Design and Development of a Forearm Rehabilitation System Based on an Augmented Reality Serious Game

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Abstract. In this paper, we propose a forearm rehabilitation system based on a serious game in Augmented Reality (AR). We designed and developed a simplified AR arcade brick breaking game to induce rehabilitation of the forearm muscles. We record the electromyographic signals using a low cost device to evaluate the applied force. We collected and analysed data in order to find a relationship between the applied force and the difficulty of the game. This research focuses on the dehospitalization of subjects in the middle or final stages of their rehabilitation where the new technologies, like Virtual and Augmented Reality, may improve the experience of repetitive exercises.

The results achieved prove that the force applied by the user to hit the virtual sphere with real cardboard cube is related to sphere speed. In a rehabilitation scenario the results could be used to evaluate the improvements analysing the performance history.

Keywords: Rehabilitation · Virtual and Augmented Reality · Brick serious games

1 Introduction

Stroke is a brain attack that occurs when blood flows to an area of brain is cut off, and it represents a leading cause of disability [1]. This situation causes death of brain cells that are deprived of oxygen. Since a stroke involves brain cells, their death has important consequences on the functions of the human body; in particular, functional deficit depends on the brain region affected by dead cells. If the stroke occurs on the right side of the brain, it will affect the left side of the body, including the left side of face. In this case, paralysis on the left side of the body, poor eyesight, quick and inquisitive behavioural style, memory loss can arise too. When the stroke occurs on the left side of the brain, the right side

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of the body will be affected, producing paralysis on the right side of the body, speech disorder, slow and cautious behavioural style, memory loss. In some cases, stroke can occur in brain stem, where, depending on the severity of injury, it can affect both sides of the body and may leave someone in a locked-in state. When this state occurs, the patient is generally unable to speak or achieve any movement below the neck [2].

Rehabilitation of people affected by a stroke is probably one of the most important phases of recovery for many stroke survivors. Rehabilitation can bring subject to his independent life, if properly addressed. To achieve this goal, monitoring EMG (electromyography) signals during stroke rehabilitation therapy can provide valuable insights on neuromuscular system, leading to increased recovery effectiveness.

In this work, we propose a novel approach to forearm rehabilitation that makes use of Myo armband, a low cost gesture controller, to acquire electromyographic signals. Our approach relies on the execution of rehabilitation tasks of a serious game in Augmented Reality (AR) using a simple video see-through setup. This choice reduces equipment and national healthcare system costs, making the system portable and allowing a true home rehabilitation.

The Myo Gesture Control Armband from Thalmic Labs (Fig. 1) is a chain of plastic, or rectangular "pods", where each of them has one medical grade stainless steel EMG (ElectroMyoGraphic) sensor able to detect the electrical pulses of muscles. Myo armband has 8 distinct sEMG (surface EMG) sensors. It communicates via Bluetooth and sends the 8 samples (one per pod) with a frequency of 50 Hz. EMG is referred to as myoelectric activity. Muscle tissue conducts electrical potentials similar to the way nerves do and the name given to these electrical signals is the muscle action potential. Surface EMG (sEMG) is a method of recording the information present in these muscle action potentials [3].

The muscle activity and the EMG signal associated may vary according to the number of Motor Units (MU) recruited and their activation frequency. A MU is the smallest functional unit, which describes the neural control of muscle contraction. During voluntary muscle contraction, two independent parameters modulates the force applied: the first one represents the number of recruited MUs and the second one is MU activation frequency. Considering an experiment, which involves the same muscle activity and the same applied force, is unlikely to observe the same pattern signal. The main parameters that influences EMG signals are:

- tissue kind
- tissue thickness
- user's temperature
- user's physiological state

Due to the non-reproducibility of EMG signals when performing the mentioned experiment, it is appropriate to apply particular smoothing algorithms to filter signals. Using appropriate processing techniques, such as Average Rectified Value (AVR) or Root Mean Square (RMS), it is necessary to evaluate the average signal trend that represents the applied force.

2 Related Works

Various approaches, different from classical therapy, have been used formerly on post-stroke rehabilitation such as virtual reality and other techniques [4,5]. In [6], it is used an active robot exoskeleton to support patients in their rehabilitation phase doing reaching/grasping tasks. Moreover, they have also developed a real time tracking system in order to let the patient interact with real objects. In [7] an arm rehabilitation robot has been studied in order to perform task-oriented repetitive exercises in patients with neurological and orthopaedic lesions, training patients with everyday life activities. In [8] an arm rehabilitation system based on Augmented Reality was developed; they use an haptic sensor to measure the wrist impedance in order to have strength feedbacks, while the AR system is used as hand tracking system. A similar work could be found in [9], where they perform different tasks for different upper art parts (hand, wrist and arm) in order to evaluate different parameters for each task.

