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A Thesis Towards Development of an Occupational Therapy Game System for Stroke Patients

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A THESIS TOWARDS DEVELOPMENT OF AN OCCUPATIONAL THERAPY GAME SYSTEM FOR STROKE PATIENTS

by
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ABSTRACT OF THE THESIS

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Persons who have suffered from stroke participate in occupational therapy to help recover occupational functionality, but therapy is expensive and maximal recovery often depends on repetitive, tedious exercises to be done by patients both in therapy sessions and on their own. Often patients do not have the resources or motivation to complete the treatment required to give them the best results. This thesis is presented as part of a larger project in which we aim to enable occupational therapists to use the Looking Glass programming environment to create computer games for their patients that can be played inexpensively and effectively, both inside and outside of therapy sessions. Looking Glass will allow for occupational therapists with little or no programming background to write customized games for their patients. Through using Wii remotes and webcams to track movement and translate it to a computer game, this solution has the potential to provide a more engaging and interesting way for patients to correctly do repetitive movements without needing constant therapist supervision or expensive and complicated equipment. It also can provide

highly customizable and adjustable game settings to accommodate for the wide range of impairments that can result from stroke. This thesis presents a study of the needs of occupational therapists and stroke patients who compose the user base of the project and implications for the design, the development of a webcam color tracking system to be used for movement tracking in games, and an application to be used by therapists to assign specific, patient-tailored calibrations and game levels as part of treatments and to track and organize improvement statistics. These are all key components required for the successful development of the overall project.

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Dedicated to my parents

Paul Yang and Dori Jones Yang

for their endless love and support

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Chapter 1

Introduction

Stroke is the leading cause of chronic disability in the United States and often leaves victims severely physically and mentally impaired [13]. Because of the plasticity of the human brain, people who suffer from strokes can often recover a significant amount of functionality and generally do so by working with occupational therapists, physical therapists, and speech therapists in different capacities during the years following the stroke [13]. The treatments and amount of time required with professionals in order to regain maximal amounts of functionality are very costly, and every year billions of dollars are spent on stroke rehabilitation [9]. Although a stroke victim's impairments may be reduced, they are still often left with permanent disabilities and must learn how to be as independent as possible and how to adapt their lifestyles and the environment around them to allow them to rejoin the community and find ways to bring purpose and meaning to their life [13]. Occupational therapists help them do this, and also push them to continue regaining movement in their upper extremities by breaking down movement patterns and doing repetitive exercises during therapy sessions in order to remap muscle control in the brain [13]. While therapists encourage patients to continue doing these exercises at home, and successful recovery depends on them doing hundreds of repetitions a day, the exercises are sometimes tedious and unpleasant and therefore motivation to do them outside of therapy is frequently low or completely lost [2]. There have been studies aimed at remedying this problem by using games or virtual reality (VR), but they tend to either require expensive or hard-to-obtain equipment such as haptic gloves [10], or require movement beyond the abilities of most stroke victims because they are created for people with normal movement patterns (such as games for the Wii console [6]). Also, because the severity of impairment for stroke victims has a large range, it is very challenging to produce games that can be used with more than a small subset of patients [11].

Our solution is to adapt the Looking Glass programming environment to allow occupational therapists to create computer games that take movement tracking input information from Wii remotes and webcams, which are cheap, easily obtainable devices that are easily customizable so that they can be tailored to the specific abilities of a patient. Because the Looking Glass system is aimed at introducing computer programming to beginners, occupational therapists with little or no programming background will be able to make their own games. These games can be created for the needs specific patients or can accommodate a broad range of movement abilities through calibration of the input devices and different tracking techniques. Ideally, therapist-created games, will cater to the personal situation and interests of the patients and will motivate them to do therapy exercises at home by providing them with engaging games. The games will also be able to track progress statistics so that the therapist and patient can see improvement trends over time. Assuming that most people have access to a computer, the cost of using this system will be very low, requiring only the purchase of a basic webcam and a Wii Remote. The system will be inexpensive and relatively easy to use and configure, so it can potentially be used on a large scale for a broad range of disability types, especially for people who have limited access to much-needed rehabilitation resources. Although this project will be a long-term challenge, the work presented in this thesis has begun to explore this path and lay important foundations for the overall project.

This thesis presents three main contributions to this project in the following chapters. Chapter 2 explores the future user base of this system and the implications of the needs, techniques, abilities and expectations of these users for the design of the software and choices of hardware. Chapter 3 discusses the implementation and use of webcam color tracking for mapping 2D movement to interaction in games. Chapter 4 presents a basic application to be used by therapists to keep track of patient data, assign games and levels as take-home treatments, and to organize, view and analyze patient progress statistics that are logged by the games. I then conclude in Chapter 5 with a brief description of future plans for this project.

Chapter 2

Exploration of the User Base

Although we are working on this project in conjunction with the Occupational Therapy department at Washington University, as computer scientists we lack basic understanding of the values and needs of the target user bases that we are designing for. This project is being developed for use by two distinct groups of individuals: occupational therapists and stroke patients. The importance of understanding these two populations and the problems they face is critical for creating both a successful interface for therapists to create games and tailor those games for specific patients, as well as methods for patients to interact with the games and use them as part of their treatment. It is therefore necessary to have background knowledge in order to bridge the gap between computer-science thought processes and the occupational therapy mindset. Through closely cooperating with and shadowing occupational therapists, attending occupational therapy lectures, sitting in on user testing with stroke patients, independently studying and reading, and meeting with physical therapists, I am able to present a comprehensive knowledge base and identify design implications that will be highly instrumental in future interface and functional design of this project. The sections following provide a description of stroke, along with its risk factors, short-term and long-term effects, as well as background information on occupational therapy, occupational intervention strategies for stroke patients, and how occupational therapy differs from and cooperates with physical therapy. The chapter concludes with a discussion of implications of this research for the design of the system and relevant work done in employing the use of computers and virtual reality (VR) games in stroke therapy.

2.1 Stroke

Stroke, also known as cerebrovascular accident, is the sudden development of injury to the brain caused by the disruption of blood flow [13]. The two main causes of this disruption are ischemia and hemorrhage [9]. Ischemic strokes are a result of a cerebral vessel blockage due to thrombosis, which is the formation of a blood clot, or embolism, which is the migration of a blood clot through a vessel [9]. Hemorrhaging is when bleeding happens inside the brain or in surrounding areas [9]. Both ischemia and hemorrhage cause oxygen deprivation to the surrounding cells and result in the death or injury of brain tissue [13]. Ischemic strokes make up approximately 80% of all strokes, while hemorrhagic strokes account for the remaining 20% [13]. Although hemorrhagic strokes are less common, they result in a higher mortality rate [1]. The location of the lesion created as well as the size and cause determine what kinds of symptoms the patient will experience[13]. Lesions can be categorized as anterior circulation strokes, or posterior circulation strokes. Anterior circulation injuries show signs of hemispheric dysfunction affecting one side of the brain and body, and posterior circulation injuries show brainstem involvement symptoms, which affect basic vital life functions such as breathing [13]. Also, further distinction in regards to the location of the stroke is made by whether the lesion is the result of a large-vessel or small-vessel disease [13]. Small vessel strokes usually affect smaller portions of the brain and often have greater prospects for recovery [13]. Stroke is the third leading cause of death in the United States and is also the leading cause of chronic disability, especially in adults and the elderly [9]. In 1999, the American Heart Association estimated that the economic burden of stroke was approximately 51 billion dollars [9]. Stroke patients compose the most commonly treated client category seen by occupational therapists [13].

2.1.1 Stroke Risk Factors

Various non-modifiable and modifiable risk factors for stroke have been identified. The non-modifiable factors include age, gender, race, and geography [9]. The risk for stroke increases with age, with the rate increasing more rapidly after the age of 60 [9]. Men are more likely to have a stroke than women until the age of 85, when the pattern reverses [9]. A similar phenomenon is evident with race, where white people are less likely to suffer from stroke than other races until the age of 85, when it switches. African Americans have a significantly higher risk, with a ratio ranging from 1.8 to 2.0 for men and 1.7 to 1.9 for women when compared to the risks that white Americans face [9]. Although the role that geography plays is not very well understood, patterns of high stroke incidence in what is called the "stroke belt," which is composed of eight states in the southeast region of the United States, are guessed to be caused by geographic differences in risk factors, lifestyle choices, soil and water micronutrient content, stroke gene prevalence, quality of health care, and socioeconomic status [9]. It is likely that some of these non-modifiable risk factors are based on or at least assisted by factors that are modifiable, so it is important to understand how lifestyle choices can affect these risks [9].

Modifiable risk factors include hypertension, diabetes, lipids, tobacco use, physical inactivity, and alcohol use [9]. Hypertension, or high blood pressure, is the most threatening as well as the most modifiable risk factor, and studies have shown that the relative risk of stroke for people with definite hypertension is about 3.1 for men and 2.9 for women [9]. Relative risk for people with diabetes ranges from 1.5 to 3.0, depending on the type and severity of the diabetes [9]. Reducing blood sugar levels and treating other risk factors such as hypertension are very important for diabetics in avoiding stroke [9]. Serum lipids such as triglycerides, cholesterol, and low-density lipoprotein are serious risk factors, and balancing cholesterol levels is an effective way of reducing risk [9]. Tobacco use has been shown to be an independent predictor of ischemic stroke [9]. Physical activity, even if it is moderate but frequent, has shown to be an effective way to reduce risk for stroke [9]. Interestingly, the moderate consumption of alcohol can also reduce risk, although excessive consumption can increase risk [9].

Some other risk factors include heart disease, atherosclerosis, oral contraceptives and post-menopausal estrogen replacement, genetics, and vascular disease [9]. It has been estimated that 20% of ischemic strokes are due to cardioembolism [9] and 70% of all strokes are related to vascular disease caused by atherosclerosis [9].

