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A Comparison of Motion-Sensing Game Technologies for use in Physical Rehabilitation

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Master of Science in Informatics
Submission date: June 2012
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Preface

This is the master thesis and the result from the final year at the Master of Science in Informatics study program with The Department of Computer and Information Science (IDI) at the Norwegian University of Science and Technology (NTNU) in Trondheim.

I wish to express a thank you to my supervisor, Professor Dag Svanæs, for his insightful guidance, opinions and expertise throughout the year. I also want to thank the expert panel for their time and patience with the focus group. Their knowledge and experience provided me with some valuable real life insights into the world of physical therapy, I hope this work can in some way help the effort in aiding patients in need of rehabilitation.

I also want to thank Terje Røsland for introducing us to the NSEP lab, his time in when conducting the focus group. Lastly thanks to Kristian Tryggestad for his cooperation and patience in the joint parts of the prototype and focus group.

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Trondheim, June 2012

Abstract

In this thesis we evaluate the use of Wii, Kinect and Move for use in physical rehabilitation. The goal of this thesis is to evaluate the feasibility of these low-cost commercially available motion-sensing devices for rehabilitation and to explore what strengths, weaknesses and challenges exist in that use. This is guided by two perspectives, the technical feasibility and the feasibility as viewed by physical therapists, on this basis we construct some high level guidelines for the implementation of games for physical rehabilitation.

This thesis uses the interpretive approach and qualitative methods, this is instantiated with the use of Research Through Design. Some qualitative methods applied were a focus group, interviews, questionnaire and prototyping. The prototype artifacts are used to provide concrete embodiments of theory and technical opportunities, these artifacts also serve as a conduit for transfer of the research.

The prototypes are used to evaluate the technical feasibility of the Wii, Kinect and Move based upon specified requirements in physical rehabilitation. The author presents a set of high level quality attributes for evaluating the capabilities of the various sensors and libraries in the context of two games developed for physical rehabilitation. The Wii, Kinect and Move all have different strengths and weaknesses for the usage scenarios specified.

Next, the prototypes are used as starting point for evaluation by the expert panel in a focus group, the focus group consisted of three physiotherapists. The physiotherapists found the motion-sensing technology very promising but could not determine on a general basis which device is the most suitable since each patient have very different individual requirements to his therapy depending on the level of injury. The experts also stated some of the most promising areas of this augmented rehabilitation was the motivational, social and tactile facets. The experts found some of the typical commercial games to be too focused on the fun aspect, lacking in concise direction of exercises, and, lacks the needed adjust-ability to the difficulty.

Based upon the technical evaluation and the expert panels feedback, the author suggest a list of guidelines for aiding construction of serious games for rehabilitation.

Sammendrag

I dette studiet evaluerer vi Wii, Kinect og Move for bruk innen fysisk rehabilitering. Målet med studiet er å evaluere gjennomførbarheten til slike lav-kost kommersielle bevegelsessensorer innen rehabilitering og utforske hvilke styrker, svakheter og utfordringer som finnes i slik bruk. Dette blir veiledet av to perspektiver, den tekniske gjennomførbarheten og gjennomførbarheten som vurdert av fysioterapauter, på denne basisen vil vi konstruere noen høynivå retningslinjer for implementasjon av spill for fysisk rehabilitering.

Denne studien benytter seg av en fortolkende tilnærming og kvalitative metoder, dette blir instansiert med bruk av Research Through Design. Noen kvalitative metoder som er brukt er fokusgruppe, intervjuer, spørreskjema og prototyping. Prototypeartifaktene er brukt til å gi konkrete legemligjøringer av teorien og de tekniske mulighetene, disse artifaktene tjener også som en kanal for overføring av forskningen.

Prototypene blir brukt til å evaluere den tekniske gjennomførbarheten av Wii, Kinect og Move based på spesifiserte krav innen fysisk rehabilitering. Forfatteren presenterer et sett med høynivå kvalitetsattributter for å evaluere mulighetene med de forskjellige sensorene og bibliotekene i kontekst av to spill utviklet for fysisk rehabilitering. Wii, Kinect og Move har alle forskjellige styrker og svakheter for de spesifiserte bruksscenarioer.

Deretter blir prototypene bruk som utgangspunkt for evaluering av et ekspertpanel i en fokusgruppe, fokusgruppen bestod av tre fysioterapauter. Fysioterapautene fant ut at bevegelsesteknologien er veldig lovende, men kunne ikke bestemme på generelt basis hvilken enhet som er mest egnet siden hver pasient har veldig forskjellige individuelle krav til hans terapi avhengig av graden av skade. Ekspertene fant også ut at noen av de mest lovende områdene med slik augmentert rehabilitering er de motiverende, sosiale og taktile fasetter. Ekspertene oppdaget at noen av de typiske kommersielle spillene er for fokusert på morsomhetsaspektet, mangler consis retning i øvingene og mangler mulighet til justering av vanskelighetsnivå.

Basert på den tekniske evalueringen og ekspert panelets tilbakemelding, foreslår forfatter en liste med retningslinjer for å hjelpe med konstruksjon av seriøse spill for rehabilitering.

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Chapter 1

Introduction

1.1 Background and motivation

The introduction of low-cost motion-sensing enabled devices like the Nintendo Wii in video gaming have inspired researchers into researching the potential benefits of low-cost commercially available devices for the use in physical rehabilitation [22]. The Wii motion-sensing controller was introduced in 2006 as a new way to control games by the use of physical motion of the body instead of only the traditional use of fingers with game pad buttons and equivalent gear, the Wii further emphasized the physical aspect with it's sports game specifically designed to complement the new controller. Other game console companies have since released alternative products inspired by the success of the Wii like the Microsoft Xbox with Kinect and Sony PlayStation with Move, which are all based on using the body as controller for a game or application. These low-cost motion-sensing controllers offer interesting possibilities for physical rehabilitation in a multiple of ways which will be further investigated in this thesis.

Cost is as always a motivating factor and [4] investigates the cost associated with spinal cord injuries (SCI), traumatic brain injury (TBI) and stroke and suggests the following facts about SCI, TBI and stroke in the United States:

- The amount of people in the US affected with SCI is about 300,000 increasing with 12,000 each year
- The average estimated lifetime cost associated with SCI is between $3 million and $7 million depending on severity
- About 3 million people are affected with TBI each year and 90,000 will be suffer lasting disability

- The direct and indirect cost associated with TBI is around $60 billion
- Stroke is the leading cause for disability with about 795,000 people suffering because of each year
- Health costs attributed to stroke is estimated at $70 billion per year
- 90% of the stroke victims are left with one sided weakness due to the stroke

Furthermore [4] states that following injuries to the nervous system the most efficient means to recover motor function is through intense and skillful practice. As demonstrated by the facts the cost associated with just SCI, TBI and stroke are very large, other conditions not included in the estimates like Cerebral Palsy and age related conditions to the bones and muscles also affect a number of people. From this we can see that any way to reduce the extent of the effect of the injuries through rehabilitation could potentially help to not only reduce the cost, but also the quality of life for the affected person in the form of increased ability to function in every day life.

The main focus of this thesis will be to analyze and compare the strengths and weaknesses of the Nintendo Wii, Microsoft Kinect and Sony Move for use in physical rehabilitation, with special attention to the feasibility of each device in terms of the suitability for rehabilitation exercises.

1.2 Research questions and method

The goal of this thesis is to evaluate the Nintendo Wii, Microsoft Xbox Kinect and Sony PlayStation Move technologies for use in physical rehabilitation, this can be formulated as the following research questions to guide the effort:

1. RQ1: What are the most important qualities of motion-sensing game technologies for the implementation of serious games for physical rehabilitation and how do the most popular game platforms compare concerning these qualities?
2. RQ2: How to physiotherapists evaluate the suitability of these technologies in physical rehabilitation?
3. RQ3: What design guidelines can be inferred for the use of these technologies for application in physical rehabilitation?

This thesis conducts an exploratory investigation and comparison of the mentioned technologies and as such, qualitative methods are most appropriate since it involves collecting and analyzing data and then make interpretations based on it [35]. Data material is collected through the production of a prototype and performing a focus group session with demonstration of the prototype, a questionnaire and an semi-structured group interview. The research method applied in this thesis is inspired by Research Through Design, this method was chosen as basis because it emphasizes the use of hands-on experience in research which is instantiated with the prototype, this method is well suited for research which is qualitative and exploratory, the specifics on the method is detailed in the Chapter 3.

ISO 9241-210 "Human Centered design for interactive systems" was also applied as a guiding standard when developing the research questions and the perspective of the thesis. In Figure 1.1[1] there are 4 iterative steps:

- Understand and specify the context of use (Understand)
- Specify the user requirements (Specify)
- Produce design solutions to meet user requirements (Design solutions)
- Evaluate the designs against requirements (Evaluate)

The "Understand" and "Specify" step was the goal in the master thesis by William Young [56], where the author evaluates and investigates the use of motion sensing technology for use in physical rehabilitation. Young uses the Nintendo Wii gaming console to see how suitable commercial available video games are, and attempts to find what challenges exist in creating therapeutic games. This thesis uses some of the findings from Young to understand the user context along with other literary sources. The requirements established by Young are some of the input to a design solution, the prototype, which will be used in answering Research Question 1. We then proceed to evaluate that prototype with a panel of experts in a workshop session which will attempt to answer Research Question 2. Finally we attempt to extrapolate some design guidelines, or heuristics, for developing rehabilitation games.

[1] ISO 9241-210

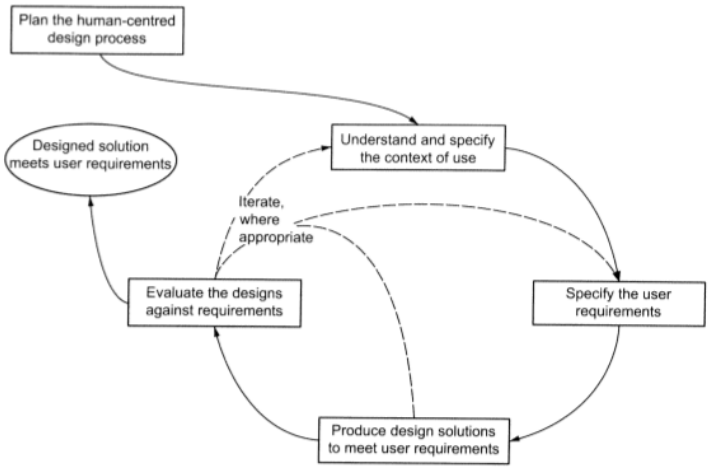

Figure 1.1: ISO 9241-210

1.3 Thesis Scope and context

This thesis tries to identify strengths and weaknesses of the Wii, Kinect and Move for use in physical rehabilitation. The main goal is to investigate how the different technologies differ and perform when trying to do actual rehabilitation exercises instead of just playing games for fun; how suitable the three technologies are a patient. The thesis is based on a study of current papers and literature within motion-sensing devices such as the Wii within the context of rehabilitation and general potential as a technology. A prototype is produced as an artifact to get hands-on experience with the material and to convey the possibilities to non-technical physical therapy personnel in a focus group. The prototype was constructed during one semester as a joint effort with the author and co-student Kristian Tryggestad working on a related perspectives on the same technologies.

The workshop was conducted at the NSEP Usability Lab located in Trondheim with the help from physical rehabilitation professionals associated with St. Olav University Hospital and researchers associated with the Department of Computer and Information Science at the Norwegian University of Science and Technology. The workshop did not include actual patients.

1.4 Typical physical rehabilitation

Physical therapy is a wide field with many types of specialties [52]. Typically it involves interaction with a physical therapist and one or more patients to assess, diagnose and set goals for a health related condition. The specialty areas in physical therapy according to the American Board of Physical Therapy are cardiovascular & pulmonary, clinical electrophysiology, geriatric, integumentary, neurological, orthopedic, pediatric, sports and woman's health. In this thesis some of the focus will be on the neurological specialty because neurological conditions like brain injury and Cerebral Palsy entails therapy exercises that involve motion and stances that are transferable to a game format. These exercises can restore and maintain bodily functions or slow the progress of some diseases [52]. Some examples of typical exercise areas are the following from Young [56]:

- General walking
- Grip
- Shoulder stability
- Rotation of pelvis
- Rotation of thorax
- Shoulder abduction and flexion
- Neck movement
- Weight transferal
- Knee movement
- Hip abduction and flexion
- Hand-eye coordination

1.5 Serious games

Electronic games have long been seen as only a medium for fun and entertainment, but recently there have been interest into using games as a vehicle for learning [5], games that have a primary function of learning are often called "serious games" a

term coined by David Rejeski of Woodrow Wilson International Center for Scholars. Serious games use the entertaining and visceral nature of electronic games to convey a particular learning objective, they use the engaging and interactive medium to teach something that can be more involving than traditional teaching alone, a good example of a serious game is flight simulators used by the military, but advances in cheap and affordable computing power offers new possibilities that doesn't need billion dollar budgets.

Educational software has been around before, as [5] states in the 1990s there was a big hype around educational software that did not turn out to be what was expected. One of the differences between the 1990s and today, is the exponential advances in computing power that enables a regular commercially available computer to run realistic 3D virtual environments [5], further there have been an increase in educational programs specifically targeted at game development and game art creation so the availability of people with the needed skills is higher than before. Today one can find free and open source game middleware to create professional grade virtual environments like the Ogre open source 3D graphics engine, advances in content creation tools have made it faster and cheaper to create game assets [5]. The advances of sensing technology like the Wii adds a new and interesting dimension to serious games by adding the tactile dimension without having to use expensive specialized equipment, [3] investigates this interaction between people and computers and the feel dimension of it; how tactile interaction can enhance the interaction experience.

Chapter 2

Motion-sensing technologies and related research

This chapter will go into the background and details of the Wii, Xbox Kinect and PlayStation Move as they are some of the foundation for this thesis, the prototype using them and the suggested usage with them.

2.1 Nintendo Wii

Figure 2.1: Nintendo Wii

The Nintendo Wii (Figure 2.1 [1]) introduced in 2006 [25] as a successor to the Nintendo GameCube, realized the concept of affordable motion-sensing input device to the mass market. The Nintendo Wii was the first mainstream gaming device, or "console", to use motion-sensing input instead of only relying on traditional game pad with buttons to control the device. The main Wii controller called a Wii Remote, or "Wiimote", has a built in accelerometer and infrared camera in addition to the traditional buttons which it uses to determine acceleration along three axes [53]. The infrared camera in the Wii Remote uses an infrared transmitter attached to the Wii to more accurately determine it's position relative to the transmitter. The Wiimote uses Bluetooth to connect to the Wii and has haptic feedback in the form of a vibrator motor and integrated speaker for auditory feedback. The Wii can support additional accessories to the main controller like the Nunchuck for

[1] Picture by Evan Amos from the Wii page on Wikipedia

use in addition to the main controller, a Wii Balance Board to detect the weight and weight distribution of a person standing on it, and more.

The Wii has been used extensively in research and publications, some related specifically to rehabilitation are [17, 19, 21, 22, 25, 14], it has even been investigated for use in music [13].

2.2 Microsoft Xbox 360 with Kinect

The Xbox introduced in 2001 was Microsoft's first game console [54], it was the latecomer to the games console market and had to compete with the more established competitors, mainly Nintendo, Sony PlayStation and Sega Dreamcast. In 2005 Microsoft launched the successor Xbox 360 and 2010 the Kinect (Figure 2.2 [2]).

Figure 2.2: Microsoft Kinect camera

The Kinect marked a change from only traditional game controllers to the addition of a motion input mode. The Kinect uses a standard RGB camera in conjunction with infrared dept sensor to determine pictorial information from the user and the surroundings [49] like shown in Figure 2.3 [3]. Software in the Kinect uses this camera information to build a motion capture model of objects within the camera field of view, which in turn can make more interesting things like a skeletal tracking available to programmers [32, 49], Figure 2.4 demonstrates the joints available[4]. The Kinect also has an array of microphones for voice commands and motorized stand to control the tilt of the device.

[2]Picture by Evan Amos from the Kinect page on Wikipedia

[3]Kinect IR and Depth by Kolossos from the Kinect page on Wikipedia

[4]Picture from Programming Guide Getting Started with the Kinect for Windows SDK Beta from Microsoft Research

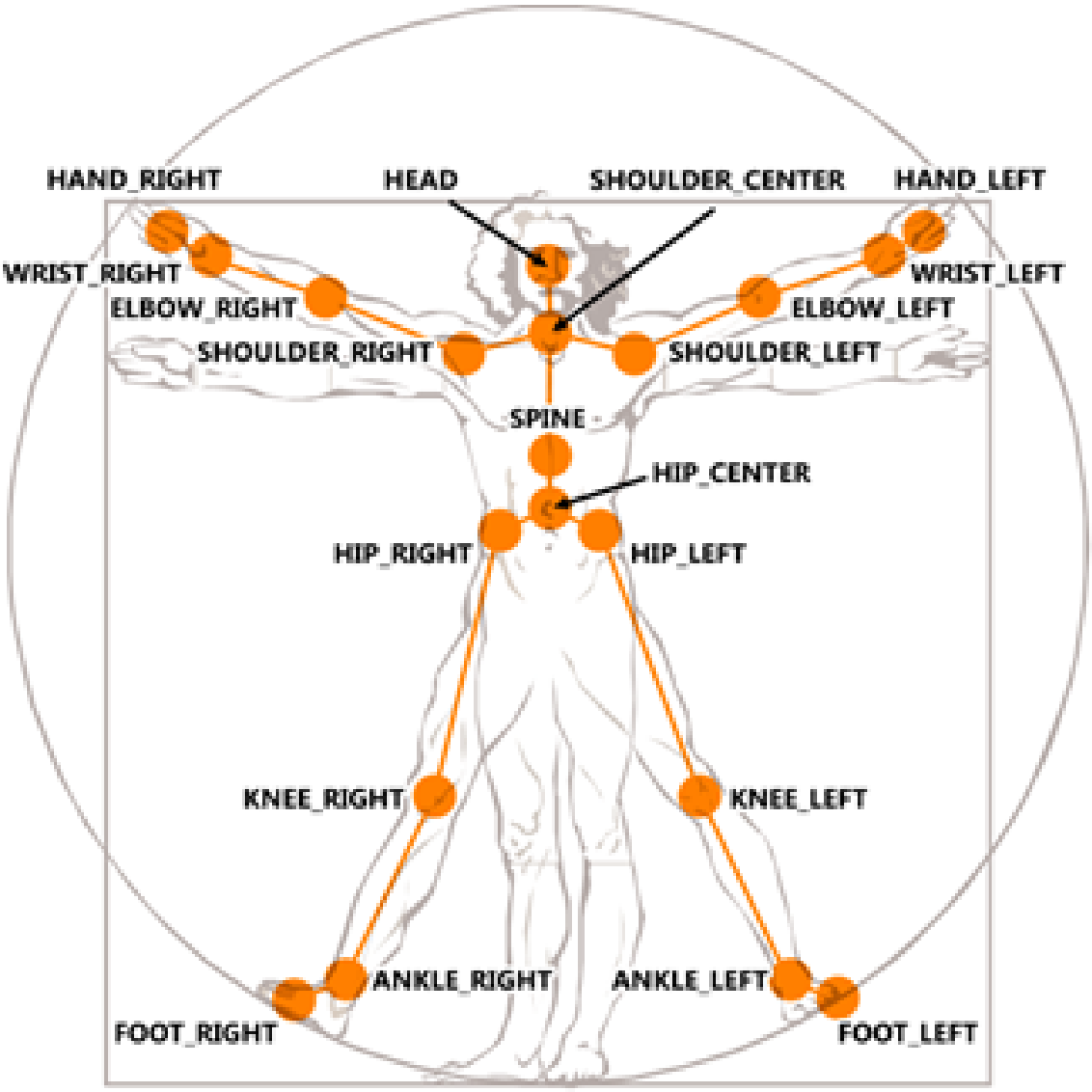

Figure 2.4: Kinect Joints in the skeleton abstraction

The Kinect spurred a lot of consumer and hobbyist amazement [8] with it's seemingly vast possibility space ever since a non-official programming interface (API) was reverse engineered, like for example aid in robotic surgery [31], augmented reality [18], robotics controller [46] and even a shopping cart driver [36]. This prompted Microsoft to capitalize on the consumer and commercial interest [33, 11], and have since released programmer friendly official drivers, programmer libraries and guides on how to best program for and use the Kinect. Microsoft's openness to the use the Kinect is a stark contrast to the Nintendo Wii programmer

interface which forces non-licensed or non-commercial entities to use home made reverse engineered libraries with less quality control and lacking documentation [25].

The Kinect is relatively recent addition to the console accessories compared to the offering from Nintendo so most publications and research according to searches on publication databases like IEEE Explore and Google Scholar at the time of writing, seems to be technical in nature like [44] and [26] and not much specifically in the rehabilitation space, but a few like [24] and [55] explores some aspects of Kinect and physical rehabilitation.