In some cases, it is important to migrate the rehabilitation phase to patients' home where it is possible to adapt the actual environment to personal needs after medical staff understood the best living conditions, for example using Virtual Reality (VR) simulations [10,11] and Augmented Reality (AR) using video or optical See-Through Devices [12,13].

We developed a serious game to evaluate the relationship between the force applied by the user and the difficulty level of augmented reality serious game used in rehabilitation tasks. Compared to state of the art our system offers a low cost and portable augmented reality setup.

In the next sections, we describe the serious game, the acquisition protocol for sEMG signals and their processing in order to find the aforementioned relationship.

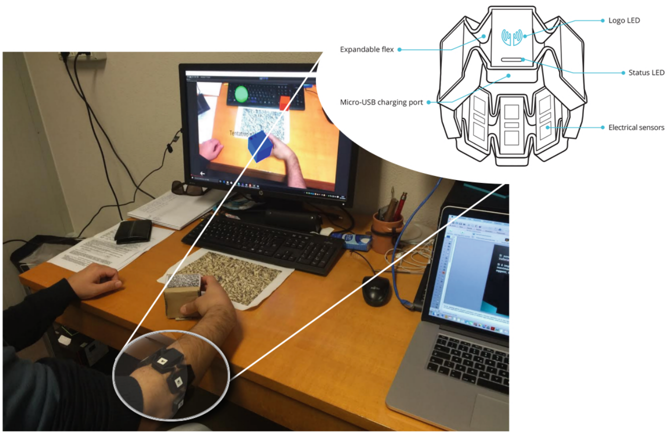


Fig. 1. Serious game setup

3 Methodology

3.1 Experiment Description

The augmented reality serious game designed is inspired by an arcade game developed and published by Atari, Inc. in 1976 and known all over the world. In the game Breakout, shown in Fig. 2, a layer of bricks lines the top third of the screen. A ball travels across the screen, bouncing off the top and side walls of the screen. When a brick is hit, the ball bounces away and the brick is destroyed. The player loses a turn when the ball touches the bottom of the screen. To prevent this from happening, the player has a movable paddle to bounce the ball upward, keeping it in play. The game difficulty is strictly correlated to ball speed.

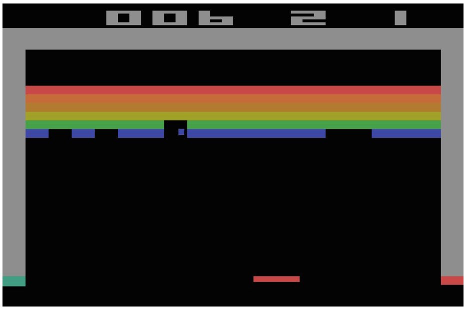


Fig. 2. The original Breakout game by Atari, Inc (1976)

Our serious game incorporates AR technology and tangible interaction techniques to provide an innovative interface to rehabilitation tasks. The system augments the captured image of the real environment with computer-generated graphics to present a variety of game or task-driven scenarios to the user [14]. The tangible interaction (through Tangible User Interface or TUI [15,16]) facilitate to interact with digital information using the physical environment. TUIs have emerged as an alternative paradigm to conventional GUIs allowing users to manipulate objects in virtual space using real, thus tangible, objects.

The designed AR serious game involves the use of two tangible markers, on which 3D objects, that are part of game, are attached. The system, via a webcam, tracks the position and orientation of each tangible markers as it is moved. The used optical tracking system is based on the natural feature tracking algorithm implemented in Vuforia [17]. The "A marker" is associated to the line of bricks and to the game area, while the real TUI "B marker" is associated to the paddle used to hit the moving ball in the game.

In order to simplify the user's movement to achieve certain results, a single target represented by a virtual cube (or cube target) was considered (Fig. 3) in the upper right corner of the "A marker". The initial position of the sphere is in the upper left corner of the scene and, during the game, it moves toward the cube (paddle) that the user grabs in her/his hand (Fig. 4).

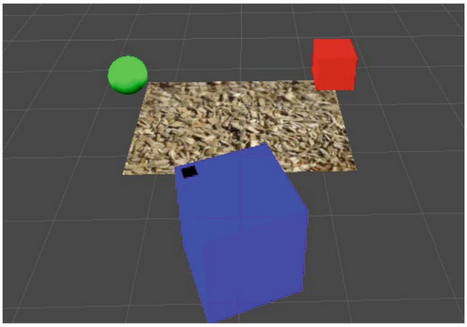
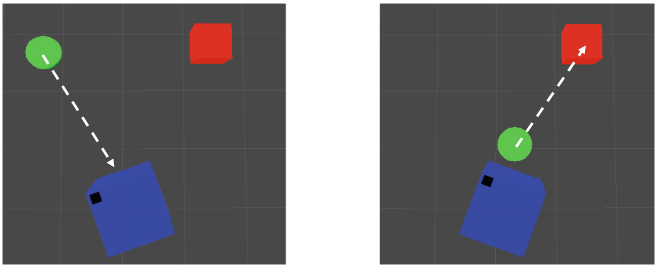


Fig. 3. The initial positions of sphere, paddle and target



(a) First Trajectory **(b)** Second Trajectory

Fig. 4. Sphere trajectories

The goal is to hit the cube target with the sphere. Unlike the original game, in this version the user does not move the paddle left-right, but s/he can only rotate the paddle on its vertical axis. This way, we consider only a wrist rotation.

