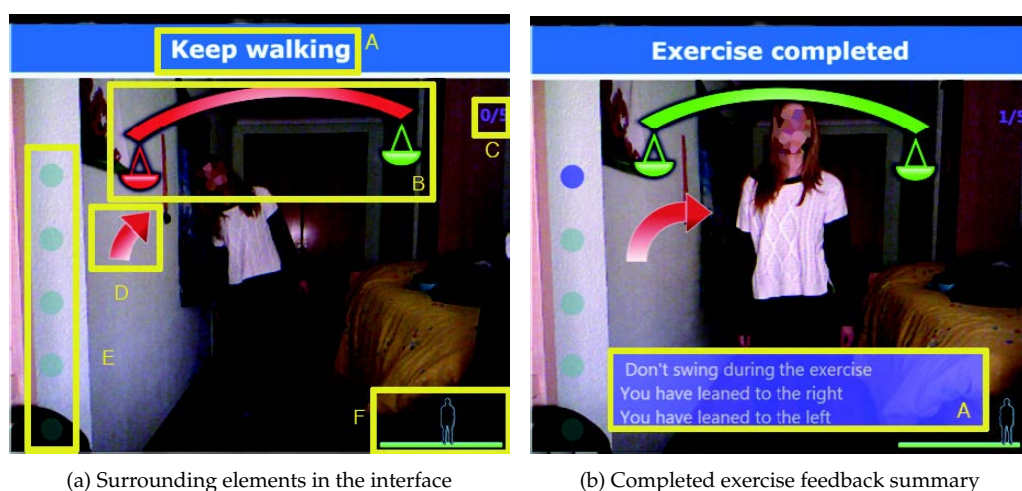


Figure 2.7: Interface of a rehabilitation training application [12]

the current exercise and the state can be displayed outside of the focus space. They should be designed to not distract the user. A feedback summary after the execution can give an useful recap about the exercise for reflection (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. [17] implemented such a user integration and in user testing they endorse to see themselves performing in real time.

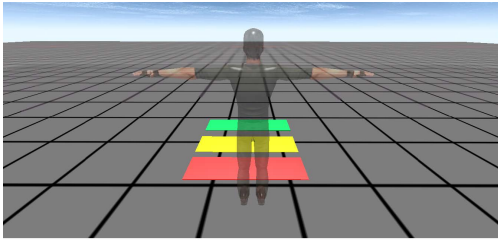


Figure 2.8: 3D Model as avatar [9]

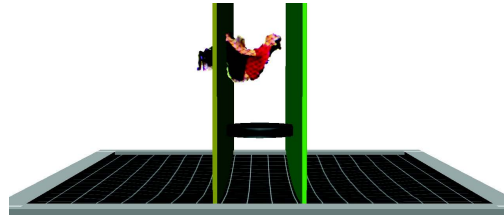


Figure 2.9: Rail-time user representation [17]

The task about the execution has to be clarified. Chang et al. [4] 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.



(a) Instruction to the game



(b) Green indicator for correct performance

Figure 2.10: User interface of a rehabilitational application [4]

2.4.2 Kinect for Windows - Human Interface Guidelines

Microsoft itself offers Human-Interface-Guidelines (HIG) for developer and designer that describes several techniques of certain areas for developing a kinect application [5]. It provides a quick introduction into the Kinect itself, design principles for interactions regarding gesture and voice, techniques on teaching complex gestures, and how to visualize appropriate feedback. Also which interactions should be used for a specific action. Therefore developer may follow this

general standard to support their end-user. In the following general principles of the guideline will be discussed on which the interactive slackline system will rely on to enhance the user experience.

Basic design principles

Context-awareness delivers the best user experience e.g. controls should be placed where user would expect them to be and interactions should be appropriate for the environment. It is important that the user feel confident by designing interactions simple and easy to learn. User will choose an input that take the least effort for the given goal. Therefore the input method should match its purpose, be reliable, consistent, and convenient. Conducting user test helps to improve the system. Not each person will use the system the same way and minor adjustments can make a huge difference in the understanding of the usage.

Visual and audio feedback

Giving the user constant feedback helps her to know what is happening. In general appropriate feedback should show if the sensor is ready, she is visible and engaging with the Kinect, and so on (Figure 2.11a). 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 (Figure 2.11b).

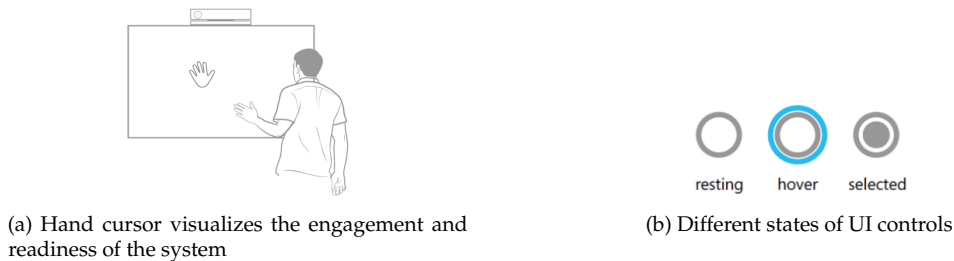
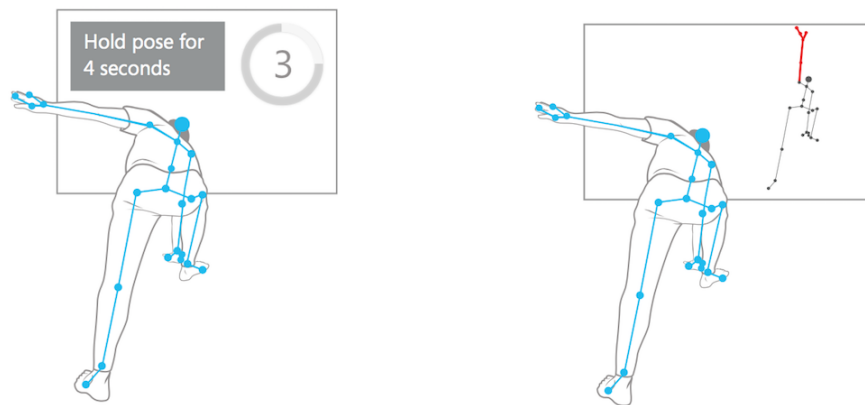


Figure 2.11: Feedback methods [5]

The most important part for complex gestures is the progress indicator described in this guideline. It supports the user if she has to hold a position, as well as if an amount of frequent repetitions have to be performed. Clear and prominent visuals should be used to show the entire progression (Figure 2.12a). If a user has to copy a specific movement an avatar or animation can be shown, before or during the movement, like in Figure 2.12b.

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



(a) Repetition and time length indicators

(b) Avatar that shows correct movement and wrong body parts are highlighted

Figure 2.12: Feedback indicator and movement visualization as an avatar [5]

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 2.13.