2.1.2 Short-term and Long-term Effects

The most typical symptom of stroke is hemiparesis or hemiplegia, which ranges from weakness to full paralysis on the opposite side of the body from the section in the brain that has a lesion [13]. Depending on the side of the brain, different cognitive impairments can manifest [13]. A stroke in the left hemisphere of the brain can result in right hemiparesis, aphasia, which is a language and communication disorder, or apraxia, which is a motor planning or organization impairment [13]. Stroke in the right hemisphere can cause left hemiparesis, visual field deficits, spatial neglect, a lack of insight and judgment abilities, or impulsive behavior [13]. Although patients often recover some physical and cognitive functionality within the first three to six months after their stroke, only 30% with severe upper extremity dysfunction ever experience partial motor recovery of their upper extremities [13]. Many stroke survivors may suffer from permanent physical impairments or handicaps, so much emphasis is put on encouraging functional recovery, to allow them to be able to do many of their activities of daily living (ADL) independently [13]. Also, it is important to take measures to avoid stroke recurrence, which is about seven times more likely for people who have suffered from stroke, as well as depression and long-term stroke mortality [13]. Stroke mortality can either be acute, which happens within 30 days due to complications, or long-term, which is often from other diseases or stroke recurrence [1]. Overall, although younger people are more likely to regain at least partial cognitive and physical functionality [1], it is frequently the case that sufferers of severe stroke will not fully recover and may need a lot of family support or access to continual therapy in order to improve or maintain their quality of life and health [13].

Hemiparesis often affects the upper extremities more severely than the lower extremities, making ADL (activities of daily living) capabilities very limited [13]. The arm is usually held close to the side and may not be able to be fully extended [13]. Typically, the elbow can be bent to about 90 degrees, shoulder movement is minimal, and the wrist and hand are not functional [13]. Even when the hand is functional, shoulder and elbow impairments make it very hard to use for ADL [13]. Neural plasticity of the brain allows remapping of function to different parts of the brain to replace the lost function of damaged area [13]. Although there is usually some spontaneous gain due to neural plasticity in the weeks directly after the stroke, rehabilitation treatment is important in order to fully take advantage of the brain's ability to recover [13].

2.2 Occupational Therapy

This system is a collaborative effort with the Occupational Therapy department and so the tools we are developing must be influenced and guided by their philosophy. Therefore, a key component of this project is to understand occupational therapists (OTs) and their views about and goals for their patients. This includes knowledge of what occupations are and how they are used as a framework for therapy and interventions, as well as intervention strategies for stroke patients. I must specially acknowledge the text *Occupational Therapy: performance, participation, and well-being* [4], from which most of the background information on Occupational Therapy came. This section also addresses the differences between Occupational Therapy and Physical Therapy and how this project also applies to the realm of Physical Therapy.

2.2.1 Importance of Occupations

Occupations are much more than a simple list of tasks or our daily activities. Although occupations involve the things we do, the term also encompasses everything from what those actions mean to us personally, to how they impact our health and well-being. Choosing the occupations in our lives helps us shape our identity and decide what our goals are and how our time can be used to influence the culture and the environment around us. Small, seemingly insignificant actions can take on spiritual meanings or bring back emotional memories for different people. For example, riding a bike may be a way to get to work for one person, while it could remind another of important time spent with a family member or a meaningful vacation. The occupations we choose depend on how the environment around us helps or hinders us, as well as personal constraints such as self-efficacy. When describing and comparing human occupations one should consider what is done, how it is done, why it is done, where it is done, and when it is done. We develop through doing our occupations, and our occupations are also a product of that development as we learn new skills and behaviors. Being able to successfully perform our occupations fills a natural psychological need for competence and autonomy. Our health, viewed as a multidimensional state, can also be influenced by our occupations, bringing positive results if they give us meaning and negative results if they encourage destructive behavior. Since patterns in our occupations over time build up our habits, routines, rituals and lifestyles, it is important to recognize what kinds of occupations fill our lives with meaning by motivating us, bringing us happiness, and helping us impact the society we live in. [4]

2.2.2 Therapy Based on Occupations

Occupational therapists are unique in that they focus on promoting health through helping people engage in occupations that are meaningful to them, help them develop and express themselves, and allow them to participate in the community they live in. They look at the specific situation of the person, as well as the environments in which the person functions to determine the best ways to help the client improve, maintain, or restore occupational performance that has been lost as a result of development, genes, disease, or injuries. OTs work to make sure that the occupations that their clients do are personally meaningful and done in relevant environments so that improvements in their therapy will translate into a positive impact on the state of their physical, cognitive and emotional health in daily life. Also, therapists try to help their clients steer away from occupations that may be detrimental to their health or that are socially or culturally unacceptable. [4]

In occupational therapy, humans are seen as occupational beings who define themselves and experience life through the occupations they choose to engage in. Therapists work with their clients, as well as other healthcare practitioners and professionals, to maximize the fit amongst the individuals, their environment and their occupation by making adjustments. Through analyzing the roles that a person wants or needs to fill, the context in which they do their occupations, and component parts of the activities they want to accomplish, therapists can help their clients engage in a balance of meaningful and purposeful occupations. Sometimes, adjustments to the environment can be made to help accommodate limited capabilities, and social support mechanisms can be mobilized to present the right amount of challenge but avoid overwhelming the individual. [4]

The main concern of therapists is how health and well-being are affected within the context of the client's daily living. The process that a therapist goes through with a client includes referral, screening, evaluation, intervention planning, intervention implementation and reevaluation, and discharge and follow-up. Practice settings can have a large amount of variation from institutional, to outpatient, to home and community. Intervention strategies are categorized as remediation, prevention/promotion, compensation, adaptation, consultation and education. Based on evaluation results, the client's goals of occupational performance, evidence from research, and expert opinion, specific strategies are chosen to help increase occupational performance. [4]

2.2.3 Occupational Therapy Interventions

Occupational Therapy's unique contribution to the health of clients and to communities is helping people acquire the skills they need to perform everyday life activities and occupations. Thus, the interventions applied are focused on promoting well-being, preventing problems and restoring health from an occupational standpoint. The belief that health is multidimensional and requires the fulfillment of humans' natural need for participation in occupations that have meaning and purpose targets both objective and subjective outcomes. As measured occupational performance improves, the client feelings of competence and autonomy should improve as well. Some key principles of intervention that focus on guiding the planning and implementation process are that the interventions be client-centered, context-driven, occupation-based, and evidence-based, and that the process be dynamically interrelated with ongoing assessment. Intervention approaches vary depending on what is required to change, if anything. This includes remediation, restoration and establishment of skills in people or populations, compensation, adaptation and modification of the environment, or matching capabilities of the person or population with the environment or task to find the best, most enabling fit. Three main classifications of intervention goals are established as promoting occupational performance through focusing on enhancing well-being or quality of life rather than fixing a problem, preventing occupational performance problems through anticipation and aversion, and resolving occupational performance problems through focusing on identifying and fixing a problem. Intervention methods are selected based on how useful they are in helping to meet the intervention goals and are established in collaboration with the client. Therapeutic activities and occupations are used to promote performance, or prevent or solve performance problems. Education transfers specific knowledge to the clients based on their needs and priorities. Consultation allows practitioners to help the clients define and solve problems and develop intervention strategies, leaving the actual implementation of the strategies up to the client. [4]

At the heart of occupational therapy is the ability to enable the client to help himself, through the principles of participation, collaboration, holism in context, and empowerment and justice. Through enabling and problem-solving, OTs help their clients meet their goals and put meaning and purpose into their lives. In order to provide demonstrable value of their services, therapists should work towards efficacy through controlled clinical trials and effectiveness through studies in less controlled and more natural conditions. Measurements can be made based on interim goals and statistics. Clients should be informed about the interventions that will be used to help enable them and about the probability that the outcome they desire will be achieved. Clinical decisions should be made based on evidence and research findings. Criteria for identifying the appropriate assessment approach are theoretical consistency, clinical utility, reliability and validity of a measure. The goals that clients set for themselves can have wide variation, but the common outcome is participation in society through meaningful occupations. A carefully planned and executed intervention can be crucial for enabling people to pursue their hopes, dreams, and goals through increased occupational performance and successful integration into society. [4]

2.2.4 Occupational Therapy Interventions for Stroke

Recovery for stroke patients falls into three stages: the acute phase, in the hospital after the stroke is no longer immediately life-threatening, the rehabilitation phase, during which the patients work with therapists in inpatient, home-care, and outpatient settings, and the reentry to the community, when the patient is ready to continue on without frequent therapy. Occupational therapy treatment for stroke victims is aimed at the rehabilitation phase and preparing for the patients move back into the community. The rehabilitation treatment that patients receive depends on their medical condition, the social support they have from friends and family, and the resources that are available to them. Occupational therapy interventions focus on restoring function, but also include teaching compensation skills when the patients have persistent, non-remediable function deficits. Employing both remedial and compensatory methods can help the patient reduce disabilities and impairments so that he or she can participate in meaningful occupations. [13]

Treatment plans for stroke patients often have to be multifaceted and address several deficit areas. Two main areas of focus that stroke patients often need treatment for are postural adaptation, which is the ability to control the trunk and maintain balance by making postural adjustments, and upper extremity function, which is regaining function in the involved arm. There are also treatments for somatosensory deficits, mechanical and physiological parts of movement, voluntary movement and function, psychological adjustment, motor learning ability, visual dysfunction, speech and language disorders, cognitive deficits, and motor planning deficits. [13]

This project is focused on helping patients recover motor function, so the four major theories that guide occupational therapy treatment for motor function will be discussed below. The Bobath and Brunnstrom methods are older and are not frequently used in practice any more, and the Carr and Shepherd and Constraint Induced Movement Therapy approaches are more contemporary and have closer ties to the goals of our project.