2.3 Sony PlayStation 3 with Move

The Sony PlayStation 3 introduced in 2006 [50] is as of writing Sony's latest generation of gaming console since the original PlayStation in 1994. In 2009 Sony released the PlayStation Move hand held controller [51] to compete with the Nintendo Wii. The wireless hand held controller uses similar technology as the Kinect, using a camera called the PlayStation Eye shown in Figure 2.5[5], but also relies on a colored ball on the hand held controller to accurately track movement as depicted in Figure 2.6. [6]

Figure 2.5: PlayStation Eye camera

[5]Picture by Evan Amos from the PlayStation Eye page at Wikipedia
[6]Picture by Evan Amos from the PlayStation page at Wikipedia

Figure 2.6: PlayStation Move controller

The orb can emit any RGB color using LEDs which the camera can track [51]. Like the Kinect the camera could track the controller without the color ball, but an active marker in the player environment makes it faster and more accurate, additionally the size of the color ball enables the software to calculate the depth, or distance from the camera, instead of using infrared depth sensor as the Kinect uses. The hand held controller also contains a three-axis linear accelerometer and a three-axis angular rate sensor to track rotation and motion. Furthermore the controller also contains a magnetometer to calibrate the controllers orientation against the earth's magnetic field to mitigate against cumulative drift by the inertial sensor and in situations where the color ball is obscured so the camera can not directly track it [51]. The controller can provide haptic feedback with the aid of vibrations. The PlayStation 3 has the option of more accessories like the PlayStation Move Navigation controller for use in conjunction with the main controller , the PlayStation Move Sharp Shooter Attachment to simulate a gun in shooting games and more.

As with the Kinect the amount of publications using the PlayStation Move is lower in volume compared to the Wii and most are of technical nature like [28] instead of use with physical rehabilitation. [10] and [4] investigates some aspects of the use of the PlayStation Move in physical rehabilitation of young adults with disabilities and compares it to the IREX VR professional grade gesture equipment.

2.4 The target audience and suitability

One of the problems in the case with physical rehabilitation and the games on the mass market is that they are in most cases designed for a typical healthy individual. This can pose problems when trying to use them with people with a disability or physical limitation, for example a person affected with stroke can some times have difficulty with lifting the arm on the affected side of their body, much less swing a tennis rack with a Wii Remote like typically done in the Wii Fit Sports game. Some games have options to set degrees of difficulty which can to a certain extent mitigate this fact, but a game designed for use in physical rehabilitation could be more suitable. Further [4] found that many games are designed with fun in mind, and not necessarily doing a exercise the correct way, some games also provided negative feedback which could be inappropriate for a patient. Games might also be a good way to bridge the gap between fun and laborious training of disabled bodily functions, especially as a continuation of the training regimen after clinical sessions at home which [4] also suggests. The current commercial games tested for rehabilitation in various literature with possibility for continuation at home after clinic sessions, appear to lack a reliable way to track and motivate the progress of the patient which the physical therapist would normally do in the clinical training session.

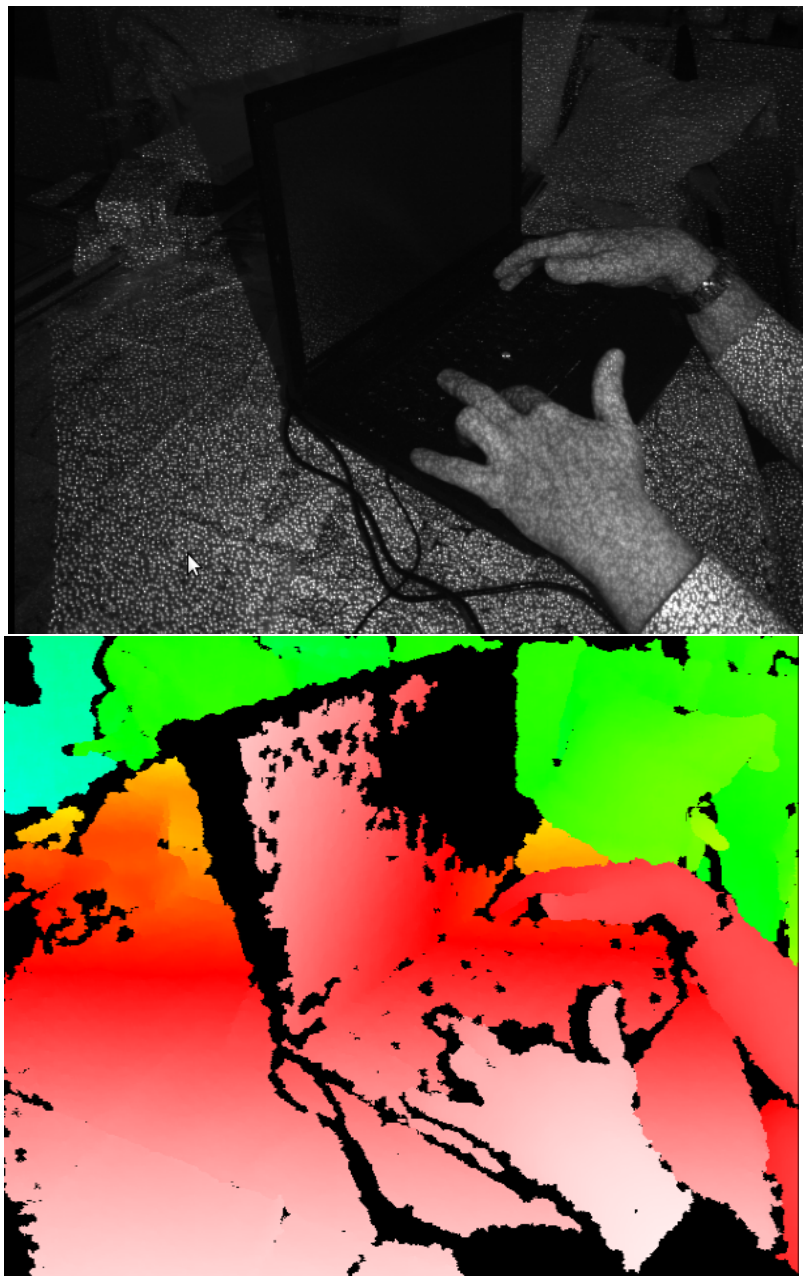

Figure 2.3: The Kinect IR image (left) with a corresponding visualized depth map (right)

Chapter 3

Methodology

This chapter presents and overview over the methods and techniques relevant to this thesis and the theory it is grounded in.

3.1 Research methods

The choice of research method is important when doing research because the method should be suitable to the perspective used and area to be researched. The most common ways to classify a research method is either qualitative or quantitative. Quantitative research methods was originally developed to study natural phenomena in natural sciences and often involves methods such as surveys, laboratory experiments, formal and numerical methods. Qualitative methods were developed in the social sciences to enable researches to study social and cultural phenomena, with methods such as observation, interviews, questionnaires, documents and the researches impressions and reactions.

The main difference between quantitative and qualitative research is that qualitative research methods are designed to:

> Help researches understand people and the social and cultural context within which they live

Further [34] suggests that combining methods from both qualitative and quantitative can be a good source of triangulation. Triangulation is useful because it can help with corroborate findings and enhance the validity of the findings by enlighten it from a different perspective. Oates [35] also suggests several types of triangulation; method, strategy, time, space, investigator and theoretical triangulation as valid approaches.

3.1.1 Qualitative methods

Qualitative research methods are particularly useful when one wants to conduct exploratory research, Svanæs [45] describes the exploratory process as:

> A qualitative study should start out with an openness towards the phenomenon, and allow for a theory to emerge from the data

According to Michael D. Myers [34] there are several philosophical perspectives as to what constitutes "valid" research and what methods are appropriate. For qualitative methods [34] and [35] suggests three major underlying epistemologies; positivist, interpretivism and critical research, these underlying perspectives represent the researches assumptions on what are appropriate methods for the research. Of special interest for this thesis is the interpretive approach since interpretive studies often attempt to understand a phenomenon through the meanings that people assign to them and the complexities of human sense making, the philosophical base of the interpretive approach is hermeneutics and phenomenology [34]. Oates [35] describes interpretivism as:

> Interpreter research in IS and computing is generally concerned with understanding the social context of an information system: the social process by which it is developed and construed by people and through which it influences, and is influenced by, its social setting

Moving from the underlying assumptions to the actual research strategy employed, the four most prominent methods in the interpretive paradigm are Action Research, Case Study, Ethnography and Design and Creation, these strategies have different ways of collecting data, Research through Design is a relatively new approach which is described in more detail in Chapter 3.2.

3.2 Research through design

Zimmerman et al. presents a model (Figure 3.1[1]) for doing research in interaction design, or "research through design" and the importance of the artifact as a part of the interaction design research, focusing on re-framing problems through a process of making *right* thing;

[1]Picture from Zimmerman, Research Through Design as a Method for Interaction Design Research in HCI

Artifacts intended to transform the world from the current state to a preferred state

Further Zimmerman states there is no agreed upon standard of what research through design means and proposes four lenses to evaluate an interaction design research contribution to determine the quality of the research:

- Process: As with anthropological research contributions, one can not expect to reproduce the same result when reproducing the process. Instead one examines the rigor and rationale applied to the methods used. The process must be reproducible from the documentation.

- Invention: The research contribution must constitute a significant invention. It must be demonstrated that the research has produced a novel integration of various subject matters to address a specific situation

- Relevance: Instead of validity as benchmark, interaction design research use relevance. Framing the work in the real world and articulate the preferred state the design attempts to achieve and why that state is preferable

- Extensibility: Ability to build upon the resulting outcome, the research needs to be documented in a way the community can leverage the knowledge derived from the work

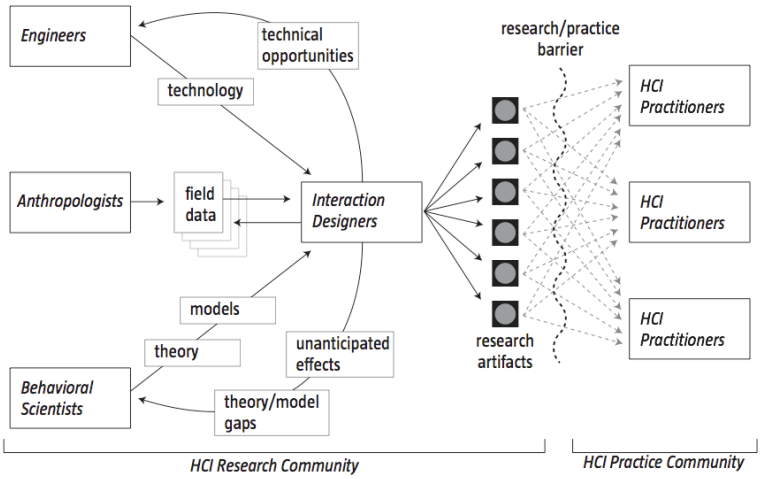

Figure 3.1: Zimmerman model of deliverables and pathways in research through design

Zimmerman claims that by using this model the researcher integrates true knowledge with he "how" knowledge and suggests the process of "ideating", iterating and critique of potential solutions, will make the researcher continually re-frame the problem in the attempt to produce the *right* thing.

3.3 Prototyping

Preece et al. [20] states that users often can't tell you want they want, but show them something they can see and interact with then they soon know what they do not want. A prototype is a time and effort efficient way to convey an idea to an audience, it can be of a new system to made or a re-envisioning of an existing system. A prototype is often a subset of a complete idea, composed of enough features to demonstrate what the system should do for a target audience. The prototype can be as simple as sketches on paper or interactive programs in Flash, Power Point or a hyper linked document, whatever is sufficient for the stakeholders to interact with the envisioned product and to explore the imagined uses.

Some prototypes are made to test usability, others purely for evaluating design and some for testing the technical suitability of a system. Oates [35] describes prototyping in the Design and Creation research strategy as an iterative way to produce something from the current understanding of a system, the new understanding gained from creating and analyzing the first prototype is then used to make a revised prototype which again continues until a satisfactory implementation is produced. One of the differentiating properties from an industrial "normal" prototype and a research prototype is the research prototype are followed with analysis, explanation, argument, justification and critical evaluation. Zimmerman [57] differentiates the commercial design practice artifacts from research artifacts in that the goal of the research artifact is to produce knowledge for the research and practice communities and not to make a commercially viable product, that the researcher focus on making the *right* thing instead of the *commercially successful* thing. Further the research contribution artifact should demonstrate significant invention:

> The contributions should be novel integrations of theory, technology, user need, and context; not just refinements of products that already exist in the research literature or commercial markets

One often talks about the fidelity of a prototype, low fidelity prototypes often have low degree of interactivity like a paper mockup, sketching and story boards, high fidelity prototypes often have a higher degree of interactivity like being comprised

of the same materials as the actual product so it looks and feels more like the real thing [20].

Preece[20] presents the following table (Table 3.1) on the different fidelities and their advantages and disadvantages.

Type	**Advantages**	**Disadvantages**
Low-fidelity prototype	Lower development cost	Limited error checking
	Evaluate multiple design concepts	Poor detailed specification to code to
	Useful communication device	Facilitator-driven
	Address screen layout issues	Limited utility after requirements established
	Useful for identifying market requirements	Limited usefulness for usability tests
	Proof-of-concept	Navigational and flow limitations
High fidelity prototype	Complete functionality	More expensive to develop
	Fully interactive	Time-consuming to create
	User-driven	Inefficient for proof-of-concept designs
	Clearly defines navigational scheme	Not effective for requirements gathering
	Use for exploration and test	
	Look and feel of final product	
	Serves as a living specification	
	Marketing and sales tool	

Table 3.1: Fidelity of prototypes

Further, Preece [20] comments that low fidelity prototypes have some particular advantages over high fidelity prototypes because high fidelity prototypes have the following problems:

- They take too long to build.

- Reviewers and testers tend to comment on superficial aspects rather than content.
- Developers are reluctant to change something they have crafted for hours.
- A software prototype can set expectations too high. Just one bug in a high-fidelity prototype can bring the testing to a halt.

High fidelity prototypes on the other hand are good for "selling an idea" and for testing technical challenges. A problem with presenting a high fidelity prototype to a customer or stakeholder can be the evaluator getting the impression he has an almost finished product already, instead of understanding the often skin deep nature of prototypes. Low fidelity prototypes often clearly show their compromises, high fidelity prototypes are often not so clear cut, but can show their limitations with rudimentary graphics, non working icons or slow response times, for example when prototyping a GUI with Microsoft Expression one can select all GUI elements like boxes and borders to be drawn to look as if they are hand drawn. Prototypes are are often "horizontal" or "vertical", the horizontal prototype focus on the breadth of a system while the vertical focus deeper on a specific function. In many cases prototyping is an iterative process, where after an evaluation one goes back to redesign based on the feedback and do another evaluation, this process then continues as much as needed.

3.4 Interview

Interviews can be characterized as a conversation with a purpose [20], often there exist an understanding about the topic beforehand, but with an interview one can attempt to uncover a better understanding of the topic. Interviews can be especially useful to understand the viewpoint of a user in the context of usability or better understanding complex themes when interviewing expert users. Some of the drawbacks with the interview is that the analyzing of the data can be time consuming, costly and the interviewee might not give honest answers [35], further the questions need to be well formulated to limit the bias. There are several main types of interviews depending on the control the interviewer impose on the conversation, Preece [20] describes them as :

- Unstructured interviews: Open ended interviews witch follow a particular topic, both the interviewer and the interviewee can steer the topic. Often follows an open format and has the benefit of potentially uncovering new

information or aspects about the topic which the interviewer had not previously explored. The cost of this method can be too much unrelated information and it can be time consuming to process the data, further it can be difficult to compare several similar interviews

- Structured Interviews: More predetermined set of questions and clear set topics to explore, suitable when the topic is well understood. Often uses short and clear wording and can use closed questions, where the question require a precise answer. One of the benefits with structured interviews is more precise data which can be easier to compare and analyze, but one might miss other aspects not specifically related to the predetermined questions.

- Semi-structured interviews: A combination of both unstructured and structured interviews, often consists of a script to steer the conversation and potentially uncover new information and probe the interviewee. The amount of predetermined questions can vary depending on how the interviewee responds as to avoid the conversation from stopping or not progressing fast enough.

When using unstructured or semi-structured interviews it is particularly important not to preempt answers with the phrasing or use of body language. Further one needs to accommodate small pauses to let the interviewee think and give them a chance to speak before continuing, probes can be useful to specifically ask if the interviewee has anything else to comment about. To reduce the strain on the interviewee and to use time efficiently, small prompts can be needed to help the subject along if he gets stuck on details like the name of a device or interface, but care must be exercised to not introduce bias and making the interviewee uncomfortable.

3.4.1 Focus group

One on one interviews can be extended to a group interview to get more input at once, one often used form of group interview is the focus group and is often used in marketing and social sciences [20], the shape and form of a focus group can vary depending on the need but typically lasts some hours and the interviewer can take the role of a facilitator to steer the topic depending on the amount of interaction needed with the subjects. The focus group appear to have high validity and are attractive because they have relatively low cost and can provide quick results. Focus groups can, however, be vulnerable to dominant personalities taking over the conversation and it can be easy to stray into irrelevant issues, Oates [35]

suggest inviting persons of similar status. It can be very useful to record the conversation since the amount of data can be quite substantial.

3.5 Questionnaire

Questionnaires are a technique to gather demographic data and user opinion [20], they can be closed or open similar to interviews. Questionnaires have the benefit that they can be easily distributed to large amounts of people and can be used in conjunction with other techniques, the answer from them can also be quickly processed if using machine processable forms or electronic surveys. One of the drawbacks of the questionnaire is the need to make very clear and well thought out questions and often one needs to separate the demographic into comparable clusters, for example when investigation if an interface is easy to use the opinion might be very different depending on how experienced the user is, so good sample ranges might be essential.

The response format on the questionnaire might have different forms depending on the question, like “yes” or “no”, a rating scale, check boxes. Two often used scales are the Likert and semantic differential scale [20] where the purpose is to gather a range of reposes to the question which can be compared across respondents.

3.6 Validity and triangulation

Triangulation is when one uses several methods to illuminate the problem at hand, this has the benefit of increasing the validity of the research and one way to do that is for example to use both qualitative and quantitative methods, method, strategy, time, space, investigator or theoretical triangulation. The researcher also needs to reflect about the data collected, [23] presents seven useful principles when doing interpretive research quoted below:

- The Fundamental Principle of the Hermeneutic Circle This principle suggests that all human understanding is achieved by iterating between considering the interdependent meaning of parts and the whole that they form. This principle of human understanding is fundamental to all the other principles
- The Principle of Contextualization Requires critical reflection of the social and historical background of the research setting, so that the intended audience can see how the current situation under investigation emerged

- The Principle of Interaction Between the Researchers and the Subjects Requires critical reflection on how the research materials (or "data") were socially constructed through the interaction between the researchers and participants.

- The Principle of Abstraction and Generalization Requires relating the idiographic details revealed by the data interpretation through the application of principles one and two to theoretical, general concepts that describe the nature of human understanding and social action.

- The Principle of Dialogical Reasoning Requires sensitivity to possible contradictions between the theoretical preconceptions guiding the research design and actual findings ("the story which the data tell") with subsequent cycles of revision.

- The Principle of Multiple Interpretations Requires sensitivity to possible differences in interpretations among the participants as are typically expressed in multiple narratives or stories of the same sequence of events under study. Similar to multiple witness accounts even if all tell it as they saw it.

- The Principle of Suspicion Requires sensitivity to possible "biases" and systematic "distortions" in the narratives collected from the participants.

Validity can be particular difficult when doing interpretive research since according to Oates [35] the interpretive approach has multiple subjective realities and has the characteristic of research reflexivity; the researcher is not neutral. To get a high degree of validity the researcher should not influence the result, but that might be difficult when the researcher have to interpret and potentially influence the data to extract a finding, so instead the researcher must be aware of his and Oates claims we have to explain how we gather the data and reflect on how we have ourselves might affected the data, the researcher can also evaluate the validity of some data gathering methods specifically, for example the validity of a questionnaire.

Zimmerman [57] suggests using relevance instead of validity when using research through design, still Klein & Meyer's principles offer useful guidance when collecting and interpreting the research. Oates [35] states that validity means using the appropriate processes where the findings do indeed come from the data and the research questions have be answered. Oates echoes Zimmerman in that he states different communities have different views on what constitutes appropriate research and process.

3.7 Research design in this thesis

This thesis uses a qualitative approach because it involves collecting opinions as much as data and then analyzing and interpreting it, the thesis attempts to answer the research questioned outlined in the introduction with the following methods:

- Prototyping (research through design artifact)
- Focus group (qualitative data)
- Interviews (qualitative data)
- Questionnaire (qualitative data)

The method perspective follows that of ISO 9241-210 described in Chapter 1.2 and focuses on the human-computer interaction, the thesis does this through a research through design approach because there was identified a need for a hands-on approach. A prototype was designed and constructed based upon literary study and previous related work, this prototype will attempt to answer Research Question 1:

> What are the most important qualities of motion-sensing game technologies for the implementation of serious games for physical rehabilitation and how do the most popular game platforms compare concerning these qualities?

Research Question 1 focuses on the technical feasibility of a implementation and especially at the controller level. Less emphasis is placed on the medium of the prototype, the graphics and amount of polish on the game play. How well can we transfer the kinesthethics of rehabilitation to the context of a commercial level motion-sensing device? What limitations exist when using the Wii, Move and Kinect for physical rehabilitation? How well can we implement the requirements established by Young [56]?

Further, his prototype was also used in a focus group with a panel of experts to test and evaluate the prototype according to Research Question 2:

> How to physiotherapists evaluate the suitability of these technologies in physical rehabilitation?

