CHALMERS
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Tracking, monitoring and feedback of patient exercises using depth camera technology for home based rehabilitation

Master's thesis in Biomedical Engineering

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Department of Signals and Systems
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2016

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Master's Thesis 2016
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Cover: Demonstration of a patient participating in the developed Kinect game based rehabilitation system.

Typeset in LaTeX
Gothenburg, Sweden 2016

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Abstract

Neurological and chronic diseases have profound impacts on a person's life. Rehabilitation is essential in order to maintain and promote maximal level of recovery by pushing the bounds of physical, emotional and cognitive impairments. However, due to the low physical mobility and poor overall condition of many patients, traveling back and forth to doctors, nurses and rehabilitation centers can be exhausting tasks. In this thesis a game-based rehabilitation platform for home usage, supporting stroke and COPD rehabilitation is presented. The main goal is to make rehabilitation more enjoyable, individualized and easily accessible for the patients.

The game-based rehabilitation tool consists of three systems with integrated components: the caregiver's planning and follow-up system, the patient's gaming system and the connecting server system. The server back end components allow the storage of patient specific information that can be transmitted between the patient and the caregiver system for planning, monitoring and feedback purposes. The planning and follow-up system is a server system accessed through a web-based front-end, where the caregiver schedules the rehabilitation program adjusted for each individual patient and follow up on the rehabilitation progression. The patient system is the game platform developed in this project, containing 16 different games and three assessment tests. The games are based on specific motion patterns produced in collaboration with rehabilitation specialists. Motion orientation and guidance functions is implemented specifically for each exercise to provide feedback to the user of the performed motion and to ensure proper execution of the desired motion pattern.

The developed system has been tested by several people and with three real patients. The participants feedback supported the use of the game-based platform for rehabilitation as an entertaining alternative for rehabilitation at home. Further implementation work and evaluation with real patients are necessary before the product can be used for commercial purpose.

Keywords: COPD, stroke, Kinect, game, ICT, rehabilitation do.

Acknowledgements

This study was performed as a master thesis project supported by grants to professor Martin Rydmark by Center for Person-Centred Care at University of Gothenburg (GPCC), Sweden. GPCC is funded by the Swedish Government's grant for Strategic Research Areas, Care Sciences (Application to Swedish Research Council nr 2009-1088) and co-funded by University of Gothenburg, Sweden. The extent of the master thesis corresponds to 30 ECTS.

First and foremost, I would like to thank my supervisors Martin Rydmark, professor of medical informatics and computer assisted education, and Lars-Åke Johansson, Managing Director at Alkit Communications, for the invaluable help and support I have received during the project. I would also like to thank Margareta Emtner, researcher at Department of Medical Sciences, and Jurgen Broeren, occupational therapist, for the support in development of the rehabilitation exercises and provided opportunity for patient evaluation of the system. Special thanks to my colleges, friends and family for the support and aid in evaluating the system. Without all of you this would not have been possible.

Anna Ridderstolpe, Gothenburg, 2016

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Introduction

1.1 Background

A challenge in society today is the growing elderly population with multiple diseases. As we live longer the risk of catching one or several chronic diseases is enhanced and the demand on health care and its resources increases. By using information technology in new ways health care resources could be used in a more efficient manner at the same time as higher quality of health care could be achieved for the individual. If this is to be achieved, new innovative ways of using ICT for different types of services are needed, which could result in health and social care being pursued in a different way. The use of ICT services in health care is referred to as eHealth and is an area that will greatly expand in an international perspective.

The focus of one group of eHealth services is to encourage the individual to more physical activity and to perform certified movements for different purposes. Medical research has shown that a variety of disease conditions can be enhanced or the disease progression or occurrence can be avoided by performing various movements [1] [2]. A variety of new types of information techniques are emerging, such as sensors, software services and communication techniques. These can be used to track motions, compare data, alert irregular activities and performing multiple continuous tests over longer time periods. However, for commercial use these solutions must be easily comprehensible and available at a reasonable price for private users.

There are two main types of movements with different purposes:

1. Assessment oriented movements - the aim is to identify different types of permits to make diagnoses or for assessing reductions or abilities.
2. Intervention oriented movements - the purpose is to influence different types of health conditions.

Some sensors are specifically geared to perform movements and these represent interesting opportunities in the area. Examples of sensors are accelerators and depth cameras or 3D cameras. These types of sensors have the potential to create various types of IT-based services where one can identify how different motions have been performed. The quality of the sensors are gradually improving, which enables better detection and thus makes it possible to identify moving patterns more in detail.

Physical activity or rehabilitation is of great importance for many diseases to regain abilities and to build up compensatory abilities. For other diseases the focus is to retain abilities as far as possible to maintain quality of life for the individual and saving society's health care resources. This project is about distributed neurorehabilitation and related to a center called Gothenburg Person Centered Care (GPCC), and to the projects called Strada-Stroke and the COPD-project. The aim of GPCC is to develop person-centered ICT services for activity management, communication and assessment of the disease progression state to improve access to care and nursing using the persons home as a base [3]. In the Strada-Stroke project a technical solution for training in the long term and sub-acute phase after stroke is reviewed in a phase II study [4]. The COPD-project is an ongoing process of developing solutions for health care of COPD patients at a distance.

In this thesis, a developed general platform for home based rehabilitation centering a Kinect sensor is presented. Specific stroke and COPD rehabilitation exercises with different field of applications are incorporated into the developed games on the platform. Each patient's respective caregiver has access to a website where they can design and schedule a rehabilitation program adapted to the specific patient's condition and needs. A server system, with connection to both the website and the game platform, is used to store and transfers the information between the systems. This framework enables the user to perform game-based rehabilitation exercises at home, with exercises that are tailored to the individual patient's therapy goals. Motion data from the sensor is collected each game session and used for motion assessment. The data is also used to provide guidelines and feedback for the user to learn the correct execution of the exercises. The project is a cooperation between Alkit Communications, Mednet at the Sahlgrenska Academy, Chalmers University of Technology, Department of Medical Sciences at Uppsala University and Angereds Närsjukhus.

1.2 Aim

The aim of the project is to examine and try out how the Kinect sensor can be used to measure body positions in order to investigate how an individual actually performs the intended movements at any given moment. To evaluate the sensors motion monitoring capability, a home based rehabilitation platform based on depth sensor technology is developed with incorporated rehabilitation exercises. The exercises ought to be entertaining, simple to understand and beneficial for the user. The gathered information and data generated by the sensor will be analyzed and presented to the user in a clear and perceptive manner through verbal and visual feedback in the game.

The hypothesis is that the game will provide a more entertaining rehabilitation experience, thereby encourage the user to perform the exercises on a regular basis. The information about the execution of the exercise could also result in improved movement patterns, providing more effective rehabilitation.

The following questions will be investigated and answered in this project:

- Is the Kinect sensor suitable for home based rehabilitation, based on how easy

it is to handle and how reliable the tracking function is?
- Is it possible to implement functions to correct and improve the user's movements?
- Can the platform be used to facilitate the workload of physiotherapists and occupational therapists?

1.3 Limitations

A Kinect 2.0 sensor will be the only sensor technique regarded in this project. It will be used to perform the game and collect the data necessary for the analysis of the movements. The sensor has been chosen specifically because it is easily accessible, relatively cheap and is considered to work well for this type of application.

The rehabilitation exercises are specifically developed for stroke and COPD patients. Hence, the project will only focus on rehabilitation regarding stroke and COPD. A hand pick of exercises for COPD will be chosen from a training program developed by Margareta Emtner (physiotherapist at Akademiska sjukhuset and professor at Uppsala University). Exercises for stroke will be chosen in a similar way. Only exercises performed standing up or sitting on a chair will be investigated for simplicity.

The rehabilitation game will not be evaluated to a greater extent, i.e. a larger study of patient trials will not be performed.

2

Theory

Following a chronic disease, the primary goal of rehabilitation is to promote maximal level of function recovery while pushing the bounds of physical, cognitive and emotional impairments. It is the foundation to enable reintegration into the community and pursued occupation. It has been demonstrated that individuals who perform and have access to multidisciplinary rehabilitation programs show faster functional gains on measures of functional independence and have shorter hospital stays [5]. Accurate and proper tracking and feedback of motion performance is important in order to utilize the maximal effect of the rehabilitation. However, with a shortage of rehabilitation specialists, increasing medical costs and an increase of chronic disease patients, the patients daily exercises cannot be supervised and guided by specialists at all times. Thus, these patients are in need of a functional and reliable home-based sensor rehabilitation system at a low cost which can provide guided help and perform visual assessment of the performed tasks.

Rehabilitation is essential to maintain and/or recover abilities for people with motor disabilities. Patients with chronic diseases are provided with recommended daily exercises. However, a study amongst stroke patients indicate that only 31 % performed the exercises as advocated [6]. Physical therapy is often based on repetition in order to expand the range of motion or gain control over a specific muscle group. Performing therapy exercises without encouragement can cause patients to lose motivation, whereupon the daily process of rehabilitation becomes frustrating and less efficient. Video games are associated with fun and by developing games as rehabilitation tools the users will perceive motivation associated with playing the games. Furthermore, by the usage of webcams or server connections connected with the games, the rehabilitation can occur at the patients home while the physicians and other related medical staff are able to follow up the progression at distance.

Tracking and monitoring movements by using sensor techniques provides a vast possibility of application areas. For rehabilitation purposes, the gained information can be used to improve the quality of the exercises by providing guidelines to the user. Assessment of physical performance is a key component in clinical practice, both for therapeutic and diagnostic purposes. The Kinect sensor along with specific software implementations can perform visual assessment of specific movements without supervision from a trained physical therapist or occupational therapist. Assessment performed by sensor technique lack subjectivity, which otherwise can cause inaccurate readings in clinical assessments.

The idea is to create a home based application platform for rehabilitation. For commercial use the tools and equipment must be cheap and also easy to handle and operate. A proposed solution is to use a Kinect 2.0 sensor which can be used for tracking joint positions and monitoring motor skills. Kinect sensors are easily accessible and can be used daily and objectively. It provides full body tracking and is compatible with Windows systems, which was used for development. Specific rehabilitation exercises for COPD and stroke patients will be added to the platform in order to test and evaluate the performance of monitoring motions using a Kinect sensor. COPD and stoke are both common diseases amongst elders where rehabilitation is an important part of the treatment.

