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Prototyping a Tablet Application for the Rehabilitation of Stroke Patients

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Abstract

Modern tablet computers come with touch sensitive displays, which make them suitable for recognition and evaluation of finger movements. This paper describes the design and development of a prototypical iPad application, which uses this capability to support therapeutic exercises for stroke patients. It is shown how this concept differs from existing stationary solutions, and how the prototype is used to explore the suitability of such a solution for stroke rehabilitation. Experiences from first user trials are described, which indicate willingness of patients and therapists to embrace the new technical possibilities, although challenging research tasks remain to be solved on the way to a proven professional solution.

Keywords: Stroke rehabilitation, Tablet computer, Touch screen, Therapeutic exercise, Mobile health.

1 Introduction

A significant part of the population suffers from long-term disabilities caused by stroke (Roger, et al., 2012). Physical therapy tries to improve the capabilities of stroke survivors, often using specialized medical rehabilitation equipment. However, the availability of therapist time and rehabilitation devices is limited. Therefore, it would be advantageous if patients were able to train independently with easily accessible therapy devices. Today's widely available mobile computing devices may help to reach that goal. They are portable, offer familiar user interfaces, and come with built-in sensors like cameras and touch surfaces. Thus, they could enable stroke patients to perform exercises in their own home without the help and supervision of a therapist.

We decided to explore the utility of the widespread iPad tablet computers for rehabilitation purposes. These devices offer important advantages compared to conventional computing hardware:

- They are easy to use even for people with little previous computing experience, ideal for the often elderly stroke patients.
- They are small and portable. Thus, patients can take them home and to the therapist's office according to their exercise schedules.
- They come with a screen surface which allows recognizing multiple finger touches and movements.
- Optionally, a touch screen stylus pen can be used as an alternative to direct finger touches.

We implemented a prototype iPad application that supports different types of exercises. The patient is required to follow curves displayed on the touch screen with one or more fingers. Simple feedback information based on the accuracy and regularity of the movements is given.

The following chapters start with an overview of comparable solutions for stroke rehabilitation. Then, the prototypical implementation with its technical challenges and solutions is described. This is followed by first experiences gained when presenting the prototype to professionals and performing initial user trials. The paper concludes with a description of the future work required to create a fully applicable professional solution.

2 State of Practice

In principle, it would be possible to use standard software and hardware for stroke rehabilitation support. For example, patients could perform different exercises while painting on the screen in an arbitrary multi-touch painting application. However, they would have to rely entirely on instructions and feedback provided by a therapist, who would have to select appropriate template pictures and check for correct finger movements of the patients according to their current tasks. Solutions specifically designed for stroke rehabilitation go beyond that.

2.1 Technical Solutions

A plethora of technical solutions for stroke rehabilitation has been proposed. Since strokes lead to very different kinds of disabilities, depending on the parts of the brain affected, no single rehabilitation method is suitable for all patients. Solutions based on electronic devices may support training of very different mental and corporal capabilities. In a first step, our focus is on the usage of devices for practicing motion sequences, particularly concerning hand movements.

Most existing solutions support some kind of motion tracking, which allows automatic evaluation of the patient's performance. With cheap web cameras available or already built into computing devices, picture recognition is an obvious choice for that. However, not all movements can be recognized reliably due to limitations in the picture recognition algorithms and possible occlusion of body parts depending on the position of the camera. In order to allow reliable position recognition using simple algorithms, some solutions require the patient to hold easily distinguishable objects during the exercise, as for example a colored sock (Alankus, et al., 2010) or a colored ball (Sucar, et al., 2010). Sucar, et al. (2010) describe a solution using a standard personal computer and web camera together with a specially built device, the "gripper", which supports camera tracking and measures hand pressure.

2.2 Supported Exercises

Different devices allow for different kinds of exercises. Solutions relying on contactless motion tracking, e.g. using web cameras, can be used for exercises involving different body parts. However, the lack of tactile feedback can lead to quite unrealistic movements. For example, simulating hand writing without something similar to pen and paper would probably be of little practical benefit for the patient.