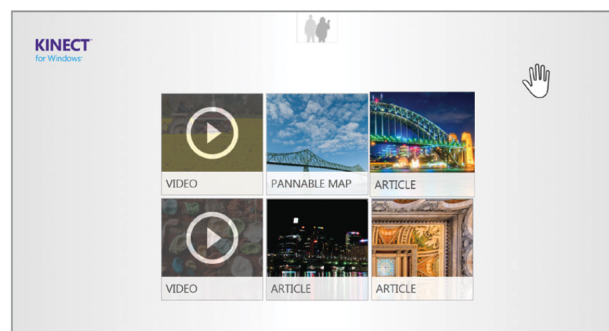


Figure 2.13: User Viewer on top [5]

Learning interaction methods

The application should teach the user how to proper interact with it right from the beginning with an introduction tutorial. An interaction itself should rely on

the real world, which can help the user to be more familiar with the product, than learning unknown gestures (Figure 2.14). Also bilateral interaction support should be applied to cover both possibilities for left- and right-handed people.

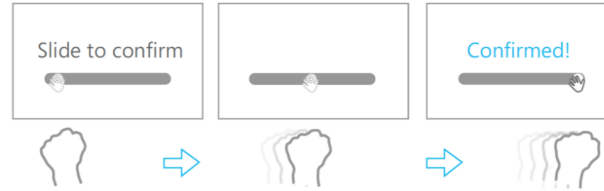


Figure 2.14: Direct manipulation of a slider with intuitive interaction [5]

Teaching complex gestures / exercises

Executing gestures is a core functionality in the slacklining assistance system. For new gestures, especially complex ones, the application should provide a tutorial that teaches and shows the user on how to execute or accomplish the gesture properly. When performing the gesture a visual indicator (a hint, animation, or notification) should acknowledge if the gesture is executed and when it is completed. (Figure 2.15).

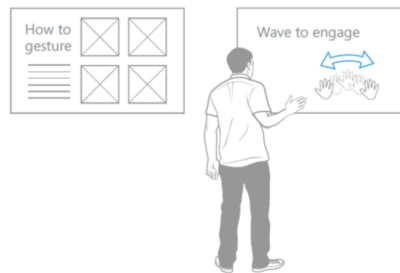


Figure 2.15: Teaching new gestures [5]

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 2.16 to have a better understanding.

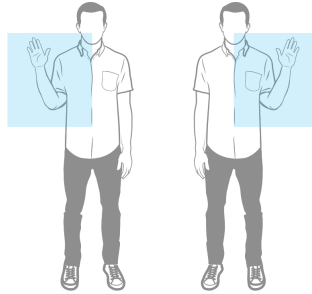


Figure 2.16: Physical interaction zone [5]

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 slacklining learning techniques

The following chapter *Introduction into slacklining* gives an understanding of the evolution, philosophy and basics of this sport activity. Further an overview about the diversity of slacklining and application scenarios can be found in section *Slacklining variations and categorization*. The last section *Slackline learning techniques* elaborates teaching methods and exercises, which will be used as a basement for designing the concept of the system.

3.1 Introduction into slacklining

The term slackline has its origin in the 1980's. Some climbers balanced on a tubular webbing in contrast to the existing balance activity tightrope, where you balance on a steel rope. Therefore they used the term *slack wire* that later transformed into *Slackline*, which means loose line [56, 1, 26].

Hence slacklining comes from the climbing sport and can be compared with ropedancing in a broader sense [22]. The line itself is made out of a nylon ribbon. Unlike in ropedancing the ribbons width is between 2.5 and 5 cm and very flat. It has to be tensed between two stable fixation points like trees, stable pillars, fixation systems on the ground, so called *A-Frames*, or on a rock with a bolt hanger and carabiner. Mostly this is done with a tension device, which is in general a ratchet or pulleys depending on the fix points [22]. Because of the nylon texture the line will expand under pressure if someone stays on it. Given this elasticity makes it very dynamic and the slacker has to outbalance every sway [23]. To be in control of her body behaviour she has to act very calm, which makes slacklining a quiet and meditative sport activity. Besides walking one can also e.g. bounce,

bob, or swing on the line. As a result various application scenarios arose from this variability, which is further described seen in the next section.

3.2 Slacklining variations and categorization

Further depending on the length, tension or height a few slackline variations have originated [26, 22, 44]. Regarding the height one can differentiate between a *lowline* and a *highline* (Figure 3.1). The former is the category in which almost all lines match because it describes a height in which one can safely jump off the line. On a *highline* this is not possible. Here you have to make safety provisions like a separate system where the person can hook herself in this system above or under the regular line [22].



(a) Common lowline



(b) Highline between mountains [49]

Figure 3.1: Low- and Highline

The following terms describe some fine granular variations of the slackline as well as categorizations in different application scenarios. They are not strict which means, they can differ in its scenario or **blend/fade/merge** into each other. The *trickline* (Figure 3.2a) is the common slackline. It is tensed a bit loose in about the height of the knees and has a length up to 30 m. A *jumpline* (Figure 3.2b) is stronger tensed to make jumps on the line possible. They have a length of 8 - 14 m and are a bit higher than the trickline.

With a *rodeoline* the line is actually more slacked and has the highest amplitude, like seen in figure 3.2c. It is a relatively short line with a length of 5 - 8 m and the fixation points are in about 2 m such that if a person stands in the mid of the line it is just about above the ground and can swing on it. Slacklines beyond 30 m are called *longline* (Figure 3.2d). The goal here is to walk as far as possible without falling off the line. Beside these there exist some terms that describe a categorization or environment where a slackline can be applied. For example

a *waterlines* is simply a line tensed over a pool, sea or a river like in figure 3.3a. *Urbanlining* can be found in urban areas, where manmade buildings or structures are used to tense the line between, like in figure 3.3b.



(a) Handstand on a trickline [50]



(b) Backflip on a jumpline [22]



(c) Rodeoline [51]



(d) Longline [48]

Figure 3.2: Slackline variations



(a) Waterlining over a river [52]



(b) Urbanlining in the city [53]

Figure 3.3: Categorization of slacklining

3.3 Slackline learning techniques

Subsection *Exercises during slackline training* showed that systematic help is not essentially necessary for learning slacklining. The user for the interactive learning system should therefore be able to learn it by herself without any further external help. To achieve this two learning concepts will be differentiated in subsection *Methods for slackline skill acquisition*. Further specific slackline exercises can be categorized like described in subsection *Stages and exercise of learning slacklining*, which structures at the same time the learning flow of the user.