The Bobath and Brunnstrom methods require the therapist to do a lot of hands-on and guiding work with the patient. The Bobath theory emphasizes the therapist guiding the patient through movements to encourage normal movement patterns. The Brunnstrom theory focuses on using reflexes and primitive movement patterns to recover voluntary movement. These two theories are considered somewhat outdated and have little supporting evidence so they will not be particularly helpful or applicable to this project. [13]

The Carr and Shepherd approach and constraint-induced movement therapy (CIMT) are more contemporary, task-oriented theories and will be heavily applied to the development of this project. The Carr and Shepherd approach emphasizes practice and use of the affected limb through engaging the client in more variable, random functional tasks during which the therapist provides oral, manual, and visual guidance. The use of the affected limb in many activities in tasks is very important, as well as the intrinsic and extrinsic feedback given by the therapist. Through being forced to practice moving their limb by themselves, patients are more likely to develop a stronger connection between the desired muscle movement and the brain. By focusing on functional tasks, the patient is able to see how the exercises they do in therapy may directly benefit their occupational recovery. Similarly to this theory, games created for this project will provide feedback to patients about the movement of the affected limb through evaluation of their speed, accuracy, and range of motion, while requiring them to use the limb for specific movements. [13]

CIMT involves participating in task-oriented therapy with the affected hand and arm while the unaffected limb is constrained. Some studies of CIMT involve participants constraining the unaffected limb during all waking hours and engaging in intensive functional tasks during therapy sessions using the affected limb. Learned non-use happens when a patient develops the habit of compensating with the unaffected limb instead of using what function they do have in the affected one. CIMT aims at either preventing learned non-use through early intervention or counteracting the effects of it later in the stroke recovery process. CIMT has shown very promising evidence towards facilitating motor recovery. Although it is most beneficial to people with less severe motor involvement, it has also shown to be effective for people who may not meet standard CIMT criteria. Through forcing the use of the affected limb, patients must concentrate on improving their control over the movement of that limb and get natural practice throughout the day, rather than just trying to find ways to avoid using it. The restriction of input to a game to tracking done by Wii Remote or webcam on one limb will draw an interesting parallel to CIMT by not collecting data from movement made by the other limb. [13]

2.2.5 Physical Therapy in relation to Occupational Therapy

In contrast with Occupational Therapists, Physical Therapists are considered movement experts and are concerned with human anatomy and kinesiology in relation to how the body moves [14]. The aim of rehabilitation with PTs is to recover normal movement patterns [12]. While the occupational therapy perspective may focus on what a person wants to be able to do with his/her arm or hand that is meaningful to them, the physical therapist considers what the motor deficits are that the person is dealing with that restrict the ability to do many tasks [14]. PTs and OTs often employ similar techniques and have similar outcomes and goals, but the way they think about these goals and the ideas behind their work are different [14]. The International Classification of Functioning, Disabilities, and Health created by the World Health Organization (WHO) classifies the three parts of a health condition as body function and structure, activities, and participation [12]. Physical therapists are more concerned with the body function and structure impairment and how it limits activities, while occupational therapists focus more on how limitations in activities restrict participation [12]. Also, while occupational therapists treat cognitive disorders and other brain- or mind-related issues, physical therapists focus on motor impairments and only sometimes use measures such as distraction as supplemental to the physical therapy [14]. While there is significant overlap between the two fields, they each have areas of rehabilitation that they cover separately [14]. Thus, an ideal recovery plan for a stroke patient would involve working with both OTs and PTs to address who the person is and what they are about, as well as what their motor system is doing, what is wrong with it and how it can change [14]. In practice, Physical Therapists work on lower extremity and balance rehabilitation and Occupational Therapists work on upper extremities and cognitive function during therapy sessions [12]. Speech and language therapists also work with patients during inpatient time. Since the focus of this project is on motor function recovery, it definitely falls into an overlapping realm between physical therapists and occupational therapists and has useful applications to both fields [12].

2.3 Implications for the System

The three main ways in which our software will be used will be: by therapists to create games, by therapists to assign, adjust and customize games for their patients, and by patients at home as part of their recovery therapy. In developing this project it is important to understand the two main groups of people that will be affected by it, specifically occupational therapists and stroke patients. As we design the interfaces and functionality of the software, we must keep in mind what the stroke patients need and how occupational therapists develop intervention strategies. Given the information above, I have identified three important goals to strive for:

1. The software must allow for the attachment of meaning to the therapy games and allow for occupational development in the physical, cognitive, emotional, and social realms.
2. The games must be easily adjustable and customizable for each patient's specific needs.
3. The software must accurately measure improvement.

Although recovery from a stroke has the end goal of restoring optimal performance in meaningful occupations, often the exercises and repetitious movement needed to take full advantage of the plasticity of the brain are tedious, meaningless, slow, and time-consuming. Therefore, in expecting patients to willingly participate in this treatment at home without the encouragement and direction of a therapist, the games must be enjoyable to the patient and have some immediate purpose and motivating factors. Clearly the definition of "meaningful" can vary greatly from person to person. Patients in different places or at different life stages will have different ideas of what is acceptable for them to do, as well as what is motivating. One way of accomplishing this goal might be to allow for easy changes in game characters or objects, to accommodate for smaller personal preferences. Also, simply enabling easy game creation will encourage therapists to make games that cater more to the individual patient's needs and lifestyle. Another important element in giving games meaning is the development of levels that are tailored to the patient's abilities and allow them to achieve small increments of success. This will boost self-esteem, motivation, and well-being, creating psychological motivation. Even giving a small a sense of accomplishment to a patient can fulfill the innate need for competence, autonomy and relatedness. Since so much of occupational therapy is geared towards return to the community, and healthy participation and collaboration, it may be important to allow for family and community members to be involved in playing the games, especially in ways that can also be interesting and fun for them. This can foster both a meaningful integration into community interaction for the patient, as well as a better understanding and acceptance of the patients' disabilities by community members, which may in turn further encourage them to get involved in helping the patient recover and function in his or her environment. For example, it is likely that a patient will be more motivated to play therapy games if he or she can also interact with a grandchild who enjoys playing with the patient and witnessing small achievements in the patient's recovery. Overall, the advantage of using games as therapy is that they are traditionally a form of entertainment and can address physical, cognitive, emotional and social needs for anyone. These four areas of stimulation are also important pieces of occupational development, so keeping all of them in mind during game creation will most likely lead to an intervention strategy that is more immediately meaningful and motivating to a patient than almost any other type of exercise.

After closely studying stroke and its short-term and long-term effects, as well as meeting and interacting with multiple stroke patients, I think the most striking realization is how much variation there is in impairments from patient to patient. One patient may be able to function completely independently, with perhaps a small limp, and be almost completely cognitively intact, just needing to work on the ability to multitask, while another patient can barely move the limbs on one side of his body, can't process anything in one half of his visual field, and has trouble remembering the date or what he is currently doing. This fact emphasizes the importance of making games easily adjustable and customizable for each patient. Aside from the specific situation of each patient, understanding the patient's personal goals as well as the environment and culture in which he or she is expected to function may also highlight ways in which games must be modifiable for the individual.

OTs work to maximize the fit between the person, environment, and occupation by making adjustments, developing specific treatment methods, and changing the environment, which can be directly mapped to how we allow for changes in games. This can include the subject matters of the games, the devices and calibrations we accommodate, and the ways we assign levels and measure success. For example, one patient may be able to grasp an object, or support the weight of a Wii Remote, while another many barely be able to move his hand if there is very little extra weight applied. One patient could perhaps move her arm over a wide range in front of her body, while another may just be able to shrug a shoulder and move an arm less than ten degrees away from his body. This means the devices and tools we require for the games must vary in weight and method of attachment to the limb, and also that calibration must allow for even very small movements to translate to big actions and encouraging abilities in games.

Another way to maximize fit between a patient and a game is to set levels and measures of success according to what the person can realistically accomplish. If a therapist can determine an upper and lower bound of ability for a patient and then set levels based on reaching just slightly beyond the upper ability, then the patient will have a real chance of "winning" and seeing improvement that is completely tailored to his or her specific situation rather than comparing the outcome to some general measure of success or to other people's improvement or success rates. These are issues that related work has often failed to address and where the Wii Console and games fail as a therapeutic technique. Real customizability and flexibility is a challenging problem, but it is one that is central to this project and is extremely important in occupational therapy techniques and stroke recovery.

Finally, although meaningful games and adjustable levels and devices are important, in the end what will really motivate continued use of this software for patients and for therapists and funders alike will be meaningful tracking and presentation of improvement statistics. From day to day, achieving new game levels and small successes may be enough motivation for patients, but in the long run, they will want to see that the time they put in to this treatment is really paying off and that their achievements in the games are contributing to overall success and recovery. As discussed above, a key component of adult learning is to know why what we are learning is important. If patients can see how they are improving over time in graphs or other visual statistical displays, they are more likely to continue. Therapists need to know which games and assignments are really helping their patients in order to know what to push, or perhaps what has already been accomplished. Tracking how much time the patient is putting into the treatment on his own, as well as having records of the patient's performances over time, will give OTs valuable information about their patients and allow them to help them more effectively even when they are not in one-on-one therapy sessions. In general, this software will gain much more support as a method of treatment if there is a reliable and accurate way to measure and display improvement statistics. It is important that these measurements be as standardized as possible so that their compilation across multiple games using multiple devices and calibrations can paint a fairly accurate picture of how the patient is progressing.

Overall, these three goals can act as guidelines for development of this software. If we keep them in mind as we work on this project, then we can ensure that the final product will be a tool that is designed specifically for its users, giving them the functionality that they need, and providing a new and unique solution to the problem.

