Digital Version of the “Open/Close Zip” Subtest included in the Sollerman Hand Function Test

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***Abstract*—The Sollerman Hand Function Test is an assessment tool which shows the ability of a patient to perform activities of daily living. It is considered highly significant in medicine for the assessment of treatments. It is commonly used by doctors and therapists to evaluate the rehabilitation of fine motor skills in patients, however the need of the physical presence of a therapist and the use of specific materials make the test time consuming and clinic dependent.**

Our presented approach is a digital version of a subtest included in the Sollerman Hand Function Test, an alternative to the physical assessment tool. Our application can be used at any place, any time. There is no need for specialized equipment. The only necessary hardware is a mid-range PC and a camera. Our system recognizes the gestures and the movement of the user’s hand and provides appropriate visual feedback, imitating the real world’s test. In the paper we introduce the configuration and the implementation techniques used to develop our application, we identify technical issues related to the system, we offer a demonstration of the application and we discuss future work than can lead to improvements.

Keywords—Sollerman Hand Function Test, Computer Vision, Rehabilitation Assessment, Upper-limb Rehabilitation, Fine Motor Skills

I. INTRODUCTION

Assessment of hand function is important to evaluate the natural history of disorders and monitor improvement after treatment [1]. A reliable and objective hand function assessment tool that can assess hand function and grip performance in activities of daily living (ADLs) can help therapists evaluate the hand performance of patients and, consequently, help them provide appropriate treatments. However, most objective hand function assessment tools only evaluate hand function according to the time needed to finish tasks [2]. The Sollerman Hand Function Test (SHT) is a standardized test to assess the overall hand function, which has both good reliability and validity [3] [4]. It contains 20 ADL tasks, each having a number of prescribed grip patterns. It is based not only on the time needed to finish tasks but also on the quality of movement (the grip patters that are used in each task).

A few major drawbacks of most known rehabilitation and assessment tools for fine motor skills, like the SHT, are that they require the presence of a doctor or a therapist, they need specific equipment, and they are generally clinic dependent. These drawbacks make it difficult for patients to follow a treatment plan that requires frequent exercising, since it is time consuming. Modern technology can provide a solution to the aforementioned problems, since computer vision offers the opportunity to imitate tasks, performed originally in a clinic, at the comfort of the patient’s house.

Based on these observations, we created a digital version of the “Open/Close Zip” ADL task included in the Sollerman Hand Function Test. Our system integrates the real-life test’s mechanisms into a computer vision approach, using the Mediapipe Hand Tracking solution for recognizing the position and the movement of user’s hand and fingers [5]. It is an innovative approach which requires only a mid-range PC and a camera for running the application and executing the task. No other specialized equipment is needed.

The remainder of this paper is organized as follows. Section II provides an overview on hand rehabilitation methods and assessment tests used by therapists on treatment plans, and it also mentions digitized approaches that have been proposed by researchers. In Section III we describe and demonstrate our digital version of the SHT subtest. Section IV presents the technical issues of the implementation and it also discusses the future work that can be done in order to further develop our system, while Section V concludes the paper.

II. STATE OF THE ART

A. Hand Rehabilitation Methods and Assessment Tests

Hand rehabilitation is a constructive activity to gradually restore health and functionality of hand and fingers. Motion disabilities of hand and fingers are a common problem and can be a result of a wide variety of diseases and traumas [6]. Hand patients have difficulty in performing activities of daily living, a fact that severely affects their quality of life and independence [7]. Hand therapy strives to increase functional capacity and quality of life for individuals with upper extremity disorders [8]; however, maximizing quality of care and achieving positive outcomes depends on the availability of adequate, evidence-based assessment tests and rehabilitation techniques.

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Hand rehabilitation techniques can be classified into two categories, classical and game-based, respectively [9]. Most protocols for rehabilitation are based on motor learning, in order to provide a mechanistic substrate to facilitate motor recovery [10]. Motor learning is known to be greater if the practice method is meaningful, repetitive, and intensive [11, 12]. That is why task-specific training and enriched-environment therapeutic approaches are commonly recommended. Classical task-specific training sessions include simple tasks that involve common household items like stacking coins, lifting plates, opening zips, pouring water into a glass, etc. Enriched-environment approaches, in addition to the procedure executed by the patients to complete an exercise, focus also on the environment that the tasks are being held in. This way, they can offer greater chance for engagement and intensive physical activity, and that is why they have been the main focus of research for many studies in the recent years. By using technology, new solutions can be offered to overcome basic drawbacks of classical rehabilitation techniques, like time consuming and clinic-dependent therapies. Part of the enriched-environment therapies are the game-based techniques, which offer rehabilitation exercises in an engaging digital environment, while sustaining the beneficiaries of physical tasks.