3.3.1 Methods for slackline skill acquisition

Methodical routine

A methodical routine can be integrated in almost every sport activity. For this a series of exercises is chosen. With further practise their difficulty is increasing. The chosen exercises are based on methodical principals that can be for example defined with easy to difficult, known to unknown, or simple to complex exercises [10]. Größing [14] describes it as follows. At the beginning of this methodical routine the trainee will execute warm up exercises. This can be useful to prepare her for the training. After that preliminary exercise will be provided, which are more specific regarding the actual exercises. With this she will learn the general motoric basics and train the movements needed to perform the activity. Further it ensures a smooth transition for the main exercises.

For slacklining skill acquisition Thomann [43] developed a methodical routine as well as an dynamical methodic. The methodical routine can be seen in figure 3.4 and inherits various approaches with different elements to reach the goal of learning slacklining. Because there is variability in the integration of the elements, each tutor can build her one routine and choose different aspects. At first, like already explained, an introduction and preliminary exercises can be integrated, which follows by material and security. In here the lines dynamic, how to jump off and controlling of the line should be covered. Following the learning of the oscillation behaviour should be implemented with or without methodical help. The same can be distinguished in the next aspect, which involves the decision of balance training. With help the trainee can directly balance on the line with providing external support. Without any further help she can decide to first sit, step on the line, or independent balance. Continuing one has to decide if first the static or dynamical balance has to be trained. Following the trainee has the possibility to train more variable with exercises like walking forwards on the line, walking backwards, with eye closed, etc. Before going to train some tricks on the line, which is on the very end of the routine, the trainee has to learn first staying across the line with her feet. This is a necessary part of various tricks and has to be learned before.

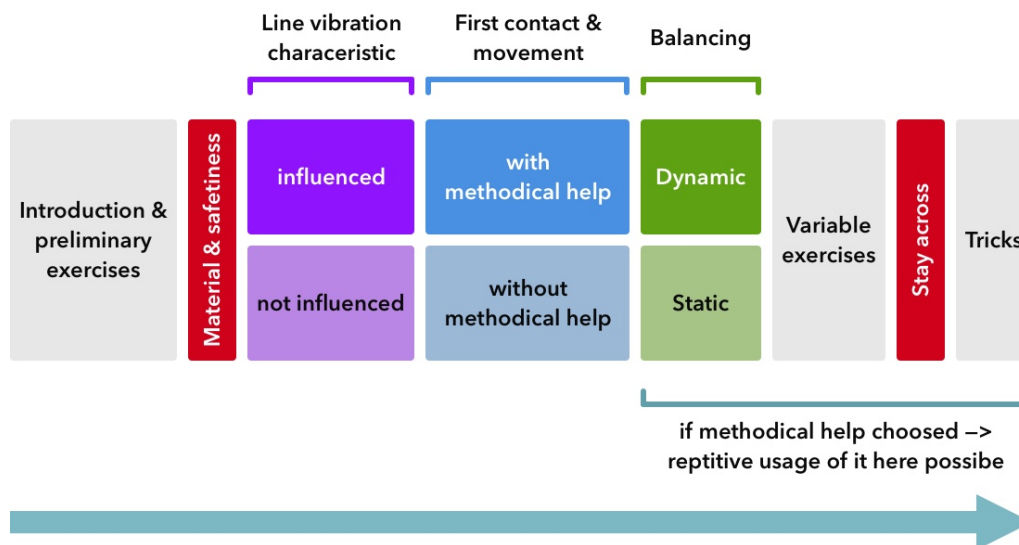


Figure 3.4: Methodical routine [43]

Differential methodic

The differential or dynamic methodic follows another approach. It is in coherence of an open learning situation [43]. This means it depends on several factors, which in slacklining would be line type, line length, tension, environment, etc. According to the interplay of these factors each trainee can construct her own training set. A dynamic methodic is a practical usage for this [2, 40]. This inherits

the model of stepping stones. In general it describes that many possibilities can lead to the same goal. Each potential way has therefore its own difficulty level. This results in a more dynamic way to reach that goal. In comparison to the methodical routine it results in bigger differences in stimulus, like compared in figure 3.5.

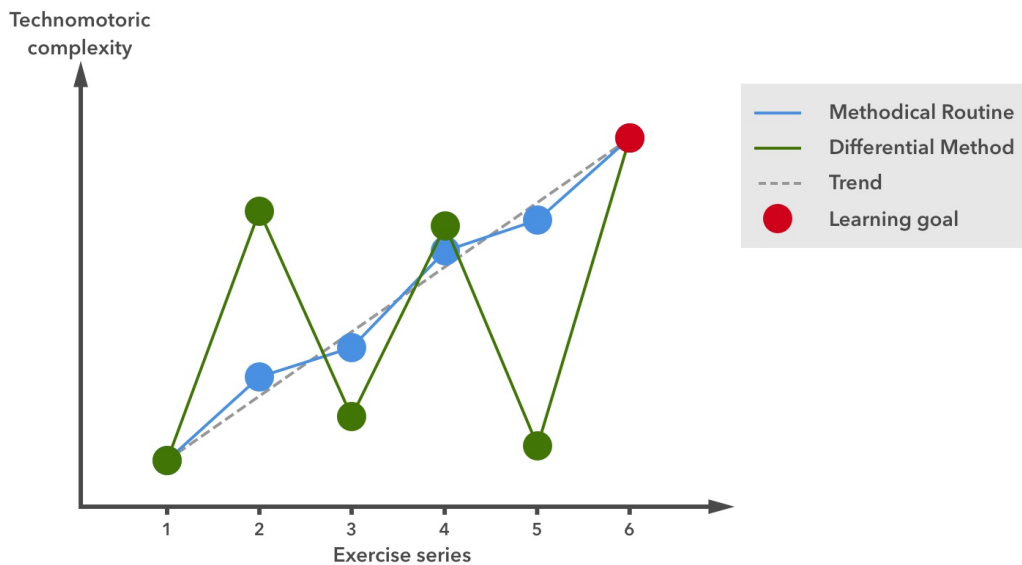


Figure 3.5: Comparison methodical routine vs. differential method [43]

At first the trainee can follow a methodical principle like seen in methodical routine. If she reaches a certain threshold of skill level more dynamic procedures can be involved in the actual learn process. Therefore the principle of differential learning can be used in which results in big stimulus differences and provide more variability in the movement execution.

The usage in slacklining can be integrated like described and visualized by Thomann [43] (Figure 3.6). On the x-axis the complexity of the exercise is given, whereas on the y-axis various learning stages. The goal is described in the upper right corner. The goal is to choose an amount of various exercise of all stages. Each more complex exercise can either integrate methodical support or the trainee can return to the lower stage for movement training for the specific exercise. With this an individual way can be formed for each trainee. Modification and integration of more useful exercises are also allowed. Structured examples can be seen in figure 3.6. The black arrows visualize a way for people that are more coordinative, more venturesome, or have background knowledge. In contrast the blue arrows visualize a path for people that are less coordinate, less venturesome, or have no background knowledge in slacklining.