This part is especially important because we need to validate the assumptions made when constructing the prototype with real experts as detailed in Chapter 3.6. The focus group will also attempt to uncover additional aspects, viewpoints and opinions for the use of low cost commercially available hardware with serious games and physical rehabilitation. Research Question 2 is further investigated with the use of additional games tailored to healthy individuals to expose the expert panel to the possibility space of motion-sensing hardware, and attempt to map that experience to rehabilitation usage. The focus group initially uses an open interview approach before conducting a semi-structured interview and a questionnaire to gather the data.

Lastly the thesis attempts to extract a set of guidelines, or heuristics, for use in constructing games for rehabilitation based upon Research Question 1 and 2 in addition to other literature.

3.7.1 Ethics

The author has considered the ethical aspects of doing work with focus groups and the participants were asked to sign a consent form which can be seen in Appendix F, the participants had the option to conclude and withdraw from the focus group at any time and were informed about the purpose and scope of the focus group. Text and pictures with information that can identify individuals have been anonymized with blur outs. The video and audio recording from the work shop is only used to analyze the session and not for any other means.

Chapter 4

The game concepts

This chapter describes the basis for the game concepts and the context from which they were derived.

4.1 Background and goal

The thesis named "Motion Sensors in Physical Therapy" written by William Young in 2010 [56], attempted to find out if the Nintendo Wii with it's existing portfolio of games was suitable for use in physical rehabilitation. The thesis also attempted to find out what design challenges existed when creating games with the Wii for rehabilitation, and, if any design guidelines could be found with the Wii type of motion control.

4.1.1 Setting

The Young thesis focused on the Wii and in the perspective of "Understand" and "Specify" parts of ISO 9241-210 depicted in Figure 4.1[1]

[1] ISO 9241-210

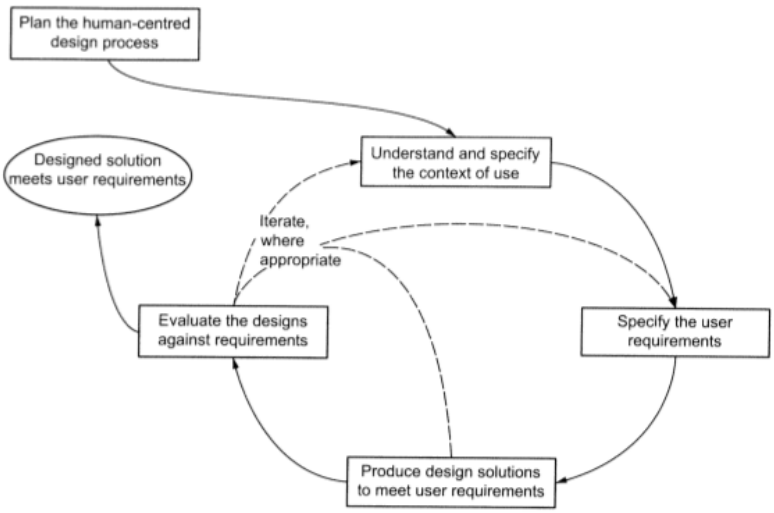

Figure 4.1: ISO 9241-210

The thesis conducted a set of observations at Orkdal Hospital and St. Olav University Hospital in Trondheim. Later on, Young conducted 3 participatory design workshops at the NSEP usability lab, the workshops was conducted with several physical therapists.

4.2 Workshops

Following are some short descriptions to how Young came to his findings

4.2.1 Technology introduction workshop

The first workshop was intended to introduce the concepts and the Wii to the therapists. The main goal is demonstrate the technologies and to evaluate the possibilities. The demonstration consisted mainly of some existing Wii games like slalom, tennis and other Wii Fit games. After the demonstration there was a brainstorming session to determine ideas and based on the therapist's view, Young found the Wii to be a potential technology for use in rehabilitation.

4.2.2 Participatory Design Workshop

The goal of the participatory design workshop was to develop more specific ideas of what could be suitable games for rehabilitation, some of the points developed

was:

- Increase in difficulty which should be adjustable
- Great sensitivity to speed
- Needs accurate mapping of motion
- Easy to learn and should be kept simple, need simple menus and clear feedback from the system
- Should have some sort of competition and logging of effort with a scoring system and measurable progression
- The Wii exercise should be transferable to daily life activities for motivational purposes
- One should combine several muscle groups
- Some restriction on motion to mitigate compensation with the help of aids should be used

4.2.3 The Third Workshop

The third workshop presented the prototypes which were made based on the second workshop and were aimed to get feedback on the ideas to examine if the researcher had understood the views of the therapists. Some of the therapists had tested the Wii on some of their patients and had the following feedback on the games:

- Canoeing and fencing represented favorable movements while cycling was too monotonous with his stroke patient
- Compensation was an issue
- Basic exercises should be trained before using the Wii
- There are a large age difference between patients
- The game should tie into some real life activity movement

It is important to remember that these Wii games are in most cases designed for fun and exercise for typical healthy individuals. Further the ideas was presented as power point slides to confirm the mental models. Some of the feedback when presenting the slide show was:

- There was a need for adjustable difficulty
- Focus on short time span
- Minimal distracting elements to keep focus

4.3 Results

The following was the ideas presented in the third workshop and constitutes the main result from the workshop.

4.3.1 Design 1 - River Adventure

The River game seen in Figure 4.2[2] is a game where the player steers the avatar, the pictorial representation of the player, on a river. The goal is to avoid obstacles like stones and to try and fetch things like a fruit or treasure chest. Some of the key features here is the motion of:

- Leaning left and right, demands balance and control over the spine
- Stretching for items, requires coordination and muscle movement, primarily in the upper arms and shoulder
- Crouching down to pick up items, requires coordination and muscle movement, primarily in the legs and some in the arms

Some of the real life activity analogues are general balance, stretching after and picking up things. The analogies to real life activities were identified as important.

[2]Pictures from Young thesis

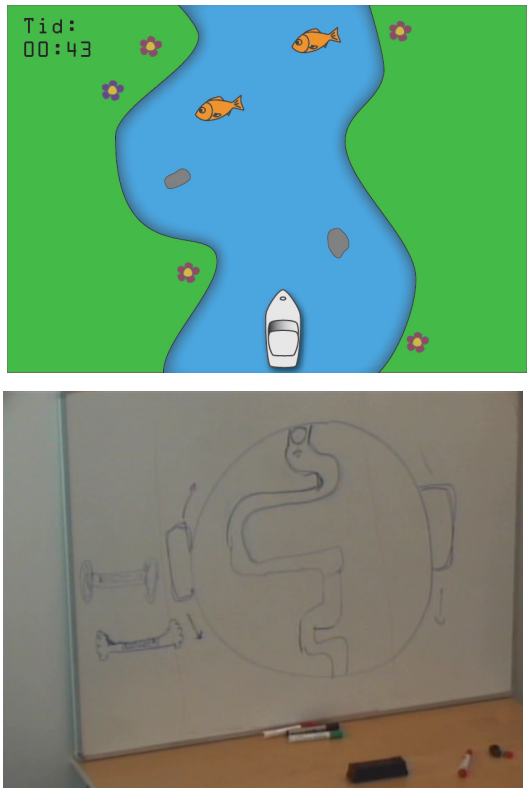

Figure 4.2: River game concept

4.3.2 Design 2 - Rotating Maze

The rotating maze depicted in Figure 4.3[3] consists of a maze where the player holds a device to control the rotation of the maze. The goal is to steer the ball through the maze to the goal area. The key focus in the maze is control over the upper arms, coordination and rotation of the arms. Some of the real life activity analogues here is the coordination and use of the arms for things like pushing down a door handle and turning a key and controlling a steering wheel.

[3]Picture from Young thesis

Figure 4.3: Rotating Maze

Some of they key movements are:

- Moving the upper arm, lower arm and wrists in circular motion
- Holding the arms in front and out from the chest, static muscle control in the upper arms

Chapter 5

Prototype

This chapter describes the implementation of the prototype and the findings from it. First we detail the goal of constructing it before describing the rationale for the choice of language and framework with a short overview of the game, then we describe how we will use the devices and conclude with the findings from using the device with the specified movements.

5.1 Goal and focus of the prototype

The goal with constructing the prototypes was to get hands-on experience with the actual implementation of a game for physical rehabilitation, and to evaluate the feasibility of the technical implementation of such a game. The functional design was based upon the work for Young described in Chapter 4. The author of this thesis and another student working on a thesis with another angle on the same theme, cooperated in the production of the prototypes. The authors used the same environment to construct the River game and Maze game. The author worked primarily on the River game while Tryggestad focused on the Maze game so the implementation details and examples will be primarily based on the River game, but the findings in Chapter 5.3 will be be from both the River and Maze game to illuminate different modes of movement.

As the title of this thesis suggests, one of the central topics in this thesis is comparing the Wii, Kinect and Move described in Chapter 1, the area of attention was detailed in Chapter 1 as rehabilitation, the perspective was set at controller level in Chapter 3.7 on the basis of the findings by Young, described in Chapter 4. One way to do this comparative analysis is to construct a game to function with all the

motion-sensing input devices and then discover the technical suitability for the specified goal.

The prototype was developed and evaluated on a PC but the findings should be transferable to the game consoles. The consoles have very different capabilities in graphics and processing power so the graphics used in the prototype was kept simple to focus on the controllers and their capabilities.

5.2 Implementation

5.2.1 Language and framework

While the fundamental interaction with the motion-sensing devices is independent of the language used to implement it, it is nevertheless an important factor because of the possibilities with the device can be easier to realize if the language is:

- Less error prone like the notorious C pointers and memory administration
- The language lends itself to increased productivity with the aid of wide frameworks like the Java SDK and .Net stack
- Easier to learn the the language intricacies
- What the developer has experience with

Another important factor is what libraries exist to develop with the motion-sensing device. The author investigated what libraries were available for use with the Wii, Move and Kinect and found that C, Java and C# were the most prominent ones. The author selected C# due to:

- The wide availability of high quality documentation through the Microsoft Developer Network and other online resources,
- All the necessary libraries were available with a C# implementation.
- The result in realizing the prototype in C# can be relatively easily transferred to a Java, and even C, environment due to the syntactical similarities.
- There are free versions of the C# development environment on the internet, even the professional grade Visual Studio from Microsoft

- The C# solution is compiled instead if interpreted which is important for games where performance is a key factor

- Easy and efficient access to the graphics subsystem through DirectX

When doing research it is important to focus on what your are actually researching, with this in mind the author selected the FlatRedBall game framework to use in the construction of the prototype. With the use of a game engine, the developer does not have to re-implement routines often used in game development, like for example the idea of a "scene", graphical artifact handling, input and output and so on. Jonathan Blow[6] wrote an interesting article on the difficulties in making modern games

> Ten or twenty years ago it was all fun and games. Now it's blood, sweat, and code.

Blow also presents a logical chart shown in Figure 5.1and Figure 5.2[1] over the systems in games in 1994 and 2004 and the increase in complexity is quite large. A prototype doesn't necessarily need to be as complex as a full commercial game, but it is nevertheless important to take complexity in mind from the beginning. FlatRedBall is a middleware which gives us many of the modern game mechanics out of the box and it strives to follow "best practices" within game programming.

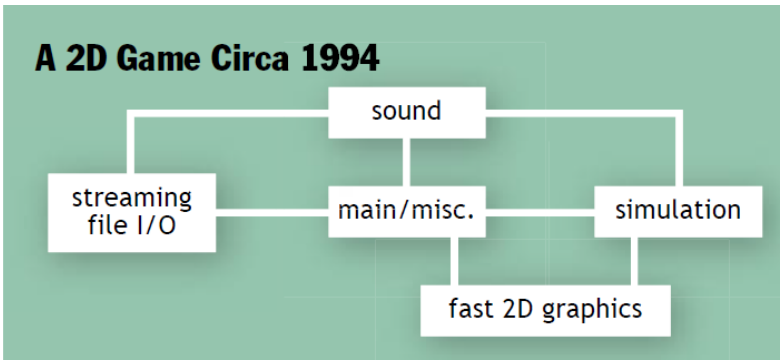

Figure 5.1: Game systems in 1994

[1] Pictures from Blow, Game Development, Harder Than You Think

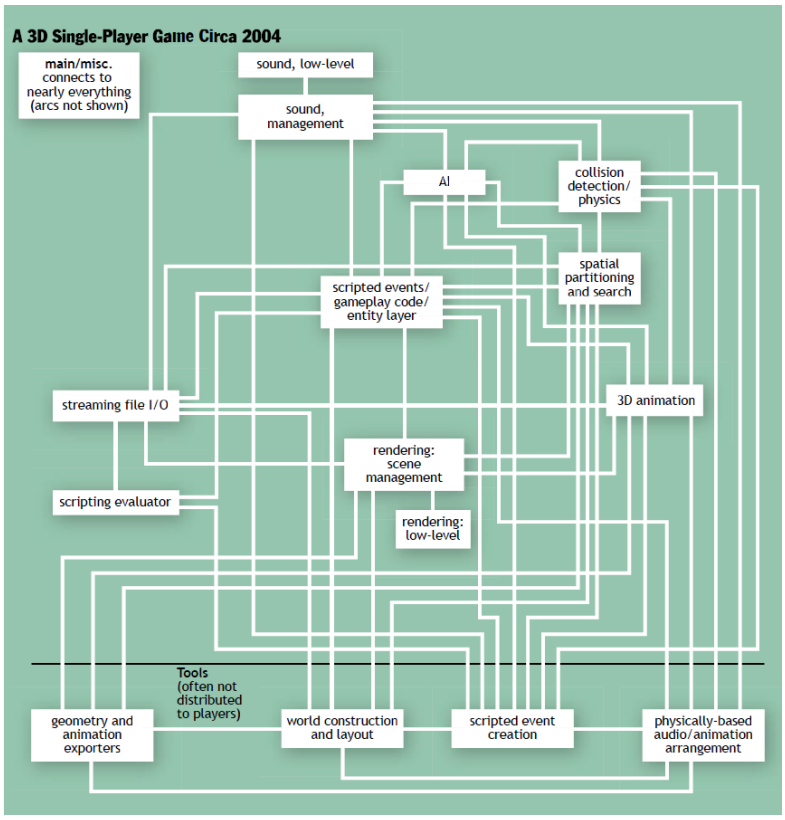

Figure 5.2: Game systems in 2004

Most game frameworks are based on C due to the speed efficiency, even tough the speed of a game written in C# has relatively negligible speed impact [40][9][39] (when proper care is exercised when programming, like for example using unchecked array operations) in many types of games except the most resource demanding. The FlatRedBall game engine is a pure C# game engine with the possibility to utilize the the Microsoft XNA game framework, .Net connectivity framework and many other libraries and frameworks, this is a benefit which can make the effort to implement the desired functionally more time efficient and less error prone.

Figure 5.3: FlatRedBall

The FlatRedBall game engine (Figure 5.3[2] is a so called "2.5D" engine, which means the games are two dimensional, but also have a depth dimension perpendicular to the screen. The 2.5D type of game has the benefit of faster and easier creation of graphical artifacts, easier management of physics and lowers the overall complexities of the game. While it is technically possible to implement a full 3-dimmensional game in FlatRedBall, the engine was not designed with that in mind [15]. The game engine being 2.5D fits well with the game concepts discussed in chapter 4 with Young's prototypes being isometric, or "top down", type of games. The games being isometric further simplifies the use of motion-sensing devices and will let the author focus on the key research targets.

One very useful part of the FlatRedBall package is the graphical map editor which enables a non-programmer to design maps and content which can be loaded into the game. The map designer is basically an application that imports and places sprites, graphical images, into an X, Y and Z position.

5.2.2 Overview over the game

Like most games the FlatRedBall framework and the prototype utilizes the concept of a game loop . This game loop [27, 48] is important when understanding the capture and processing of the input from the motion-sensing devices. The game loop depicted in Figure 5.4[3] shows the common version of the loop, the capture of motion input happens the same way as regular input with the addition of a few Process and Update steps:

- Determine selected input mode (Wii, Kinect, Move or Keyboard)
- Capture input stream from motion-sensing device (User Input)
- Transform the input to a device specific movement command (Process Data)
- Store the input in device specific state representation (Update State)
- Update the generic global state representation with the input (Update State)
- Perform the current state representation (Output)
- Loop until exit condition

[2]Logo picture from flatredball.com
[3]Picture from Wikipedia

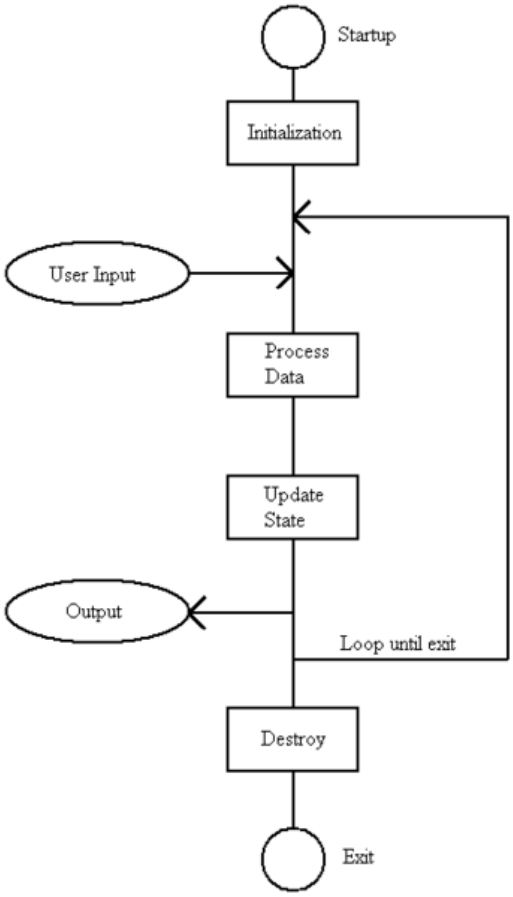

Figure 5.4: A game loop

The additional Process steps is added to attempt low coupling and high cohesion between the modules, since the motion-sensing devices have very different raw data as output. It is possible in the prototype to use more than one input mode at the same time, like for example the Wii weight board and the Kinect, but the prototype is not designed to handle and merge multimodal input simultaneously, for that to work one would need a more refined input processing and state representation like that described in [29] or QuickSet [38].

5.2.3 Some important functions in the game

The prototype consists of a many parts and components to operate, the entirety will not be reproduced here instead some important parts will be described to convey the overall way the prototype is designed and functions. The player global

state is store in the struct shown below (Algorithm 5.1), the intermediary state representations for the Wii, Kinect and Move are similar to the PlayerState except they are stored in the Wii.cs, Kinect.cs and Move.cs classes and have some differences due to the state the device effectively can represent and to provide separability where the specific representations can easily be serialized and sent around.

Algorithm 5.1 PlayerState

```
public struct PlayerState      {
        internal Boolean LeaningLeft, LeaningRight,
        HandLeftUp, HandLeftDown, HandRightUp,
        HandRightDown, Crouching;
        internal bool StopMoving;

        public void Stop()       {
                LeaningRight = false;
                LeaningLeft = false;
        }

        public void LeanLeft()   {
                LeaningRight = false;
                LeaningLeft = true;
        }

        public void LeanRight() {
                LeaningRight = true;
                LeaningLeft = false;
        }
}
```

The main class GameScreen.cs gets a reference at initialization to the classes of the other motion-sensing devices and collects their respective state representations when the device has been selected for use, overall the GameScreen.cs class manages:

- Initializations and loading of assets
- Loading in the map, building and placing polygons
- Update the global PlayerState from the specific motion player state

- Actuating the player state defined in PlayerState
- Performing collision detection between the player avatar and objects
- Manage the input mode changes

The flow of control and data follows that of the Model-View-Controller pattern, where the Wii, Kinect and Move classes act as controllers, the controllers store their respective model data in the global model of the player which then acts as the data source for the player graphical representation, or avatar,

5.2.4 Wii

The Wii class manages all input coming from the Wii controller and translates that data into a Wii state representation. The most important function of the class can be seen in Appendix A. The Wii class is dependent on the WiimoteLib library, a DLL written by Brian Peek at the Channel9 internet site [37] for using the Wii controller on a PC with C# and .Net. The Wii controller and balance board is connected to the developer PC through a Bluetooth connection.