In order to choose an appropriate hand rehabilitation treatment plan for patients, therapists need tools that can effectively assess hand function. The hand function may be defined as the capacity to use our hands in ADLs depending on the anatomical coordination, strength and dexterity [13]. There are few tests for the hand function assessment based on ADLs, most of the them created several decades ago, but still being used extensively, such as the Jebsen Hand Function Test [14] and the Sollerman Hand Function Test. The latter contains more varied and representative ADLs, which were selected based on the most common hand grasps [3], while most tasks used in assessment tests that incorporate ADLs, can also work as repetitive hand rehabilitation exercises.

B. Digitalization of Methods and Tests

A basic problem with typical rehabilitation exercises is that many of them cannot be performed at home without therapist's supervision [15]. That is why researchers, especially Human-Computer Interaction researchers, try to find alternative ways to the traditional exercises' method. Lately, the main focus of the field's researchers is to develop digital games or virtual therapists as alternatives to the traditional methods [16]. There have been quite a few approaches proposed on digital versions of hand rehabilitation exercises and tests.

Everard et al. propose a virtual reality version of the Box and Block Test [17], which is one of the most used and recommended tools to evaluate unilateral manual dexterity. It was developed using the Oculus Quest 1, combining the use of the haptic controllers and headset to recreate a virtual version of the real-world Box and Block Test. Experimental results showed strong correlations between the number of blocks displaced by patients in the two versions of the test. Pereira et al. in their study present a Virtual Reality game to improve conventional physiotherapy in hand rehabilitation [18]. The Oculus Quest was chosen again as hardware solution in order to render the environment of the game and recognize the necessary hand gestures. The users make specific daily living gestures which allow them to interact with elements of the game like clouds, vegetables, etc., and complete given tasks. Testing of the system has produced several positive comments. Another approach in digital hand and wrist rehabilitation has been made by Batista et al., with the development of the FarMyo Serious Game [19]. FarMyo uses an electromyography system to recognize the gestures performed by the user. The game structure consists of three different mini games, each one addressing different set of rehabilitation exercises. The mini games imitate daily living tasks performed in a barn, a henhouse and a vegetable garden. System testing with rehabilitation professionals suggested that the game could prove to be important in the recovery process. Kanzler et al. in their study propose a Virtual Peg Insertion Test for the assessment of functionally relevant sensorimotor impairments in arm and hand [20]. Their system consists of a commercial haptic end-effector device, a rapid-prototyped grasping force sensing handle and a virtual reality environment on a personal computer. The virtual reality environment displays a virtual pegboard task that requires the insertion of nine virtual pegs into nine holes. System experiments that have been made provide evidence that these kinds of digital approaches can enable robust, sensitive and objective ways to assess arm and hand sensorimotor impairments. Research made by Elnaggar and Reichardt studied the development of a digital solution for hand rehabilitation using serious games to aid patients in rehabilitating their hand [15]. They developed a web based serious game using Leap Motion, which is a markerless motion capture device, providing patients with great ease of use. System testing reports show that it can be an effective tool in the hand therapy process.

We should point out that the researches mentioned in this section are just a few indicative paradigms of digital approaches that have been made on hand rehabilitation exercises and tests. Many more researchers have been studying the sector, developing new solutions. Nonetheless, there are not any digital approaches proposed on the Sollerman Hand Function Test, even though it is one of the most commonly used assessment tests.

III. THE DIGITAL SOLLERMAN HAND FUNCTION TEST

Our system, the Digital Open/Close Zip Test (DOCZT), is an innovative approach of the standardized hand function test of Sollerman and Ejeskar. The application we developed allows patients to perform the open/close zip subtest with the use of a single computer and a camera. There is no need for any extra equipment. The user just stands in front of the camera and performs the hand grip and the moves indicated by the test, while the system recognizes the gestures and the movement, providing appropriate visual feedback.