For proper user training with the system the trainee should follow a clear workflow. As a first approach for a prototype the methodical routine is the better choice as a learning concept in an interactive learning system. It follows a clear linear workflow, in which stages and exercises can be designed as levels. The

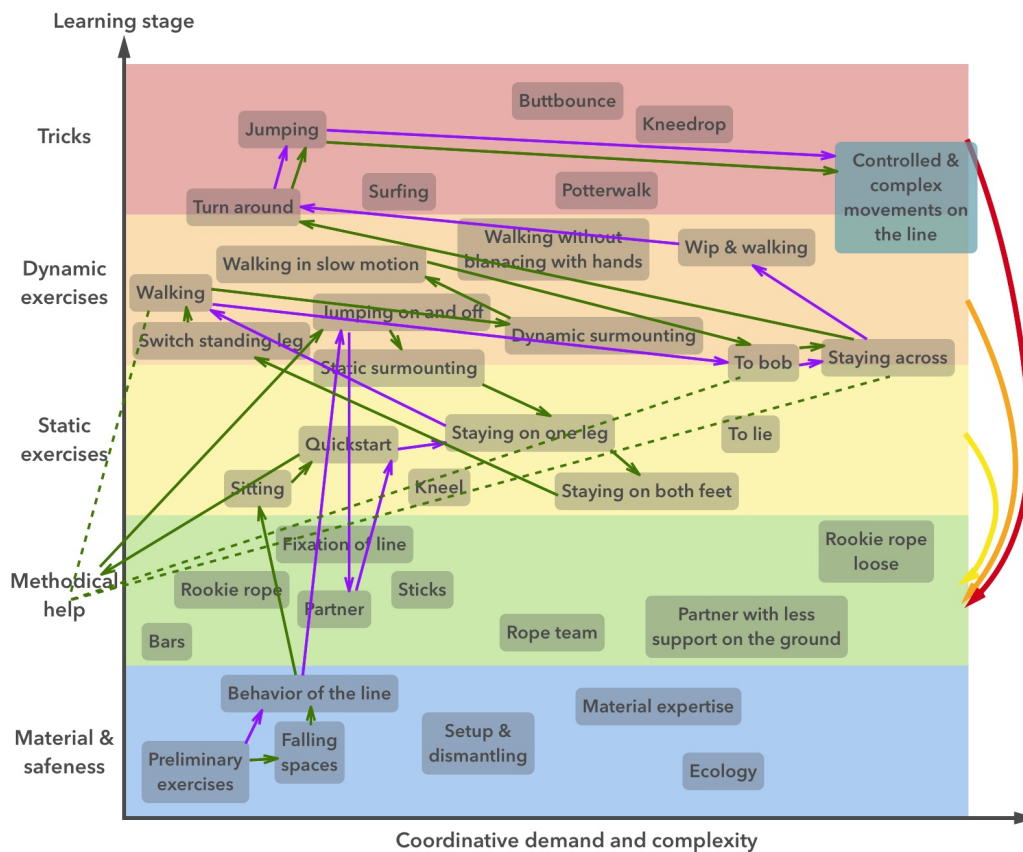


Figure 3.6: Dynamic methodic in slacklining [43]

trainee can unlock further levels by successfully executing the prior exercise. Also he learns right from the beginning essential aspects of slacklining that are relevant and build up on each other. The next subsection *Stages and exercise of learning slacklining* will therefore cover a clear workflow integration of exercises for a learning system.

3.3.2 Stages and exercise of learning slacklining

Now that an overview about slacklining and its learning techniques are given several practical exercises have to be considered. Repetitive trials are one approach of learning to walk on the line. However this could result in dangerous situations and frustration of the slacker because of her missing skills. Therefore an exercise set has to be considered that teach and guide the slacker to reach her goal. The teaching goal should be that the slacker can balance with a controlled manner on the line and be able to walk a few steps on it. In general to be able achieve this one has to acquire three core skills [23]. At first the slacker should be able to stay on one foot. This is essential because most of the time the slacker has a standing foot on the line and the other foot serves as balance component. Second the

balancing on a narrow surface since the slackline exists of a limited width. Lastly managing the height is also important due to the fact that the slackline is mostly tensed around the knee height and above.

As a groundwork the elaborated exercises are based on Kroiß [23]. He elicited slacklining learning exercises for beginners within a school class, which gives a good basic on the exercise integration. Further several other references [1, 6, 7, 13, 21, 22, 32, 43] have been researched to elaborate exercises that fit the best in this system. Each exercise is therefore categorized in one of four tiers, which represent the fundamental basis of the exercises routine. In the following each tier is introduced, its goal clarified, and the learning aspects described.

Tier I - Preliminary exercises

The first tier serves as a preparation for the subsequent exercises. In here just exercises on the ground will be executed. This is to train and strengthen the slacker general physical balance. In general it is recommended to train barefoot or with socks to have a better feeling in the foot. The knees should be bent to have a better initial position for movement compensation. Keeping the head up and setting a focus point can help to calm the visual sense of balance. In almost all exercises of this tier the arms have to be stretched to the side, be over the shoulder and bent in about 135 degree. This is the biggest balance function overall because you have freedom in all directions and it can shift the body's center of gravity. Further all exercises should be executed slowly and controlled to master your body behaviour.

Tier II - First contact with the line

Mastering the general physical balancing leads the slacker to her first experience with the slackline. The goal is to get a feeling for the slackline and to be able to get up on the line and hold herself for a short amount of time. For this the slacker has to become familiar with the line, feel the imbalance, how the body wants to behave, and get a feeling for counterbalancing unpredictable movements. Therefore starting at the sweet spot, that's about 1/3 of the line, can help. It's an area with a comfortable vibration characteristic. The foot should be always in alignment with the slackline to have the biggest amount of surface of your foot covered with the line, which results in more contact. If the slacker has problems with holding her hands over the shoulder, she can turn the palms to the top and the hands will then raise automatically up. A relaxed but straight upper body can help to hold the right position.

Tier III - Static exercises

In here the exercises are getting more difficult. The slacker is now familiar with the line and able to stand for a short amount of time on it. This tier has the goal

that the slacker should stay confidently on the line and it serves as preparation for walking on the line. All prior learned techniques have to be directly applied. The non standing leg now comes more into action. It serves as an addition balancing parameter to both of the arms. If the slacker has problems with going up on the line, she can keep the balancing leg vertically in line with the standing leg while up going and then move it to the side. The pressure is mostly around the ball of the foot.

Tier IV - Dynamic exercises

This is the last tier and it involves the dynamical part for the slackline. The slacker should now be able to stay confidently on the line with one foot and both feet. The goal is to learn how to make the first steps as a result for walking on the line. In general it is applying static exercises together. While staying on the line and when the slacker wants to make a step she can guide her balancing foot to the side of the line and shift it then forwards. Letting the knees together when making a step forward helps because the legs can support each other. Making small steps won't shift the body's center of gravity that much forward, which results in more control.