2.1 Related work

Commercial video games, such as the Nintendo WiiFit, has recently gained a lot of interest as a rehabilitation tool for physical therapy. Although video games have the potential to be used as efficient motivators for performing physical activity, there is a limitation of published research regarding the effectiveness and feasibility of utilizing the motion sensing capabilities of available commercial gaming systems for rehabilitation [7] [8] [9] [10] [11]. According to initial case studies commercial video games can be useful for balance rehabilitation among stroke patients [8] [9]. However, not all commercially available video games are suitable for exercises required for therapy. Occasional studies have observed that some commercial games provide negative visual and auditory feedback during the exercise session [11] [12]. These observations denote the significance of designing games specifically for physical, cognitive or occupational therapy if the intended objective is rehabilitation.

Research has shown that commercial motion sensor controllers, such as Nintendo Wii remote from the video games industry, can be useful tools for physical rehabilitation [13]. The combination of motion sensor technology and fun video games also have a positive effect on the motivation to perform daily exercise activities [14]. A drawback with motion sensor controllers are the inconvenience and discomfort of wearing the device or holding on to it. In addition, it is quite easy to cheat the Nintendo Wii remote trackers by performing minor movements, such as twisting the Nintendo Wii remote with the wrist instead of performing a full arm swing. The Nintendo Wii remote is also not sensitive enough to measure performance accurately and is thus not suited as a high quality rehabilitation tool.

Another commercial motion sensor controller is the PlayStation Move. It extracts hand motion position and orientation in a similar fashion as the Nintendo Wii remote but generates 3D positions more accurately. Although, the motion sensor controllers provide a fun rehabilitation environment, there are no randomized large-scale controlled trials published that states the actual benefits of using the controllers as rehabilitation tools. [15]

The use and incorporation of various ICT devices in occupational therapy have been developed across numerous settings for people with motor disabilities. An assessment and training device featuring virtual reality and haptics were developed for motor rehabilitation after stroke. Within the VR environment, the patient can perform tasks in a controlled environment and measure the success level in real time. The haptic device enables the user to interact with objects in the 3D environment through touch. Although the research showed promising result for using VR and haptics to reduce motor impairments, the project was cancelled due to the high production cost of the device ($\tilde{\$}$20 000), rendering it too expensive for home rehabilitation. [16] [17]

Technologies, such as optical systems, inertial or electromagnetic sensors, are used to capture motions over a broad filed of applications. One of the most common motion capture techniques is optical systems with reflective markers [18] [19]. Although the marker based system provides a very accurate body position, the system is not feasible as a home-based motion capture system. It is expensive and requires a controlled environment with several cameras at different positions to acquire high-quality data. A marker has to be visualized by at least 2 cameras to determine the 3D position. Furthermore, positioning the markers correctly requires knowledge and can be very time consuming. [20]

Markerless motion capture systems offers a more attractive solution for home-based platforms. In general, the precision that marker based system offers cannot be obtained with the markerless option due to the lack of temporal and spatial correspondence that is guaranteed with tracked markers [20] [21]. However, the Kinects sensors precision is sufficient enough for tracking motion performance in rehabilitation and provides a pervading accessibility applicable for home-based rehabilitation systems [22] [23].

In this project a Kinect sensor-based system is developed for home-based rehabilitation. The Kinect sensor enables the user to interact with the console using body gestures without the requirements of a controller or bound body sensors. The Kinect sensor is considerably cheaper compared to common complex multi-camera systems [20]. It is considered to be a 3D markerless motion caption system due to the possibility to display a simplified skeleton in real time without special clothing or body equipment. The Kinect 2.0 sensor can track 24 joints that makes up the skeleton [24], see figure 2.2. Although the accuracy of the Kinect sensor cannot emulate the accuracy of a marker-based systems, it can be used for rehabilitation purpose where the execution of the motion can be validated without extreme preciseness. Several validation studies of joint movements captured by a Kinect sensor has shown that the obtained accuracy is sufficient for most rehabilitation exercises [20] [22] [25] [26].

In 2013 PlayStation released PlayStation camera, a motion sensor with depth sensing technology for the PlayStation 4 console. The device can recognize and track head, face and hands and be controlled by voice commands, similar to Microsoft's Kinect. The SDK for the PlayStation camera is available to the public for game development. However, the Kinect sensor is more targeted for development of rehabilitation games than the PlayStation camera, most likely due to better gesture control and compatibility with PCs through USB input. [27]

An American team developed a Kinect sensor-based balance rehabilitation tool for stroke, traumatic brain injury (TBI) and spinal cord injury (SCI) patients in 2011 [10]. The key features of the game design was developed through interviews with clinicians, researchers and patients. In the game, the player travels through a mine while picking up gems and placing them in a cart. Initially a calibration pose was necessary for initiating tracking with the used OpenNI software. 20 participants with either stroke, TBI or SCI where studied and 8 of them could not perform the required position for tracking. The other 12 participants needed assistance from a clinician to perform and maintain the pose needed for calibration. [10]

Another team in Thailand developed a Kinect sensor-based system for stroke rehabilitation in 2015 [28]. The game is a jigsaw puzzle intended to assist stroke patients regain control of their hand and upper limb movements. The test subjects had no problem participating in the game. However, improvements can be made in order to fulfill the rehabilitation tasks further. [28]

In 2013, a Kinect-based rehabilitation training assistant system was presented with the aim to improve the posture accuracy for stroke patients with hemiplegia. The system uses a Kinect sensor to collect data of the user's limb positions. The data is then continuously compared to stored standard action data to provide posture guidance to the user. No evaluation of the system with test subjects has been presented. [29]

2.2 Motion sensors

The process of sensing an objects change in position relative to its surrounding is defined as motion detection. Motion sensors are devices which detects and tracks motions of an object in real time. An objects motion can be tracked by: passive and active infrared sensors, optic systems, sound, magnetic and vibration sensors and through radio frequency energy by radar, tomographic and microwave sensors. [30]

Electrical motion sensor devices often apply optical or acoustic detection of an objects position. Infrared light or laser technology can be utilized for detection by depth sensors or IR cameras in optical systems. Depth sensors are a combination of an IR emitter and an IR camera. A projection pattern of dots are transmitted in infrared from the IR emitter and captured by the IR camera. The video feed from the IR camera is processed by the depth sensor to generate the depth of the object through analysis of the displacement of the dots. The pattern is dense if the object is far away and spread out on objects near the camera. [31]

Depth sensors enables capturing of 3D data independent of ambient lightning conditions, relating the 3D objects surface position to the camera. In motion capture applications depth sensors are preferred over RGB cameras since segmentation and background subtraction is more accurate and considerably easier. Depth information can also be extracted from an RBG image. However, the process is quite complex and computationally expensive. [23]

In the following subsections a couple of widely used commercial available motion sensors are presented. A comparison of the devices is found in subsection 2.2.5. This project focus on the use of the Kinect sensor as a rehabilitation tool, since it fulfills the requirements of the rehabilitation tasks.

2.2.1 Microsoft Kinect

Kinect is a line of motion sensors developed by Microsoft compatible with Windows PCs, Xbox 360 and Xbox One consoles. The device is a black rectangular box with a camera, sensors and a microphone, connected to a small base, usually placed on a shelf or table near the TV screen. The webcam-styled system allows the users to interact with the console or computer through body gestures and spoken commands without needing a game controller. The tools and APIs needed for development of Kinect-applications are provided by the Kinect for Windows SDK, programmed with languages C#, C++ or .Net. The Kinect Windows SDK enables developers to access body joints information from skeleton tracking. [23]

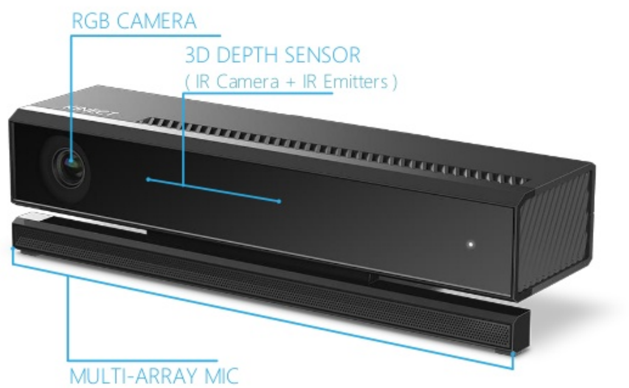


Figure 2.1: Visualization of a Kinect 2.0 sensor. [32]

The latest Kinect model is the Kinect 2.0 sensor, see figure 2.1. Its features of voice recognition functionality and motion tracking is vastly improved, a HD camera has been added and the field of view is wider than its predecessors. A comparison between Kinect for Windows 1 and Kinect for Windows 2 is presented in table 2.1.

Table 2.1: Comparison between features of Kinect for Windows 1 and Kinect for Windows 2. [33] [34]

Feature	Kinect for Windows 1	Kinect for Windows 2
RGB camera resolution	640 x 480 (30 fps)	1920 x 1080 (30fps)
Depth camera resolution	320 x 240	512 x 424
Max depth distance	$\tilde{4}$.5 m	$\tilde{4}$.5 m
Min depth distance	$\tilde{4}$0 cm	$\tilde{5}$0 cm
Horizontal field view	57°	70°
Vertical field view	43°	60°
Tilt motor	Yes	No
Skeleton joints defined	20	25
Full skeletons tracked	2	6
USB standard	2.0	3.0
Supported OS	Win 7, Win 8	Win 8, Win 8.1, Win 10

The Kinect device features a RGB camera, depth sensor and a multi-array microphone, see figure 2.1. It uses a technique called structured lightning which is a computer vision technique to capture motion data to interpret specific gestures and body movements [35]. This is accomplished by the depth sensor that contains an infrared projector and a monochrome CMOS (Complementary metal–oxide–semiconductor) sensor. The Kinect sensor can recognize and track 6 peoples skeletal information at the same time. The skeletal information includes orientation and position of 25 joints per active individual, see figure 2.2. In order to be recognized the individual must face the sensor and the joints need to be visible by the camera to be tracked. Skeleton information cannot be maintained behind furniture and other obstacles. [23]

The Kinect 2.0 sensor captures infrared, depth and full HD resolution (1920 x 1080) RGB streams at 30 fps. The Infrared and depth stream resolution is 512 x 424 and the 13-bit depth corresponds to 8192 different depth sensitivity levels. The RGB stream frame rate mode is 16:9 in color format YUY2 and comes in 16-bit resolution, i.e. 4096 different colors (4 bits for each R, G and B component) with 16 levels of transparency per color. The depth map and RGB data are synchronized internally by the sensor. [36]