2.4 Related Work

Since treatment of motor function impairment often involves repetitive activities, and occupational therapists aim to help patients do meaningful tasks that improve their well-being, the use of virtual reality and games has been explored as a method of stroke rehabilitation [10]. Some research has been done examining the use of existing commercial games such as Playstation 2 Eye Toy [8] and Wii Sports [6] in therapy; however, because these games were created for people with full range of motion, their ability to help stroke patients with severe motor impairments is limited [8, 6]. The use of games did, however, did show signs of curbing depression, as well as boosting motivation for improving performance [6].

Other researchers took the approach of developing their own games and technological devices for the treatment of stroke patients. Although there are many such studies, some interesting examples are described below.

Colombo et al. [5] created a robotic arm that has wrist and elbow-shoulder manipulators and can measure the force/torque that the user exerts in the movement direction. This arm was used to play a simple game, and although no control group was used, the patients' motor deficits improved and they were motivated to adhere to the training program. Jack et al. [10] conducted a study using haptic gloves and involving patients in games that measured range, speed, fractionation, or strength. The games were simple, visual displays on a PC that required the patient to do actions such as control a window wiper to display a landscape behind fogged "glass," push virtual piano keys, or catch balls. This VR system was noted as being very helpful in providing objective measures of patients' performance, and while the patients did improve, the improvement cannot be definitely attributed to the VR treatment. Burke et al. [3] used webcam color tracking, magnetic sensors, and Wii remotes as tools for all patients to play games such as whack-a-mole and whack-a-mouse, along with a physics-based catching game.

Some recent research has been done in an effort to study what properties are important in stroke rehabilitation games [11, 2, 7]. Among the properties found to be significant are identification of the target audience, visibility, feedback, meaningful play and challenge, and consideration of differences in entertainment for the elderly [7]. These criteria were used in studies of a number of games to examine what made certain games more successful or popular for rehabilitation than others.

All this previous work highlights important implications about the potential for this project to utilize the benefits of stroke treatment using games, while also providing more flexibility through relatively inexpensive technology and the ability of therapists to create and tailor games to be case-sensitive and specific.

Chapter 3

2D Movement Tracking

As seen above, many devices currently used for movement tracking in virtual reality games, such as haptic gloves and robotic arms, are beyond the budget and obtainability of most people. Also, for people with stroke it is often hard to even lift or move the limb itself, so any tracking device that must be attached to a limb cannot add any significant weight. Our solution to movement tracking was initially aimed at using exclusively Wii remotes, but after some shortcomings were encountered, we added webcams as available input devices for the therapy games. Both of these devices are commercially available, easy to obtain, inexpensive, and can be used in ways that do not burden upper extremity limbs with too much weight. Below we discuss the use of Wii remotes for 2D tracking and their shortcomings, and the resulting implementation and application of a webcam color tracking system.

3.1 2D Tracking with Wii Remotes

Wii Remotes are wireless input devices, developed for the Nintendo Wii Console. Using the freely available, Java-based WiiRemoteJ [15] library, we can use them with PCs to input data from the built-in three-axis accelerometer and infra-red (IR) camera. Although the project is currently making more use of the accelerometer for measurements to use in games, my initial exploration of how to incorporate Wii Remotes focused on the scenario of tracking IR LEDs (infra-red light-emitting diodes) on a two-dimensional plane. The movement exercise scenario was designed for a patient who is not able to support his or her arm or hold it freely in space, but may have movement capabilities if the arm is propped on a table. Tracking IR LED points on the patients' hand could allow them to play games that required either one-dimensional or two-dimensional movement while only requiring them to move their hand around on the surface. This type of tracking could also be used freely in space for one- or two-dimensional input in the same way, but requiring the patient to support his/her arm in the air to move the IR LED around in front of him/her with the IR camera pointed straight instead of downwards.

The environment set up for the table-top tracking involved attaching the Wii Remote to a tripod, with the IR camera facing directly down at a desk surface and then attaching a USB-powered IR LED to a hand. I adjusted the height of the tripod so that the camera range covered a sufficient amount of the surface to detect the IR LED as it moved to the limitations of reaching ability. I anticipate that this range would have to be slightly adjusted according to the capabilities and range of motion of each patient.

Figure 3.1 Wii Remote on tripod for IR tracking

The implementation of this Wii Remote functionality required 1) connecting the Wii Remote using a Bluetooth adapter, 2) using the WiiRemoteJ [15] library to discover the Wii Remote in range, and then 3) frequently receiving and processing IR input through the Wii Remote's camera. During the processing step, I translate the locations received to movement in a Looking Glass scene. In the example created, a penguin moves around a scene, following the movement patterns of a tracked IR LED on a desk.

Since the Wii Remote's IR camera can detect up to two IR LED points, we also experimented with two-point tracking. Although the tracking was fairly precise when the lights were held up within a foot of the camera, this method was not feasible for tracking normal movement on two points of a person's arm, for example wrist/elbow, or elbow/shoulder, because the range of the camera is too narrow when in close proximity to the lights, and not accurate enough when positioned further away. In order to achieve a wider field of view, and to avoid having to attach objects with any significant weight to patients, we turned to webcam tracking as a solution for 2D movement tracking.

3.2 2D Tracking with Webcams

While detecting motion with a webcam is fairly easy, tracking specific movements presents a challenging problem. Detecting a person's limb as it moves from analyzing pixels in an image is an extremely hard computer vision problem. One easier possibility is to attach an object to a person and use an object-tracking algorithm to find the object as it moves from frame to frame. Since the webcam gives us color information with each pixel in each image, the simplest, and potentially most accurate solution is to track colors. Also, since analyzing colors is computationally easier than running algorithms for line and shape detection, we can do it at higher frames per second, resulting in closer to real-time tracking.

OpenCV (Open Source Computer Vision) is a library of programming functions that do computer vision in real-time and is free for both academic and commercial use. Its abilities include very advanced computer vision functionality such as face-recognition, and object identification that would have been useful to experiment with, as well as color tracking. However, OpenCV is only available in C++, C, and Python, and our system is entirely in Java. In attempting modify our code to be able to use the C++ version we faced many roadblocks. MATLAB also has some built in color tracking ability, but, similarly, could not be easily integrated into our code. There are no comparable Java libraries available, so we decided to implement the color tracking functionality ourselves.

Using webcams, along with the Java Media Framework (JMF) and Java Advanced Imaging (JAI) libraries we created a simple, multipoint color tracker. This tracker allows users to select colorful points to be tracked in a scene. The tracking works best in well-lit settings where the objects selected for tracking are of colors that are unique throughout the rest of the scene. In experimenting with colorful trackable objects, we have used painted ping-pong balls and brightly colored socks and beanbags. It is important that these colorful objects be light in weight, so that they do not add extra burden to patients who already have trouble just lifting their affected limb, and that they be in some way attachable to the body for patients who cannot grasp objects. In consideration of these constraints, we have used Velcro attachments and have found the flexibility of colorful socks, both with and without holes at the end, very useful.

The three steps used in the implementation of color tracking are color calibration, initial point location, and mean shift point tracking. Each of these steps will be described in the sections below.

Figure 3.2 Color tracking objects: a sock and beanbag

3.2.1 Color Calibration

To calibrate the color tracker, the interface presents the user with real-time video of the scene, where he/she uses the mouse to select the approximate, smallest rectangular area that encompasses the whole object to be tracked in the camera image. When the user releases the mouse, we save the selected area of the current frame image, and the mean color of the image patch is calculated. We calculate the mean color using a custom JAI method that finds the average red, green, and blue values in an image, individually. Once we detect the mean color, we set it as the color to track. We then convert the color from RGB (red, green, blue) components into the HSV (Hue, Saturation, Value) color space.

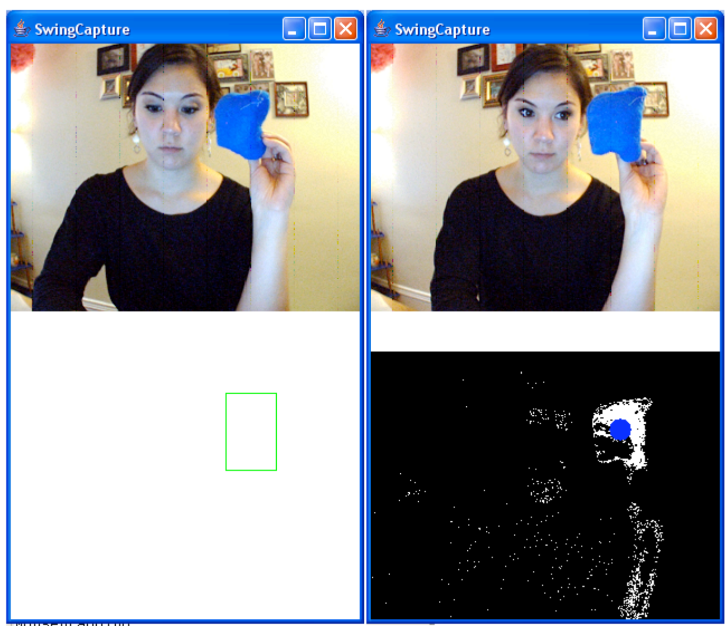

Figure 3.3 Webcam color object selection and filtering effects

Using this HSV-converted color, we set upper and lower color thresholds for all HSV components in order to define the acceptable range of deviation from the mean color. We initiate these upper and lower thresholds at the exact HS and V values of the mean color. Then we recursively adjust them, such that the lower threshold makes 90% of the pixels black, and the higher threshold makes 90% white. This range, calculated for each

HSV component, provides for the closest detection of hue, saturation and value to the mean in any subsequent image, so long as the lighting is approximately the same.