Chapter 4

Concept

In chapter *Related Work* and *Slacklining and slacklining learning techniques* chapter is described how other applications realized similar application with other activities, what slacklining in particular is and which learning techniques exist to learn and master it. Mostly this is done with a professional who already knows how to act on the line and where particular attention must be paid. In contrast to such a human personal trainer this thesis will elaborate an interactive slackline learning system with real-time feedback. The idea of this system is, that the user can learn slacklining only with the given application. One main feature is that it should be an autonomous system. This gives the opportunity to be independent of other human help and therefore it can only be controlled by the by the user that is currently interacting with the system. To help her with exercise execution it responds to the actions of the user and provides him with feedback such that the user can correct himself. To built such a system a concept has to be built, which is part of this chapter. Therefore in the following a conceptual analysis will be elaborated. It involves section *General Information* where basic requirements of the entire system are described. This is followed by the more specific sections *Interaction*, *Stages* and *Exercises* as well as *Feedback system*. These describe how feedback is properly given to the user. Lastly the section *Scenario* gives a good overview about the workflow of the particular components and *Conclusion* will wrap up of each part of the concept.

4.1 General Information

Usability heuristics are useful to identify problems in an user interface. In general the system should be a user friendly in sense of usability. It should be easy to learn as well as to interact. Hence it will rely on the interaction design principles

by Nielsen [28] described in subsection *Ten heuristic principles for interaction design*. General aspects that have to be considered can be found in subsection *System specific basics*. These will give an overview about certain task of the system. With this a standard is given to build a foundation with a good user experience.

4.1.1 Ten heuristic principles for interaction design

Nielsen created his ten heuristics by comparing several sets of usability heuristics with existing usability problems from certain projects. With this he was able to determine what heuristics identify usability problems the best and therefore creating a set of them. For preventing that a system results in having such problems they can also be used as a guideline for designing and developing a user friendly system. Therefore the system will follow the principles, which are discussed in the following.

Visibility of system status

The system should always keep user informed about the current state through appropriate feedback in an adequate time.

Match between system and the real world

The system should provide the user with familiar terms and information. It should not confuse him with technical terms with which she is not familiar. Therefore information should be natural and in a meaningful order.

User control and freedom

If the user clicks accidentally on something she should be able to leave this state without any troubles.

Consistency and standards

It should follow a clear design standard and therefore provide consistency. The user should not be distracted whether different terms or elements mean the same.

Error prevention

Conditions and actions that could easily result in errors should be prevented or the user should be informed about the consequences that the action may have and then has to actively commit it.

Recognition rather than recall

The users memory load should be restricted. She should not remember every action or information. Therefore elements, actions and options should be visible and instructions about the usage should be easily retrievable.

Flexibility and efficiency of use

Providing quick options and allowing to skip certain steps can speed up the interaction of more familiar users. Hence the system should take care of both novice and experienced users.

Aesthetic and minimalistic design

Information should just contain aspects that are relevant to the user and that she really needs. Each irrelevant data decreases the intelligibility.

Help users recognize, diagnose, and recover from errors

Error messages should accurately indicate the ongoing problem such that the user knows what is wrong. Also it should provide a constructively solution.

Help and documentation

In the best case the system can be used without any further documentation. It may be the case to provide help and documentation. If so it should be easy to find it and clearly show the relevant steps.

4.1.2 System specific basics

One person at a time should be able to interact with the system. This is because mostly just one person can stay on the slackline especially for beginners. However it should provide the ability to have multiple user profiles, where they can switch between such that several persons can have a profile on the same application.

For proper user training it should follow a clear workflow. Therefore two methods have been discussed in subsection *Methods for slackline skill acquisition*. As a first approach for a prototype the methodical routine would be a better choice in the system integration. This is because follows a clear linear workflow, where the stages and exercises can be designed as levels. These should be locked at the beginning and the user can unlock them by successfully executing the prior exercise.

Another important part is the user tracking. The system should be able to track the user in an appropriate accuracy, such that it can match the users movement with the actual exercise. This is in correlation with properly providing real-time feedback, which is further discussed in section *Feedback system*. Further all relevant data should be immediately saved when it is needed, for example when successfully accomplishing an exercise and so on.

4.2 Interaction

The interaction can be seen as one of the bigger parts of the system since it is autonomous. So the user should be able to navigate through the system by herself with her hands as input for the interaction. A cursor should always be visualized to navigate through the systems interface. If the user initially starts the system, there should be an engagement gesture to convey that the system initially recognises and responds to a user action. Further a small tutorial should be given in which the user will be trained on how to use the interaction possibilities with the system. To make her familiar with these, she should directly apply these techniques in the tutorial. The current state of the interaction should be properly visualized, such that the user knows if she is in default mode or in progress of an interaction regarding an element. Sometimes to be able to interact with elements, the user should stay in the right position, so that the system knows if the user is ready to start. This could be useful before starting the actual exercise. Interaction will also play a role in exercise execution. In here the user interacts with the system by trying to match the predefined gestures. She should then get appropriate feedback, which is further explained in section *Feedback system*.

4.3 Stages

The system covers predefined gestures, which are subdivided in stages that have been elaborated in subsection *Stages and exercise of learning slacklining*. Since the interactive slackline system follows a slightly exergame like approach, the stages and exercises should be designed as levels, which the user could select has to unlock. Therefore a menu should exist for all available stages as well as for all exercises within a stage. To give her a starting position, the very first stage and exercise should be interactable. She can then unlock the next stage by accomplishing all exercises in the last one. Hence it can be assured that the user is able to encounter with the more difficult exercises. She should also be introduced in each stage to know how its purpose and goal. At last a summary can be given to show an overview of her performance for the entire stage.

4.4 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 4.1. Every exercise is locked except the first one to provide a starting point, like with the stages. The next exercise should be unlocked by accomplishing both sides of the current exercise. Similarly a side will be 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. The system will also recognise if the user is ready to start with the exercise. During the execution she should get real time

feedback about her current performance. An exercise summary should show the performance of the execution with several performance parameters regarding the given gesture.