2.2.2 Leap Motion

Leap is a motion sensing device manufactured by the American company Leap Motion. It is a USB peripheral device, usually placed on a table or desktop in front of the screen of a PC or notebook, see figure 2.3. The device contains three infrared LEDs and two monochromatic IR cameras and has a field of view of a hemisphere with radius of about 1 m. [23]

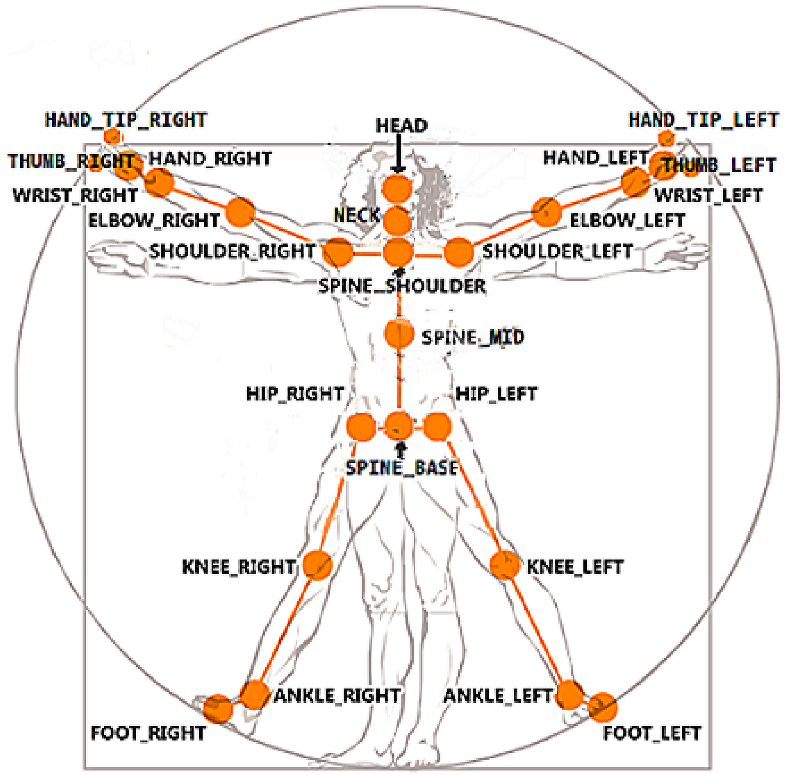


Figure 2.2: Visualization of the joints possible to track with a Kinect 2.0 sensor. [24]

Leap utilizes 3D modeling with finger and hand motions as input in order to mimic conventional computer input devices that requires hand contact, such as mouse and keyboard. The Leap can also detect and track tools, such as a pen, and provides information of tracked position, velocity and direction. [23]

Figure 2.3: Visualization of a Leap Motion sensor setup. [37]

2.2.3 Xtion Pro Live

The Xtion Pro Live was released by Asus in 2012, see figure 2.4. It is a motion capture device compatible with PCs with support for the game engine Unity3D. The device uses adaptive depth detection with an infrared sensor to track body movements. Xtion can detect whole body gestures and hand gestures as well and register voice commands through a microphone. With the OPNI NITE-compliant SDK motion-based applications and games can be developed. There are more than 8 predefined body poses in the SDK used to operate the user interface, such as click, circle, push and wave. [38]

Figure 2.4: Visualization of the Xtion Pro Live. [38]

2.2.4 Intel Creative Camera

Intel's motion sensor Creative Senz3D was released in 2013 intended for PC use only. The device features a depth sensor, HD webcam and a dual array microphone, see figure 2.5. It uses advanced depth sensor technology for close range tracking of upper extremities, such as finger and hand gestures. The microphone also enables voice recognition. [39]

Creative Senz3D provides 3D positions of objects relative to the cameras position similar to Xtion Pro and Kinect. The difference is that Creative Senz3D uses the technique time-of-flight in order to determine distance, i.e. the time required for light to travel to an object within the field of view of the device and reflect back from its surface. As a result, the edges are sharper but at lower resolution compared to Kinect. [39]

Figure 2.5: Visualization of the Creative Senz3D control. [39]

2.2.5 Comparison of motion sensors

A comparison of the presented sensors in section 2.2.1-2.2.4 is shown in table 2.2. Each sensor has different specifications and applicable field and should be chosen according to the requirements of the application. The Kinect and Xtion Pro live sensor is preferable for whole body or lower limb motion tracking in a space about the size of a living room. The Leap motion sensor has a smaller observation area with higher resolution and is thus more suitable for finger/hand tracking. Intel Creative camera is more desirable for tracking upper extremity exercises applications.

The Kinect sensor was chosen for the application in this project because it offers full body tracking with good enough precision for rehabilitation at an affordable price for private users. It also has the ability to track up to six bodies at the same time, which enables the creation of multi user exercises.

Table 2.2: Comparison of features of common commercial available motion sensors. [23]

Feature	Microsoft Kinect	Leap Motion	Xtion Pro Live	Intel Creative Camera
Size	25 x 6.5 x 7 cm	7.5 x 3 x 1 cm	18 x 4 x 5 cm	11 x 5 x 5.5 cm
Frame Rate	30 fps	30 fps	30/60 fps	30 fps
RGB resolution	1920 x 1080	N.A.	SXGA (1280 x 1024)	1280 x 720
Depth resolution	512 x 424	N.A.	VGA(640 x 480), 30fps QVGA(320 x 240), 60fps	QVGA(320 x 240)
Sensing range	0.5-6 m	0.025-0.6 m	0.8-3.5 m	0.15-0.4 m
Field of view	60° (Vertical) 70° (Horizontal)	N.A	45° (Vertical) 58° (Horizontal)	73° (Diagonal)
Tracking	Whole body	Hand/finger/tools	Whole body/hand	Hand/object

2.3 Chronic obstructive pulmonary disease

Chronic obstructive pulmonary disease (COPD) is an obstructive lung disease caused by lung damage, resulting in that the airways becomes narrower than normal. In Sweden between 500 000 – 700 000 suffers from COPD, which is about 5-8 % of the total population [40]. Presumably, 50 % of the people whom has been smoking for several years will have developed COPD at the age of 75 [41]. There is no cure for the disease and the damage that has already occurred to the lungs cannot be repaired. The medical cost for COPD alone in Sweden is 9 billion SEK each year [42]. Of these 9 billion SEK, 42 % stands for direct costs for medication, doctor visits, hospital stays, oxygen therapy and so on. The remaining 58 % is allocated to indirect costs such as sick leave [42]. This number will only increase with time if no measures are taken since more and more people get older and live longer.

The main symptoms of the disease are difficulties breathing, tiredness and coughing and sputum production. Weight loss, osteoporosis, cardiovascular disease, urinary incontinence, as well as depression and anxiety are other problems that affect COPD patients. The disease is caused primarily by smoking and develops slowly over several years. In the beginning, the disease is associated with mild discomfort. However, with continued smoking the disease worsens and can result in difficulties coping with everyday life. Therefore, the medical treatment is focused on preventing further deterioration and destruction of the lungs. However, quit smoking is the most important step to hinder the progression of the disease. COPD can also affect non-smokers. There is a hereditary disease, which entails a lack of a protecting substance (alpha 1- antitrypsin), that increases the risk of COPD. Furthermore, passive smoking, large amount of dust particles and gases in certain environments can result in COPD amongst non-smokers. [41]

In addition to structural and functional changes in the respiratory system, COPD can also impact other parts of the body through systemic effects. This is because the body's cells do not receive enough oxygen due to the reduced breathing ability. Blood circulation is affected by chronic respiratory failure, as is the kidneys and heart vascular system (especially the pulmonary circulation and the heart's right ventricle). A systemic effect demonstrated in many COPD patients is skeletal muscle dysfunction. It has been shown that the musculature, mainly in the lower limbs, is both weaker and less durable. [43]

To avoid further muscle degradation, physical activity is a substantial part of the treatment. Even small improvements can mean a lot. At least 30 minutes of physical activity per day is recommended [42]. Both cardio and strength exercises are needed to increase the physical capacity and to maintain quality of life. The training must be adapted according to the severity of the disease and the capabilities of the individual. General physical exercise is encouraged, such as walking, biking and water aerobics. Most patients have physiotherapy as part of the treatment. The physiotherapists provide the patients with COPD specific rehabilitation exercises that should be performed daily. It is however not feasible to have a physiotherapist present during each rehabilitation instance. Hence, a better solution would be to use a validated ICT tool to register the movement pattern and provide feedback to the user.

2.4 Stroke

Stroke is a state in which the parts of the nerve cells in the brain has suffered damage due to lack of oxygen. This state is caused by cerebral hemorrhage or cerebral infarction. Each year there are about 30 000 cases of stroke in Sweden. More than 80 percent of those affected are over 65 years old. In each stroke case there are a series of needs which all require resources. For example health care and home care services, but also the costs that arise when the patients are forced to stop working, which entails a loss of production. The total cost for the society is 16,1 billion SEK each year, or 741 000 SEK per stroke patient. [44]

The body's physical and cognitive abilities and personality are affected by a stroke.

How the body is affected depends on which part of the brain is affected and to what extent. A common physical complication is when half the body becomes paralyzed. The degree of paralysis can decrease to some extent with time, especially in combination with proper rehabilitation. Through rehabilitation the patient can regain some of their lost abilities and learn to cope with and compensate for residual disabilities. Rehabilitation is also important for reducing recidivism and increase long-term survival after stroke. [45]

3
Methods

The elaborated home based rehabilitation platform consists of a Kinect 2.0 sensor, a computer with software and a display. The reason for this setup is that the equipment could be easily presented to the user. Provided that the user already has a screen and a computer, the software and the Kinect sensor can be delivered to the user in a reasonably small box at an affordable cost.

The games were tested continuously during the development of the platform system and modified in order to implement the exercises in a good manner. Alongside the development of the platform layout, were the integration of other related and connected systems. A server connection was established through Rest API implementation and a video-conferencing service was added.