A. System Configuration and Implementation

The main novelty of our system is the use of a single camera to record the position and the moves of the patient's hand, without the need of any other equipment like gloves, headsets, etc. Our goal was to implement an application that would be eligible for use by patients at their place, with non-expensive hardware they probably already have. For the camera hand detection, we use the MediaPipe open-source platform which provides a high-performance palm detection and hand landmark model. We have chosen the JavaScript API to develop an application that will be easy to use even by people of low computer skills, without the need of installation, as it can be accessed like a simple everyday website.

Moreover, our system has high portability and can be easily maintained.

Initially we grab raw camera input which we feed to our display. The system recognizes if a hand is present in the frame and draws 21 red landmarks on it, connected with green lines. Afterwards, we create a 3-dimensional environment with the use of the Three.js library. We present a white purse on a table, with a zip on top. At the left end of the screen, we place a score counter which starts at 4 and decreases over time, a timer which starts at 60 seconds and a quit button which can be used to end the test at any point. Furthermore, at the top of the screen we can see a text description that asks the user to open the zip. The test is not running until the start button, which appears at the center of the display, is pressed.

After we have pushed the start button, it disappears from the screen and the timer begins to count down. Then, if the user makes a pulp pinch by touching the tips of the thumb and the index finger without any other fingertip being close to the pinch, the system recognizes the gesture and turns the red landmarks of the hand in the camera feed into green. This way the patient understands that the gesture has been made correctly. Since we grab frames consecutively, we are able to understand if the user moves the hand towards any direction. In case the hand moves left or right, while holding the pinch, we change the position of the purse's zip accordingly. Following this pattern, we are able to simulate the real-life procedure of opening and closing a zip. When the user moves the zip all the way to the left side of the purse, we consider the zip as open and the description at the top of the screen changes, asking the patient to close the zip, by moving it all the way to the right of the purse this time. If the user succeeds, the test is completed and a message appears on the screen giving the user a score for their performance. Figure 1 shows the high-level architecture of our system, while our application is available here [21].

B. *Application Demonstration*

The user stands in front of the camera and clicks on the button that starts the timer and enables the features of the application. Then the user needs to make a pulp pinch (thumb and index finger tips touch). When the grip has been made successfully, the color of the red hand landmarks drawn in the camera feed changes to green, as shown in Figure 2. While holding the grip, moving the hand from left to right and vice versa makes the zip displayed on the screen move accordingly. The goal is to open the zip by moving it all the way to the left, and then close it by moving it all the way to the right.

To assess the functionality of the hand we use the same metrics and logic used in the original Sollerman Hand Function Test. If the user completes the drill in less than 20 seconds, 4 points are awarded and the exercise is considered to be executed with no abnormal findings (Figure 3). When the task is completed in more than 20, but less than 40 seconds, 3 points are awarded and the exercise is considered to be executed with slight divergence from normal. If the user fulfills the task in more than 40 seconds, 2 points are awarded and the execution is being characterized by great difficulty. In the case the user is not able to complete the exercise in 60 seconds the procedure stops. If until then the zip has been opened but not closed there is 1 point given and the task is described as partially performed, while when the user has not even opened the zip before 60 seconds elapse, the exercise is described as not performed at all and there are no points given.

IV. TECHNICAL ISSUES AND FUTURE WORK

Our system's testing revealed two technical issues that need to be addressed. The first one regards to the accuracy of recognition of the hand's gesture. The test we are digitizing requires a specific hand pose to be made in order to perform the given task. So, recognizing that this gesture is made correctly by the user is crucial for our application. We need to identify the position of the hand when it is visible in the camera feed and also, we have to accurately conclude at any given time if the fingers of the user are posing the required gesture. This way we are able to decide whether the simulated movement is similar to the one in the real world's test or not. To achieve this, we are using the MediaPipe library, which appears to be a valuable tool for hand tracking and identifying landmarks that can be used for gesture recognition. More specifically, we have chosen the Javascript solution offered. We should mention here, that we tested our application through various browsers and there were no significant errors, but Mediapipe developers recommend Chrome as the browser to use. The drawback we faced in our implementation is that the lighting conditions of the room and the camera calibration can affect the process and provide us with non-accurate finger readings. To overcome this difficulty and avoid bad quality camera feedback we recommend using the application in a naturally lit room and placing the camera about 50cm away from the hand of the user.

The second issue we need to address is the high speed of camera frames processing. In order to have an accurate digital test related to the real world's test, it is crucial to process all image frames captured by the camera as close to real time as possible. This is because except hand recognition, we also have to present three dimensional objects on the screen (purse, zip, etc.), which change their status and position according to the gestures and the moves the user makes. The whole process of reacting to the user's movement needs to feel seamless. To achieve decent performance in this area, we use the "Control" utility package offered by the Mediapipe library, which offers satisfying results, even on mid-range hardware (30-40 milliseconds process time per frame).