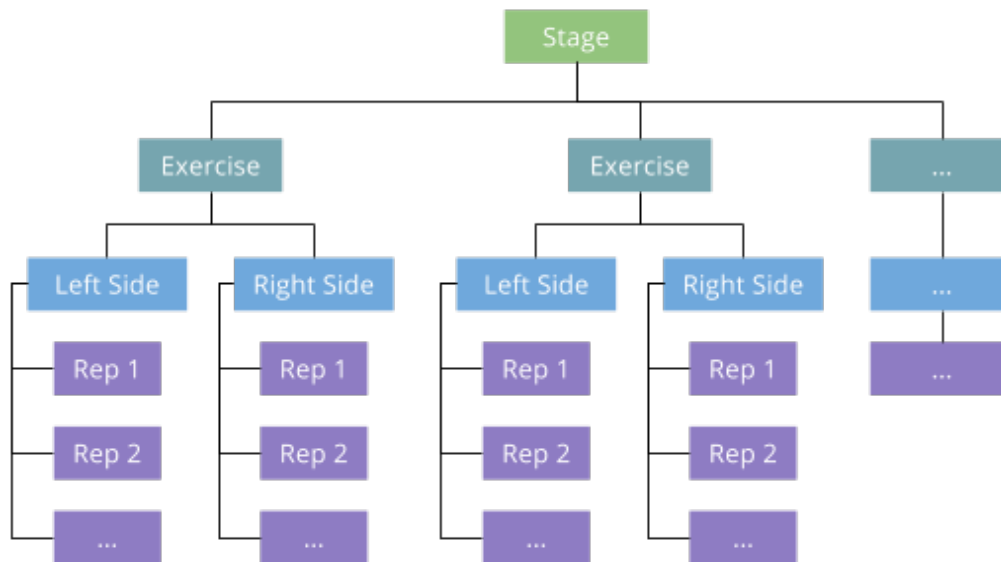


Figure 4.1: Exercise structure

4.5 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 be designed in a way, that the user knows at any time what she has to do or has done. In general audio and visual feedback will be 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 it is essential to provide real-time feedback. This supports her during the performance and enhances the learning effect more than with post feedback methods, like discussed in *Approaches and techniques for providing feedback*. Hence the overall exercise execution can be improved by providing appropriate real-time feedback. The system should therefore response to the user like seen in other applications [cite, maybe Related Work -> Nike + / EA SPORTS Active 2]. These responses should indicate if the current execution is performed correctly or not, visualize the the performance of the user regarding the predefined gestures, and show the execution progress. The user should also see herself mirrored in an appropriate environment to know

how she executes the exercises and if she is in detection range of the kinect sensor. With this a baseline is built for appropriate real time feedback to the user.

4.6 Scenario

To have a better understanding regarding the interplay of the several components a generic scenario workflow will be given from a users point of view. The users name is Bob and he is 21 years old. While climbing with friends in a climbing hall he noticed a new interactive learning system that they provide to visitors to learn and approach them to slacklining. He heard once of this activity by friends but never had the chance to try it. So he decides to test it and wants to execute some exercises. He stands in front of the system, which recognizes him. At the beginning it introduces him regarding the interaction possibilities. After that he selects a stage and is then informed about the goal and basics of this stage. Once he confirms that he read everything he chooses the first available exercise. Within that he is taught about how to execute it properly. Right after starting the exercise he gets helpful real time feedback to correct himself for a successful accomplishment of the execution. When finished with the exercise Bob gets an overview about his performance for the just finished exercise.

4.7 Conclusion

The interactive slackline system should support the user in learning slacklining by providing her real-time feedback. Summarizing for proper realization a few things have to be considered. The system should comprise an appropriate amount of user experience. By following and respecting Nielsens ten usability heuristics it provides an overall standard of usability. Further some system specific ground-work should be integrated. This involves for example autonomous interaction, proper user tracking, and supportive real-time feedback. More specifically the stages and exercises should be designed as a level like integration that can be unlocked by successfully completing exercises. Each of the exercises should be introduced to the user to give her an understanding of the correct execution. At last the feedback system is one of the biggest component. It involves audiovisual real-time feedback for the user interaction as well as exercise execution, and general feedback for rating her performance regarding an exercise or the entire stage. The next chapter *System integration* relies on this concept and describes the development process of the interactive slackline learning system.

Chapter 5

System integration

This chapter shows the implementation of the interactive learning system with real-time feedback regarding the conceptual elaboration. Like seen in subsection *Comparison of tracking technologies* the Microsoft Kinect v2 will be used as tracking technology. Hence before going into the implementation detail section *Technical feasibility* clarifies the feasibility and the performance of tracking persons on a slackline with the Kinect. Further section *Gesture Construction* describes the recording and training of predefined gestures for the exercises in the system. After this section *System architecture* describes the general system architecture which involves the interplay of the Kinect SDK with Unity3D as game engine. Further it involves more specific how the data management, engagement, interaction components, gesture integration, and real-time feedback are implemented. Finally section *User Interface* covers the design process of the application including scribbles, mockups and the final integration.

5.1 Technical feasibility

Now having the concept and system integration, this section clarifies questions regarding the technical feasibility. 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.

As seen in several movement scenarios, in the area of balance training, the user were successfully trackable by the tracking 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 positioning have been tested.

5.1.1 General setup of the study

A slackline itself is the most essential part needed for the experiment. But it exists in many different forms and variations as seen in section *Introduction into slacklining*. Also all lines have to use a fixing mechanism and are therefore in general 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 for testing purposes. Hence a mobile slackline device provides the needed mobility. 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.

5.1.2 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 part 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 feet 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.

5.1.3 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

5.2 Gesture Construction

The system should provide predefined exercise on which the user is guided for learning slacklining. To give feedback in an appropriate manner the exercises are represented as custom gestures. There are two approaches of creating custom gestures. The first is one is to do heuristics, which means manually tracking the position of each joint and write code according to the action that should happen if the joints exceed a threshold or are in a defined range. This is used and implemented for simple gestures like raising the hand over the head. For more complex gestures, the developer must have a good understanding about how the human body behaves and moves. In the most cases developer have not the appropriate expertise. Hence for complex gestures like the specific slackline exercises the second approach is to use the Visual gesture builder (VGB) provided by Microsoft.

5.2.1 Visual gesture builder

This tool relies on machine learning and looks at the data given by the developer via pre recorded clips. With these it builds a database that can then be used to track the actual gesture in an application. The more data is provided to it the better the detection by the Kinect. Another advantage is that environmental factors are not that complex to handle as in comparison to heuristics. For example if the sensor is set too high or too low the developer has to consider this in his code and it can blow up managing and maintaining such factors in code. With the VGB the developer just records data with the sensor on the appropriate height and let the machine learning algorithm learn it. The cons are the huge file size of the recorded clips which can take very much disk space. Also setting the keyframes for parts that the builder should detect is time consuming whereas on the other hand it is simple and user friendly.