3.1 Platform development

The games were produced in collaboration with rehabilitation specialists. The inspiration for several of the exercises came from professor Margareta Emtners document of standard rehabilitation exercises for COPD patients with sketch figures demonstrating the exercises. Ten exercises were picked from the program and remade into Kinect games. Physical rehabilitation is essential for both stroke and COPD patients. Thus, the chosen exercises includes a variation of strength, cardio, mobility and stability training for different body parts. Cognitive training is also very important for stroke patients and therefore a couple of cognitive exercises were also created. The theory behind two of the stroke related games were developed by occupational therapist Jurgen Broeren. Other exercises were inspired by commercial games and common real life sport activities.

All software code for the home based platform were written in C# and XAML due to the software requirements of the Kinect for Windows software development kit (SDK). The Kinect SDK was used to a wide extent to access for example the Kinect depth sensor technology of locating and tracking joints with the sensor. Most parts of the interface layout were written in XAML code and the dynamic code were written in C#.

For simplicity, the exercises were developed as alternate reality games, using the real world as a platform. The Kinect sensor projects an image of the surrounding onto the screen. The user sit or stand up (depending on the exercise) at an appropriate distance away from the sensor so that the entire body is reflected on the screen. In the game mode, 2D images are placed on the screen in order to activate the user. The user's task is to interact with the object using different body parts. The placement of the images and the target joints in question determine the type of exercise.

Each game is based on a specific pattern of motions. In order to assess if the user performs the exercise correctly, the entire exercise execution is first divided into sub-parts and a start and stop position is defined. Motion orientation and guidance controls specific for each exercise with consideration to the defined steps and points, were implemented in the code to ensure the correct execution. The guidelines were created to emulate regular instructions that are normally provided by the therapists in a rehabilitation session. Other corrections were implemented in order to prevent cheating movements, detected when observing test subjects playing the games. Some of the controls inhibit the progression of the game until the proper motion has been achieved. Other controls provide user guidance through text and voice instructions when the functions are triggered by specific movements.

After a few rehabilitation exercises were implemented, the initial collection and analysis of data for performance assessment was conducted. Functions and algorithms were developed to collect essential data in real-time. Some of the collected data is presented at the end of each game through visual feedback stating the obtained result. Position data of each joint is collected continuously during the game, which can be used in the future for example to create 3D models or measure distances. Furthermore, an individual high score list was created to compare the results to previously achieved scores. The collected data of game results and assessment tests has been made available in the game environment for the user to access.

3.2 Platform interaction and connected systems

The user interacts with the system through hand gestures recognized by the Kinect Region, which avoids the need for additional control devices. The Kinect Region is an interaction area for Kinect applications provided by the Kinect for Windows SDK 2.0. The user activates the cursor by holding up an arbitrary hand to the camera and controls the cursor through hand gestures, such as grab, hold, slide and push. The practical function of the cursor has been tested and evaluated by several test subjects and modified to fit the user's desires.

A server connection were established by implementing a representational state transfer API service. The data collected in the games is transferred to the server for storage. The data can also be visualized and presented to the caregiver through a connected web-based server service explained more in detail is section 4.1. The web-based server service was created in the Strada-Stroke project and not handled in this project. However, the web-based server service is not fully developed and thus only partial information about the result can be found in the current state.

A video conferencing option was added to the platform by including a dll file containing operational functions for a previously developed video conferencing system called Confero. The code were implemented in a fashion so that the platform can communicate with the web-based server service.

3.3 System testing and validation

The system platform with its functions, has been tested by several people during the progression of development. Most of them were "healthy" persons trying out the functionality. A first version of the games were created and tested, first by workers at Alkit Communications and then by rehabilitation specialists. The focus of the first tests were purely to check if the intended motions was achievable in the games.

The rehabilitation specialists offered guidance of how to adjust the levels of difficult in the games and how to perform the exercises correctly. From the gathered information, new implementations were made. Ten different levels were set for each game and visual guidance was provided for some of the games. Assessment tests designed for COPD patients, employed to assess the current state of the patient's health, were also added to the functionality of the platform after input from the rehabilitation specialists.

In a second round, three real patients tried out a selection of the games. The participants provided feedback of their experience of the games and suggested improvements. However, no larger systematic evaluations have been performed which requires ethical approval. By observing how the participants performed the exercises given the limited guidelines, new ideas for guidance and cheating precautions were acquired. These motion restriction functions and instructions were implemented in the final version. Voice instructions were also recorded and added in the last step. Due to lack of time, the final version was only tested by workers at Alkit Communications.

3.4 Posture correction function

Investigation and implementation of posture correction functions was performed in the final stage of the project. The goal was to create posture correction functions that can detect improper postures within the game environment. It is important to maintain a proper posture while performing rehabilitation training to obtain full benefit of the exercise. Four different posture scenarios were investigated:

- A normal upright posture, used as control
- A hunched forward posture
- A hunched backwards posture
- A tensed shoulder posture, i.e. the shoulders raised upwards.

The objective was to determine if it is at all possible to detect small changes in posture based on data point positions of joints provided by the sensor in real time. Each joint position is described by a 3D coordinate system measured in meters with origo located at the center of the Kinect IR sensor. The x-axis is directed in a horizontal direction perpendicular to the camera and increases to the left side of the camera. The y-axis is the vertical component and the z-axis represent the horizontal direction in line with the cameras view.

Data from 8 different test subjects were collected and observed to locate patterns for incorrect posture positions. The test subjects were placed in front of the camera and told to maintain the four above stated postures, first while standing up and second while sitting on a chair. Instance camera space coordinates were collected from the head, neck, shoulders, mid-spine, hips and knees generated by the sensor. The normal upright position was used as a control to which the improper position data was compared. The obtained correction functions were however never tested in practice due to lack of time.

4
Results

4.1 Technical system overview

The rehabilitation platform consists of three systems with integrated components:

- The caregiver's planning and follow-up system
- The patient's gaming system
- The server/web system

The caregiver's system consists of a web-based server service, one for stroke patients and another one for COPD patients. Each caregiver has a user account on the system with access to planning tools and progression reports on the associated patients accounts. The website enables the caregiver to design rehabilitation programs, based on the developed exercises and assessment tests, that can be adjusted for each individual patient needs and condition. An integrated audiovisual communication system enables the caregiver to interact with the patient through live video and audio. A video of the screen image is then sent back to the caregiver's side, so that the caregiver can visualize the same view as the patient and provide feedback when the patient is performing different tasks in the game. The result and session information of each performed exercise is visualized in the and progression of the executed exercises are visualized by graphs and tables on the website.

The patient's gaming system is a stand-alone software application running on a computer in the patient's home. The game has two settings, on guest setting and one patient specific setting. A guest player can access all the developed exercises from a menu and adjust the level by choice. The guest setting does not require Internet access since the result from the performed exercises is not recorded. The patient specific setting is accessed with the username and password from a QR-code from the registered patient account on the web-based server service. As a specific patient the only accessible exercises are those exercises that are planned for the day on the web-based server service. The patient specific setting requires Internet access to maintain its connection to the server and to support video-mediated communication with a caregiver. During a video conference, a small video displaying the caregiver appears in the lower right corner of the screen so that the patient can perform the exercises while conversing with the caregiver.

The server system operates as a memory storage of patient specific information that can be transmitted between the patient's and the caregiver's system. The server is used to store patient information, such as planned exercises, result from exercises and assessment data. Once the caregiver has planned a patient specific rehabilitation program on the web-based server service, the information is sent and stored on the server. The information of the daily planned exercises are obtained at the game platform and the result of the executed exercises are sent back to the server. The high score information of each exercise is however stored locally on the computer hard drive for each specific user.

The game platform operates as a client with connection to the server through the use of an implemented Rest (Representational state transfer) API service. The Rest API works as a uniform interface between the client and the server and enables resource-based representations to be transferred between them. Each call from the client side consists of a HTTP message, mostly HTTP POST calls, with JSON as the object transport protocol inside. The generated response also has the same protocol. A session on the server is initiated and a session ID is generated through a login call containing the patient's username and password as parameters. In the following calls the session ID needs to be sent along for each interaction to transfer information. The session is ended once a logout call has been made.

The Rest API in this particular case is used to collect daily exercise data for the specified patient and report back the result of all the completed exercises. Furthermore, reported results from completed exercises during a specified time period can also be accessed. This service is required to generate the result information displayed on the client side and on the website.

4.2 Software and hardware

The game application is developed using the Kinect for Windows SDK 2.0 version 2.0.1410.19000, that support voice and gesture recognition based on Kinect sensor technology. The operating system is required to run Windows 8, Windows 8.1 or Windows 10 and Windows Embedded 8 Standard with 64-bit processor to support the SDK. Furthermore, the SDK can only be used in the software development environment Windows Visual Studio 2012 and later versions. The recommended hardware configuration from Microsoft using the Kinect are listed here:

- 4 GB RAM or higher
- Physical dual-core 3.1 GHz processor or faster
- DX11 capable graphics adapter

The Microsoft Kinect 2.0 sensor has to include a USB cabling and power hub to interact with a computer system. The sensor connects to the computer through a USB 3.0 port or through a USB 3.0 host controller adapter that is Windows 8 compatible and supporting Gen-2.

The video conference system Confero is programmed to operate for the same conditions as the Kinect sensor. The system utilizes the first prime detected speaker unit unless the dll configuration settings are set differently. The configuration settings can be changed in case the prime detected speaker unit function is not satisfying.

The Rest API service requires network connection in order to send and receive information from the server. The patient rehabilitation platform operates better with higher broadband rates, due to the lack of system drags. A calling operation is interrupted and render an error message if the call cannot be completed within the time limit of the Rest API service.

4.3 Patient's game interface

A flowchart over the interface structure is presented in figure 4.1. At the beginning of each exercise session the start screen appears, giving the user two options: to play as a guest player or as a specific user. There is also an option button at the start menu, where the settings for the game environment is set. The three choices of game environment are: color, infrared and skeleton view. The color environment is a color projection background of the room captured by the camera in real time. The infrared option is a camera projection, similar to the color option, where the background is a grayscale image captured by the IR camera with lower resolution. In the skeleton view, the entire background is dark gray and the body is represented by a line skeleton of the tracked joint positions from the sensor.
A guest player has free access to all the developed exercises and does not require Internet access to play the games. The guest player selects one game at a time by scrolling through the menu of exercises. Information about each exercise is presented after the selection of the exercise in question. The information layout consists of a written description and an instruction video with clear directives of the aim, purpose and execution of the exercise. The level is set by the user, by closing the hand around a slider and pulling it sideways to the desirable level. The game session is initiated by clicking the start button and the obtained result is displayed on the screen at the end of the session. None of the result is saved and no new high scores can be obtained in guest player mode.