Instead, specialized solutions have been created just for the purpose of the rehabilitation of handwriting skills. Mullins, Mawson and Nahavandi (2005) describe a hardware solution based on a simulated pen. This allows tracking of hand movements and providing haptic feedback. A study using a graphic tablet and a digital pen is described by Curtis, et al. (2009). Patients played interactive games specially designed for these devices to improve their handwriting skills.

2.3 Physical Feedback

For therapy, it is not only advantageous to recognize movements of the patient, but also to guide them and possibly provide physical feedback. Little standard hardware is available for these purposes. One solution involving a force-feedback joystick is described by Feng and Winters (2009). However, professional products usually rely on hardware specially constructed for rehabilitation purposes. A hand exoskeleton designed for stroke therapy is described by Fu, et al. (2011). Another solution (Hwang, Seong and Son, 2012) uses magnets to individually guide the patient's fingers.

Tablet computers like the iPad allow similar tracking of finger movements. However, despite the advantages of direct manipulation, the movements practiced on a touch screen hold little resemblance to real-life activities like grasping and moving things in the real world. Also, in contrast to special hardware solutions, no external control of the finger movements is possible. Thus, there is no way to correct the patients during active training other than by visual feedback, and passive training is not possible at all.

3 Design of the Application

Motivated by the advantages of custom software on standard tablet devices, a prototypical iPad application was designed and implemented. This chapter describes its functionality and user interface.

3.1 Types of Exercises

In order to find out how well different types of exercises work, the prototypical application contains tasks which differ regarding the following aspects:

- A varying number of fingers is allowed and required to be used at the same time.

- Fingers have to be moved either separately to simulate grasping, or together to simulate handwriting.
- Lines of different complexity have to be followed, from straight lines to cursive writing. Tasks for two separately moved fingers even enforce rotary hand motion.

Figure 1 shows an exercise which requires the patient to follow two lines simultaneously.

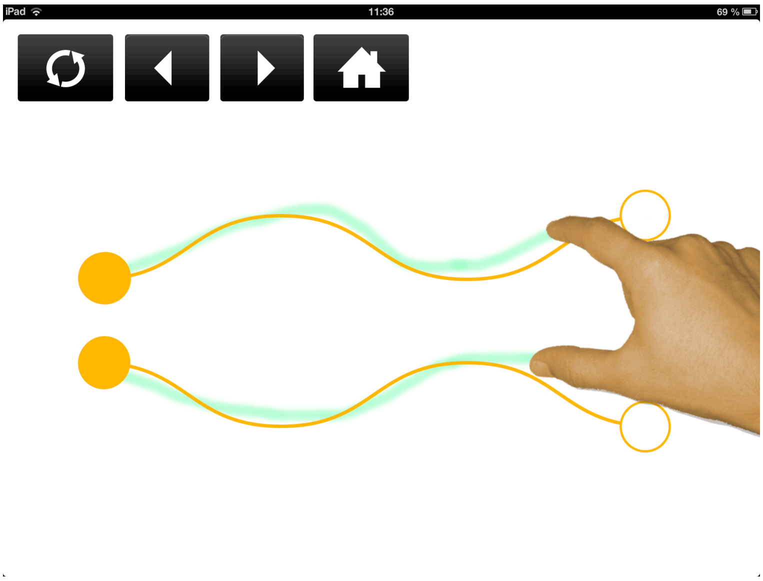

Figure 1. *Following a line with two fingers.*

3.2 Feedback Mechanism

A simple feedback mechanism for independent training is included: For each task, a success percentage is computed according to the accuracy, uniformity, and steadiness of the patient's movement.

For this purpose a list of point coordinates is stored for each displayed line. While patients follow a line with their finger, the distance of the actual touch position to the nearest point in the line is computed. The mean value of all distances determines the accuracy result. It is also measured, how long it takes the patients to move from one point to the other, and uniformity is rated according to differences between these measurements. Finally, the steadiness of movement is computed by counting how often the patient loses contact to the touch surface.

No precautions have been set in order to prevent cheating; for example, if the patient only follows easily reachable parts of a line and then immediately touches the end point, the application will still compute a high success percentage.

3.3 Navigation within the Application

The application contains a start screen with buttons leading to the different kinds of exercises. Each exercise contains different line pictures sorted by level of difficulty. They can be browsed through using arrow buttons. One picture contains one or more tasks, which can be completed in arbitrary order. After completion of all tasks the mean value of their success percentages is displayed as feedback to the patient.