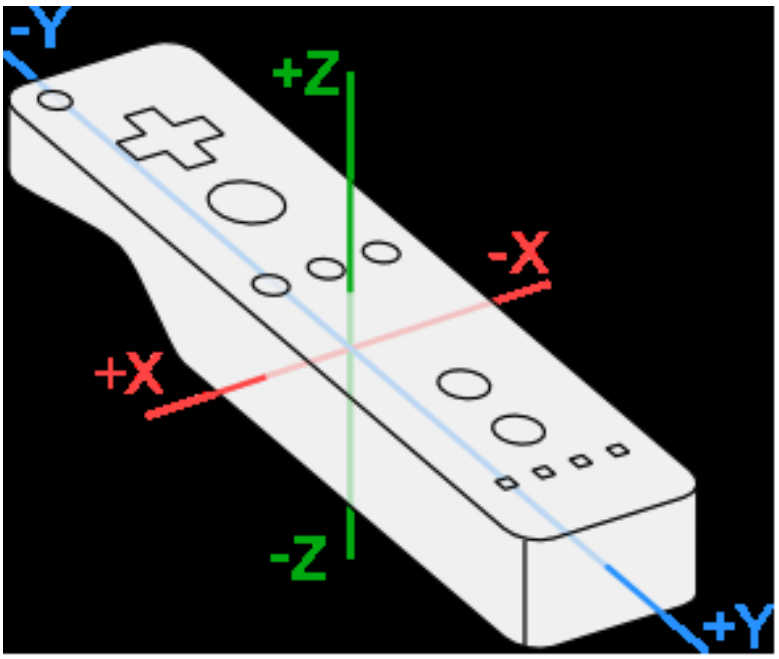

Figure 5.5: Wii axes

As described in the Chapter 2.1 the Wiimote offers us an accelerometer and infrared sensor to provide the data. The WiimoteLib library sends the acceleration values in X, Y and Z (Figure 5.5[4]) and the Wii class uses those acceleration values to determine if the player have performed a move according to those specified for the River game in Chapter 4.3.1, mainly:

- Wiimote controller in the left hand or right hand
- Hand moved up
- Hand moved down

Some typical move interpretations can be seen in Figure 5.6[5].

Figure 5.6: Wii gestures

In addition to this data, we have the Wii Weight board which offers the weight distribution data on the balance board (Figure 5.7[6]) as depicted in Figure 5.8[7] , with the balance board data we can determine if the player standing on it is:

- Standing still
- Leaning to the right
- Leaning to the left

With the Wiimotes and the balance board we can effectively determine all the moves needed for performing the actions specified in Chapter 4.3.1. The infrared sensor is used for precisely determining where the Wiimote is and where it is pointing when using the Wiimote to navigate the Wii menu, one must point the Wiimote at the transmitter much like a TV remote. The Wii class does not use the

[4]Picture from Young thesis
[5]Picture from Young thesis
[6]Picture from Young thesis
[7]Picture from Young thesis

infrared sensor since no infrared transmitter were available at the time of development and the movement paths as specified did not fit well within the range of the infrared sensor.

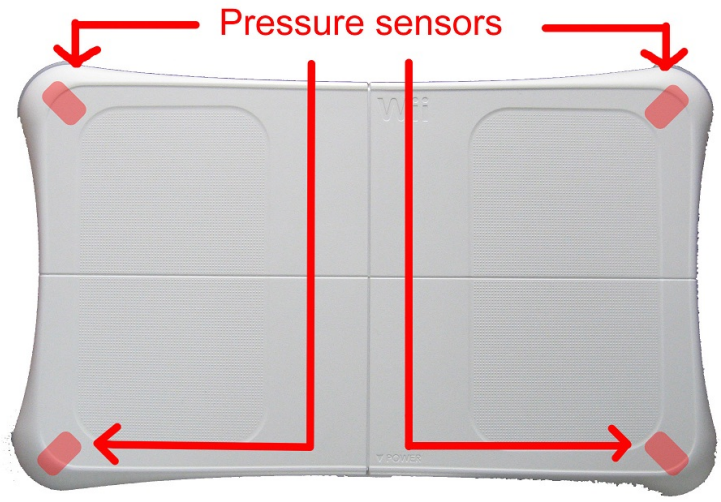

Figure 5.7: Wii Balance board

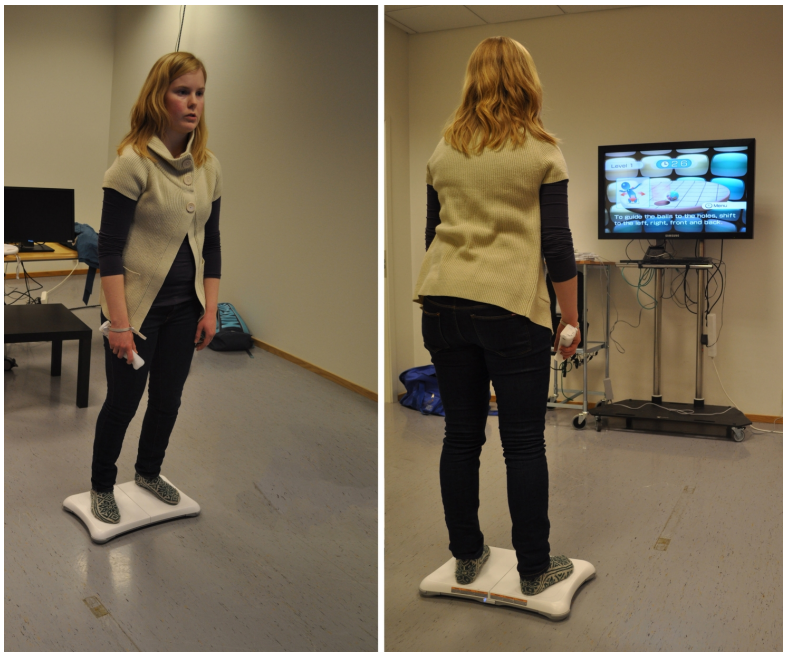

Figure 5.8: A player on the Wii board with a Wiimote

5.2.5 Kinect

Similar to the Wii class the Kinect class handles all the input from the Kinect device and translates that into a Kinect state representation, the most important function is shown in Appendix B. The Kinect class uses the Kinect library to convert raw data into usable formats shown in Figure 5.9[8](NUI was the library name with the beta version, release version changed the name to Kinect) , the Kinect DLL follows with the Microsoft Kinect installer which installs the Kinect driver, C# libraries and some sample C# code. The Kinect is designed to work with a Xbox, but full Windows support was added with version 1 of the Kinect driver package, Kinect is connected to the developer PC through USB.

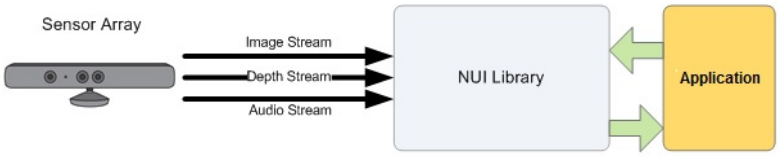

Figure 5.9: Kinect API

As described in Chapter 2.2 the Kinect hardware offers several raw data streams, namely the RGB image stream, the infrared depth image stream and a microphone audio stream. The Kinect library offers functions for working on a higher abstraction level than the image streams, this is available through the skeleton abstraction where the skeletal joints are retrieved from a Skeleton object such as the right hand, hip, left leg and so on, all the available joints are shown in Figure 2.4 and Figure 5.10[9] show how it looks in practice.

[8]Picture from Programming Guide, Getting Started with the Kinect for Windows SDK Beta from Microsoft Research

[9]Picture from Programming Guide, Getting Started with the Kinect for Windows SDK Beta from Microsoft Research

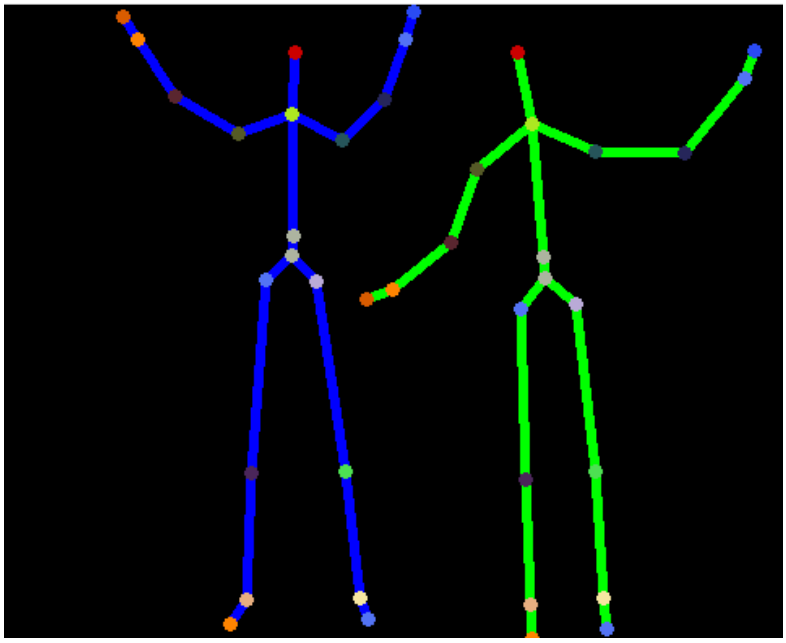

Figure 5.10: Kinect Skeleton

Each separate joint have X, Y and Z values in relation to the Kinect cameras as shown in Figure 5.11[10] with the sensor in the origo.

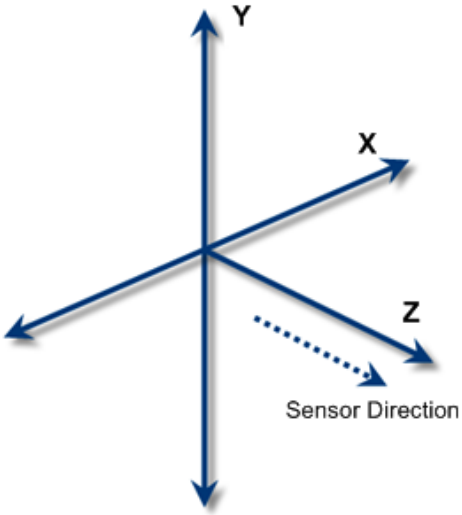

Figure 5.11: Kinect dimensions and orientation

[10]Picture from Programming Guide, Getting Started with the Kinect for Windows SDK Beta from Microsoft Research

The Kinect class uses these X, Y and Z coordinates of the joints to determine if the player has performed an action as defined in Chapter 4.3.1 for the River game:

- Right hand lifted or lowered
- Left hand lifted or lowered
- Player standing or crouching
- Leaning to the left or right

The image, depth and audio streams are not used directly, too keep the processing simple, but they could be used to overlay the player image directly into the prototype or be enhanced with voice commands.

5.2.6 Move

The Move class handles all the input coming from the Move controller but where the Wii and Kinect was directly connected to the developer PC, the Move controller can only connect to the PlayStation 3. As described in Chapter 2.3 the Move controller and camera work in conjunction to determine spacial placement and movement of the controller, both the camera and controller are connected to the PlayStation 3 and all data has to be sent over the network to the developer PC as shown on Figure 5.12 [11].

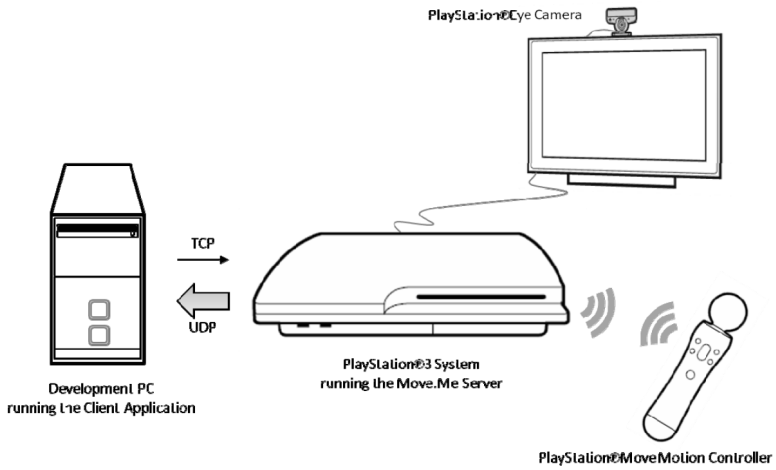

Figure 5.12: PlayStation Move connections

[11] Picture from Move.Me Network Protocol

The PlayStation 3 must have the Move.Me application (Figure5.13[12]) installed to allow connections to it. Unlike the freely available Wii and Kinect libraries, the Move.Me is a $99 purchase. The Move.Me homepage provides example source code in C# to process the raw data coming from Move.Me, the data processing is at packet level but the sample code can be compiled and used without modification to produce state information for the Move controllers. The processed data for each Move controller is then stored in a simplified Move state representation much like the Wii and Kinect in the Move class. The most significant function for the Move class is shown in Appendix C

Each Move controller provides X, Y and Z coordinates which is used to determine the location of the controller relative to the camera, the player must have one Move controller in each hand and one at the abdomen area, like in the belt or a chest holder. With these three controllers we are able to determine the player movement actions as specified in Chapter 4.3.1:

- Controller in right hand, left hand or abdomen
- Hand moved up
- Hand moved down
- Player standing or crouching
- Leaning left or right

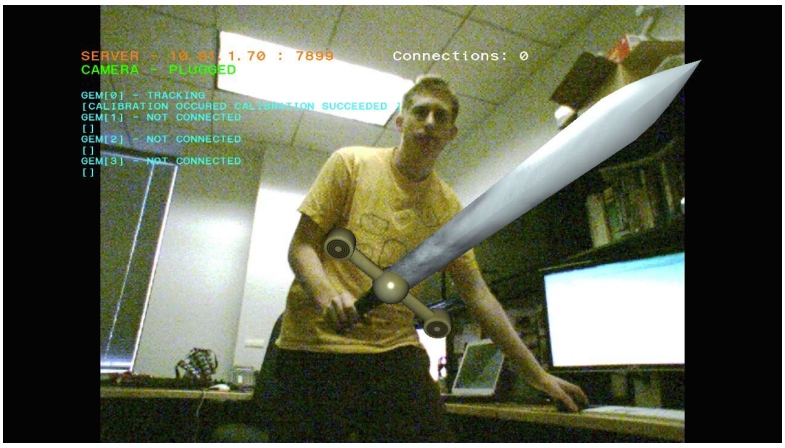

Figure 5.13: Move.Me application

[12]Picture from Move.Me Network Protocol

5.3 Findings

This section will describe some of the findings that have implications for the feasibility as defined in RQ1.

All the motion-sensing devices manages to capture the necessary information and the processing classes do convey the specified actions as envisioned by Chapter 4.3 All tough the devices have some different strengths and weaknesses.

5.3.1 Wii

5.3.1.1 Connectivity and libraries

The Wii controllers and balance board connects to the developer PC through Bluetooth, these connections however have difficulties in remaining stable and frequently drops out from the PC and a new pairing process has to be done. There library used to connect to the Wii controllers are also unstable, resulting in numerous crashes and errors which can only be remedied with a new pairing of the controllers.

5.3.1.2 Sensors and usage

The Wii controllers uses acceleration to determine the increases in acceleration in positive and negative X, Y and Z, this presents a problem for accurate determination in the River game defined in Chapter 4.3.1 since the change in acceleration can not be used to determine where the controller actually is, we can approximate rudimentary where the controller is but due to drift the error increase rapidly. Due to this we can only detect what direction the player moved the controller and the intensity of the movement, from that we can extrapolate that the player moved the hand up and down in accordance to the stretch movement in Chapter 4.3.1, it would be difficult to detect if the player actually moved the controller far enough to reach the goal item. Slow movements also presented extra difficulties in registering as movement, it was very difficult to determine if the player was standing or crouching since the player often has many random micro movements during the play.

The movement patterns for the Maze game defined in Chapter 4.3.2 is well suited to the Wii accelerometer since it involves rotation as the primary function, it can not however detect if the rotation is occurring at the right point in space.

Usage of the infrared sensor could potential alleviate the accuracy problem, but due to the way the controller is hold in the hand when stretching the arm, the

sensor would not receive the infrared signal much of the time and would be very dependent on the player knowing how to position the angle of the controller, so in such a case the controller would need to be attached to some additional accessory which could maximize the amount of time the sensor is in view of the infrared signal.

The weight board works very well in determining how the player is standing and leaning by the shift of weight on the board sensors.

5.3.2 Kinect

5.3.2.1 Connectivity and libraries

The Kinect connection through USB works very well and the libraries provided my Microsoft were stable with few errors. The skeleton abstractions proved to be very useful.

5.3.2.2 Sensors and usage

The Kinect is reasonable accurate in determining the position of the skeleton joints for the River game defined in Chapter 4.3.1, however the latency from an movement to when it registers in the prototype is noticeable. The Kinect is also vulnerable to changes in the view of the camera and can loose the lock on the player which require some seconds to regain. Kinect also has some slight trouble when a joint is obscured by another object. Overall the Kinect had no problems in detecting the necessary information to determine the player movements, and was very good at determining the standing and crouching movement. Movement is determined by registering the changes in the X, Y and Z coordinates relative to a "rest zone" defined around the camera, a change in coordinates has to be outside the rest zone in the right direction to register as a change in the player state which will enable the player to grab the objective or move to the left or right. The player state resets when the joints are back in the rest zone.

The Kinect can also detect the movement patterns defined in 4.3.2 quite well, but it can have trouble with small increments in the movement and it can be hard to position the hands in the correct position in space to begin with. Further it can detect if the position in space is correct with the depth value of the joints.

The Kinect does work in a sitting position but some spontaneous errors in the skeleton tracking can occur at random when sitting, officially by Microsoft the Kinect only supports standing players. Kinect is the only device that can detect if

the player is performing the move with the correct joints or instead the body as a whole to gain the same effect, the Move could achieve this with object recognition with the use of the camera, but that would require further work.

5.3.3 Move

5.3.3.1 Connectivity and libraries

Since we can not connect to the Move controller directly we have to use the PlayStation 3 and the Move.Me application, it uses both TCP and UDP packets and that caused firewall issues, the TCP data was received but UDP did not, only after disabling the firewall completely did the UDP packets arrive. The source code for the packet processing library has little to no documentation or comments except packet codes and some superficial explanation of how some of it works. The prototype needs to be given the IP-address and port of the Move.Me application to receive the controller data. Once the connection was in place the the libraries worked well with few errors. The response time for the controller was very low with little jitter, however this was dependent on network traffic and some spikes of latency did occur.

5.3.3.2 Sensors and usage

The Move controllers have very accurate sensors for determining positional information and the magnetometer negates the drift very well, even when the camera loses track of the light emitting orb. The Move controller is able to deliver information necessary to perform the actions specified for the River game in Chapter 4.3.1 and like the Kinect the movements are based upon registering X, Y and Z coordinates relative to a rest zone defined around the camera, when the player moves the controller outside the rest zone far enough and in the right direction that will register as a movement and change the player state which will enable the player to grab the objective or move the avatar to the left or right. The player state resets when the controllers are back in the rest zone.

The Move manages to measure the movement patterns defined for the Maze game in Chapter 4.3.2 very well, the precise sensor couple with the depth value from the orb and the low response works good for the movement patterns..

5.3.4 Summary

All devices did manage to provide the information necessary to determine if the action was performance as desired by the specification, but the were significant differences. The Wii is relatively cheap and child friendly, but suffers from lack of positional information and connection issues. The Kinect doesn't require the player to hold anything but is depended on spacious surroundings and has some latency. The Move is very fast and accurate but depends on elaborate connecting procedure if used on a PC, it also needs a controller in the abdomen area to determine the standing position. Both the Kinect and Move are much more expensive than the Wii, only the Wii and Kinect can be used independently of the console box.

It is intriguing to consider the combined usage of the devices but that would only work on a PC and would rule out an easy to deploy game to run on a console box such as in a home setting.

5.3.4.1 Compensation

One particular issue in physical rehabilitation is compensation; compensation is when the patient achieves the result without performing the intended action completely as specified, for example instead if using the arm to move an object the patient instead moves only the wrist and then twisting the torso. One important facet of a game for physical rehabilitation is to what degree we can counter act compensation. When a patient is in training with a physical therapist, the therapist normally issues corrective commands when the patient is compensating, the compensating actions often happen unconsciously by habit. The motion-sensing devices have different capability to counter act this effect:

- Wii has the balance board which can ensure correct weight transfer and balance but the controllers themselves offer little to counter act compensation. The Wii has a large number of accessories such as weight additions and vitality sensors.

- Kinect has the advantage of seeing the entire skeleton, where, what and how the player is moving so it has good potential to counteract compensation, however more complex algorithms would be needed to process the increase in parameters. The depth sensor is slightly less useful when the joint is moving perpendicular to the sensor. For some exercises one would want to hold something in the hand and some items can cause issues with the joint tracking especially if the object is skin colored.

- Move have better positional control than the Wii much similar to that of the Kinect but with lower response time, the player can manipulate the controller to achieve the goal through compensation, we also need 3 controllers properly placed to determine the positions and movements as defined for the Maze and River game.

Chapter 6

Focus group

This chapter describes the participants, planning, execution and findings from the focus group. First we present the setup and the participants, highlighting why we consider the participants to be an expert panel. After wards we present the plan for the session detailing what was done, how it was executed and why it was done. Finally we present the findings with some analysis on the results.

6.1 Setup and participants

The focus group was conducted at the NSEP[1] usability lab, the lab has a multitude of cameras, microphones and other usability lab features for performing and recording the session Figure 6.1[2] have some pictures of the setup.

[1]The Norwegian Electronic Health Records Research Center
[2]Picture from the focus group

Figure 6.1: Focus group setting

Three participants were invited to the session as an expert panel and provided the following information with a general information form (Appendix E) about their expertise and experience:

Participant #	Profession, specialty, field	Experience with the profession, field	Experience with game consoles on a 1-5 scale (5 highest)
1	Physiotherapist neurology stroke	30 years therapy 12 years neurology	1
2	Physiotherapist Cerebral Palsey	25 years therapy 10 years CP	1
3	Professor in Movement Science motor skills	20 years	1

Table 6.1: Participants

In addition to the expert panel there was the author and Tryggestad acting as facilitators, oversight and input was also added from Professor Svanæs.