A game can be interrupted in mid-session if the "stop-move" is performed during the exercise, returning the view to the game menu page. To perform the stop-move, the left hand is placed on the right shoulder and the right hand is placed on the left shoulder.

Each patient has a personal user account which is created and maintained on the web-based server service by the caregiver. In the "Select User" category the patient can login to that specific account to perform the planed daily activities and access personal stored result data in the "Result" category. The initial menu layout when logged in is general for all patients. However, the information and functions within each subcategory is centered around a specific patient group, i.e. COPD or stroke in the current state. The scheduled exercises for the day are available under the "Daily Exercises" category. These exercises are scheduled by the caregiver as a recommended daily amount of Kinect rehabilitation. Beyond the daily exercises, the caregiver can also recommend exercises which are optional for the patient to perform in case the patient wants to do more. These are found in the "Optional Exercises" category. Information displayed about the exercises are similar to the ex-

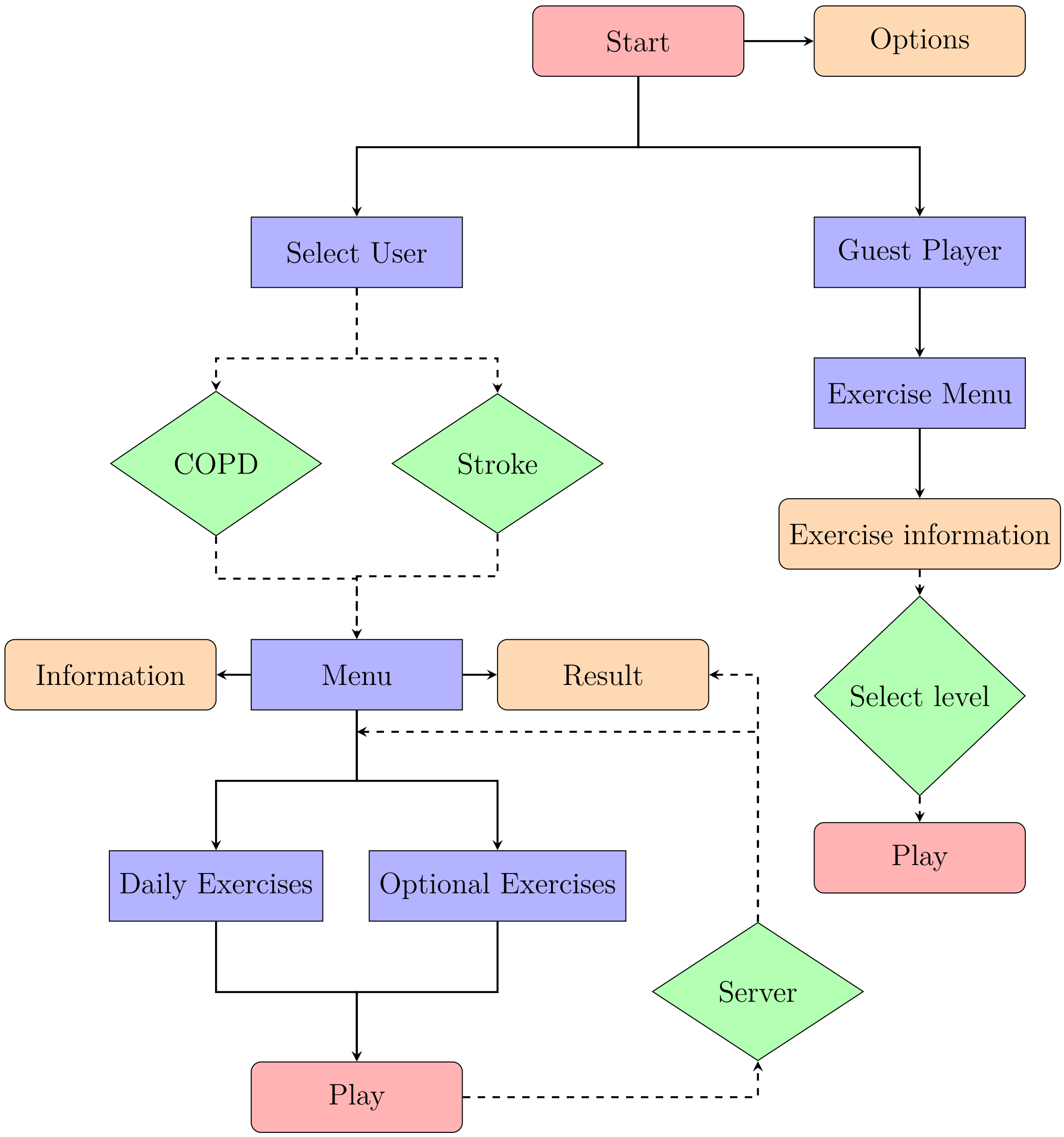


Figure 4.1: Flowchart of the game interface.

ercise information in the "Guest Player" category. Although, there is no option for level adjustment since the level settings are predetermined on the web-based server service.

The exercise session is initiated by pushing the start button. Once an exercise session has ended, the result of the game is presented on the screen and information and data about the exercise is sent to the server. Furthermore, the final score is compared to the current high score stored locally on the hard drive. If the new result is better than the previous set high score, a positive feedback illustration is displayed on the screen indicating that a new high score was set. The high score list is individual for each user and the game high scores are set separately for each level. If the game is interrupted during the session by performing the "stop-move" as mentioned above, the user interface goes back to the selected user menu and no result of the started session is recorded.

The "Information" category contains information regarding the patient's specific disease and the "Result" category displays patient specific results from gathered server data. The high score is one of the subcategories in the "Result" category. Another subcategory contains the information about the performed activity the past 30 days. Data from the past 30 days are collected from the server and presented in a list, with the name and level of the executed exercise and the number of times the exercise has been performed on that level. These two subcategories are featured for both COPD and stroke users. In addition for COPD users, there are visual graphs displaying the result from the assessment tests (see section 4.5 for details) completed during the past two months. For each graph there is a text description on the side, explaining the features, function and purpose of the test.

The user interacts with the game through hand gestures recognized by the Kinect sensor within the so called "Kinect Region". It recognizes the active users hand movements and mirrors a hand cursor on the screen at the tracked position, see figure 4.2. In the cursor function provided by the Kinect for Windows SDK 2.0, button clicking is performed by placing the hand cursor over the button and moving the hand forward in a pressing motion. While the hand is being pushed forward, the cursor is filled with color to indicate the progression of the press. There is also a visual state of the cursor that indicates when the user has pressed enough to complete a click followed by a manually added clicking sound effect.

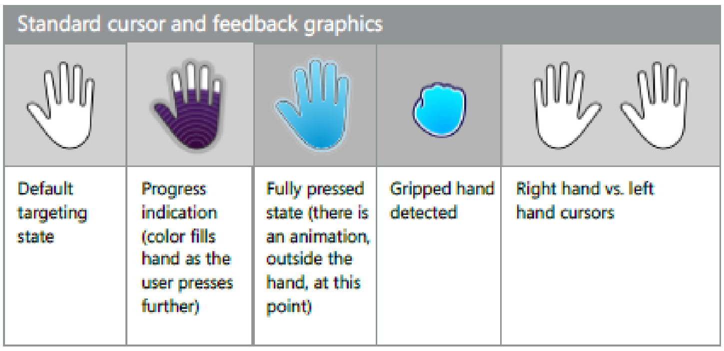


Figure 4.2: Visualization of hand cursor states operated within the Kinect Region.

In the previous versions of Kinect, the click function was performed by a click on hover feature. However, the click on hover feature was removed from the Kinect for Windows SDK 2.0 due to research indicating that the pressing motion is a better interaction model [46]. However, several users prefer the click on hold feature since it is easier to handle. Through some manipulation of the code, it was possible to recreate the click on hover feature with Kinect 2.0 as well. Visual feedback is provided in form of a green loading indication on the hovered button and a click sound effect is applied after the performed click. The hover time over the button necessary for performing a click is set to 2.5 seconds.

4.4 Developed games

A comprehensive variation of exercises is essential for creating an adapted person centered rehabilitation program. Each individual has different requirements depending on the state of the disease and their personal physical and mental abilities. In total 16 different games has been developed specifically for rehabilitation purpose of COPD and stroke patients in collaboration with specialists within the area. The main focus of the exercises is to improve the physical and/or mental health of the user and thereby facilitate the performance of daily life activities.

Descriptions and functionality of the developed games are presented in the following subsections. Each exercise involves a specific moving pattern and the games are developed in a fashion so that the subject is basically required to follow the pattern accordingly to complete the exercise. This is maintained by regulations coded into the game and through verbal and visual guidelines provided in game session. Initial placement instructions are provided at the beginning of each game session and some position data is recorded at the start for guidance and movement control purpose during the game.

Each game has 10 different levels, where level 1 requires the least effort and level 10 is the most difficult setting. The successive increase of difficulty is particular for each exercise and described further in the sections below. The games are performed standing up or sitting on a chair depending on the subject's physical capabilities and condition. Hence, the difficulty of the games can also be adjusted by alternating the user's performance positions. The start position in the simplest case would be sitting on a chair with the back up against the backboard. Next step would be to sit on a chair with no backboard and then standing up as a final step. To aid the balance in the standing position a chair or likewise object can be used as support. Thus reducing the risk of falling. To increase the load further, the subject can hold dumbbells or likewise options in the hands, or use elastic rubber bands while performing the exercises.

4.4.1 Picking Bananas

The aim of the game is to pick as many bananas as possible as fast as possible. The subject reaches for the banana, which is placed an arm length above the shoulders, using one hand at a time. The position of the banana is set at a physical distance from the shoulder location translated into scaled pixel coordinates on the screen. Thus, the distance is the same, regardless of the environment or the subject's position relative to the camera. After each picked banana both hands need to be lowered below the waistline before the next banana appear as a cheating precaution. If the arms are not stretched directly upwards to pick the banana, a voice command is given to correct the movement.

Picking Bananas is performed in a sitting or standing mode. From this exercise the subject gets mobility training in shoulder joints and stability training for torso/back. The quantity of repetitions increases and the speed enhances gradually in each level. At the end of the session the fastest speed, average speed and the number of taken bananas are presented in text on the screen.