5.2.2 Building gestures workflow

The workflow looks like in figure [figure workflow note pad](#). First clips have to be recorded with Kinectstudio. This is a monitor and recording software for the kinect. The clip must be recorded in raw data to have the necessary information about the streams. Like seen in figure [figurename](#) several streams can be selected as well as recording audio and so on. The most important for the VGB are the [infrared, body, bodyindex?](#). After finishing with this a new project can be built with the VGB. This can be done either manually in one screen or with a wizard that guides the user through the process. In here the developer considers on which parts of the body the gestures relies on. After that she has to choose if it is a

discrete or a progress gestures **explain both**. Discrete gestures are more of static ones, like staying on one leg or punching. Progress gestures can have multiple steps like switching the standing leg. Figure **VGB project hierarchy** shows the project hierarchy. In part A of figure **VGB project hierarchy** the actual training data, the recorded clip of Kinect studio, is inserted. With this the developer has to set keyframes that define the gesture movement to track. If it is a progress gesture more fine granular keyframes, e.g. for turning a steering wheel from the right side to the left are possible. After finishing this the database can be built and then analyzed via the live preview that can be seen in figure **figure live prev** or with other recorded clips in the analyze area. With this the VGB sets its own keyframes on the clip regarding the database it is tested. The developer can then accept these, adjust it, and move it into training clips if necessary.

The database can then be implemented in the application for gesture detecting. The structuring of the systems architecture is part of the next section.

5.3 System architecture

In the following several components of the general system architecture will be described that are necessary for the functionality of the interactive learning system with real-time feedback and for the study afterwards. An overview can be seen in figure **systemarchitecture**.

5.3.1 Hardware and software components

As slackline the mobile *alpidex POWER-WAVE 2.0* is used. It is placed in front of the *Microsoft Kinect v2*, which is used as tracking device. The Kinect itself is attached on a **modell** tripod with a height of about **height, hüfthöhe?**. A *Steambox PC footnote specs* served as development device that fulfilled the recommended specs of the Kinect: **kinect specs**. To give the user a more immersive feeling a projector **modell** with a resolution of 1920x1080 was attached on a traverse system. With this a projection screen with a size of **2x3m** is used.

For software realization the cross-platform game engine *Unity3D* by *Unity Technologies* is used. This is a game engine which is mostly used for developing Applications developed with this can be deployed for several platforms on desktop, mobile, web, console, TV, VR, and AR (e.g. Windows, macOS, Android, iOS, Oculus Rift, Windows Mixed Reality and so on). It is widely used for developing games but has also very high compatibility with devices like *VR Head Mounted Display*, *Leap Motion*, or the Kinect.

For accessing the data stream of the Kinect the *Microsoft Kinect SDK v2.0*¹ has to be installed on the PC. Microsoft offers also a *Kinect for Windows Unity package*¹, which delivers all required scripts to manage the data stream in Unity for creating

¹<https://developer.microsoft.com/de-de/windows/kinect/tools>

a Kinect based unity application. Since *Unity 5* it can be used with the free personal edition, whereas before it could be only used with the pro version. Also the *Kinect v2 Examples with MS-SDK*² by Rumen Filkov were used for making data access and interaction implementation more simple as well as getting an idea on how to handle incoming data from the Kinect.

5.3.2 Software implementation

The software development process consists of the interplay of two system components (figure [image unity and kinect sdk](#)). First Unity itself, which is used to display and manage actions by the user on the interface. Second the Kinect SDK plugin for accessing the users action recognized by the Kinect device. In the following the data structure and management, interaction integration, and feedback implementation of the system are further described.

Data management

The data will be stored in JSON files, which is more human-readable and makes accessing and updating data simple in Unity via the JSON serialization feature³. For each object containing key-value pairs a class is generated, i.e. for Users, Tier, Exercise, Sides, and Repetitions. In listing [ref c# code example](#) an example for the *Tier* object can be seen. A class must be marked as serializable to work with the JSON serializer. It contains variables, which match the JSON structure on listing [ref json code. c# code example and json file](#)

With this an instance of the class can be created and the value accessed for adjustments (listing [ref img class instance](#)). This can then be serialized into a JSON object. Line [ln number](#) shows how existing JSON data can be converted back into an object instance. This is needed to fetch user data that already exists.

[img class instance](#)

In the system a default exercise JSON file was created that is used as reference for all users. Each user has therefore the same basement regarding the exercises right from the beginning. For proper data management a internal exercise and user editor was created in Unity (figure [ref editor window](#)). The data files can be managed and adjusted more easily for testing purposes.

[img editor window](#)

The files are stored within the *StreamingAssets* folder of unity. It serves as location where files that should be accessed via path name of the target machines file system should be stored. The overall data structure can be seen in figure [img ref data structure](#).

[image of data structure](#)

²<https://www.assetstore.unity3d.com/en/#!/content/18708>

³<https://docs.unity3d.com/Manual/JSONSerialization.html>

Engagement gesture

The engagement gesture is the very first interaction with the system. The user raises her hand, such that she initially knows that the system recognizes her actions. An example on how to access the Kinect and manage this gesture can be seen in the code snippet in listing 5.1. The *KinectManager* exists as an empty *GameObject* in the scene and has to be referenced in the script. The *KinectInterop* class delivers several utility and interop function and calls the sensor interfaces. Here it is used to assign the proper joint type for tracking them. For the functionality the script has to assure that the Kinect is initialized, a user has been detected, and the relating joints are recognized. In line 29 the condition checks if the current vertical position of the right hand is greater than the current position of the head joint. If this is the case, the next scene is loaded. This is actually part of the script for the first scene in the application, in which the user has to engage with the Kinect by doing the described movement.

Listing 5.1: C# example code for tracking a raising hand

```

1 public KinectManager KinectManager;
2 private KinectManager _kinectManager;
3 private KinectInterop.JointType _jointHandRight, _jointHead;

5 void Start ()
6 {
7     _jointHandRight = KinectInterop.JointType.HandRight;
8     _jointHead = KinectInterop.JointType.Head;
9 }
10 void Update ()
11 {
12     if (KinectManager == null) return;
13     _kinectManager = KinectManager.GetComponent<KinectManager>();

15     if (_kinectManager &&
16         _kinectManager.IsInitialized() &&
17         _kinectManager.IsUserDetected())
18     {
19         long uId = _kinectManager.GetPrimaryUserID();

21         if ((_kinectManager.IsJointTracked(uId, (int) _jointHandRight) &&
22             _kinectManager.IsJointTracked(uId, (int) _jointHead))
23         {
24             Vector3 jointPosHandRight =
25                 _kinectManager.GetJointKinectPosition(uId, (int) _jointHandRight);
26             Vector3 jointPosHead =
27                 _kinectManager.GetJointKinectPosition(uId, (int) _jointHead);

29             if (jointPosHandRight.y > jointPosHead.y)
30                 SceneManager.LoadScene("Tutorial");
31         }
32     }
33 }

```


Starting position

After engaging with the system the user is introduced in how to stay in the proper starting position. This is required by some actions like just before starting the exercise execution. It ensures the user is ready and to get her initial joint positions for primarily calculating the y-axis of the joint (cf. [section Feedback integration](#)). This initial joint position can differ if the user stands closer or more far away from the sensor because of the Kinects angel regarding its height. Hence the z-axis joint position of the left and right feet will be compared with each other to have the same value with a little tolerance. Hereby the user has to stand with both feets in line and in front to the Kinect like in figure [ref illustration](#).