4 Preliminary User Tests

The application has already been tried in practice by five patients: one 23 year old patient with craniocerebral injury, four patients with cerebrovascular insult at the age of 35, 55, 64, and 70 years. Testing started with early versions of the prototype, with only a restricted number of exercises and little success feedback. During the next few weeks, improved versions of the prototype were used. Most of the tests were conducted at a rehabilitation clinic in the presence of therapists who specialize in neurology and hand therapy.

These tests were documented using manual notes, photos and video recordings. However, patients were also allowed to explore the application independently on their own. Figure 2 shows the application as it was used in practice.

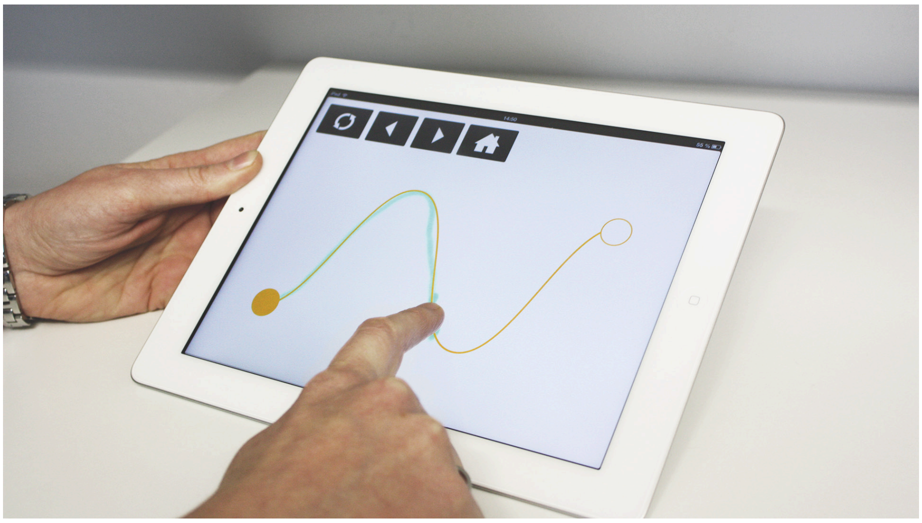

Figure 2. Using the prototypical application in practice.

4.1 Users' Reactions

Patients and therapists reacted very positively to the application. They found the optical design appealing and the idea interesting due to its novelty, and wanted to try out the application immediately.

It was obvious for them how to perform single-touch exercises, but they did not understand the multi-touch exercises without instructions. They thought that the application was broken when they received no feedback on single touches. Success feedback turned out to be very important for the patients' motivation. However, it was criticized that it was not clear how the percentage came about. Information was requested about the influence of different kinds of deviation from displayed lines.

The following statements have been made by patients using the prototype application:

> *"I can practice opening my fingers daily at home, as long as it's fun. In the meantime this works better in everyday life, too."*
>
> Patient, who had brain tumor as a child. Opening his fingers has been almost impossible since age 6. After intensive therapy, there is now improvement.

> *"The application motivates me to train each of my lazy fingers. I always switch between index finger, middle finger, and ring finger. This way, training remains exciting."*
>
> Patient, who had a cerebrovascular insult 2 years ago. After several rehabilitation stays and ambulant treatment he now uses the application for additional training.

Thus, there is definitely high demand for user-friendly, easily mobilized rehabilitation tools for stroke patients. Our iPad prototype application was encountered with high interest and willingness to give it a try by patients and therapists

5 Conclusion

The currently implemented exercises are based on the built-in technical capabilities of the iPad tablet computer for single and multi-touch recognition with visual feedback, and vary widely concerning handling and difficulty. Representative studies will be necessary to find out which touch motions are most beneficial for therapeutic progress. Then, both attractive and therapeutically effective exercises will have to be designed.

The prototype application is limited concerning usability and functionality, and some features do not work sufficiently well yet. Research will be required to develop reliable automatic evaluation mechanisms to measure therapeutic progress. This will be crucial for the intended application area of independent training. Nevertheless, preliminary user tests have shown that already now it can be useful in practice, and that there is generally a lot of potential in the application of a standard tablet computer for stroke rehabilitation,

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