4.4.2 Picking Apples

The aim of the game is to pick as many apples as quickly as possible. The apples are placed at a horizontal distance from the shoulders. The apples on the right side are picked with the left hand and the apples on the left side are picked with the right hand. A vocal guidance is provided if the user reaches for the apples with the wrong hand. Between each picked apple, both hands must be brought back to the center of the body before the next apple appears as a cheating precaution.

Picking Apples is performed in a sitting or standing mode. The distance of the apples position from the shoulders increases with the levels and so does the speed and number of repetitions. In this exercise the user practice mobility training in shoulder joints and stability training for torso/back. If the subject is standing up while performing the higher levels the exercise also provides leg strength or balance dependent on the feet distance separation. At the end of the session the fastest speed, average speed and the number of taken apples are visualized on the screen.

4.4.3 Nodding Balloons

The aim of the exercise is to nod as many balloons as quickly as possible. The subject starts of from a sitting position and stands up in order to nod the balloons that appears directly above the head. While the head is in position with the balloon a regulation control checks the position of the hips in relation to the head to ensure that the subject is standing up properly when nodding the balloon. Thus, the balloon is only taken when the subject is fully stretched. The next balloon appears once the subject sits down again on the chair.

This exercise is for leg strength training, especially in the quadriceps. The number of repetitions increases for each level. At the end of the session the fastest speed, average speed and the number of nodded balloons are visualized on the screen.

4.4.4 Boxing

The exercise is performed while sitting on a chair or standing up with the hands placed in defensive position. Target boards appears at random location within a restricted area around the upper body with equal amount placed on the left and right side of the head. The aim is to hit the targets as fast as possible by punching them with one hand. After punching the target both hands must once again be placed in defensive position before the next target appears. Guidance will also be provided if the subject is not holding up the hands in a defensive position.

The exercise provides mobility training in the shoulder joints, as well as endurance strength in the arm/shoulder muscles. The speed and the repetitions increases with the levels. At the end of the session the fastest speed, average speed and the number of target hits are presented in text on the screen.

4.4.5 Kicking Footballs (sitting down)

The subject is sitting on a chair or standing up while performing this exercise. One football at a time is placed at a distance alternately above the left and right foot. The aim is to kick as many footballs as quickly as possible. If the subject moves both feet a specific distance forward compared to the initial starting position, a voice command is given to move back. A restriction control also checks that the active foot is brought down to the floor again after kicking the ball before the next one appears.

At the lower levels the footballs are placed closer to the feet. The repetition and speed increases for each level. The exercise provides endurance strength of the quadriceps and stability training for the torso/back. At the end of the session the fastest speed, average speed and the number of kicked footballs are visualized on the screen.

4.4.6 Kicking Footballs (standing)

Kicking Footballs is performed while standing up. A football falls from the top of the screen and the goal is to keep the ball in the air as long as possible. This is achieved by kicking the ball with the feet or knees while moving sideways in order to align the body to the position of the ball. If the subject changes position related to the camera drastically during the game a voice command is given to move back or forward depending on the change. This exercise provides balance training, coordination and to some extent leg muscle strength. The speed of the ball increases at higher levels. At the end of the session the number of kicks and the total game time with the ball in the air is presented on the screen.

4.4.7 Avoiding Airplanes (stationary)

The subject stands up, positioned in the middle of the screen. An airplane flies across the screen around the same height as the subject's head. The aim of the exercise is to dodge the airplanes by bending the knees while it passes by over the head. It is important that the dodging technique is correct, i.e. the user must bend the knees and not just lean the upper body forward. To correct this behavior guidance is provided through voice command when necessary.

The exercise is executed in standing position. A chair can be placed on either side of the subject in case balance support is desired. It is important that the chair is placed on the side of the user in order to not block the visual field of the camera. The exercise provides leg muscle training and balance in case no support is used. The airplane flies lower at higher level so that the user needs to bend the knees further. At the end of the session the number of correctly dodged airplanes and the total number of dodged airplanes is visualized on the screen.

4.4.8 Avoiding Airplanes (with side-movements)

This exercise is similar to the stationary variant of Avoiding Airplanes. The aim is also to dodge as many airplanes as possible. The difference is that this version includes side way movements. The subject starts of in the middle of the screen inside a blue marked area. Once the subject is located inside that area, a new blue marked area appears at a distance on varying sides. When the subject enters the new area an airplane appears that should be dodged in the same way as the previous exercise. After the airplane passes the subject moves back to the blue marked area in the middle of the screen and the exercise is repeated. Just as in the previous case, the bending technique is of great importance and checked by a regulation control.

The exercise provides cardio, leg muscle and balance training. The distance from between the blue areas and the quantity of repetitions increases with the levels. At the end of the session the number of reached red platforms and the number of dodged airplanes is presented on the screen.

4.4.9 Head, Shoulders, Knee and Toe

The exercise is performed in standing or sitting position. A red line is drawn between the left and right hand with size and gradient depending on the distance between the hands. A wide blue area is marking the positions of first the head, then the shoulders, knees and toes and so on. The user's task is to shift the positions the hands to locate the red line inside the blue area. Once the line is inside the target area, the next blue marked position is displayed. After finishing one repetition of the defined moving pattern, with the toes as the last position, the subject has to straighten the back again to repeat the pattern.

The exercise provides mobility training in the shoulders, arms, torso, hips and legs. The main difficulty is the bending down to touch the toes part, especially for COPD patients whom may find the breathing troublesome when executing the motion. This motion is associated with daily activities, such as tying your shoe laces, putting on pants or picking up object from the ground. The height above the toes of the blue marker and the number of repetitions is adjusted for each level. In the end of the session the number of located areas are displayed.

4.4.10 Kicking Balls

Kicking Balls is performed in an upright position. Colorful balls are placed around the same height as the hips, alternating between the left and right side. The task is to kick the balls with the knees as fast as possible. After each kicked ball the leg has to be lowered to the ground once again before the next ball appears.

The exercise provides endurance strength in the quadriceps and can also provide cardio training in high levels. The height placement of the ball is moderately increasing with each level. The speed and repetition quantity increases with the levels as well. At the end of the session the number of kicked balls, the average kicking time and the fastest kicking time is displayed.

4.4.11 Stomping Mushrooms

The patient sits or stands while performing this exercise with both feet placed closely together. Mushrooms appears at a distance next to the feet, alternating between the left and right side. The patient's task is to stomp on the appearing mushrooms as quickly as possible. Once a mushroom has been stomped the feet must be placed closely together again for the next mushroom to appear.

This exercise provides mobility training in the hips, quadriceps strength, hip flexors and stability training in the torso/back area. The speed, number of repetitions and distance between the feet and mushroom increases for each level. At the end of the session the number of stomped mushrooms, the average stomping time and the fastest stomping time is visualized.

4.4.12 Pineapple Game

A pineapple is placed above the user's head and a blue line is placed a specified distance above the head. The users task is raise the whole pineapple above the blue line. This can be performed in two different ways depending on the user's initial position. If the user is standing up, the pineapple is raised above the line by performing heel raises. In this case the exercise provides training for the calves and balance if no support is used.

If the user is sitting down the exercise becomes more similar to the Nodding Balloons game but with a lower upraising distance. The level of difficulty in the sitting position is dependent on the user's feet placement. In a regular sitting position with the feet placed perpendicular to the knees, the game becomes purely an exercise for the quadriceps. By placing the feet closer to the center of the body almost underneath the chair, the user also activates the calves just as in the standing position. Thus providing training in both the quadriceps and the calves.

The blue line is removed once the pineapple is located above the line. The next line appears once the user has returned to the initial position. Balance support can be utilized if needed to reduce the risk of falling. The number of repetitions increases with each level. At the end of the session the number of pineapples detected above the line is presented.

4.4.13 Juggling

Juggling balls are falling on at a time from the top of the screen. The user's task is to keep the balls in the air for as long as possible using the hands to push them upwards. The game is developed so that the balls can only be pushed upwards at a limited angle interval in order to simplify the task of keeping the ball within the screen.

This exercise provides mobility training in the arms/shoulder area and coordination practice. The number of balls to juggle and the speed of the balls increases with the levels. At the end of the session the time period the balls were kept in the air is displayed.

4.4.14 Catching Rectangles

Rectangles are traveling in a horizontal direction across the screen. The rectangles are colored red until they pass the middle of the screen and turn blue. The red rectangles cannot be captured, only the blue once can be. The task is to capture as many blue rectangles as possible with the active hand marked by a purple dot. This dot can be transferred between the hands by bringing the hands together, thus changing the active hand. Each rectangle's y-position on the screen is adjusted to match a limited height span from the head, so that the user will always be able to reach it without extreme effort.

This is a planning and execution type of exercise designed specifically for stroke patients. The size of the rectangles decreases and the speed of the rectangles increases with the levels. At the end of the session the total number of captured rectangles, the amount taken with the left hand and the amount taken with the right hand is displayed.

4.4.15 Snake

The snake's head is controlled by the hand, first the right hand and in the second round the left hand. Initially the snake only consists of one blue dot. Smaller pink dots, which represent snake food, appear one at a time on the screen at different location. For each taken pink dot the length of the snake increases by one blue dot. The aim is to navigate the snake towards the smaller pink dots without crossing the tail. If the snake's head controlled by the hand crosses the blue tail line of dots the game ends.

This exercise practices coordination, strategy and planning. Furthermore, the exercise provides mobility training and endurance strength in arms and shoulders especially when controlling longer snakes. The pink dots appear closer to the body's location on the screen at lower levels, whereupon the user can sit while performing the exercise. At higher levels the pink dots are further away and therefore is a standing position more suitable. At the end of the session the length of the snake controlled by the right and left hand and the play time for each active hand is presented.

4.4.16 Bounce the Ball

The patient sits or stands while performing this exercise. A moving blue ball travels in one direction across the screen and only changes direction if touched by the user's hands. A black frame marks the game area which the ball should be kept within. The task of the game is to keep a blue ball within the frame for as long as possible. The ball travels in the opposite perpendicular direction from where the hand touched the edge. Once the ball crosses one of the edges of the frame the game ends.

This exercise practice coordination and planning. The speed of the ball and the size of the frame increases for each level. At the end of the session the total active time and the number of hand touches within that time is visualized.