The participants expressed interest in technology which could help in physical rehabilitation and some of them had experience with other professional grade equipment, but little experience in commercial consoles with motion input devices.

6.2 Procedure

This section describes the methods and procedure followed during the session, the session was three hours long and designed to follow certain milestones but otherwise let the conversation flow by itself.

The room was set up with all the consoles and related equipment like camera and hand controllers, the Xbox 360, Wii and PlayStation 3 were connected to a large screen TV with a laptop close by, demonstrated in Figure 6.1.

The session started with an introduction in typical HCI manner introducing the concept and equipment, the Wii, Kinect and Move were also presented to the expert panel. It was explained that the prototypes were developed on PCs and because of that the motion-sensing devices were connected to the PCs.

The facilitators demonstrated the River and Maze game before letting the experts try out the games in turn (Figure 6.3[3]) with the Wii, Move and Kinect.

[3] Screen shot from the River game

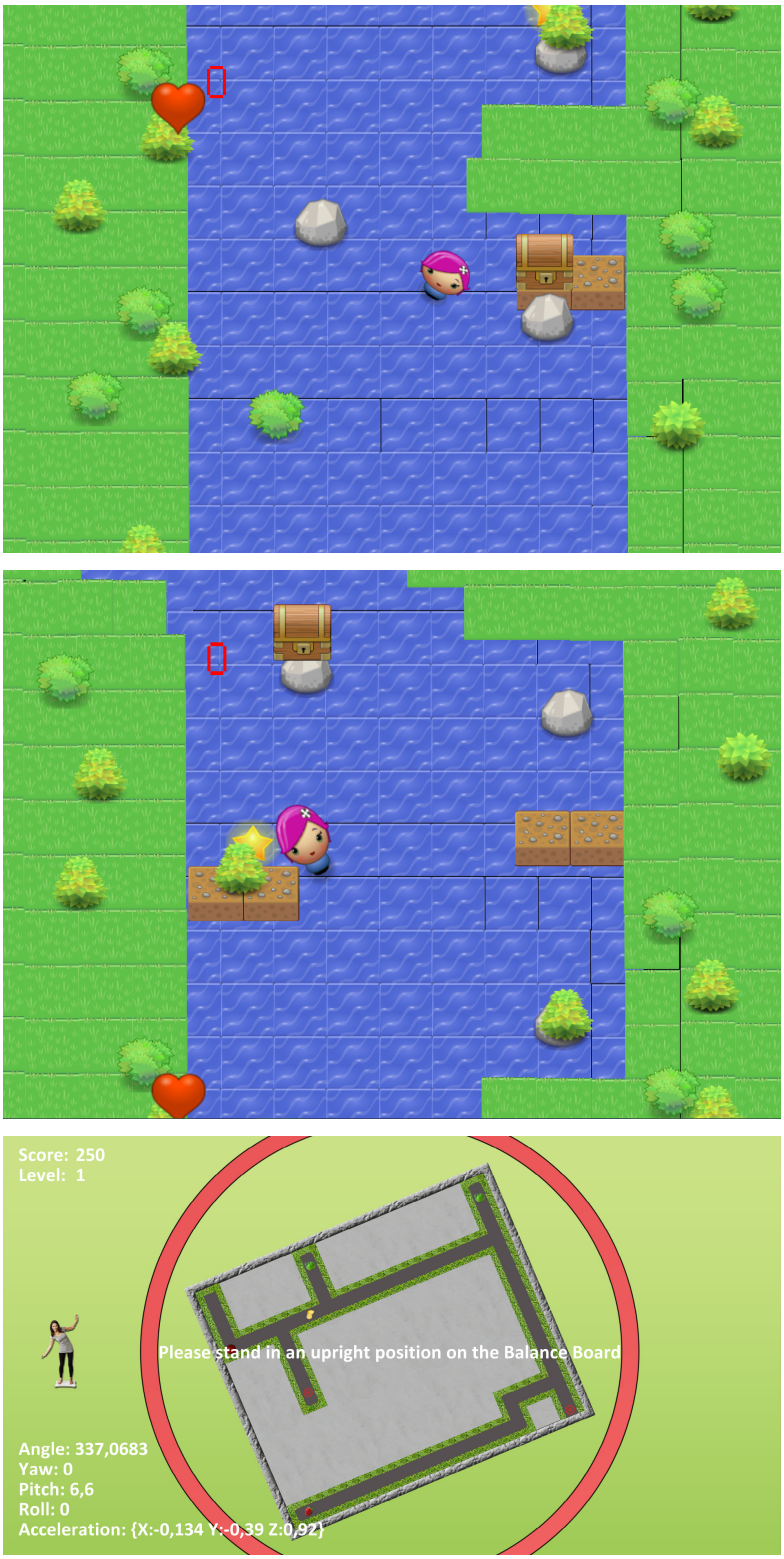

Figure 6.2: River and Maze

After the prototypes were tested there were a short discussion with card ranking on the devices based on the tested games, the card ranking as described in [1] is used to aid the discussion by providing a visual cue for the participants. Next the facilitators demonstrated some selected commercial games, some games were selected because the game were available on all the platforms providing good base for comparison, some are pictured in Figure 6.3[4], others were selected because they involved some interesting movements:

- Ultimate Fighting Championship were available on all the platforms and the following modes of play were selected:
  - "Freestrike", the player has to hit a punching bag
- Wii Fit, Hula Hoop
- Kinect Your Shape: Fitness Evolved, Hula Hoop
- Kinect Your Shape: Fitness Evolved, Stack'em Up
- Move Get Fit with Mel B (dancing fitness)

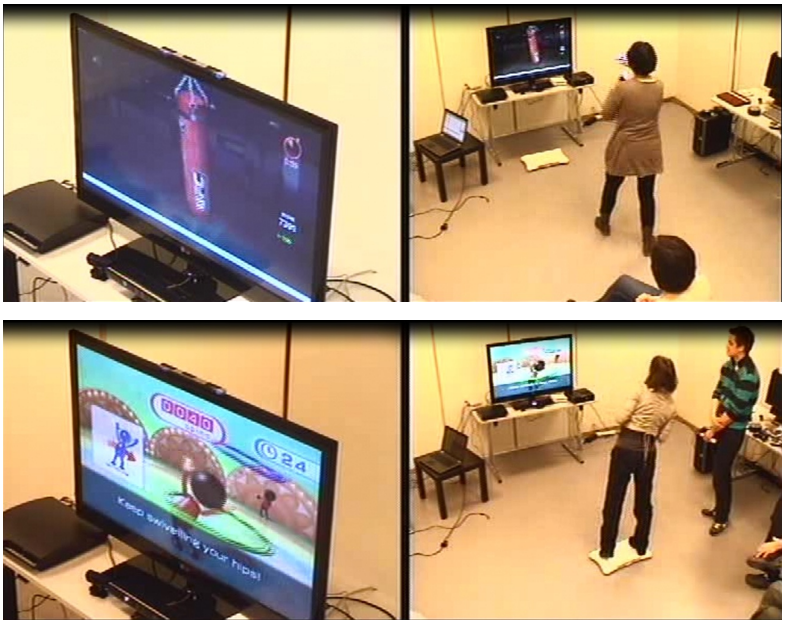

Figure 6.3: Commercial games

[4]Picture from the focus group

Not all games on the plan were demonstrated due to time constraints, Wii Slalom, Kinect Virtual Smash, UFC “Hit the mitts” and UFC “Flip the wheel” were left out, it was decided that the chosen games represented a good technological representation of the fundamental idea. The plan was made to accommodate a flexible amount of time on each game such that the games that proved to be more interesting to the expert panel could be focused upon.

Finally, the session was ended with a semi-structured group interview, a questionnaire and concluding remarks.

Open and semi-structured group interview

The session was from the start laid out as an open interview also known as unstructured interview, the themes was introduced and followed based on the responses from the expert panels. At certain times the facilitators shifted the discussion to cover more grounds. At the end of the session the format was changed to a more semi structured group interview with some more concise questions which the facilitators had worked out based on literary studies, Young’s work and experience when constructing the prototypes. General results, findings and observations are listed in Chapter 6.3.

The semi-structured group interview was formed to gather some specific information on topics the author discovered during the literary study, previous work by Young and during the prototype construction. The questions are listed in Table 6.2 under and the results in Chapter 6.3.2

General:
How suitable in general to the expert panel find the three technologies for use in physical rehabilitation
Can they see any particularly suitable conditions for the technologies
Body:
How well do you feel the motion-sensing devices can transfer motion as done in traditional exercises
What do you think is the most significant advantage to the technology demonstrated
What disadvantage can you see with the use of the demonstrated technology
What do you feel about thee difficulty in the games for patients
What do they feel needs to be done to make the games more suitable than are today
Can you envision a patient continuing with the technology at home
Compensation:
In what way do you think we can counter act compensation
What do you think we can do to minimize the chance for wrong execution of the exercises with the technology
Image:
How do you feel about the different avatar representations of the player, invisible, animated and real photo
How important is it for the player to see themselves and what they do while they exercise with the technologies

Table 6.2: Questions for semi-structured group interview

Questionnaire

At the end the expert panel were also asked to fill out a questionnaire based on their experience with the games and their background. The questionnaire was formed from information from the Norwegian Physiotherapist Organization about conditions where physical therapy are reported to help, and from the work by Young [56]. The questionnaire response form followed the Likert scale as described in Chapter 3.5 and [20].

The complete questionnaire is listed in Appendix D and were guided the leading question:

> Seen in relation to only traditional exercises in physiotherapy, to what degree do you think this device could help in increasing the effectiveness of the exercises

Following that that were a list of conditions or area of interest like Cerebral Palsey, stroke, increase balance et cetera, and a Likert scale from 1 to 5 on each of the devices (Wii, Kinect and Move) with 5 being the highest score. The results are listed in Chapter 6.3.3

6.3 Findings

This section describes the findings and results from the focus group

6.3.1 Feedback and observations from the session

The following presents some freely expressed opinions and statements by the expert panel as the prototypes and commercial games were presented, in addition some observations made by the facilitators are added.

The expert panel stated they had heard about motion-sensing devices used with typical games as a means to active elderly and expressed enthusiasm over the technology. Some of the expert panel had been in the workshop conducted by Young, targeting CP patients where the patient were sitting.

The first expert tested the River game on the Wii, there was a lack of guide from within the game in the beginning so the facilitator had to explain how to play the game. The tester stated the speed was an important factor. An interesting observation with the Wiimote was the facilitator used a shaking motion on it during the setup test procedure, which lead to some of the testers shaking the Wiimote instead of just stretching the arm, this shows how easy it is to establish the wrong kind of movement pattern. Further it seems the Wiimote had problems registering a movement when the player had stretched for an item and when the arm was fully flexed it had to be shaken to have it register as motion, it seemed to be difficult to time the movement left and right with the acceleration in the stretch movement.

The second device to be tested was the Move with River game. The setup with the three Move controllers proved to slightly confusing, but worked much better to follow the stretching and bending motions as defined in the requirements. The expert liked the fact that the Move controller was very responsive to small movements. Some experts had to move too far to actual trigger a left or right movement

in the game, the crouching movement proved to be slightly difficult to coordinate. They also stated to prefer the Move over the Wii board. One expert had a tendency to walk to the sides instead of leaning, signifying problems with the sensor calibration.

The Kinect with the River game had slight problems initially to get a fix on the skeleton potentially from interference with all the objects in the room. The experts had to move the entire body more than intended to get the movement action registered indicating need for calibration for their skeleton dimensions. They stated that the pelvis could be better than the spine for movement to the sides. Positioning in relation to the Kinect camera proved to require some practice. The experts were shown the Kinect Skeleton Viewer from the Microsoft sample programs and expressed interest in the fact that one could focus on for example just the upper body or separate joints. Further the experts were intrigued by the Kinct's ability to see such detailed skeleton map and stated it could have interesting possibilities. They also stated the skeleton could function as a good indicator of what one is supposed to do in a motion game. One weakness the experts showed was from joints obscured by the body.

The experts inquired about the possibilities to adjust the sensor sensibility stating it would be good to have configurable sensitivity.

The second round was the Maze game starting with the Wii, after some initial Wii connectivity problems the game play was explained. The Wii was taped into a small plastic wheel. One expert unconsciously tried to compensate with moving the upper body instead of twisting the arms which the Wii balance board detected and gave feedback on, there were some trial and error with learning how to control the Wiimote. The expert expressed interest in the choice of different sizes of the controller for different usage and was interested in adjustable speeds and difficulty. The Wiimote showed on of it's weaknesses in the inability to control the distance from the chest to the Wiimote, further the different sizes of the Wiimote demonstrated it could be used to control which muscle groups to activate. The Wiimote taped to a longer object proved to be easier to use than the small plastic wheel, but still rather large twists was needed to rotate the map enough indicating it could be problematic for instance with a stroke patient. The expert said the small wheel required too much of a patient and a large controller would be easier for some patients.

One of the strengths of the Wii proved to be the fact that it can be attached and put in all kinds of devices to make it more appropriate for an exercise.

The Maze was then tested with the Move. The Move controller had less possibilities to be attached to other artifacts since the controller LED ball should be visible for the camera. The first expert did often compensate with the upper body

instead of just twisting the arms. One experts expressed the controllers was much more alike for the Maze game than the River game, that the River game showed much more difference in using the controllers. The experts specifically tested for cheating and found it quite possible. The expert stated the Maze was easier to play and that they targeted different usage scenarios.

Then the experts tested the Kinect and Maze. The expert liked the Kinect's possibilities in controlling compensation and the rules for the position of the hands. The Kinect did work with using an artifact in the hands. One expert stated the Kinect could potentially do many things that required focus and an artifact to hold on could make it easier. The Maze map and ball could perhaps benefit from larger objects. The Kinect did sometimes experience interference with the additional artifact when it had a color close to that of skin or clothing.

After demonstrating the prototypes the experts were asked to discuss the games with the use of card ranking to aid the discussion. The experts were asked to rate the potential of the devices for use in rehabilitation, advantages and disadvantages with the following result:

- The experts felt the Kinect's direct relation with the Kinect skeleton and what you do on the screen had large potential, especially on more advanced motion.
- The Kinect was a little difficult to control in the maze
- The Wii had an edge in the Maze with the balance board and simple control scheme
- The Move could have issues when sitting, where the Wii had an advantage with the balance board
- The Wii board could be better in combination with the Kinect for exercised involving weight transfer with for example CP patients where the patient could barely move to one side. The Kinect could be very good as feedback in that case, but with danger of too many impressions at once.
- Small pictures and information text in a corner or on the screen would be confusing, for instance using the skeleton to show the movements could be too much at once in the River game, but on the other hand the skeleton could prove useful info regarding weight transfer
- The use of the skeleton and a kind of dance game was suggested as a potential game, where the goal is to step on colored areas. This was something especially useful for activating elders

- The experts stated that different patients has different requirements in what they need to do and each device had strengths with different kind of movements. No one device was best on a general basis
- The need for network with the Move was a drawback if a PC was to be used
- The Wii and Kinect were identified as potential good complement to each other, since the Wii had balance board and the Move does not

After the discussion the focus group continued to demonstrate the commercial games.

- UFC Freestrike with Wii: The Wii had problems with control and almost any kind of motion would register as a hit, which the experts stated was too much chaos and too little controlled action and too little specific
- Freestrike with Move: The experts stated the grip on the Move and Wii could be a limiting factor in some cases
- Freestrike with the Kinect: One benefit observed was more freedom of movement since no objects need to be in the hands

A short discussion on the Freestrike with the devices were then conducted with the following points observed:

- The experts felt the Kinect was best in the Freestrike game, but it might have had an advantage since the game involved boxing. One of the issues with the boxing game was the lack of control over the movement need for any action to register as a hit
- The expert stated the Wii's stylized cartoon graphics could be better in motivating the patients since the exaggerated graphics lend itself to fun instead of serious practice, the more realistic styled games could be interpreted as too serious.

Next the focus group tested the Hula hoop on Wii and the Kinect with the following observations:

- With the Wii it looked to be very easy to get lost in the fun aspect and forget the underlying goal. The board was somewhat unstable during weight transfer

- The experts stated the Hula hoop game was a very lightly toned game suitable for kids and elderly
- The expert stated the prototypes was good in focusing on specific movements, but the commercial games were also good in inducing a more general movement pattern and activity, which could be suitable for kids and elderly
- The expert again emphasized the too time consuming setup process with some games. The experts felt the game was focused too much on healthy people wishing much action and excitement instead for controlled movement
- The expert liked the fact that they could see their movements from the visual representation on the screen. The experts felt there was a lack of feedback on when they were doing it correct or not

Regarding the benefits of Kinect vs Wii on the Hula hoop game:

- The experts liked the Kinect's visual representation figure
- The Wii balance board was a little restrictive in movement option
- The Wii had an advantage in this game since it didn't require constant attention
- They also expressed the best option of Wii or Kinect would depend a lot on how injured the patient is

Lastly, the Kinect game Stack'em Up was demonstrated with the following points found:

- The game lent itself much more to slow and controlled balance movements.
- The experts expressed the static movements would have limited use, and that dynamic movements would be more beneficial. The slow speed and lack of movement was too slow to be useful. But there were potential in training attention awareness and reaction with a faster speed
- Some potential for eye-hand coordination exercises and balance but the game should be faster

One interesting observation during the demonstrations was the competitive instinct was present even during such a non-persistent game session, which could show inherent potential for games as motivation with the focus on framing it in being fun. The experts did not like the lengthy calibration and introduction on all the devices, also data such as BMI calculations and calorie consumption would in most cases not appropriate for patients. Also, one issue that manifested itself when playing the commercial games was the focus on very fast and frantic movement instead of controlled actions, showing that commercial games as they are today would not be appropriate for many patients.

6.3.2 Semi structured group interview results

At the end of the session the facilitators put out some more precise questions as described in Chapter 3.4 and the responses can be condensed to the following list with direct quotes where appropriate:

In what way do you think we can counter act compensation:

- It is difficult to counter act cheating since the patients often are very adept at figuring out how to cheat.
- One way could be making the game more difficult or strict.

Can they see any particularly suitable conditions for the technologies:

- Orthopedic conditions were identified as having especially good potential, also in general in a home setting

  Everything that involves motion has potential with these devices, both neurological conditions, muscle and skeleton conditions, the goal is to initialize motion and motion experience, we try to focus on correct movement but it is not always the primary goal and we feel one of the best potential is making it a motivating experience

- One of the main goals was to initialize motion and getting motion experience at the basic level, especially bringing in a fun aspect of training and to focus on the small motions first as a stepping stone to more exercises

  Elderly are often afraid to move, afraid they will break something

- It would be necessary with instructions from the therapist before letting a patient use such a device, that way the risk of erroneous actions would be lower

How do you feel about the different avatar representations of the player, invisible, animated and real photo.

How important is it for the player to see themselves and what they do while they exercise with the technologies:

- For youths and children especially, some sort of fun figure would be good to show the movements on the screen, many don't like to see themselves in real picture since their own view of the can be negative, otherwise it is good to see what you do on the screen, just not too detailed

What do you think we can do to minimize the chance for wrong execution of the exercises with the technology:

- Not so big risk for erroneous exercising since they would not let patients who are vulnerable to injury take such a device home. Responsibility would be on the therapist to consider such cases

Prevention of conditions:

- There were identified a large potential in the prevention of conditions, but games would need to be selected carefully. Also it could act as a good low threshold offer.

The following questions were from the co-facilitator and his thesis but included here for completeness:

What do you feel about the usage PC versus console:

- A big point is to be able to take the device home after clinical training and instruction, there needs to be simple access to the devices and as easy as possible to get started

  You want it to be simple when you exercise

- Storing medical data for progress tracking would need special care due to strict regulations

Considering the prototypes demonstrated, based upon their level of completeness, how would you evaluate them as suitable for for usage:

- There would be a need for flexibility to adjust the game difficulty, like speed, amount of motion to get an action to register

If you were to start a project today on this topic, where would you start with regards to condition, age group and similar, can you see any low hanging fruits:

- It would be good to focus children and elderly, those around 65 now might have a very different relationship to electronic aids then those in their 80s today

On the requirements for the equipment in physical therapy, would you consider any of the consoles better than the others in regards to cost and ease of use:

> The less equipment you need and the easier it is to handle, there more likely is it it will be used

- Can not expect the patients to buy the equipment themselves, some sort of loan scheme would be required. The equipment is cheap relative to much other medical equipment
- The Wii, Move and Kinect were identified as cheap compared to traditional hospital equipment

Considering the space requirements with the devices, can you see any issues:

- Therapists would often need to conduct a home visit to to ensure proper setup and adequate space, depending on the patient condition
- People involved with interventions would often be willing to re-arrange their living rooms to accommodate the equipment

Usage of the motion-sensing devices on PC vs console:

- It should be as easy as possible to get started and long and complex introduction should be avoided

Can you see any potential problems with some conditions and the navigation of menus:

- They would need a choice in control modes, for example not only allow use of the right arm, but in addition the left arm or a hand held controller

Other remarks and comments:

- The possibility to play with others is important, the social aspect needs emphasis and to be able to see your progress
- The need for feedback on your exercises is important, some sort of feedback on how well you perform the exercise would be beneficial
- The simple graphics on the Wii was more inviting with a "fun" expression
- When considering commercial existing games as they are today, they are not quite adequate for patients, there would be a need for large adaptations to the game parameters like speed and difficulty. The more damaged a patient is the larger is the need for adjustable difficulty
- It is important with a easy trial run before game starts and before advancing in difficulty to establish correct base movements
- The experts were happy to be able to test the devices and see their possibilities and expressed enthusiasm over the potential

6.3.3 Questionnaire results

The responses from the questionnaire proved to be a surprise to the author because the expert panel stated they found it very hard to fill out because the individual patient varied so much, and as such it is difficult to generalize what conditions could be aided by a rehabilitation game. They stated it was difficult to say if the Wii was better than the Kinect or Move for a specific condition, that their assessment would be based on what they observed during a clinical session with the patient.