3.2.2 Initial Point Location

We separate the original selected patch of image into its HSV bands. We then binarize each band of the image using both the lower and upper thresholds of the applicable component of the mean color, and then subtract the top threshold image from the bottom. Since binarizing an image with JAI returns an image such that all pixels above the provided threshold are 1, and the rest are 0, the resulting subtracted image highlights all pixels within the acceptable range. Then, we combine the resulting images for the hue, saturation, and value bands of the image by first using the JAI "and" function on the subtracted H and S images, and then "and"ing the resulting image with the subtracted V image. The JAI "and" function creates an image by taking two binarized images and using logical "and" for each pixel in one image against its corresponding pixel in another image to decide the outcome of the corresponding pixel in the new image. We then use another custom JAI method to process the combined image with all threshold-accepted pixels highlighted and find the center (mean location) of all white pixels. Next, we record the center point as x and y coordinates and set it as the starting point location for tracking. Finally, we start a thread that continuously grabs the image from the webcam to process.

3.2.3 Mean-shift Point Tracking

Each processed frame follows a similar pattern to the initially selected image patch. We process each image in the same way as the patch above, using the already established mean thresholds to binarize the image and create an image in which only acceptably colored pixels are white (1) and the rest are black (0). Then we select an image patch of this processed image, centered at the last tracked location point and within a 100 by 100 pixel box (may be smaller because of bounding considerations). We find the mean of the white pixels in the same way described above, and translate it to an x, y location. If this location is too far away from the last recorded location, we repeat the mean finding process for the whole image, rather than just the patch. Otherwise, we set the new location as the current location.

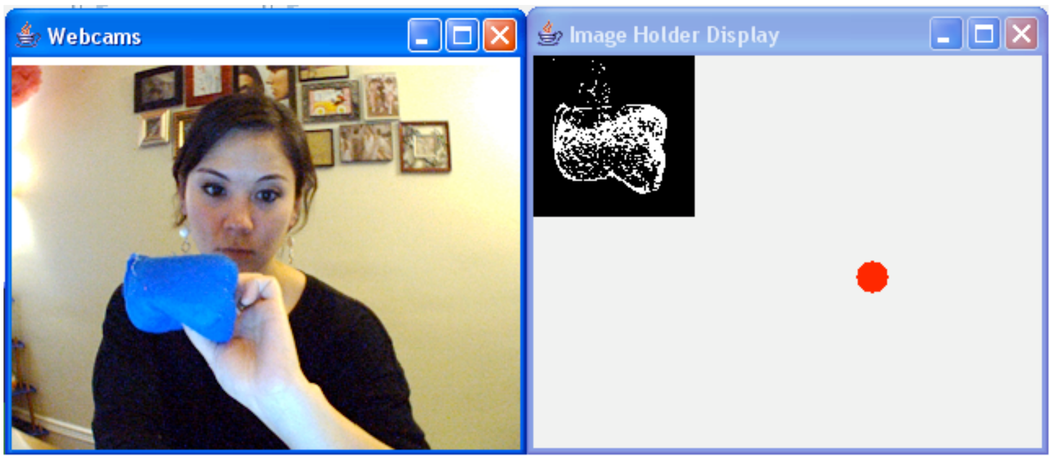

Figure 3.4 Mean-shift tracking. Red dot marks current location and image patch shows image location of interest

As each new image frame grabbed by the thread changes these locations, we track the color through the scene. We can repeat this process from the beginning to store and track multiple colors, where each color has its own mean and thresholds, and we process each image separately for a chosen color to find the new location of each color in the scene.

3.2.4 Development and Testing Strategies

In developing and testing the implementation of color tracking using webcams, we developed a tool to allow visualizations of how the upper and lower thresholds set for each of the hue, saturation, and color bands affected the subtracted images for each band, and then the final "and"ed image. Using this tool, one can adjust the thresholds to see the resulting images in real time. This is how we developed the recursion to find the threshold values in the final version. The tool allows for the selection of a color we choose to track, and then manual adjustment of each HSV upper and lower threshold.

As figure 1.5 below shows, next to the original webcam image is the final combined product of all applied thresholds and combined subtracted images.

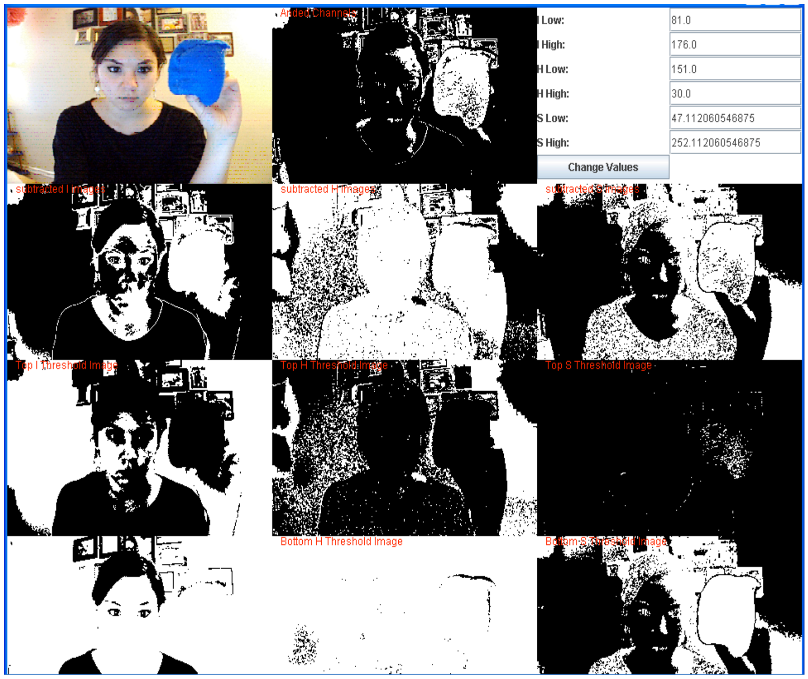

Figure 3.5 Tool tracking images, before manual adjustment of thresholds

The second row from the top shows the subtracted images from the V, H, and S thresholds. The third row from the top shows threshold images for V, H, and S, and the bottom row shows the corresponding bottom threshold images. At first, using the estimated values as thresholds, the final image is only vaguely clear. After we adjust the thresholds (see Figure 1.6), the image becomes more and more clean so that the colored object's location contains mostly white pixels. This tool is extremely helpful in understanding how hue, saturation, and value changes affect an image and will help to search for a specific color.

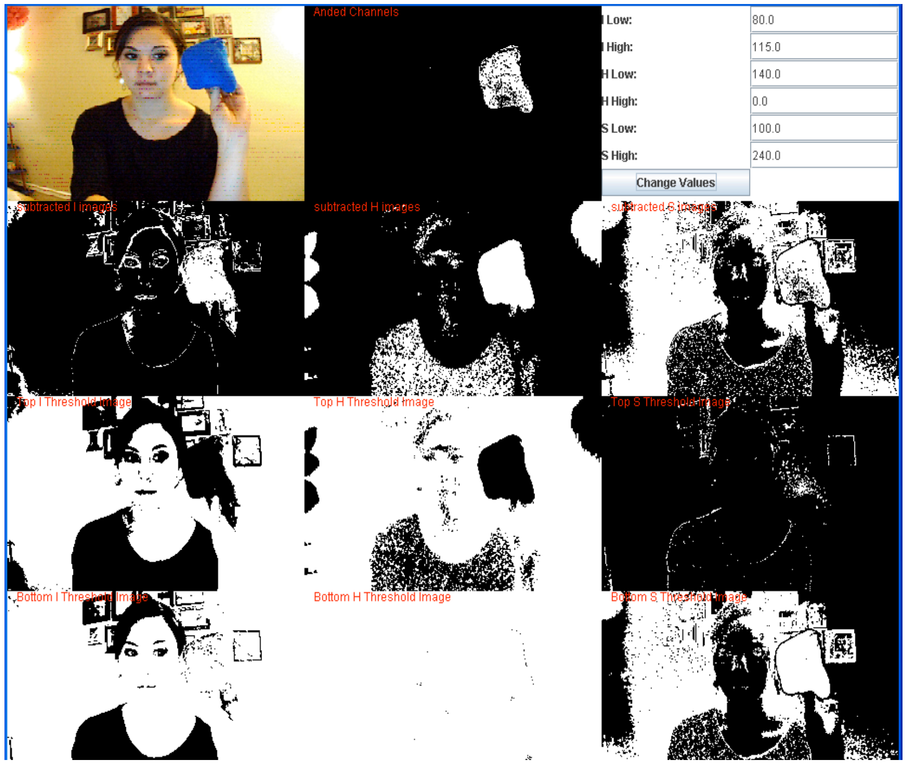

Figure 3.6 Tool tracking images, after manual adjustment of thresholds

3.2.5 Webcam Tracking Use in Games

This webcam color-tracking framework has since proved useful in the development of test games for stroke patients to play as treatment. The webcam tracks 1D or 2D motion, for one point, or multiple points. Some examples of how we use this tracking in our games include using movement of one or two tracked colors to control a glove in order to catch a baseball, to control the up and down movement of a helicopter as it flies over buildings, and to pick up "dynamite" to drop on weeds in order to save flowers. So far, in user testing, patients have shown interest in these games and the tracking has been sufficiently stable and accurate enough to track their movement as they sit in front of a computer. Our current work with improving this webcam system includes a better calibration for the range of motion capabilities of each patient.