4.5 Assessment tests

In addition to the rehabilitation exercises, three different assessment tests have been included for COPD patients. The assessment tests are made in order to determine the current state of the disease. The tests are called CAT, Borg CR10-scale and Balloon test. CAT and Borg CR10-scale are two validated and commonly used assessment questionnaires in clinical facilities. The Balloon test is a special developed test for this application used as an indication of the patient's current leg muscle capacity.

CAT stands for COPD Assessment Test and it is a validated questionnaire designed to measure the impact COPD has on the patient's health and daily life. There are 8 questions in total and each question is answered with a score ranging from 0-5. The result of the test is given by the final total score. A result ranging from 1-10 suggests very low impact, 11-20 suggests a medium impact, 21-30 suggest a high impact and 31-40 suggests a very high impact.

The Borg CR10-scale is a measurement of breathlessness. The patient's estimates their level of breathlessness from a scale ranging from 1-10, where 1 stands for no breathlessness at all and 10 represent extreme breathlessness. This test is performed after the last daily planned exercise is completed as a measure of the subject's work-out intensity experience.

The Balloon test is similar to the Nodding Balloon game presented in section 4.4.3. The patient gets up from a sitting position to nod the balloon, the sits down again and repeat. The goal is to take as many balloons as possible during 30 seconds. This exercise is endeavoring for the legs muscles and the result is therefore useful as an in indication of leg muscle strength.

The CAT and Balloon test is recommended to perform every second week and the Borg scale should be performed after every rehabilitation session. However, the operative caregivers can schedule the tests whenever they consider them to be appropriate for each individual patient.

4.6 Posture Correction

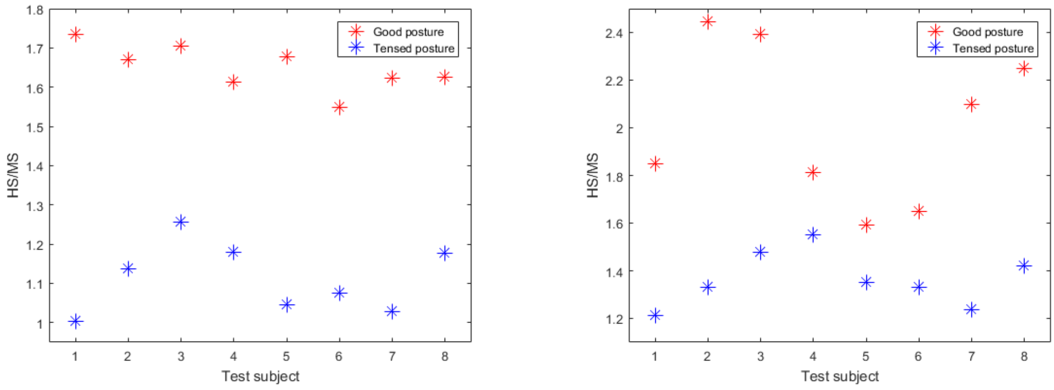
In order to have a functional posture correction function within a game without an initial calibration gesture, it is important to find measures that does not differ between subject. The collected data has been used to detected threshold value correlated to observed visual outstanding motion pattern in the improper postures. In the following subsections, the analyzed collected data results of the improper posture is plotted with the correct posture data as comparison.

4.6.1 Tensed Shoulder Posture

In the case of the tensed shoulder position, the shoulders are raised upwards towards the head which changes the y-position of the shoulders by a few cm. The normal y-difference in a correct posture position between the shoulder and an arbitrary joint such as the head, depends strictly on the physical appearance of the individual and differs a lot between different persons, which render it an inappropriate method for detection. Through analyzing the tensed shoulder posture and the result of the test subjects, two different ratios independent on the subject's physical appearance were chosen for further analyze as indication values for tensed shoulders.

The first ratio, denoted HS/MS, is the y-difference between the head and shoulders divided by the y-difference between the mid-spine and shoulders. An average y-value for the shoulders is used in order to compensate for possible shoulder rotations in relation to the cameras location. The calculated ratio values for the data points collected from the test subjects are displayed in figure 4.3. The mid-spine - shoulder difference (MS) becomes larger and the head - shoulder difference (HS) becomes smaller as the shoulders tenses and raises upwards. Therefore is the HS/MS quota smaller with this posture, which can be seen by the lower HS/MS quota for all subjects in this case. For subjects standing up, there is a clear difference in the HS/MS quota detected by the sensor between the correct posture and the tensed shoulder posture, visualized in figure 4.3(a). The result from the upright posture positions for the subject sitting down are more diverse compared to the same results generated from the subjects standing position. From the result displayed in figure 4.3(b), a threshold value dividing the proper and improper postures can be obtained. However, the division is marginal. The variance of the tensed posture values, displayed by the blue markers in figure 4.3(a) and 4.3(b), is a result of different levels of tenseness among the test subjects.

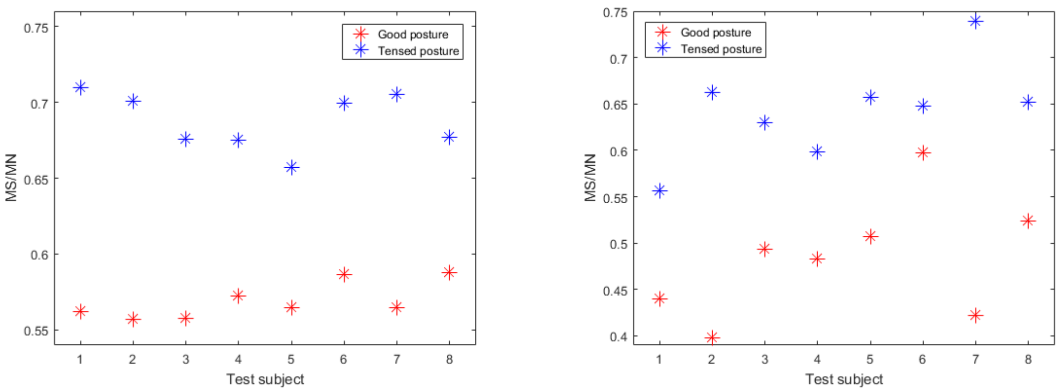
The second ratio, denoted MS/MN, is the y-difference between the mid-spin and the shoulders divided by the y-difference between the mid-spin and the neck. The calculated MS/MN ratios from the collected data points are presented in figure 4.4. The difference between the mid-spin and neck has about the same value for a proper posture compared to a posture with tensed shoulder. Since MS increases and MN remains the same, the MS/MN ratio becomes larger for tensed shoulders as seen by the results in figure 4.4. As the HS/MS ratio, the MS/MN ratio also appear more



(a) **(b)**

Figure 4.3: The HS/MS ratio calculated from the data points collected from the test subjects. The red marks represent the ratio of the subject's normal posture position and the blue marks represent the ratio of the subjects tensed shoulder position. (a) shows the result from the data points generated from standing subjects and (b) shown the result from the data points collected from subjects sitting down.

reliable for standing subjects from comparison of the results in figure 4.4(a) and 4.4(b).



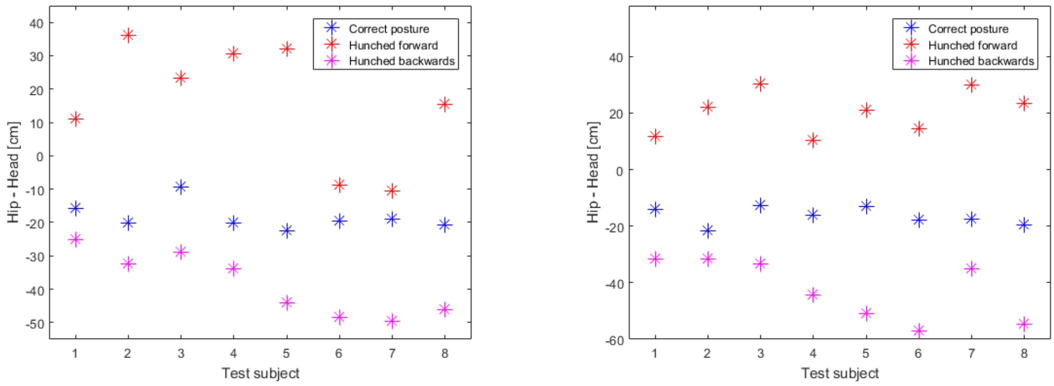
(a) **(b)**

Figure 4.4: The MS/MN ratio calculated from the data points collected from the test subjects. The red marks represent the ratio of the subject's normal posture position and the blue marks represent the ratio of the subjects tensed shoulder position. (a) shows the result from the data points generated from standing subjects and (b) shown the result from the data points collected from subjects sitting down.

4.6.2 Hunched Posture

If a person posture is hunched forwards or backwards the main visual detectable difference is the upper body's change in z-position in comparison to the hips. The results presented in figure 4.5 and 4.6 from 8 different test subjects in hunched positions demonstrate that this effect can be detected by the sensor.

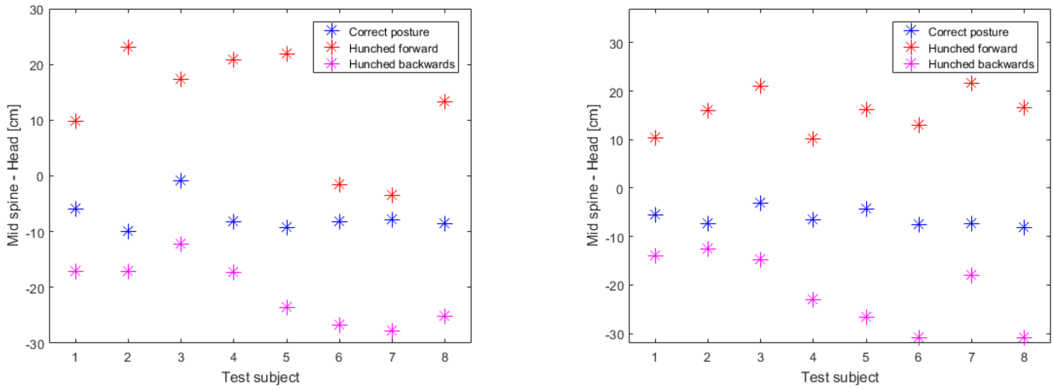
In figure 4.5 the z-position of the head in relation to the hips is displayed. The z-position value of the hips used in the calculations is an average value of the left and right hip. The average value is used to reduce the impact of body rotation in relation to the sensors position. The variation of the red and purple marks in figure 4.5 and 4.6 is due to the degree of forward/backward hunching of the test subjects.