The expert panel filled out the questionnaire where they felt they could generalize, but because of this the questionnaires will be less useful, instead this response at least tells us that a patient with a condition will not automatically be suited for a game based rehabilitation, but instead *might* be suitable after individual evaluation of the condition and how motivated the patient is.

> It is very difficult to to so specific, it depends a a lot on the person, the motivation and preference

The conditions the expert panel did fill out and felt they could generalize to some extent are listed in Table 6.3

Condition	**Wii**	**Kinect**	**Move**
Mainly youth, back injury and similar	4, 4	4, 4	4
Cerebral Palsey			
Balance	5, 5	3	3
Increase general physical function	3	3	3
Mainly elderly			
Balance, reduce change of falling	4, 5, 5	3, 3	3, 3
Increase chance to survive stroke	1, 1	1, 1	1, 1
Increase mental function and behavior with dementia patients	5, 4	5	5
Reduce depression and increase physical function	4		
Reduce pain and morning stiffness (arthritis)	5	5	5
Increase strength and motion	4	4	4

Table 6.3: Questionnaire results

As we can see the answers seem to cluster around the same conditions, no other condition on the questionnaire were selected. This might indicate some particular area where games and motion-sensing devices can be of use, but the comments from the expert panel during the fill out clearly suggested that it depended on the patient. The expert panel further stated that on a very general basis they felt all the devices might have the potential to aid in almost all exercises, but each device had different strengths in different conditions, motivation and joy could be a beneficial side effect.

Chapter 7

Discussion

This chapter discusses the findings as described in Chapter 5 and 6 and puts the findings in light of the research questions defined in Chapter 1.

7.1 The prototypes and RQ1

In the introduction we asked the question:

> What are the most important qualities of motion-sensing game technologies for the implementation of serious games for physical rehabilitation and how do the most popular game platforms compare concerning these qualities?

When we ask a research question and do work to explore it, it is also important to define the success parameters, we need a way to measure and determine how to answer the question. One often used technique is to define objective parameters like amount of faults per time unit, accuracy within an error over an amount of time and so on. However one central aspect in this thesis is the perceived quality of the controller input, how well can we do the defined motion and actions with the device? With this in mind we set out to determine how well the motion-sensing devices can be used in an application for physical rehabilitation, that measure of ability goes beyond the raw accuracy or amount of faults, it involves the subjective feel dimension; how well does the device manage to reconstruct the exercise in the virtual space from a user centered point of view? How well does the device manage to implement the needs as they are physical rehabilitation? The focus is on the perspective of the future user and what they will have to interface with.

On this basis a table is constructed (Table 7.1) with a series of factors with a rating on how well the author consider the device to perform in relation to the tasks we have defined under the restriction of the prototype. We can not test and evaluate every potential situation so we have to limit our self to the scope of this thesis which is a small part of physical rehabilitation, furthermore the prototype might not allow for the device to fully express it's capabilities but we need to keep it within the constraints of the prototype to manage the complexities. The factors used to evaluate the motion-sensing devices are on this basis evaluated as objectively as can reasonable be expected, but nevertheless the weights will have a substantial subjective aspect, not only due to the interpretive background of this thesis, but also to the fact that the weighting ultimately is based on the subjective opinion of the author and his experience. The sum of these considerations specified below constitutes how well the device are feasible for the specified usage from a technical viewpoint.

The factors are described as follows:

- Accuracy: How accurate does the device feel when it is used? How easy is it to hit the intended target?
- Delay: How responsive does the device feel when performing the defined actions?
- Sensitivity: How much movement does it take to produce a specific movement on the screen and how much error is there in that movement?
- Error & drift: How many errors occur under the defined usage? How much does the device drift?
- Connectiveness: How easy is it to connect and maintain the connection during the defined use?
- Documentation: How well is the device hardware and software documented and commented?
- Ease of programming: How easy is it to convert and manage the raw input data to usable data for the defined use?
- Overall motion sensing quality: How easy is it to perform the movement as defined with the device?
- Overall motion sensing quality for compensation: To what degree does the device offer sensor data to counter act compensation?

Quality\Device	Wii (included balance board)	Kinect	Move
Accuracy	X	XX	XXX
Delay	XX	X	XX
Sensitivity	XX	XX	XXX
Drift	X	XX	XXX
Connectiveness	X	XXX	X
Documentation	X	XXX	X
Easy of programming	X	XXX	X
Overall motion sensing quality	XX	XXX	XX
Overall motion sensing quality for compensation	X	XXX	X

Table 7.1: Motion-sensing devices strengths from a technical standpoint

7.1.1 Justification for the quality factors

The following points demonstrates how the author has evaluated the perceived sensor quality when with the prototype as implemented. The number of X's in the table can be translated into on a scale from 1 to 3, where 1 is little or weak strength, 2 is some or medium strength and 3 is significant or high degree of strength in the perceived quality of the factor. It is important to remember that these quality attributes are in relation to the prototyped games and their implementation with the motion technologies and the prototypes ability to capture and make use of the input provided by the hardware, through the libraries and on to the avatars and game play.

Accuracy

The Wii suffers from lack of corrective sensor since the accelerometer drifts after short amount of time, because of this the accuracy of the Wiimote is very poor and can only be used to detect changes in acceleration, the infrared sensor could be used to alleviate this problem, the weight board however is quite accurate.

Kinect have decent accuracy but can have problems with small movements, the Move is the most accurate thanks to it's magnetometers and is very accurate even at tiny movements.

Delay

The delay of the Wiimote is decent and the delay on the weight board is good, however due to the presence of only accelerometers some of that accuracy might be difficult to capture and might require repeated movements.

Kinect suffers from some delay, possibly due to the complexity of image segmentation the Kinect has to perform, this can present issues known as "lag" where the movement of the user is around half a second slower than the actual movement. The Move has excellent responsiveness despite having to go through the network stack.

Sensitivity

The Wiimote again suffers from the lack of corrective measure, the accelerometers are very sensitive, but that sensitivity does not let itself be transferred into the application, the balance board is good. Kinect has decent sensitivity to user movements but require larger movements and can miss small actions. The Move again has excellent sensitivity and the smallest of action register in the application.

Drift

The drift and error on the Wiimote is quite significant, this can be somewhat mitigated with complex algorithms, the weight board is good in regards to error and drift. The Kinect manifest some error but low drift, the constant adjustment of the Kinect device works well, however it is vulnerable to disturbances in the frame of view from the camera and sitting positions can produce significant artifacts. The Move have very low error and drift.

Connectiveness

The Wiimote and balance board is difficult to connect and to have to stay connected, it often loses the connection due to inexplicable conditions. The Kinect is excellent with it's USB connection. The Move works decent through the network stack but sometimes suffer from network latency.

Documentation

Both the Wii and Move have weak documentation and little to none code comments. Kinect have excellent documentation through it's Microsoft Developer

Network and documentation following the installation of the SDK.

Ease of programming

It was difficult to implement some of the movements with the Wiimote due to the lack of absolute positioning, but the balance board was decent, effective use of the Wiimote in the Maze game to mitigate drift required complex algorithms. The Kinect has some excellent abstractions like the skeleton tracking which greatly simplifies the realization of the movements and offers further data streams for additional use. The Move was somewhat difficult to use in realizing the movements since it work on a packet level, however the reference implementation worked well and the absolute positioning was decent to program with, it does however have quite complex code.

Overall motion sensing quality

The overall motion sensing quality can bee seen as the other quality factors evaluated together with focus on the Accuracy, Delay, Sensitivity, Drift and Connectiveness.

The Wiimote was not very good in the River game due to the lack of positioning, the balance board worked well for registering shifts in weight distributions, the movements in the Maze game worked better since it is based in changes in angle which the accelerometers works well with. The Kinect was very good in performing the actions both in the River game and the Maze game, the Move was almost as good as the Kinect, but requires 3 controllers in the River game which detracts from the experience.

One particularly interesting finding can be observed from the Kinect's three crosses in this category, despite the noticeable delay from the action to the effect can be seen in the game, the other strong quality factors with the Kinect makes it able to compensate and mitigate this delay in a good manner, so the synergistic effect from some factors can compensate for other weaker areas.

Overall motion sensing quality for compensation

The Wiimote offers little to counteract compensation but the balance board works well to control shifts of the center of gravity. The Move offers some ability to counter compensation with it's depth sensor in the Maze game but offered little for the River game. Kinect has some good opportunities to counteract compensation

since it can check the actual movements and placement of each joint; where they are against where they should be for both the River and Maze.

7.1.2 Additional factors

There are several others factors not illustrated by the table, but which could be significant for the use in physical rehabilitation and the prototype games, for example what extensions and add-ons exist for the console, the Wii offers a multitude of additional peripherals, like a heart monitor, weight add-ons, racing wheel, some are illustrated in Figure 7.1[1].

[1] Picture from ambritgames.com

Figure 7.1: Wii accessories

The Kinect is unique in which it does not require the user to hold anything, but in some cases it could be difficult for a patient *not* to hold any kind of representation of a device. The Kinect also has some unique sensing abilities used in computer vision applications, as demonstrated in [8]. Both the Wii and Kinect can work on a PC whereas the PlayStation Move requires the PlayStation 3 to function, however there are some sporadic blogs and fan-based libraries who claim to connect the Move to a PC directly such as a Summer of Code project on Google [7].

Another factor is the development environment and there are some significant differences between he device platforms, for instance the Wii developer kit is not available to non-commercial entities and is reported to be expensive [56], the Kinect on the other hand is freely available for anyone interested in working with the Kinect through official developer kits from Microsoft with thorough documentation and examples, Microsoft looks to have put effort into refining the Kinect for multitude of uses, for example when the prototype was created a beta version of the SDK had to be used, at the time of writing they had already released version 1.5 with enhanced performance and quality, in addition to support for sitting position which would be a significant advantage for the Kinect. Nintendo and Sony have not demonstrated such commitment to the Wii and Move software packages, the libraries used for the Wiimote are at the time of writing still based upon "hacks" and reverse engineered software and the Move has not gotten any refinements to the original limited documentation.

All of the mentioned abilities here are not *directly* factored in in the evaluation of the devices, but nevertheless can be a important consideration especially for future work.

7.2 The focus group and RQ2

The technical feasibility is one thing, but how does actual physiotherapist evaluate the motion-sensing devices? Do they emphasize the accuracy and sensitivity of the device; or is it enough that the device can replicate the broad strokes of what the patient is supposed to do? In this part we expanded the area of focus from just the controllers and their qualities to include other factors such as the graphics and the consoles as a whole. To find out how real experts evaluate the motion-sensing devices we conducted the focus group on the basis of Research Question 2:

> How do physiotherapists evaluate the suitability of these technologies for physical rehabilitation?

This part was important to get a better understanding of the usage and context as viewed by experts from the field. The experts stated on multiple occasions

that they liked the technology and felt it has potential. During the focus group session the experts were asked to compare the technologies based on what they had experienced so far in the session, the results however showed to be a mixed bag. Some of the central findings are the following:

According to the experts, current commercial games are more suitable for typical healthy individuals, they focus on fun, speed and challenges for the player. These games are too fast and frantic for a patient and lacks the appropriate pedagogical features. The experts stated because of this further work was needed to make specialized games for particular patient groups and conditions.

One of the recurring findings over the session was the experts found it difficult to generalize what games and controllers would be most suitable to what conditions, they stated that each condition and the patients degree of injury along with the motivation and age, would dictate what controller and what game would be most suitable. The questionnaire effort clearly illuminated this difficulty in grouping conditions and controller and the expert were not able to say which technology was best on a general basis. However the Wii and Kinect did appear to gather more positive feedback than the Move, this could be biased by the fact some of the participants had some experience with the Wii and people in general like to stick to what they know. One impression gathered from the experts was the the Wii could do almost everything the Move could do but the Move could not do everything the Wii could, when we consider the balance board and the Wiimote together, this observation is however based on the prototype games which had a limited set of actions. Further the experts expressed enthusiasm over the Kinect's sensing abilities and felt the Kinect could have much potential.

The experts liked the Wii's simplistic art style, it has a very specific kind of graphical style where the art is very cartoon-like with exaggerated body parts and a low polygon count, this has benefits like reducing the processing power needed for the graphics and it shifts the focus over to a more fun state of mind than the more realistic graphics style seen in some Kinect and Move games. Different demographics might have different sensitivity to the graphical style, from the experts opinions the simple graphics might be especially beneficial for young children and elderly, it is unclear how teenagers or young adults would respond to the Wii-like graphics style, maybe specially so because many young adults today are exposed to games with almost photo realistic graphics like for example Crysis and Battlefield. The prototypes were constructed to mimic the Wii type of graphics, some added benefit from this was the faster time to construct them and the relatively small requirement in processing power, the experts seemed to appreciate that aspect.

The experts did emphasize the importance of making a game for rehabilitation easy to install and easy to get started with exercises. The setup used in the focus group with devices connected to a PC would be too extensive for a home setting according to the experts and packing a game into a console would be needed. However the experts did express some interest in combining motion sensors like the Kinect's excellent camera possibilities with the Wii's balance board or similar in a clinical setting where the therapists would manage the setup. A potential use for this could be an enhanced form of calibration and training with the therapist using a PC setup with multiple sensors in the clinic, and the patient continuing the training with the simpler game representation at home with just a console, but still getting the benefits from extended training and calibration.

The mentioned points could lead one to think the Wii or Kinect would be better for use in physical therapy, however further study on movement patterns for a larger more specific set of conditions would be required, as emphasized by the expert's difficulty in generalizing. There appears to be a small discrepancy in what the author expected to be significant and what the experts expressed as the most significant aspects of the motion-sensing technologies. The author emphasized the correct performing of exercises, mitigating compensation, the accuracy of the movement patterns compared to some ideal, whereas the experts stated some of the most significant gains in the use of this technology would be the act of initializing patients, making exercise fun, possibilities to socialize, giving feedback on the exercises and similar. The experts were less concerned with the games forcing the patient to do the right movement and to counter act compensation, since the experts would themselves instruct and determine which and when patients would benefit from motion games.

On the basis of this the following points can be constructed as a more direct answer to RQ2 placed into suggested categories and perspectives the finding concerns[2]:

- Input: The experts consider all the three technologies as having great potential in physical rehabilitation
- Input: The experts viewed the Kinect as having most interesting possibilities and the as Wii more suitable in some areas
- Input: There seems to be particular suitability in orthopedic conditions, prevention of injury and as motivator for children an activator for elderly
- Input: More appropriate games would be needed, where they target specific conditions

[2]"input" means in relation to the input from the motion-sensing devices for rehabilitation

- Flexible: Such games would require substantial ability to adjust the difficulty, speed and sensor parameters to account for each patients degree of injury
- Usability: The possibility to give instant feedback is important, both as instruction and as correction
- Usability: Rehabilitation game setup for home use would need to be focused on easy installation and fast start up of the games
- Social: The social aspect would be important, where family, friends or co-patients could participate
- Motivation: A goal from the experts point of view would be to make the exercise fun and act as an motivator and initialize for exercise
- Motivation: Simple art style like the Wii uses can act as a motivator and make the games more approachable for some patients
- Motivation: The technologies could be an extension to clinical exercise where the patient takes the game to the home setting

7.3 RQ1 in light of RQ2

Chapter 7.1 and 7.2 offer some interesting perspectives on the technologies. The technical suitability investigated in Chapter 7.1 and the experts opinion in Chapter 7.2 illuminate the different possibilities for the use of these technologies in physical rehabilitation. If one takes the results from Chapter 7.2 into consideration then the Kinect does indeed offer some great potential when looking at the technical possibilities, the development challenges and the experts views on the devices. The Wii does not offer as much from a technical standpoint as the Kinect but it has the benefit of additional accessories like the balance board and sometimes tactile feedback from the controller can be more suitable than just using your hands and body. The Move has very good sensors but suffers from falling between the cracks of Wii and the Kinect when taking the experts feedback into account.

The experts also gave some interesting viewpoints on the use of a PC or the consoles, the PC gives more flexibility and possibilities for combining motion sensors, but the PC setup would not be suitable for a home setting so we would have to choose among the consoles. Different patients might use different consoles based on their respective strengths, for example Xbox with Kinect for conditions that require the whole body or the Wii with the Wiimote and balance board for hand

and coordination conditions, this would however add more development cost since more than one platform would need to be maintained.

During the development of the prototypes the author noticed that to integrate the simultaneous use of different input modalities, also known as sensor fusion, there could be a benefit to design for that with the proper abstractions and interfaces, such as using mediators, interfaces, shared models and so on. With such a design one could potentially modularize the code for the input devices which would make it easier to switch between input modes when using a PC setup. The Wii, Kinect and Move as used in this thesis did this by translating each device specific input into a more generic set of state representations, these intermediary representations were then translated to a more generic global representation of the player movements. This also made it easier to compartmentalize the code for each input device, in theory it could be extended to any kind of input device or same-time integration of the inputs.

There are other important factors however which the experts do not consider and that is the development environment for each of the technologies. Since the experts stated several games or modules within a game would be needed for the specific conditions, this would put a larger requirement on the development effort. The Kinect does have the benefit of much public interest as illustrated in Chapter 2 with it's openness towards development. The Wii has a much more closed platform but it was the first one out with this kind of technology and it has been publicized the most of the three devices. The Move also has a somewhat limited openness in it's platform as shown by the need to use the controllers over the network and via the PlayStation 3. These factors were particularly evident as the author did not have access to the professional tools from the companies behind the platforms which commercial entities would probably have.

In the evaluation of the technical feasibility of each device in RQ1 we had to base that evaluation on just the prototypes produced, the focus group session shows that if different games and movements are needed for different conditions then the strengths of each device would probably turn out differently and would suggest need for further research.

7.4 Design guidelines, RQ3

The following section attempts to extract some guidelines, or heuristic, on the development of games which use motion-sensing devices for use in rehabilitation, based upon the findings in Chapter 7.1 and 7.2. There is a need for further study on this topic so the guidelines should be viewed as an opinion based on a relatively small amount of data. In Research Question 3 we asked:

> What design guidelines can be inferred for the use of these technologies for application in physical rehabilitation?

It is a reasonable assumption that the expert panel knows physical rehabilitation and how it works in real life, because of this the expert feedback should act as a guiding thread and some considerations are also added from the technical findings in relation to Research Question 1. On the basis of this the author suggests the following guidelines:

1. Consider different motion-sensing technologies
2. Focus on the basic movements first
3. Give feedback
4. Minimize noise
5. Make it easy to get started in the home
6. Track progress
7. Fun and motivation
8. Social enablement
9. Adjustable difficulty and speed
10. Encourage the player to avoid compensation

Some of these points resonate well with the heuristics from Preece for design of user interfaces, such as the minimizing of noise and giving feedback and with Young's thesis. The more general usability considerations would of course be important such as affordance, mental mapping, continuity, space-time multiplexing and so on but those are not directly considered here. The rationale for each point is listed in the following section.

Consider different motion-sensing technologies

In the discussion of how the physiotherapists evaluate the suitability of motion sensing technologies for physical rehabilitation in Research Question 2, one of the central findings with the expert panel was the fact that they could not generalize which motion-sensing device would be best for a patient with a specific condition, the individual degree of injury to each patient would to a large degree dictate their

suitability for rehabilitation games and what device would be most appropriate, the most basic movements would be challenging to the most injured patients. The devices have different requirements and physical affinities to interpret the input as discussed under Research Question 1 and considerations should be made about which specific conditions to target and what degrees of injury it is suitable for with the relevant device.

Focus on the basic movements first

The experts panel stated it was important for the patient to get comfortable with the use of the device and to learn how to do it the right way. Because of this is would be important to have slow and controlled introduction exercises before advancing to more advanced exercises

Give feedback

The expert panel stressed the importance of giving the users feedback on what they are supposed to do and how well they are doing it. The experts emphasized the important of some sort of visual representation of the player, but not so detailed as a picture since many patients do not like to see their realistic dimensions on the screen. The feedback should be compact and sufficient, but otherwise there should be minimal distracting elements.

Minimize noise

Too much feedback can quickly turn into noise, the experts felt the commercial games provide too much “fun” elements but those elements would often turn into noise for patients playing a serious game. Some patients are elderly or have reduced state of mind which would lower the threshold for what is considered noise. Another point is the player should have control over what is happening on the screen, random events should be minimized and an reaction should be as a response to an action.