[illustration feets parallel](#)

Hand cursor interaction

To be more familiar with the system the user interacts with her own hands. With this she is in constant system interaction and gets more used to it. A cursor visualizes where the user currently is and with this she can interact with other interface elements. As interaction gesture four different approaches were tested. First hovering with the hand over elements (Figure [interaction variation A](#)). This gesture is a good approach specific small elements should be selectable. The problem was that relatively big and many interaction elements exists. Therefore the user accidentally hovers over elements which resulted in unwanted misclicks. The second one is interacting by closing the hand to a fist (Figure [interaction variation B](#)). In testing periods many user accidentally triggered a click although they thought they did nothing wrong. Problems exist here concerning the users anatomical behaviour. The difficulty was that the users hand, closes automatically during hand movement. No user will stretch and spread her hand out because it is uncomfortable. Hence they tend to close the hand a little bit, which is more comfortable and results in a misclick recognition of the Kinect, which is fortified by the enlarged standing position of the user (Figure [comparison default & target](#)). A better interaction gesture is the *V-sign*. The user makes simply a pointing gesture with the index as well as the middle finger (Figure [interaction variation C](#)). The event is triggered when the user releases into the default hand state. It clearly distinguished from the fist gesture and will be accurately recognized. To give the user appropriate feedback the state is visualized like in (Figure [img handcursorPointing](#)). The last gesture is pushing the hand towards the Kinect. This is related to the real world like pushing a button down and therefore the most intuitive gestures (Figure [interaction variation D](#)). Since in this gesture the hand has to move from point a to point b in the z-axis the progress is visualized by a filling circle like seen in figure 5.1.

The pushing gesture is implemented as the main interaction technique because of its natural movement and real world reference. A fallback gestures is also implemented if something went wrong or the user feels uncomfortable with the

pushing gesture. The *V-sign* is the next best technique for this, since there were less problems than with the remaining gestures.

img interaction variations A - Hover&wait, B - fist, C - pointing, D - push

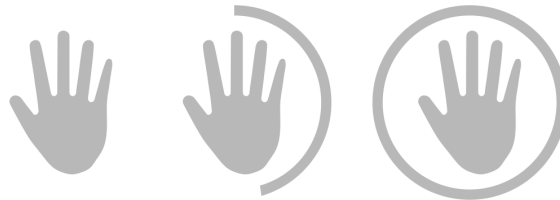


Figure 5.1: Progress of handcursor (Left: Default, Middle: In progress, Right: Finished)

User selection

The user profile are created by the developer. In the user selection the trainee should select the right profile by herself to cover the condition of multiple user that can train with the system. When selecting a user the system checks if the JSON file has any data. If no data is available the default exercise JSON file will be copied. The users name and id are saved in as *PlayerPrefs*. This is a class in Unity that provides the possibility to be globally accessible in the application. The respective code for setting and getting the values can be seen in listing [ref listing playerprefs](#). This is needed to find the correct path for the JSON files to save the data.

[listing playerprefs](#)

Tier & exercise menu

The tier and exercise menus are designed as levels the user has to accomplish. A locked tier can be unlocked by executing all exercises of the previous one. This is done by storing a boolean variable named *accomplished* for every tier and its exercises. The structure already seen in section 4.4 is adapter for storing the corresponding information for the tier, exercise, side, or repetition.

Exercise execution, providing feedback

The most functionality is implemented in the exercise execution. Feedback indicators provide the user with information about the current exercise in real time. This should support the user to successfully accomplish the exercise performance. In the slackline system the following feedback indicators are integrated:

- Correct performance of an exercise

- How good the exercise is currently performed, namely the confidence
- Elapsed time the user is performing the exercise
- When the repetition was successful (i.e. minimum time has been reached)
- When a repetition attempt was not successful
- Amount of repetitions in general, finished, and left
- Checklist about key elements of an exercise (hands up, foot stretched, etc.)

After each successful exercise execution the user is lead to a summary screen. Here she gets an overview about her performance. It shows parameters about the execution time, attempts, and the confidence for each repetition as well as an average value for the accomplished side. A similar summary screen exists also for the entire stage with the same parameters but only the average value for the entire exercises.

5.4 User Interface

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.

The user starts with an engagement gesture like raising her hand over the head to convey that the system initially recognises and responds to a user action. After that a tutorial about the interaction with the system will be given that covers clicking and scrolling techniques. Now she's confident with the system interaction and can select a profile in the user select to train. This loads the profile which leads to the stage selection menu. In here she can select a stage, whereas initially the first one is can be selected and the others have to be unlocked by successfully accomplishing all exercises in the preview stage. Selecting a stage leads to the exercise menu. In here she has to read initially the stage introduction to become a basic understanding about the exercises in here. After reading this, it unlocks the first exercise. Selecting an exercise leads to the side selection, where the user has to choose the side she wants to train for this exercise. This is followed by an introduction of the exercise, in which is explained how to perform it correctly. If the user is ready, she should stay in a starting position to be able to start the exercise execution. In here she find all relevant elements to perform the exercise, like indicators for the time, repetitions, confidence and a checklist, which helps her to correctly execute the exercise. After successfully executing the exercise, a summary is shown which summarizes the user performance. Then she can return to the main menu or directly approach the next exercise. A stage summary gives an overview about all exercises with average performance parameters.

replace figure with directional flow

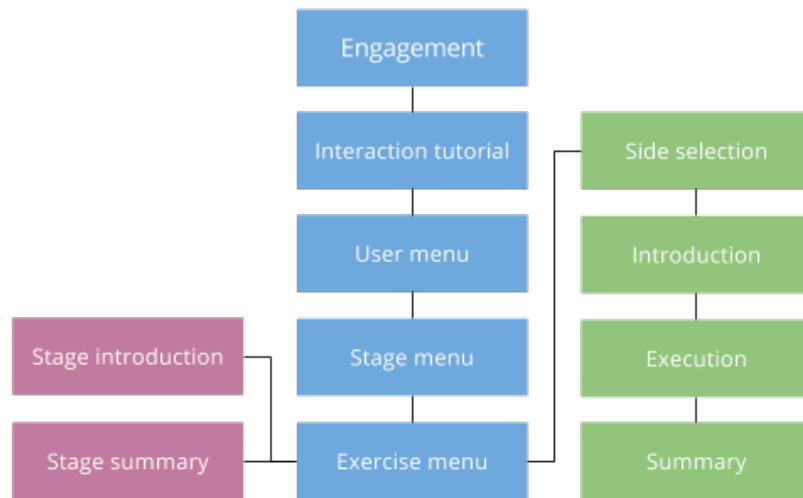


Figure 5.2: Scenario workflow

Chapter 6

Study

Chapter 7

Conclusion and Outlook

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