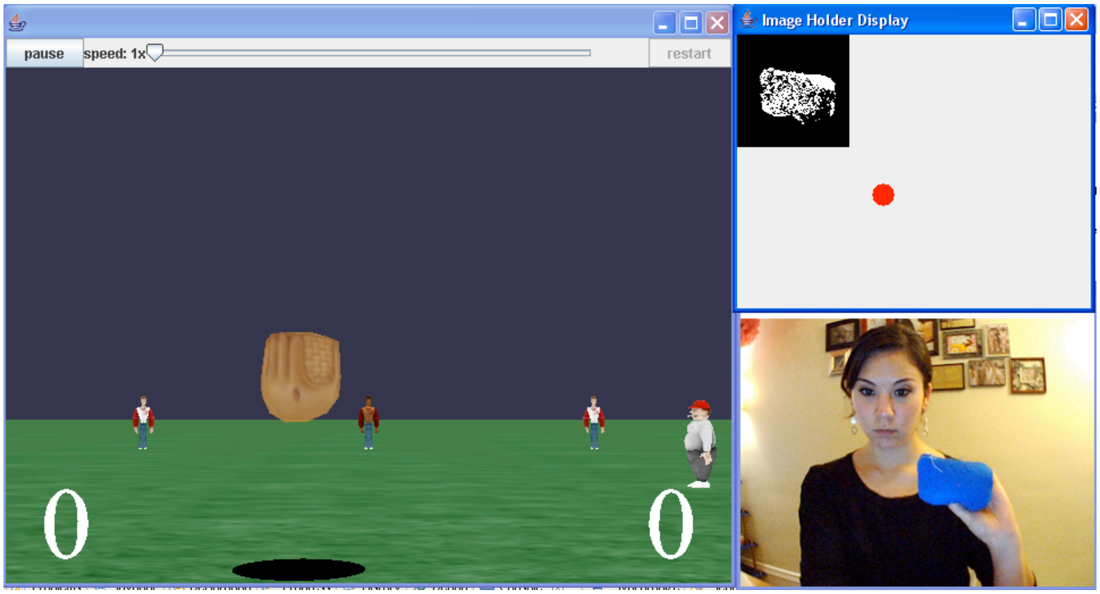

Figure 3.7 Example use of tracking in a baseball catch game. The location of the colored object controls the location of the mitt in the scene

Chapter 4

Patient Data Organization and Game Treatment Assignment

Once games have been developed and are ready for patients to take home and use, there must be a way for occupational therapists to organize information about their patients and customize games and levels for patient-specific treatments. If the games are going to provide a wide range of flexibility, then in order to fully utilize the available options, we need an easy interface for therapists to use to make sure each game is tailored for their patient and is being used correctly towards their goals. Also, once patients have been using the games as therapy for a while at home, it is important that both the patient and therapist can see if and how the patient is improving through the statistics logged by each game that they play. These statistics could be critical in securing funding or insurance money for the continuation of therapy. The following sections present the framework for an interface that will collect and display patient information for therapists, allow therapists to assign treatments and customize games for patients, and organize and display patient statistics to track and measure improvement.

4.1 Collecting and Displaying Patient Information

Therapists will most likely be working with many patients at a time, and therefore will need a way to store data about the patients and organize the treatments and games that they are assigned through this system. This interface allows for the creation and storage of game therapy data from multiple patients and all of their related information, as well as easy navigation through this information by providing a left-hand-side interactive list of patient names and a large center display. Clicking on a patient's name will change the center display of the interface to display the patient's information.

Figure 4.1 Interface navigation and information display

4.1.1 Adding a New Patient

Clicking the "+" button at the top of the patient list allows a user of the interface to add a new patient into the system. A "New Patient Information" view opens in the center display with text fields in which one can record the following information:

- Name
- Date of birth
- Diagnosis
- Medical history
- Client-defined goals
- Likes
- Dislikes

These fields were specified through collaboration and discussion with our partners in the occupational therapy department. They provide useful information about a patient that can remind therapists of their specific situations, as well as goals and preferences that may be helpful when assigning games. The “Client-defined goals” field is specified because the therapists will define their own long-term goals for the patient that may be different from the goals that the patient defines.

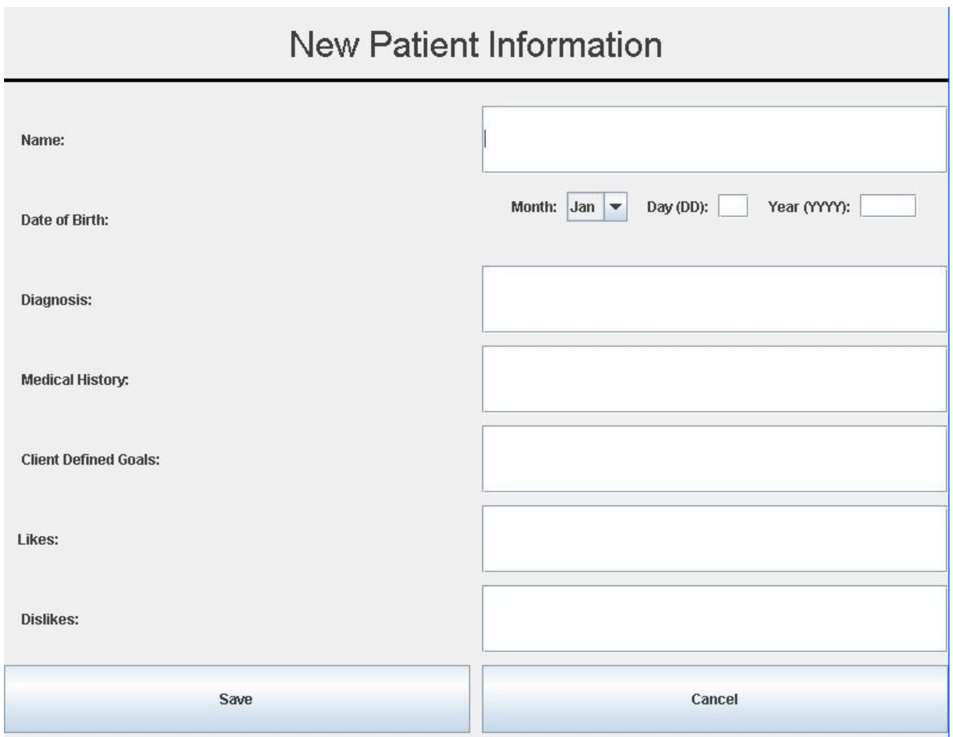

Figure 4.2 New Patient Information input view

Once the “save” button at the bottom of the “New Patient Information” view is pressed, a new directory with the name of the patient is created in the “Patients” directory in the program files for the application, the name of the patient is added to the patient list on the left, and the center display changes to display the information. Within the patient’s directory, a “Treatments” directory is created in which all treatment information will be stored.

4.1.2 The Center Display

The center display either displays the information for the patient currently selected in the patient list, or the "New Patient Information" view if a new patient is being added to the system. It allows for organized and easy access to all information in the system for any single patient. When the center display is showing an existing patient's information, it is composed of three tabbed views: Patient Information, Treatment Plan, and Progress Statistics.

The "Patient Information" tab displays the information that is stored when the patient is entered into the system, described in the bullet points above, as well as a Long Term Goals manager. Figure 4.1 shows an example "Patient Information" display. Table 4.1 shows realistic example data that could be entered into these fields.

Table 4.1: Example patient information entries

	Patient 1	**Patient 2**
Diagnosis	L CVA, frontoparietal, R hemiparesis	R CVA, frontal, L hemiparesis
Medical History	HTN, hyperlipidemia, DM, GERD	HTN, hyperlipidemia, DM, s/p CABG x3
Client-Defined Goals	Take a bath without help, knitting, prepare a full meal	put on pants (I)ly, fishing, driving
Likes	knitting, cooking, spending time with grandkids, playing cards	fishing, watching sports on TV, hunting
Dislikes	exercise	cooking

The Long Term Goals manager is a list of long-term goals with buttons to "Add New," "Edit Selected," or "Delete Selected." When a user selects to "Add New," a dialog is launched that requests input of a "Goal Title," "Goal Description," and the specification of a "Goal Color Representation" using a color chooser. There is also a checkbox that can specify whether or not the goal is met.

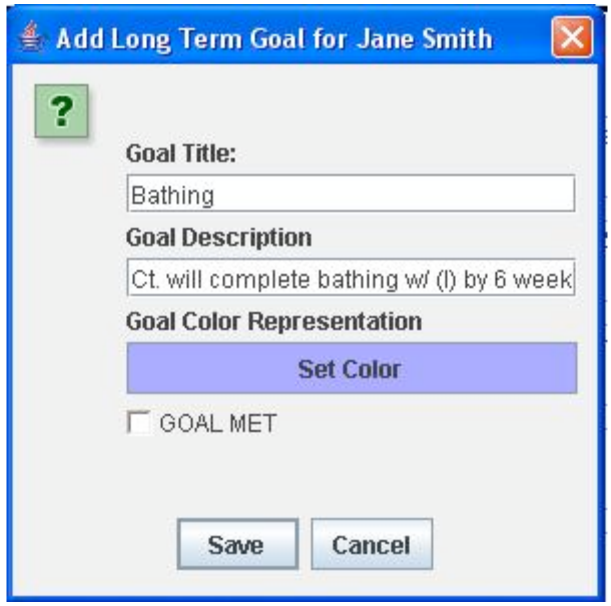

Figure 4.3 Creating a Long-term Goal

Once the goal is saved, it appears in the list, with background color set to the color chosen to represent it. It has an icon of either a progress circle or a check mark depending on if the goal is marked as met. Selecting it and pressing "Edit Selected" can change each goal's information, color, or status. Table 4.2 shows some examples of long-term goals and descriptions.

Table 4.2: Long-term goal example data

Long-Term Goal	**Description**
Bathing	Ct. will complete bathing w/ (I) by 6 weeks.
Meal-prep	Ct. will prepare a 2-course meal in own kitchen w/ (I) by 6 weeks.
LE Dressing	Ct. will perform LE dressing w/ (I) by 6 weeks.
Fishing	will complete all fishing tasks w/ mod (I)/AE by 6 weeks.

Defining long-term goals is critical for further use of this interface because all short-term goal assignments are made to reference one of these goals. This design decision was made in collaboration with occupational therapy students to encourage therapists to work within the technically correct framework of working towards long-term goals through incremental short-term goals in order to have solid measures of progress and success.