Make it easy to get started in the home

Rehabilitation games should be quick and easy to get started with the least amount of navigation hurdles according to the experts, the patients motivation and eager

can be diminished if they have difficulties in getting started with the exercise, this is especially the case in the home setting without the support of a therapist. The commercial games tested often had lengthy introduction calibration sessions to setup things like height, weight, BMI and so on. The experts stated those calibrations should be kept minimal but still gather the needed base data, or the base data could be entered by the physiotherapist instead of the patient performing them.

Track progress

The experts said tracking of progress could be important both as a monitoring tool to track the progress of the player, but also as a motivating tool to show the progress the player has made. Care must be taken as not to discourage the player from lack of progress but instead focus on motivation and encouragement to play more.

Fun and motivation

The experts stressed the fun-factor as important, a fun game increases the level of presence and is important to make it an enjoyable experience overall to increase the chance of the patient continuing the training regimen, particularly at home away from the pressure and encouragement from the therapist. People have different ideas of what fun is, but it is important to consider the target group and to try and determine what their idea of fun generally is.

Social enablement

The experts said the social aspect of games for rehabilitation is an important factor, the ability to bring the social aspect into the training session can increase the motivation and be synergistic with the fun-factor. Some forms of this could be to enable multiplayer by several patients or turn taking, for example with assistance from friends and family.

Adjustable difficulty and speed

The difficulty was found to be very important by the experts, the range of injury from patient to patient vary wildly, some can hardly move the relevant body parts

while others are almost healthy. There are many factors to what determines difficulty such as the complexity of events and goals, the threshold levels for movements to register as actions, but the speed is one if the easier to vary and as such the speed and other difficulty related factors must be adjustable. The threshold levels for actions is also an important parameter since the possible movement for each patient is highly individual. The difficulty must also be able to account for player progress and should be raised when appropriate to giver the proper challenge.

Encourage the player to avoid compensation

The experts stated that patients are very adept in compensating in exercises, it could be difficult to counter act compensation with some devices while others have potential to mitigate against it. Some compensation moves can be hard for patients to train away so instead of giving negative feedback when it occurs one should consider a more positive feedback when it is detected to encourage the patient to not compensate, it would be non-constructive to have patients give up because of lack of progress due to anti-compensation mechanics.

7.4.1 RQ3 and current literature

The current literature on comparing the Wii, Kinect and Move is for use in physical rehabilitation is somewhat limited. Much of the publications are technical in nature and targeting specific features of the devices. The Wii has the most publications since it was the first device offering commercial level motion-sensing equipment, the Kinect and Move do have some research using them but most are technical focused. The Kinect however have shown a great sense of research enthusiasm as described in Chapter 2. One particularly interesting one is [16] detailing the University of Minnesota's Institute of Child Development have been using several Kinect's connected together to detect early signs of autism in children, this echoes the expert panels enthusiastic view over the Kinect sensing possibilities and the sensors capabilities to track very subtle changes and would be fitting to observe small basic movements like in a patient with high degree of injury only capable of small movements (Point 1)

[55] investigated the use of Kinect in rehabilitating teenagers with motor impairments such as Cerebral Palsey, they had a small sample size of two but did find the intervention with Kinect to bee better than the baseline and increased the amount of correct movements using the Kolmogorov–Smirnov test. One of the significant findings was the of reduced workload on the physiotherapist since the patient would need less direct instruction from the therapist after being trained with the

Kinect, and, the exercise would become a more enjoyable experience increasing the effectiveness of the exercise and could foster social interaction. This finding echoes the importance of the fun and social aspect (Point 7 and 8) and to some extent Point 5 (easy to get started), since those factors would be a important for patients acceptance and could lead to required additional therapist intervention. [22] also find the Wii to be feasible in a school setting for children with Cerebral Palsey and showed improvements in postural control, visual-perceptual processing and and functional mobility and found social benefits (Point 8) and "unexpected therapeutic benefits" in the form of "turn taking, strategy sharing, and encouragement."

[2] uses the term "exergames" for games that combine physical activity with digital gaming. The article suggests these exergames have some unique capabilities in relation to traditional monitors like hearth monitors, indirect calorimetry and similar, in that the exergames can provide less imposing measuring. In addition the exergames can measure additional factors such as game challenges, player movements and performance in a more unobtrusive way. The article even suggest the use of exergames can provide a better external validity for research due to the reduced burden on the subject compared to traditional measuring equipment. These findings relate well to the importance of minimizing noise (Point 4) and tracking progress (Point 6)

[17] reports that the use of Wii in rehabilitation has had great success, especially in increasing patients motivation and encouraging full body movement. The article further states the current commercial games are too difficult for patients and they mainly target upper body gross motor functions, lacking support for customizing tasks, grading and quantitative measurements, these findings resonate with the importance of tracking progress (Point 6), considerations of different motion-sensing technologies (Point 1), focus on the basic movements first (Point 2) and adjustable difficulty (Point 9).

[10] used the PlayStation Move camera in rehabilitation of older adults with disabilities and compared that to healthy adults and the use of the GestureTek's IREX VR system in terms of sense of presence, level of enjoyment, control, success, and perceived exertion. The article found the sense of presence to be the same with the PlayStation as the professional grade IREX and the level of enjoyment to be high, which could act as a motivator for the patient and influence performance, this shows the importance of feedback (Point 3) and the fun factor (Point 7). Further, [10] found the PlayStation camera to be sensitive to differences in the performance of younger vs older adults and between people with or without disabilities, which it describes as necessary to be useful in a clinical setting, this illuminates to some degree the importance of considering different motion technologies (Point 1). The article also states one of the problems they found with the PlayStation camera was

inability to adjust the difficulty and the therapist had to compensate to make the exercise easier, in addition the article states the lack of recording of performance to be a limiting factor. These findings resonate well with points 1 (consider different motion technologies), 5 (easy to get started), 6 (track progress) and to some degree illuminates Point 10 (compensation), further [10] found the fun and social aspect to be important (Point 7 and 8).

[19] tested the Wii on patients in the chronic phase post-stroke using Gait speed, walking endurance, balance (Dynamic Gait Index), balance confidence (Activity Balance Confidence Questionnaire) and dual task mobility (Timed-up and Go). The article states the percentage increases was overall greater in the Wii based program, but retention of improvements was lower with the Wii than the traditional program and suggest further study on the efficacy on retention of gains, this also stresses the importance of point 6 to properly track the progress to get more information on what is working and what is not.

[4] investigates the use of Wii and Move for enhancing rehabilitation of spinal cord injuries, stroke and brain injury. Among the findings were the need for more practice or tutorial sessions (Point 2), need for an easy navigational menu (Point 5). Additionally the article states feedback is important (Point 3) and the games should be "easy to learn, yet hard to master" stressing the importance of adjustable difficulty and speed (Point 9), further the article touches upon the aspect of performing the exercises correctly (Point 10 Compensation), where patients were easily able to play the games without performing the correct and required movements.

[47] investigates the use of infrared markers and an infrared sensitive camera like the Move and Kinect uses and suggest the Move and Kinect for rehabilitation use, in this cases for use with Parkinson's Disease. The article stresses the importance of the integration of clinical techniques, principles of neuroscience and multimedia technology to form an approach to maximize the therapeutic outcome. Further the article states the current lack of games designed for rehabilitation and they do not target specific symptoms or conditions (Point 1 considering different motion technologies), the lack of requirements to fulfill the movement (Point 10 compensation), can frustrate injured patients (Point 9 adjustable difficulty) and lack of tracking of progress (Point 6), and, the potential of visual cues (Point 3 feedback).

When we look at the amount of literature available for the various points, we see that the amount of literature on point 10 (compensation) is limited, this indicates that the impact and importance of compensation in relation to motion-sensing games in physical rehabilitation needs more research. Additionally the literature covering Point 1 (consider different motion-sensing technologies) is also somewhat limited and generally not very focused on the importance of degree of injury

and appropriate motion-sensing devices, most literature focus on one or maybe two devices this also indicates more study is needed.

7.5 Reflection on methods and process

7.5.1 Theory

The research methods applied in this thesis are qualitative methods, with the interpretive approach as underlying epistemology. As Zimmerman [57] and Oates [35] describes the interpretive approach is often used in social sciences due to the focus on understanding the humans involved and their context. This means that the researcher must analyze and interpret the findings which give less objectivity than other methods based upon for example the positivist epistemology. Objectivity is difficult to maintain in interpretive research since the researcher will affect not just the premise and bounds of the research, but also the act of observing, interviewing, and being present, which is clearly shown in the Hawthorne effect [20].

Oates further states the following on traditional quality metrics in relation to the interpretive approach:

- Objectivity: There will always be bias, no observations can be made independently of how the researcher choose to conceptualize them on the basis of prior theory or previous experiences
- Reliability: The thing being studied is a social construction by individuals, short lived an changing, so the same situation is unlikely to obtain the same results
- Internal validity: No single objective reality exists, but multiple constructed realities. There is no ultimate benchmark to test the findings
- External Validity: The interpretivist accepts the uniqueness of contexts, individuals and their constructions, making identical findings in other context are less likely

Oates continues to argue the need for different criteria in evaluating the quality of interpretivist research and states the research community has yet to arrive on an agreed set of criteria, Oates does suggest the following factors as a response to the typical evaluation factors used in positivist research:

- Trustworthiness: instead of validity, we ask how much trust we can place in the research
- Confirmability: have the research presented enough about the study to judge whether the findings flow from the data and the experiences in the setting
- Dependability: how well is the research process recorder and data documented
- Credibility: was the inquiry carrier out in a way that ensured the subject of the inquiry was accurately identified and described so that the research findings are credible. This can be achieved with triangulation, prolonged engagement in the problem situation
- Transferability: Can the findings in one case be transferred to another. Each situation is still unique, but can that example exemplify a broader class of things so that we can generalize. Thick descriptions is important in this point so the reader can judge whether their own situation of interest has similar features

This lack of community agreement on evaluating interpretivist research also show itself in Zimmerman's criteria for evaluating Research Through Design, which is an interpretive and qualitative approach:

- Process: As with anthropological research contributions, one can not expect to reproduce the same result when reproducing the process. Instead one examines the rigor and rationale applied to the methods used. The process must be reproducible from the documentation.
- Invention: The research contribution must constitute a significant invention. It must be demonstrated that the research has produced a novel integration of various subject matters to address a specific situation
- Relevance: Instead of validity as benchmark, interaction design research use relevance. Framing the work in the real world and articulate the preferred state the design attempts to achieve and why that state is preferable
- Extensibility: Ability to build upon the resulting outcome, the research needs to be documented in a way the community can leverage the knowledge derived from the work

Lastly, [41]presents some arguments for Research Through Design as a valid research approach, the article suggest that Grounded Theory with a postmodern approach can be the methodology for putting together all the data in the quest of Design researchers for construction new knowledge.

7.5.2 Reflection

It is always difficulty for the researcher to navigate a field where he is not an expert in, this means the content selected may not be the entire possibility space for the problem in question. The focus group mitigates this problem by asking experts, this did reveal gaps in the researchers knowledge and assumptions of the field as demonstrated with the Questionnaire. Despite the lack of community agreement on the evaluation criteria for interpretive research, we shall use Oates' traditional terms and look at with Klein & Meyers Klein [23] seven principles for interpretive research in mind.

Validity Oates states; "No single objective reality exists, but multiple constructed realities" and calls for "trustworthiness" additionally, in light if Klein & Meyers we have to think critically about the interaction between the researcher and the expert panel. Especially Klein & Meyers Principe 3, 5, 7 are relevant for the validity:

- The Principle of Interaction Between the Researchers and the Subjects Requires critical reflection on how the research materials (or "data") were socially constructed through the interaction between the researchers and participants.
- The Principle of Dialogical Reasoning Requires sensitivity to possible contradictions between the theoretical preconceptions guiding the research design and actual findings ("the story which the data tell") with subsequent cycles of revision.
- The Principle of Suspicion Requires sensitivity to possible "biases" and systematic "distortions" in the narratives collected from the participants.

The focus group was an artificial session with small sample size and some findings might be particular to that social constructed setting, the participants had some different prior knowledge with motion-sensing technologies and this affects the internal validity and is described by Klein & Meyers principle 7. Further the social interaction between the participants and the researcher highlighted in Klein & Meyers principle 3, was mitigated by participants of equal comparable social status, professional knowledge and experience and the fact that the participants were comfortable with each other.

Oats uses the term "credibility" instead of internal validity and it concerns whether the study was carried out such that the subject was accurately and identified and

described and suggests prolonged engagements in the field, triangulation, respondent checking the previous findings. Since this study is limited in scope and time, this has an impact on the credibility. Ideally there should be more than one focus group to refine the credibility in the research and this thesis could have benefited from more triangulation of the findings, like conducting more focus groups, observations with real patients, conducted field studies and similar, but the scope of this thesis had to be limited in size and time, to mitigate this we apply Klein & Meyers principle 3, 5 and 7 in addition to critically evaluate the findings.

The questionnaire is a particular example and shows a collision between Klein & Meyers principle 5 and the internal validity of that data gathering method, which led to the questionnaire not being used with any weight other than suggestive and as basis for investigation into *why* it was so difficult to generalize. Oates [35] uses the notion of content validity, construct validity and reliability when evaluating questionnaires, the content validity as understood by the author was perceived as a balanced sample of the domain but the level of abstraction was found to be difficult to reconcile with the experts view on the area in question, the construct validity, whether or not we are measuring what we think we are measuring, and the reliability will because of this be less than satisfactory. The guiding questions used in the group interview are subject to Klein & Meyers principle 5, but their open nature did minimize the amount of preconceptions and facilitated for the subjects true opinions and experiences.

Based upon the preceding, the author would argue for good degree of trustworthiness and reasonable credibility since the work has been thoroughly documented, external experts and critical peers have been involved in the study and the process and findings have been reflected upon.

Objectivity It is important to consider the researchers impact on the research and the consequences that can have for the findings, Oates claims that for interpretive research "There will always be bias, no observations can be made independently" and argues for confirmability instead. Confirmability according to Oates is about telling enough about the study to let a research auditor look at and analyze the raw data such that he can set himself in the shoes if the original researcher. Further, in light of Klein & Meyer we should take into account especially principles 2 and 5:

- The Principle of Contextualization Requires critical reflection of the social and historical background of the research setting, so that the intended audience can see how the current situation under investigation emerged

- The Principle of Dialogical Reasoning Requires sensitivity to possible contradictions between the theoretical preconceptions guiding the research design and actual findings ("the story which the data tell") with subsequent cycles of revision.

When we apply these principles to the prototypes and focus group we can see that:

- Construction of the prototype is based upon the researchers understanding and impression of previous research. This in turn will to some degree affect what the expert panel sees in the focus group
- The evaluation of the prototype quality factors has significant degree of subjectivity
- The researchers prior knowledge will impact the objectivity of the prototype, the devices and the contents of the focus group
- The researcher has been an observer, facilitator and interviewer
- The focus group contents is planned and formulated based upon what the researcher selects based upon the understanding at the time
- The questions for the open interview is prepared and formulated based upon the researchers understanding and knowledge of the domain of physical rehabilitation, which is not the area of expertise of the researcher
- The questionnaire contents and selection of answers were constructed by the researcher

The author argues for decent degree of confirmability, from what one can expect from interpretive research since extensive records have been presented about the the study and how it as used to arrive at the conclusions, with the presence of inherent bias as presented by Oates, but mitigated with the principles of Klein & Meyers.

Reliability As Oates states the reliability for interpretive research is a social construct, short lived and changing, unlikely to give the same results again, we can not expect another focus group to reach the same findings as the one conducted here, but the general themes and abstractions could point to the same things, which could indicate reliable work. Additionally, Oats calls for "dependability" as measure instead of the traditional reliability, stating that we have to document the process, leave an audit trail to enable others to trace the process. The author has in

previous chapters presented extensive documentation over the process and methods used with the results found, this should give reasonable level of dependability on the work.

Transferability Instead of external validity Oates uses transferability, an interpretivist research situation is often more or less unique, nevertheless findings can be often be generalized and themes can be established. Oates suggests using "thick (detailed) descriptions" such that the reader can determine if the findings is relevant to their own situation, interpretivist research is less strict about the need to make generalizations than positivism.

Chapter 8

Conclusion

This chapter presents some concluding remarks to this thesis and presents some suggestions for further research.

8.1 Conclusion

The motion-sensing devices shown in this thesis presents some interesting opportunities for use in physical rehabilitation. This thesis has investigated two perspectives on the feasibility of the Wii, Kinect and Move for physical rehabilitation and based upon the findings postulated a set of design guidelines for making such games more feasible and appropriate.

Research Question 1 The research presented has used several different ways to obtain the data foundation, the technical evaluation for Research Question 1 was based upon literary study and the construction of a prototype, in answering Research Question 1 we present some findings based upon the prototype as specified by the requirements . The technical feasibility of the Wii, Kinect and Move vary for different usage scenarios and each device has it's strengths and weaknesses as we can see in Figure 8.1. The Wii is relatively cheap and is used in many publications, but the sensors offer limited precision and accuracy.

Quality\Device	Wii (included balance board)	Kinect	Move
Accuracy	X	XX	XXX
Delay	XX	X	XX
Sensitivity	XX	XX	XXX
Drift	X	XX	XXX
Connectiveness	X	XXX	X
Documentation	X	XXX	X
Easy of programming	X	XXX	X
Overall motion sensing quality	XX	XXX	XX
Overall motion sensing quality for compensation	X	XXX	X

Table 8.1: Motion-sensing devices strengths from a technical standpoint

The Wii platform is also restrictive in what games can officially be put on it. The Kinect seems to offer the greatest potential with it's sensor capabilities rivaling that of motion capture and Microsoft seem to have embraced this culture of non-traditional experimentation, Microsoft offers many tools and documentation for the use of the Kinect not only on the Xbox but also on the PC. The Move have very accurate and responsive sensor but the closed system forces developers to use complex software to utilize and develop for it, this factor might not be as present when a game is actually deployed to a PlayStation 3.

Research Question 2 To answer Research Question 2 we performed a focus group with a panel of experts to get insight into their context and understanding as physiotherapists. No patients was included in this study and only one focus group was conducted and as such the findings should be viewed as suggestions and potential basis for further elaboration. The focus group findings contrasts the findings in Research Question 1 from the perspective of physiotherapist and revealed some interesting observations about what they view as the most potential area for these devices, some of the most significant were the following:

- Input: The experts consider all the three technologies as having great potential in physical rehabilitation
- Input: There seems to be particular suitability in orthopedic conditions, prevention of injury and as motivator for children an activator for elderly

- Input: More appropriate games would be needed, where they target specific conditions
- Flexible: Such games would require substantial ability to adjust the difficulty, speed and sensor parameters to account for each patients degree of injury
- Social: The social aspect would be important, where family, friends or co-patients could participate
- Motivation: A goal from the experts point of view would be to make the exercise fun and act as an motivator and initialize for exercise

The experts expressed enthusiasm over all the devices presented, with preference towards the Wii and Kinect. They could not however generalize which one was the best for the specific conditions and stated it was too dependent on the individual conditions and degree of injury and that each device had an advantage under different conditions. This shows that further study is needed to determine which conditions are suitable and the degree of injury needs to determine which device is most suitable along with what scale of difficulty one should use.

Lastly the development of motion-sensing technologies are moving very fast, with the next generation of Wii on the way, improvements are done to the Kinect drivers, new versions of the consoles could open more avenues of approach to this domain, man interesting and useful applications can emerge and researchers investigate the possibilities with these devices.

An interesting observation from the findings and discussion in Research Question 1 and 2, is that it looks like we can not make one single "game for rehabilitation", it appears as different games, or at least different modules or modes in a game, needs to be targeted to specific conditions and levels of injury, also the literature mentioned all focused on more or less specific conditions or cases.

Research Question 3 The following ten points were suggested based upon the work with Research Question 1 and 2, with additional literary study to ground the suggestions:

1. Consider different motion-sensing technologies
2. Focus on the basic movements first
3. Give feedback

4. Minimize noise
5. Make it easy to get started in the home
6. Track progress
7. Fun and motivation
8. Social enablement
9. Adjustable difficulty and speed
10. Encourage the player to avoid compensation

8.2 Summary of reflections

As discussed in Chapter 7.5, the potential sources for errors is numerous, but with Oates' definition on objectivity, validity and reliability, combined with Klein & Meyers seven principles for interpretive research we can manage and mitigate the complexities. The prototypes were constructed based upon study on previous thesis work and other literary sources, along with the questionnaire, focus group content and interview questions. The expert panel proved to be a very useful source of data to confirm and reject some of the assumptions and findings, this is well demonstrated with the questionnaire and the difficulty in generalizing conditions suitable for rehabilitation games since each patient has such individual span in degree of injury, age, motivation and other personal factors. Some of the findings in the previous work [56] were reinforced in this focus group, for example the importance of a simple game interface, giving feedback, adjustable game difficulty and speed.