(a) **(b)**

Figure 4.5: The z-position of the head in relation to the hip z-position, calculated from the data points collected from the test subjects. The red marks represent the hunched forward head position, the purple marks represent hunched forward head position and the blue mark represents the head position in a normal upright posture position. (a) shows the result from the data points generated from standing subjects and (b) shown the result from the data points collected from subjects sitting down.

In figure 4.6 the z-position of the head in relation to the mid spine is displayed. The data used in figure 4.6 is the same as the data in figure 4.5 which can be seen by the similar pattern of the marks.



(a) **(b)**

Figure 4.6: The z-position of the head in relation to the mid spine z-position, calculated from the data points collected from the test subjects. The red marks represent the hunched forward head position, the purple marks represent hunched forward head position and the blue mark represents the head position in an normal upright posture position. (a) shows the result from the data points generated from standing subjects and (b) shown the result from the data points collected from subjects sitting down.

4.7 Patient tests

The patients only tried out an early variant of the platform with limited guidance. However, the COPD patients had no problem playing the games. The stroke patient required longer time to grasp the concept of the games. However, the stroke patient's movements became faster and better with repetition, indicating that the exercises were relevant. Some of the game level settings in the first patient trial were set a bit too low and did not exceed the desired effort level. In the second round the levels were adjusted to suit the target better.

Most of the test subjects complained about the inbuilt click by push function, as being difficult to maneuver. Therefor the click by hold function was included in the later version of the platform. Only two of the patients had the change to try the click by hold function. However, the conclusion was that the click by hold option was more user friendly and a vital addition to the platform to avoid frustration.

The skeleton background option was preferred by many participants trying out the game. It provides better visual feedback of the tracked movements and is easier to understand and use compared to the color and infrared background options. Providing less visual feedback increases the level of difficulty since it requires the user to rely more on internal sensory perceptual orientation to control their movements.

In general, the feedback from the test subjects were positive. They thought that the games were entertaining and suitable for home based rehabilitation. It was concluded that the platform might not be desirable for all users and should thus be an optional alternative for those who wants it.

The clinicians evaluating the platform were excited to see the product. They thought it was innovative and showed promising prospects for the future. The clinicians were however concerned about the delivery process of the platform home to the patients. Who would install the device and provide the patients with operational instructions? An idea to introduce the platform to the patients at clinics and rehabilitation centers was put forward, so that the patients can familiarize themselves with the product before using it at home.

4.8 Kinect setup

The Kinect sensor cannot detect bodies and joints with obstacles blocking the sight. Thus, all support objects or added tools should be placed and handled in a fashion that does not distort the cameras view of the body.

In order to access the function of all developed games, the Kinect sensor must be placed so that the user's entire body is visual by the camera. The Kinect sensor is in its natural state tilted a little bit upwards. Hence, placement on a lower table or normal chair is recommended ($\sim$ 50 cm high), to include the lower parts of the body. The space required for each game is particular to each game. Although, a general rule of placement is around 3 m from the camera.

Reflective objects in the surrounding environment or clothing should be avoided they can impact the sensor's tracking ability. It is also stated in the user guidelines manual for the Kinect 2.0 that black clothes also can interfere with the skeleton tracking [46]. However, this effect has not been observed in this project for users with black clothing.

5
Discussion

The home-based rehabilitation system functions as a cross organizational cooperation, where the participation of different care and nursing unit actors is required. All actors involved can access selected information, adjusted for the actor's role in relation to the individual, from a distributed unit. The main focus is the patient's general condition, situation and needs. The purpose of the rehabilitation platform is not to replace the overall recommend rehabilitation activities, but to facilitate and enhance the patient's daily physical or cognitive activity.

The Kinect sensor does in general work well for rehabilitation at home. The tracking precision is not perfect which results in difficulty tracking really small movements. However, for the chosen exercises the precision is valid. Through the tracking of the Kinect sensor, the guidance provided in the game can mimic the directions provided by a real therapist. Thereby decrease the demand on therapist to assist in training. The system also allows for rehabilitation to be performed at home for those who have difficulty traveling back and forth to rehabilitation centers. Furthermore, the games provide a more entertaining environment for rehabilitation which helps motivate the patients.

Storing the results after each performed exercise and test enables therapists to monitor and follow up the progression in a new way. The level of difficulty can be adjusted individually for each patient and altered from input of the progression. The video conferencing system enables patient interaction with caregivers with the possibility to engage the patients more into their own care.

The participants feedback supported the use of the game-based platform for rehabilitation. The users enjoyed the exercises and provided suggestions on how to improve the system. One request was to include multiplayer exercises in the game, allowing multiple users to engage in the activity simultaneously. These games could be performed at the same location or at a distance through video-mediated communication. The addition of friendly interactions through conversation and peer encouragement is expected to make the rehabilitation more enjoyable.

A complaint from a few of the users testing the games was the inbuilt hand control with click on push function. The click on push interaction is harder to comprehend especially in the beginning and the motion requires a certain amount of aim to click the right button, which is more difficult for some patient groups. For this reason, the click by hold functionality was included so that the user can choose between the clicking methods. The click on hold function is easier to maneuver but takes longer time (2.5 seconds to click) and becomes tiresome for the arm to after several clicks in a row. An alternative could be to utilize the voice recognition function provided by the Kinect for Windows SDK to control the layout with voice commands.

Motion controls and guidance in the game is important for optimal rehabilitation performance. However, it is important to adjust the amount of regulations so that it does not impact the level of excitement the user experience while playing the games. The task of the motion controls developed in this project is above all to prevent cheating in order to ensure sufficiently good moving patterns and to provide guidance and feedback to the user when necessary without interfering with the game in an eminent manner.

It is not always possible to recreate the exact execution of a rehabilitation exercise into a game. An example of this is the Picking Banana exercise where the subject reaches for bananas placed above the head in the game. Outside the game-environment this exercise would be performed in a similar way by reaching the hand up in the air while following the location of the hand with the eyes. The added part of looking at the hands contributes mobility training for the neck muscles to the exercise. In the game-environment it is only natural that the user's eyes are fixed on the screen when interacting with the game platform. Hence, the otherwise performed neck-movements are hard to obtain in the game-environment.

The game is currently developed as a single player game. If only one subject is inside the field of view of the Kinect sensor, then that subjects automatically becomes the active user. However, the Kinect sensor has the possibility to locate 6 people inside the field of view at the same time, which issues a challenge in the game to detect the correct active user. No precautions to locate the desired user has been taken at the moment. The active user is randomly selected among the people inside the sensors field of vision. Anyone stepping into the game zone thus becomes a distraction that can potentially steal the focus away from the user. This prevents other locally present individuals to interact and give support to the user at a close distance, limited by the sensors visual range.

Posture correction guidelines for tensed shoulder postures has only been implemented for standing positions in a few selected games, using HS/MS and MS/MN threshold values to trigger the function. The result from the HS/MS and MS/MN ratios for sitting subjects showed to inconsistent to operate as indication values of improper posture. This could be due to the Kinect sensor's joint tracking working better with standing subjects or that the upper body's positioning of sitting subjects are different in comparison. Several other measures and ratios were also investigated to find usable threshold values for tensed shoulder postures. However, none of them proved to be reliable enough.

The most prominent examined detection methods for hunched positions presented in section 4.6.2 utilizes the hips or the mid spine as reference points. The disadvantage of these points as reference points to the head is that the original distance between the head and hip/mid spine in an upright posture position is dependent on the user's physical shape. Thus, a defined threshold value cannot be valid for all users. A solution is to use a calibration position to retrieve data necessary for the control to function for all users.

Addition of a calibration position at the start of each rehabilitation session could be used to collect individual data from the user. The data could be used to related predetermined positions in the games to the specific user's physical appearance. For example, by using the user's arm length as the height the bananas are placed above the shoulder in the Picking Bananas game, or the length of the thigh as the height the balloon is placed above the head in the Nodding Balloons game. This could reduce the risk of placing the object at a to short or an unreachable distance if the calibration measurements are accurate enough. However, if the calibration is not performed correctly the generated data could have an opposite effect, rendering the objects placements at undesired locations. Depending on the physical capabilities of the patient, a calibration position might be difficult to execute and maintain. If there is a fault in the detection of the desired distances in the calibration, due to sensor detection failure or an incorrect position of the user, the collected data could result in inaccurate guidance from the system or game failure. In addition, performing a calibration gesture at the beginning of each rehabilitation session can be thought of as annoying and time consuming. Consequently, no calibration process has been implemented in this project.

6
Conclusion

Neurological and chronic diseases have fundamental impact on a person's life, with lack of motivation and depression as common adverse effects. Rehabilitation is an important part of the treatment in most of the diseases. Motivating these patients by providing feedback and encouragements is very important in order to prevent that the daily process of rehabilitation become frustrating and less efficient. The purpose of the rehabilitation platform is not to replace the overall recommend rehabilitation activities, but to facilitate, motivate and enhance the patient's daily physical or cognitive activity.

A game-based platform was developed with functions and exercises designed for COPD and stroke patients. Initial assessment of the platform with clinicians, healthy test subjects and a few real patients demonstrated that the platform has potential to be used as a rehabilitation tool for home usage. The participants in the evaluation process provided valuable input on system improvement and refinements. Further development of the system and evaluation is necessary for the product to reach the commercial market.

The developed rehabilitation platform has the possibility to provide cost effective and improved continuity of care, reduce the need for travel, and encourage the performance of physical activities on a regular basis. Hence, this e-health service for home based care and rehabilitation, including video communication option with health care professionals, have a great potential to aid in the challenge with progressive demands of care due to an aging population.

7

Future work

In accordance with request from people testing the system, the next step in development would be to integrate multiplayer exercises. Local group exercises can be created for up to six people simultaneously using the Kinect SDK. In order to implement exercises at a distance, the video conferencing system needs to be adjusted to allow communications with other platforms and a communication link between the computers needs to be established. The communication link could for example be a known server which all game members computers connects to through ZeroMQ technique. The server could thus store body data and object positions vital for the game and transfer this information upon requests from the distributed computers. It would be interesting to analyse the effect of games with both collaboration and competition purpose with this setup.

A new process of logging in to the system should be established in order to increase patient security. For each patient created on the web-based server service a personal QR-code is produced. This code could distributed to the patient to display in front of the Kinect camera to login. As a result the patients would not need to remember any username or password.

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