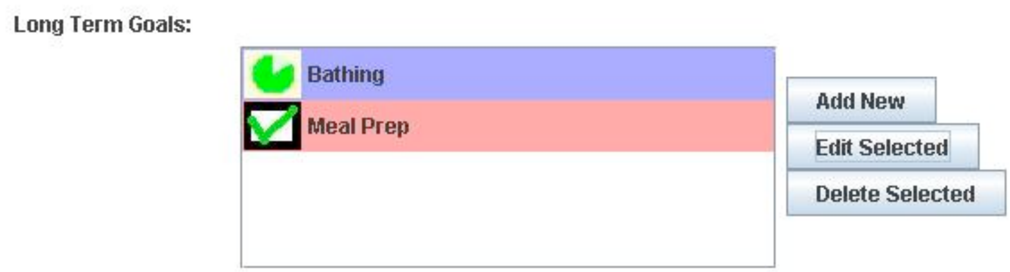

Figure 4.4 Long-term Goal Manager

The "Treatment Plan" tab opens a view in which treatments can be created and displayed. The idea of a treatment is that a patient will come in for a session with a therapist and the therapist will create a new treatment, which will serve as a way to assign games and goals to the patient to work on until the next meeting. Each treatment displays the date and time it was created, offers a text field to hold notes for the therapist, and allows the therapist to add short-term goals. Short-term goals will be discussed in further detail in sections below. Since each short-term goal is associated with a long-term goal, colored icons are placed next to the treatment's date header for quick reference to which long-term goals were being worked on at that time. If a short-term goal has been met, then the icon representing it is "X"ed out. The latest treatment is always displayed at the top and then as the user scrolls down, the past treatments are listed in descending order from the current time. When a new treatment is created, it automatically carries over any goals from the previous treatment that have not been marked as completed so that the patient can continue working towards his or her short-term goals. This design decision was also made after consultation with occupational therapy experts and is aimed at encouraging completion of short-term goals. New treatments also create new directories in the "Treatments" folder for a patient, which are named for the date of creation (mm.dd.yyyy).

Figure 4.5 Single treatment display with two short-term goals

The third and final tab in the center display is the "Progress Statistics" tab and displays and organizes patient statistics in an interactive graph (see figure 4.7). This feature will also be discussed in further detail in the following sections.

The three center display tabs collectively represent all information that a therapist needs for assigning and keeping track of each patient's data and game treatment assignments. As changes are made to the patient's information and as goals and treatments are added, the patient object is serialized and saved in a file "PatientInfo.ser" in the patient's directory.

4.2 Assigning Treatments and Customizing Games

An important benefit of this system is that not only can it be customized to fit specific patients in general, but it can be altered to fit the abilities of a patient at all points in the recovery process. This means that each time patients meet with their occupational therapist, the therapist can set up new calibrations, levels, and games for patients to encourage them to keep challenging themselves and to maintain interest and motivation in the exercises. As a way to organize all these incremental changes and settings, customizable options in the system are wrapped up into constructs called short-term goals.

Each short-term goal is linked to a specific long-term goal and should be considered a stepping-stone towards achievement of that long-term goal. In the interface, short-term goals are created and added to a specific treatment using a dialog through which the user specifies the related long-term goal, the target joint (wrist, elbow, or shoulder), the device type that should be used for games played towards this goal, and the input type. Once these options are set, a calibration window is popped to allow for calibration of the selected device and input type. A directory is created for the short-term goal within its treatment folder and the calibration file is saved in this folder.

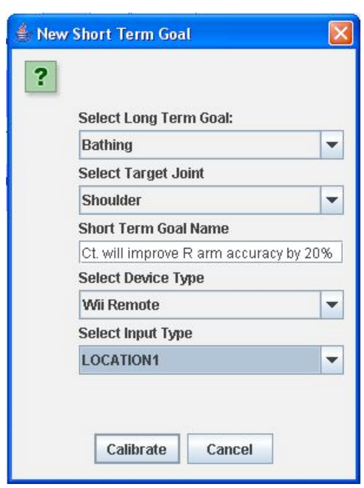

Figure 4.6 Creating a new short-term goal

Each short-term goal has a game manager, which consists of a list display and buttons labeled "Add Game," "Delete Game," and "Edit Settings." Once a game is selected and added from a list of available games, choosing to "Edit Settings" for that game will launch the game using the calibration file already saved for the parent short-term goal. The idea here is that when the therapist and patient meet, they will set up the short-term goals, calibrate with the patient using the device in the correct way, and then will edit the settings of the games together in order to set up realistically achievable levels. The game launched from this view will run in "OT mode," which will bring up a window for level adjustment and creation.

Table 4.3 Short-term goal example data

Description	Associated Long-term goal	Target Joint
Ct. will increase wrist ROM (sup/pron) by 15 degrees	Fishing	Wrist
Ct. will increase elbow flexion by 20 degrees	LE Dressing	Elbow
Ct. will increase speed of elbow movements by 5 seconds	Fishing	Elbow
Ct. will increase R elbow extension to 15 degrees	Bathing	Elbow
Ct. will improve R arm accuracy by 20%	Bathing	Shoulder
Ct. will increase sustained hold time by 7 seconds	Meal-prep	Shoulder

Level creation will allow the therapist to adjust all settings of the game and define a lower bound for the settings, such that the patient can be successful fairly easily, and an upper bound for the settings that are just slightly beyond the current capabilities of the patient. The therapist can then specify a number of levels to generate. Once the therapist selects to generate levels, the levels will be created with even intervals of difficulty variation ranging from the lower bound to the upper bound, and saved in a directory for the specific game inside the parent short-term goal directory. In this way, game levels will be linked to specific short-term goals. Any given game can be set up for any number of short-term goals but will use different calibrations and level settings for each one. For example, a therapist may want to assign Pong as a game to exercise both the shoulder shrug and wrist rotation of a patient. These movements are very different and will require different calibrations and perhaps different input devices. The ability of the patient to rotate his/her wrist may also be much less developed than the patient's shrugging ability, so levels for the wrist exercise may have to have easier settings than those generated for shoulder treatment. When the patients go home, they can run the game, select which short-term goal they are working on, and the calibration and levels will automatically adjust to use the defined settings for this short-term goal. Thus, every week, patients can have their game therapy treatment refitted to any changes or improvements in their movements.

4.3 Organizing and Displaying Patient Statistics

As described above, it is extremely important that progress achieved from treatment using the therapy games be easily visualized and kept track of, as motivation for the patient, reassurance for the therapist, and for funding and resource allocation purposes.

In order to keep things simple, the "Progress Statistics" tab for each patient comprises one graph. Graph controls above the graph determine what is displayed on the graph.

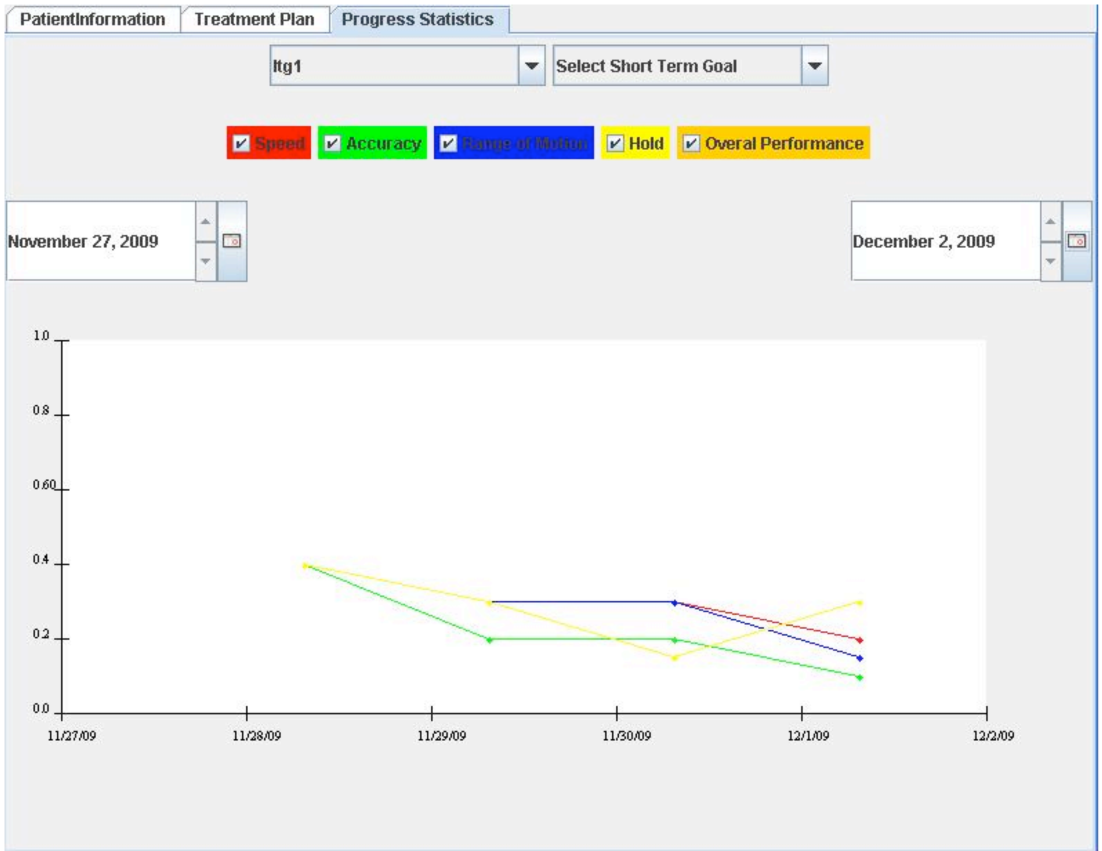

Figure 4.7 Progress Statistics view

Directly above the graph are two calendar controls. On the left side is one that determines the start date, and on the right side is one that determines the end date. When dates are selected by these controls, the graph adjusts to accommodate and display information logged between the two selected dates for the selected patient. The default view is one week, with the end date set to the current date.