8.3 Further study

There are several areas where further research could be based. The author suggest the following:

- Investigate the feasibility with games focused more directly at specific conditions, this would need more input from experts and perhaps patients to determine how to design appropriate exercises. Which conditions would potentially gain the most from this kind of augmentation and what degrees of injury are they appropriate for

- Conduct observations, focus groups, workshops, field studies or some other method to determine the suitable level of difficulty for various patient groups and their degree of injury
- Conduct more focus groups to gather more data from experts as an attempt to define exercises suitable for patient and to define a scale of injury in relation to that
- Conduct patient trials with games designed for rehabilitation, this can reveal not only usability issues, but also design issues and assumptions about the needs of the patient. Preferably those games would target specific conditions along the lines of what the expert panel expressed in the focus group in this thesis.
- Investigate the use of PC versus the consoles Wii, Xbox and PlayStation. Research done on the PC as surrogate for the console can not uncover all aspects to the process of getting a game suitable for use in rehabilitation, more research might provide important insights into these challenges. The process to get games onto the consoles by official channels can be a difficult one as [56] also described, where the company behind the platform might have restrictions what the game and can not do.
- The world of motion-sensing technology is advancing rapidly with new and interesting technology, one example of that is the new sensing device from Leap Motion called Leap 3D [43], the manufacturer claims it is 100 times more accurate than the Kinect and suggests relatively low price of around $70. The focus of the Leap 3D is on fine control over the hands as shown in Figure 8.1[1].

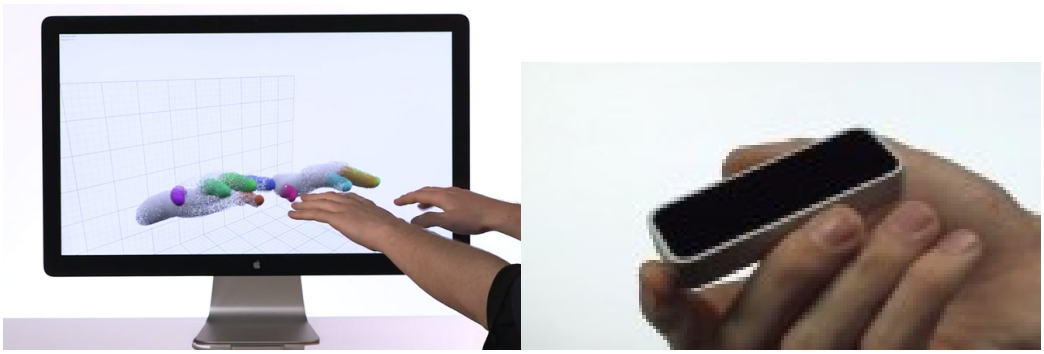

Figure 8.1: Image from visualizing sensor data with the Leap 3D (left) and the sensor (right)

[1]Picture on the left from [43], right picture from Leap Motion home page

The suggestions presented here are based upon the findings in this thesis and what the author identifies as especially conducive to further study under these usage scenarios. The Introduction in Chapter one presented some motivational facts as to why this is useful research. As the research foundation grows hopefully some production quality product can emerge from it.

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Appendix A

Wii class, UpdateWiimoteChanged

The function where the raw input from the device gets translated to a state representation

```
void UpdateWiimoteChanged(object sender, WiimoteChangedEventArgs args)
{
    WiimoteState ws = args.WiimoteState;

    switch (ws.ExtensionType)
    {

        case ExtensionType.MotionPlus:
            Wiimote wm = ((Wiimote)sender);
            if (ws.AccelState.Values.Y < -1.0
                || ws.AccelState.Values.Y > 1.0)
            {
                //LeftHandAction
                state.LeftHandAction = true;
                state.RightHandAction = true;

            }
            else
            {
                state.LeftHandAction = false;
                state.RightHandAction = false;

            }

            break;
        case ExtensionType.BalanceBoard:
            try
            {

                float Left = ws.BalanceBoardState.SensorValuesKg.BottomLeft +
                    ws.BalanceBoardState.SensorValuesKg.TopLeft;
                float Right = ws.BalanceBoardState.SensorValuesKg.TopRight +
                    ws.BalanceBoardState.SensorValuesKg.BottomRight;

                //left bottom+top Left
                //right bottom+top Right

                if (ws.BalanceBoardState.WeightKg > 20
                    && ws.BalanceBoardState.CenterOfGravity.X < -5)
                {
                    state.LeaningLeft = true;
                    state.LeaningRight = false;
                }
                else if (ws.BalanceBoardState.WeightKg > 20
                    && ws.BalanceBoardState.CenterOfGravity.X > 5)
                {
                    state.LeaningRight = true;
                    state.LeaningLeft = false;
                }
                else
                {
                    state.LeaningRight = false;
                    state.LeaningLeft = false;
                }

            }
            catch
            {
                //Wii board failed
            }
            break;
    }
}
```

Figure A.1: Wii UpdateWiimoteChanged

Appendix B

Kinect class, nui_SkeletonFrameReady

```
void nui_SkeletonFrameReady(object sender, SkeletonFrameReadyEventArgs e)
{

    SkeletonFrame skeletonFrame = e.SkeletonFrame;
    //SkeletonFrame skeletonFrame = e.SkeletonFrame;

    foreach (SkeletonData data in skeletonFrame.Skeletons)
    {
        if (SkeletonTrackingState.Tracked == data.TrackingState)
        {

        }
    }

    //get the first tracked skeleton
    SkeletonData skeleton = (from s in skeletonFrame.Skeletons
                             where s.TrackingState == SkeletonTrackingState.Tracked
                             select s).FirstOrDefault();

    //need to check that we got a skeleton lock before trying to process it
    if (skeleton != null)
    {
        // the various joints
        RightHand =
            skeleton.Joints[JointID.HandRight].ScaleTo(1024, 720, .5f, .5f);
        LeftHand =
            skeleton.Joints[JointID.HandLeft].ScaleTo(1024, 720, .5f, .5f);
        Spine =
            skeleton.Joints[JointID.Spine].ScaleTo(1024, 720, .5f, .5f);
        Hip =
            skeleton.Joints[JointID.HipCenter].ScaleTo(1024, 720, .5f, .5f);
        ShoulderCenter =
            skeleton.Joints[JointID.ShoulderCenter].ScaleTo(1024, 720, .5f, .5f);

        //now need to check if the shoulder is to the left or right in relation to the hip
        if (ShoulderCenter.Position.X > (Hip.Position.X + 50))
        {
            //leaning to the right
            state.LeaningRight = true;

        }
        else state.LeaningRight = false;

        if (ShoulderCenter.Position.X < (Hip.Position.X - 50))
        {
            //leaning to the left
            state.LeaningLeft = true;
        }
        else state.LeaningLeft = false;

        if (RightHand.Position.Y <50)
        {
            //right hand is lifted over the head,
            //could also check for distance from the spine/shoulder in X direction
            state.RightHandUp = true;
            state.RightHandDown = false;

         }
         else if (RightHand.Position.Y > 250)
         {
             state.RightHandUp = false;
             state.RightHandDown = true;

         }
```

Figure B.1: SkeletonFrameReady Part 1

```
        if (LeftHand.Position.Y < 50)
        {
            //left hand is lifted over the head,
            //could also check for distance from the spine/shoulder in X direction
            state.LeftHandUp = true;
            state.LeftHandDown = false;
        }
        else if (LeftHand.Position.Y > 250)
        {
            state.LeftHandUp = false;
            state.LeftHandDown = true;
        }

        if (ShoulderCenter.Position.Y>250)
        {
            state.BentDown = true;
            //the hip is very close to the knee so we assume a crouching position

        }
        else state.BentDown = false;
    }

}
```

Figure B.2: SkeletonFrameReady Part 2

Appendix C

Move class, updateState

```
public void updateState()
{
    //get the latest state info from the server
    PSMoveSharpState state = moveClient.GetLatestState();
    PSMoveSharpCameraFrameState camera_frame_state = moveClient.GetLatestCameraFrameState();
    if (processed_packet_index == state.packet_index)
    {
        return;
    }
    processed_packet_index = state.packet_index;

    moveState.ControllerLeftHand.GemState = state.gemStates[0];
    moveState.ControllerLeftHand.Position.Current_X
        = moveState.ControllerLeftHand.GemState.pos.x;
    moveState.ControllerLeftHand.Position.Current_Y
        = moveState.ControllerLeftHand.GemState.pos.y;

    if (state.gemStates[1].tracking_flags > 0)
    {
        moveState.ControllerRightHand.GemState = state.gemStates[1];
        moveState.ControllerRightHand.Position.Current_X
            = moveState.ControllerRightHand.GemState.pos.x;
        moveState.ControllerRightHand.Position.Current_Y
            = moveState.ControllerRightHand.GemState.pos.y;

        if (state.gemStates[2].tracking_flags > 0)
        {
            moveState.ControllerCenter.GemState = state.gemStates[2];
            moveState.ControllerCenter.Position.Current_X
                = moveState.ControllerCenter.GemState.pos.x;
            moveState.ControllerCenter.Position.Current_Y
                = moveState.ControllerCenter.GemState.pos.y;
        }

    }


    if (((moveState.ControllerLeftHand.GemState.pad.digitalbuttons
        & PSMoveSharpConstants.ctrlTriangle) != 0))
    {
        //left controller
        moveState.ControllerLeftHand.Position.Initial_X
            = moveState.ControllerLeftHand.GemState.pos.x;
        moveState.ControllerLeftHand.Position.Initial_Y
            = moveState.ControllerLeftHand.GemState.pos.y;
        //Triangle pushed, calibrated LeftHandto Initial position with x,y:

        if (state.gemStates[1].tracking_flags > 0)
        {
            //calibrated RightHand

            //right controller
            moveState.ControllerRightHand.Position.Initial_X
                = moveState.ControllerRightHand.GemState.pos.x;
            moveState.ControllerRightHand.Position.Initial_Y
                = moveState.ControllerRightHand.GemState.pos.y;

        }

        if (state.gemStates[2].tracking_flags > 0)
        {
           //calibrated Center
            moveState.ControllerCenter.Position.Initial_X
                = moveState.ControllerCenter.GemState.pos.x;
            moveState.ControllerCenter.Position.Initial_Y
                = moveState.ControllerCenter.GemState.pos.y;
        }
        //Triangle pushed
```

Figure C.1: updateState Part 1

```
}
else
{
    if (moveState.ControllerLeftHand.Position.Current_Y
        > moveState.ControllerLeftHand.Position.Initial_Y + 200)
    {
        moveState.LeftHandUp = true;

    }
    else if (moveState.ControllerLeftHand.Position.Current_Y
        < moveState.ControllerLeftHand.Position.Initial_Y - 200)
    {
        moveState.LeftHandDown = true;

    }
    else
    {
        moveState.LeftHandDown = false;
        moveState.LeftHandUp = false;
    }

    if (state.gemStates[1].tracking_flags > 0)
    {

        //Right hand
        if (moveState.ControllerRightHand.Position.Current_Y
            > moveState.ControllerRightHand.Position.Initial_Y + 200)
        {
            moveState.RightHandUp = true;
        }
        else if (moveState.ControllerRightHand.Position.Current_Y
            < moveState.ControllerRightHand.Position.Initial_Y - 200)
        {
            moveState.RightHandDown = true;
        }
        else
        {
            moveState.RightHandDown = false;
            moveState.RightHandUp = false;
        }

        //center
        if (state.gemStates[2].tracking_flags > 0)
        {

            if (moveState.ControllerCenter.Position.Current_Y
                < moveState.ControllerCenter.Position.Initial_Y - 100)
            {
                moveState.BentDown = true;
            }

            else
            {
                moveState.BentDown = false;

            }
            if (moveState.ControllerCenter.Position.Current_X
                < moveState.ControllerCenter.Position.Initial_Y -100) {
                moveState.LeaningLeft = true;
            }
            else if (moveState.ControllerCenter.Position.Current_X
                > moveState.ControllerCenter.Position.Initial_Y + 100)
            {
                moveState.LeaningRight = true;
            }
            else {
                moveState.LeaningRight = false;
                moveState.LeaningLeft = false;
            }
        }
```

Appendix D

Questionnaire

Spørreskjema

Sett i forhold til bare tradisjonelle øvelser innen fysioterapi,
hvor godt mener du denne maskinen potensielt kan hjelpe med å øke effekten av øvelser?

3 = omtrent lik effekt som bare tradisjonell øvelse

1= lite eller ingen forbedring i forhold til tradisjonell øvelse

5 = veldig stor forbedring forhold til bare tradisjonell øvelse

Sett sirkel rundt det tallet på skalaen som du mener passer best	Maskinvare		
	Wii	**Kinect**	**Move**
Hovedsakelig yngre, også ryggskader o.l.	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Cerebral Parese	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Gripeevne	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Skulderstabilitet	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Nakke, sidebøy	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Balanse	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Tyngdeoverføring	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Kne (artrose)	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Bedrer generell fysisk funksjon	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Rotasjon av overkropp (thorax, columna)	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Rotasjon av underkropp (pelvis)	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Hjertesvikt og sirkulasjonsforstyrrelser	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Svimmelhet og balansesvikt	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
KOLS og andre luftveisproblemer	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Revmatiske lidelser	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Hovedsakelig eldre			
Øke balanse, reduserer fall	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Bedrer beintetthet og reduserer risiko for brudd	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Forebygger beinskjørhet	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Reduserer smerte hos de med beinskjørhet	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Øker sjansen for å overleve et hjerneslag	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Bedrer mental funksjon og atferd hos demente	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Reduserer depresjon og bedrer psykisk funksjon	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Hjerneslag, bedrer evnen til å greie seg selv og gangfunksjonen	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Parkinsons, bedrer evnen til å greie seg selv og gangfunksjonen	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Reduserer sjansen for forverring av følgende av et slag og reduserer smerte.	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Reduserer smerte og morgenstivhet hos pasienter med leddgikt og slitasjegikt.	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Øker styrke, bevegelsesutslag og	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
generell funksjon hos pasienter med leddgikt og slitasjegikt.	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5

Vennligst skriv inn navnet ditt her:

_____

Figure D.1: Empty questionnaire

Spørreskjema

Sett i forhold til bare tradisjonelle øvelser innen fysioterapi,
hvor godt mener du denne maskinen potensielt kan hjelpe med å øke effekten av øvelser?

3 = omtrent lik effekt som bare tradisjonell øvelse

1= lite eller ingen forbedring i forhold til tradisjonell øvelse

5 = veldig stor forbedring forhold til bare tradisjonell øvelse

Sett sirkel rundt det tallet på skalaen som du mener passer best

	Maskinvare		
	Wii	**Kinect**	**Move**
Hovedsakelig yngre, også ryggskader o.l.	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Cerebral Parese	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Gripeevne	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Skulderstabilitet	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Nakke, sidebøy	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Balanse	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Tyngdeoverføring	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Kne (artrose)	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Bedrer generell fysisk funksjon	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Rotasjon av overkropp (thorax, columna)	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Rotasjon av underkropp (pelvis)	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Hjertesvikt og sirkulasjonsforstyrrelser	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Svimmelhet og balansesvikt	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
KOLS og andre luftveisproblemer	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Revmatiske lidelser	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Hovedsakelig eldre			
Øke balanse, reduserer fall	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Bedrer beintetthet og reduserer risiko for brudd	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Forebygger beinskjørhet	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Reduserer smerte hos de med beinskjørhet	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Øker sjansen for å overleve et hjerneslag	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Bedrer mental funksjon og atferd hos demente	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Reduserer depresjon og bedrer psykisk funksjon	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Hjerneslag, bedrer evnen til å greie seg selv og gangfunksjonen	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Parkinsons, bedrer evnen til å greie seg selv og gangfunksjonen	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Reduserer sjansen for forverring av følgende av et slag og reduserer smerte.	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Reduserer smerte og morgenstivhet hos pasienter med leddgikt og slitasjegikt.	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Øker styrke, bevegelsesutslag og	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
generell funksjon hos pasienter med leddgikt og slitasjegikt.	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5

Vennligst skriv inn navnet ditt her:

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Page 3

Figure D.2: Questionnaire #1 filled out

Spørreskjema

Sett i forhold til bare tradisjonelle øvelser innen fysioterapi,
hvor godt mener du denne maskinen potensielt kan hjelpe med å øke effekten av øvelser?

3 = omtrent lik effekt som bare tradisjonell øvelse

1= lite eller ingen forbedring i forhold til tradisjonell øvelse

5 = veldig stor forbedring forhold til bare tradisjonell øvelse

Sett sirkel rundt det tallet på skalaen som du mener passer best

	Maskinvare		
	Wii	**Kinect**	**Move**
Hovedsakelig yngre, også ryggskader o.l.	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Cerebral Parese	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Gripeevne	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Skulderstabilitet	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Nakke, sidebøy	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Balanse	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Tyngdeoverføring	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Kne (artrose)	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Bedrer generell fysisk funksjon	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Rotasjon av overkropp (thorax, columna)	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Rotasjon av underkropp (pelvis)	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Hjertesvikt og sirkulasjonsforstyrrelser	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Svimmelhet og balansesvikt	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
KOLS og andre luftveisproblemer	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Revmatiske lidelser	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Hovedsakelig eldre			
Øke balanse, reduserer fall	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Bedrer beintetthet og reduserer risiko for brudd	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Forebygger beinskjørhet	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Reduserer smerte hos de med beinskjørhet	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Øker sjansen for å overleve et hjerneslag	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Bedrer mental funksjon og atferd hos demente	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Reduserer depresjon og bedrer psykisk funksjon	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Hjerneslag, bedrer evnen til å greie seg selv og gangfunksjonen	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Parkinsons, bedrer evnen til å greie seg selv og gangfunksjonen	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Reduserer sjansen for forverring av følgende av et slag og reduserer smerte.	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Reduserer smerte og morgenstivhet hos pasienter med leddgikt og slitasjegikt.	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
Øker styrke, bevegelsesutslag og	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
generell funksjon hos pasienter med leddgikt og slitasjegikt.	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5

Vennligst skriv inn navnet ditt her:

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Page 3

Figure D.3: Questionnaire #2 filled out

Vanskelig spørreskjema, hva er hensikten?

Spørreskjema

Sett i forhold til bare tradisjonelle øvelser innen fysioterapi,
hvor godt mener du denne maskinen potensielt kan hjelpe med å øke effekten av øvelser?

3 = omtrent lik effekt som bare tradisjonell øvelse

1= lite eller ingen forbedring i forhold til tradisjonell øvelse

5 = veldig stor forbedring forhold til bare tradisjonell øvelse

Sett sirkel rundt det tallet på skalaen som du mener passer best	Maskinvare														
	Wii					Kinect					Move				
Hovedsakelig yngre, også ryggskader o.l.	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Cerebral Parese	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Gripeevne	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Skulderstabilitet	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Nakke, sidebøy	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Balanse	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Tyngdeoverføring	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Kne (artrose)	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Bedrer generell fysisk funksjon	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Rotasjon av overkropp (thorax, columna)	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Rotasjon av underkropp (pelvis)	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Hjertesvikt og sirkulasjonsforstyrrelser	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Svimmelhet og balansesvikt	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
KOLS og andre luftveisproblemer	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Revmatiske lidelser	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Hovedsakelig eldre															
Øke balanse, reduserer fall	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Bedrer beintetthet og reduserer risiko for brudd	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Forebygger beinskjørhet	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Reduserer smerte hos de med beinskjørhet	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Øker sjansen for å overleve et hjerneslag	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Bedrer mental funksjon og atferd hos demente	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Reduserer depresjon og bedrer psykisk funksjon	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Hjerneslag, bedrer evnen til å greie seg selv og gangfunksjonen	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Parkinsons, bedrer evnen til å greie seg selv og gangfunksjonen	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Reduserer sjansen for forverring av følgende av et slag og reduserer smerte.	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Reduserer smerte og morgenstivhet hos pasienter med leddgikt og slitasjegikt.	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Øker styrke, bevegelsesutslag og	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
generell funksjon hos pasienter med leddgikt og slitasjegikt.	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5

Vennligst skriv inn navnet ditt her:

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Som tillegg til dagens behandling har alle spill potensjal til å øke effekten

Page 3

Figure D.4: Questionnaire #3 filled out

Appendix E

General information form

Informasjon om deltagere.

For at vi bedre skal forstå deltagerene håper vi dere kan fylle ut litt informasjon om dere:

1) Navn og alder

2) Yrke, spesialitet, fagområde

3) Hvor lenge har du drevet med ditt yrke/spesialitet?

4) På en skala fra én til fem, hvor mye erfaring har du med spillkonsoller (som Wii) eller bevegelsesteknologi? 1 = lite/ingen erfaring, 5 = mye erfaring

5) Annen informasjon du ønsker å dele kan skrives here

Figure E.1: Form used to gather information about experts

Appendix F

Consent form

Brukersentrert utvikling spill for fysisk rehabilitering.

Deltakelse på workshop ved NSEP/NTNU.

Samtykkeerklæring

Jeg har mottatt skriftlig og muntlig informasjon om studien, og fått anledning til å stille spørsmål. Jeg er klar over at det er frivillig å delta, og at jeg kan trekke meg fra studien når som helst uten å oppgi noen grunn. Jeg samtykker i å delta i studien.

Det vil bli tatt video- og lydopptak. Dette gjøres for at vi skal kunne vurdere sesjonene i etterkant og for å sikre oss at vi har forstått deres utsagn og handlinger riktig. Vi vil sørge for at materiale vil bli anonymisert slik at det ikke vil være mulig å føre opplysningene tilbake til enkeltpersonene som deltar i prosjektet. Dette innbærer at informasjon som blir formidlet til offentligheten ikke vil kunne settes i sammenheng med den enkelte. Det er kun de involverte i prosjektet som vil kunne se opptakene i ettertid.

Trondheim,_____

_____

Underskrift