Having surpassed the technical difficulties, we can focus on future work that can be done around this project. There is much potential for further development. Our primary concern is to test our system with diverse groups of people. Testing will allow us to conclude with a high level of certainty that the scores made in our application have strong correlations with the scores made in the real world's test. The whole testing procedure, and the analysis of the results, will be carried out within the framework of the "Rehabotics" project [22]. Following testing, we will optimize the system by adding features that will enhance users' experience. First should be the creation of a platform where test results will be stored, so that patients can track their improvement. Also, it is important to create a detailed user manual, which besides written explanation of the system's usage may include demonstration videos, in order to help users fully understand the way our application works, even without the presence of a system expert. Moreover, we can create a mobile version of the application, making it available even to people who do not own computers.

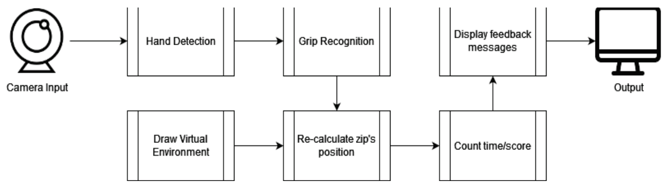

Fig. 1: High-level architecture of the system

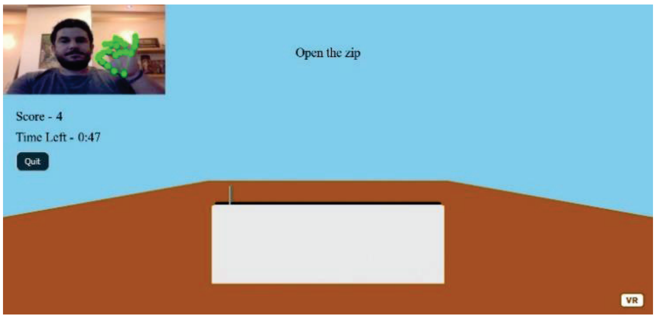

Fig. 2: Demonstration – Hand Gesture Recognition

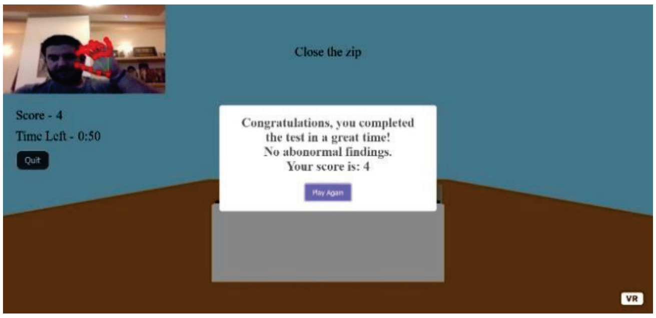

Fig. 3: Demonstration - Completion Message

After the optimization of our system, a logical next step would be to develop more digital versions of subtests included in the Sollerman Hand Function Test. This way, we will be able to provide better assessment to patients concerning their physical hand condition, since there will have the option to exercise on different grips and hand gestures. Furthermore, we can create serious games that will use the eight main hand grips of daily living that the SHT focuses on. Doing that will give the option to patients to exercise in an entertaining environment, which can lead to increased engagement and better treatment results.

Achieving the development of various digital assessment tests and serious games for hand rehabilitation, will allow us to pursue one of the basic goals of the "Rehabotics" project, which is the development of a rehabilitation platform that will serve patients and therapists as a significant treatment tool. The platform will contain all our digital tests and games, offering patients the opportunity to follow an intensive treatment plan, with various exercises, at the comfort of their place. Users are going to be able to register either as patients or therapists, allowing therapists to overview at any time the progress of their patients. Performance data will be stored and visualized helping the users to analyze treatment results. Patients will be able to communicate with their therapists through the platform and therapists will have the option to recommend to their patients digital exercises included in the platform.

V. CONCLUSION

We described a digital system that can be used as a hand function assessment tool and also as an exercise for improving fine motor skills. This approach does not need any specialized equipment, other than a mid-range PC and a simple camera. It is a lightweight and portable application, whose design ensures ease of use. It is easily maintained and there is much potential in place for further development.

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