Figure 4.8 Graph filtering tools

The information is filterable first by long-term goal, then further by short-term goal, and then by specific game. These filter options are displayed in drop-down menus at the top of the view. At the most filtered level, the display shows only statistics logged for a certain game, played as part of a certain short-term goal, which is linked to a certain long-term goal. The default view is to display compiled statistics at the long-term goal level.

I have defined metrics that must be measured by any game in the system in order to display meaningful statistics. These metrics include: speed, accuracy, range of motion, sustained hold, and overall performance. These statistics are read in from XML log files that will be generated by each trial of a game that a patient attempts or completes. They are each plotted as separate, color-coded lines on the graph for any given filtered view. Check boxes, one for each metric, are above the calendar controls. When a box is checked, the corresponding line is displayed in the graph. If a box is unchecked, the line will become invisible. This way specific metrics can be viewed alone, or in comparison with other metrics.

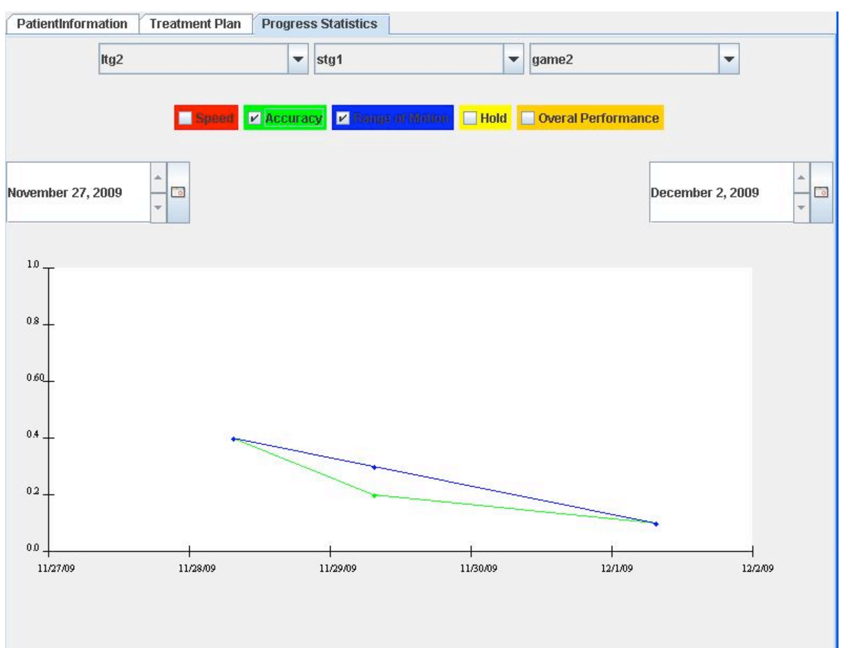

Figure 4.9 Example filtered graph view

The metrics are currently measured on a scale of 0 to 1, with 1 being the most accurate, the fastest, etc. and 0 being the least successful. Over time, as patients generate large amounts of data through playing the games, the statistics will provide meaningful information about how they are progressing in their use of the games as therapy treatment. The exact ways in which the games will define and set these metrics must be further explored and discussed with occupational therapy experts, but I have defined an XML structure with which they must comply in order for the progress statistics to be successfully loaded and displayed. The metrics themselves were specified by occupational therapists as useful measurements of progress that would be interesting to track and be able to reference. Further research may also define additional statistics or graphs that would be useful to track or display in this view.

4.4 Future Extensions of this Interface

As with any successful user interface, it is important that this design be put through multiple iterations of user testing, which will most likely begin in the next few months. Even though it has been designed with constant input and feedback from our partners in occupational therapy, much of the success of this project depends on whether or not this interface allows therapists to easily and effectively assign and customize games to their patients. Therefore this design will serve as a strong starting point for a more robust design that will result from future user testing data.

Another issue that must be resolved to make this interface fully functional is that in order to allow patients to generate log files from the games they play as therapy, and the therapists to view and analyze this data, we must explore methods of information transfer that comply with moving medically sensitive data. We must be careful with this data, as there may be legal implications if it could possibly be exposed in any public way while being transferred.

Finally, ongoing effort must be put into deciding the best way to measure and display data so that it is meaningful to patients and therapists, and also could prove the success of this system as a method of treatment. This includes everything from the metrics we measure, to the scales they are measured on and the meaning of these scales, to the possibility of combining and filtering patient data for comparison and display. Important metrics may vary from region to region, so we must allow for some flexibility in this area for future designs.

Chapter 5

Conclusion

This system for allowing occupational therapists to create, assign, and customize games as therapy treatments for their stroke victim patients is clearly a long-term, large-scale challenge, but the work presented in this thesis provides a basis for understanding and designing for the target users, as well as some key components of the system that will be highly instrumental in future development.

The research and background information about stroke and occupational therapy presented above will be available in greater detail for the use of all people who work on the development of this system. This will ensure that everyone involved will have at least a foundational understanding of the future users of the system and will help to curb uninformed assumptions made when making design decisions. An important part of doing cross-departmental work is to strive for mutual understanding to enable greater cooperation and avoid misinterpretation whenever possible. Although the disciplines of computer science and occupational therapy are vastly different, this research will help bridge the gap and help us work together more closely to develop a system that is user friendly and effective.

Webcam color tracking is proving to be a very important source of 2D movement data as input for the games that have been developed thus far because it doesn't involve attaching weighted objects to patients and can track multiple points. Many games that were configured initially to take input from Wii remotes can also take input from webcam color tracking. Webcam tracking can also accommodate more complex game environment setups. For example, in a game that is currently being used for testing called "Garden," a patient with a colored sock on one hand picks up and moves a colored beanbag. These two colors are tracked and translated to picking up and moving dynamite in the game to blow up weeds and save flowers. Recently we have developed a way for webcam-tracked movement to be calibrated, so that a patient's limited range of movement can be translated to the whole scene of a game. As we continue to user test games that use webcam color tracking as input, we can keep fine-tuning the system so that it is increasingly easy to configure and caters to the needs and abilities of the patients.

The therapist interface has not yet been tested with users, but its development brings us much closer to tying together the pieces of this project to make it a usable system. As it stands now, we have example games that take input from Wii remotes and webcams, and some initial work in setting up Looking Glass to allow game creation, but without this interface, it would be difficult for therapists to actually use the games as meaningful therapy once they are created. The success of this interface will be central to the success of the system as a whole, as its usability may determine whether or not therapists actually decide to use the system as treatment for their patients. If it is intuitive and easy to use, potentially even therapists who would not want to create their own games could use it to assign previously created games to their patients as therapy. Perhaps eventually, even patients who cannot afford to go to therapy could use it with a family or community member to assign game treatments and do game therapy on their own.

Future work for this project includes continued user testing with both therapists and patients on the test games that have been created and the interface described above, further development of interfaces and systems to allow these tools to be used as treatments, and continued work on integrating game creation abilities into Looking Glass. The success of this project has exciting implications for the future of stroke rehabilitation and could impact and improve the quality of life for millions of stroke survivors and their families.

References

[1] Bogousslavsky, Julien, 2002.*Long-Term Effects of Stroke*. New York: Marcel Dekker, Inc.

[2] Burke, J., McNeill, M., Charles, D., Morrow, P., Crosbie, J., and McDonough, S. "Optimising engagement for stroke rehabilitation using serious games." *The Visual Computer*.

[3] Burke, J., McNeill, M., Charles, D., Morrow, P., Crosbie, J., and McDonough, S. "Serious Games for Upper Limb Rehabilitation Following Stroke." *VS-GAMES* '09, (2009), 103-110.

[4] Christiansen, Charles H., Baum, Carolyn M., Bass-Haugen, Julie, 2005. *Occupational Therapy: performance, participation, and well-being*. Thorofare, NJ: SLACK Incorporated.

[5] Colombo, R., Pisano, F., Mazzone, A., et al. "Design strategies to improve patient motivation during robot-aided rehabilitation." *Journal of Neuroengineering and Rehabilitation* 4, (2007), 3.

[6] Deutsch, J.E., Borbely, M., Filler, J., Huhn, K., and Guarrera-Bowlby, P. "Use of a low-cost, commercially available gaming console (Wii) for rehabilitation of an adolescent with cerebral palsy." *Physical Therapy* 88, 10 (2008), 1196-1207.

[7] Flores, E., Tobon, G., Cavallaro, E., Cavallaro, F.I., Perry, J.C., and Keller, T. "Improving patient motivation in game development for motor deficit rehabilitation." Proc. 2008 *Intl. Conf. on Adv. in Comp. Entert. Tech., ACM* (2008), 381-384.

[8] Flynn, S., Palma, P., and Bender, A. *Feasibility of using the Sony PlayStation 2 gaming platform for an individual poststroke: a case report*. Journal of Neuro. Physical Therapy: JNPT 31, 4 (2007), 180-189.

[9] Gorelick, Philip B., Alter, Milton, 2002. *The Prevention of Stroke*. New York: The Parthenon Publishing Group.

[10] Jack, D., Boian, R., Merians, A.S., et al. "Virtual reality-enhanced stroke rehabilitation." *Neural Systems and Rehabilitation Engineering*, IEEE Transactions on 9, 3 (2001), 308-318.

[11] Jung, Y., Yeh, S., and Stewart, J. "Tailoring virtual reality technology for stroke rehabilitation: a human factors design." *CHI '06 extended abstracts on Human factors in computing systems*, ACM (2006), 929-934.

[12] Lang, Catherine, Interview with the author, October 27, 2009.

[13] Radomski, Mary Vining, Trombly Latham, Catherine A., 2008. *Occupational Therapy for Physical Dysfunction, Sixth Edition*. Baltimore, Philadelphia: Lippincott Williams & Wilkins, a Wolders Kluwer business.

[14] Ross, Sandy, Interview with the author, October 26, 2009.

[15] WiiRemoteJ. http://www.world-of-cha0s.hostrocket.com/WiiRemoteJ/.

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