3.2 Testing

System Setup. Starting the experiment, it is necessary to place ARTags in a correct way. The "A marker" must be placed on a table in front of the user, while the "B marker" must be placed between the "A marker" and the user. The user should seat in a way that both, the centre of the marker attached on the cube and the shoulder relative to the forearm under rehabilitation, lie in the same sagittal plane as shown in Fig. 5. The user wears the Myo armband, s/he has to relax the arm to warm up the device. During this phase, the Myo establishes a strong electrical connection with the muscles. It is not necessary to perform the usual calibration. In fact, in this work, the Myo device is used as an array of sensors to record the sEMG signals and not as a gesture controller.

In the initial stage of rehabilitation at home, users have to be trained in order to handle and to move the cardboard cube in the correct way. This is necessary to reduce the noise caused by the tension of other muscles registered involuntarily in the event.

(a) Starting Position **(b)** Ending Position

Fig. 5. Handle and movement

Experiment Start. When the application is started, a setting panel is shown, where an operator may insert:

- **IP Server:** the address on which game sends message to start and stop process that saves samples;
- **Name:** the user's name;
- **Initial Speed:** the sphere speed at first attempt;
- **Speed Increase:** the value that is added to sphere speed of the previous attempt to get the sphere speed of the actual attempt;
- **Levels number:** the number of trials in an experiment

An experiment consists of two trials. In particular in the first attempt the sphere has a speed equal to 0.17 m/s while in the second trial it increases to 0.39 m/s. When all the objects are framed on the scene, the sphere, starting from initial position as described previously, moves towards the paddle; the user has to hit the sphere in such a way that it bounces off pointing to the virtual target and s/he has to hold final position until the sphere hits the target or exits the scene. In order to make trials having the same duration, the sphere speed is decreased after hitting the paddle. For each trial we recorded 150 samples.

4 Experimental Results

For this study 5 healthy persons aged between 24 and 30 years (mean 27,2 sd 1,9) were recruited. For each subject the sEMG signal related to the two trials was registered. First of all, collected samples were processed to detect the two sensors with the greatest variance on the measured signal, let name them sensor A and sensor B. In Table 1 the values of variance for each user and each sensor are shown for each attempt.

Then it was performed an amplitude analysis on the samples recorded by the two sensors identified in the previous step. It was calculated the RMS which represents an evaluation of the force applied by the user during the test [18]. Table 2 shows the results. Finally, it was normalized the forces on the value obtained in the trial with higher sphere speed (Table 3).

Table 1. Variance for each user, attempt and sensor

		Variance							
User	Attempt	Sensor 1	Sensor 2	Sensor 3	Sensor 4	Sensor 5	Sensor 6	Sensor 7	Sensor 8
User1	1	15,717	39,954	6,8857	5,2445	1,8161	2,4166	5,2088	44,573
	2	64,438	267,28	52,15	11,376	4,2205	5,0629	40,165	48,774
User2	1	25,791	343,44	24,067	16,43	17,333	4,4695	6,1601	6,0148
	2	33,191	811,82	50,73	26,702	28,311	5,3037	11,19	11,551
User3	1	198,82	857,45	88,023	54,348	38,033	32,275	16,984	23,764
	2	353,08	1102,4	110,56	39,936	35,501	19,564	29,805	23,284
User4	1	77,42	514,69	64,463	15,036	14,129	5,8494	19,85	91,609
	2	133,23	768,49	100,22	20,408	16,62	10,426	46,777	218,01
User5	1	17,587	201,64	121,63	48,898	11,282	4,155	25,702	125,14
	2	77,925	873,64	1148,1	374,18	35,847	12,066	13,237	162,76

Table 2. RMS values for each sensors

		RMS values		
User	Attempt	Sensor A	Sensor B	Average
User1	1	6,3322	6,6696	6,5009
	2	8,0503	16,403	12,22665
User2	1	5,0599	18,735	11,89745
	2	28,445	7,1401	17,79255
User3	1	14,072	29,187	21,6295
	2	18,75	33,284	26,017
User4	1	22,669	9,6737	16,17135
	2	27,614	14,769	21,1915
User5	1	14,164	11,198	12,681
	2	29,573	33,799	31,686

5 Discussion and Results

In order to consider only the sensors activated during the movement, it was calculated samples variance for each sensor. It were chosen the first two sensors on which was registered greatest variance (sensor A and sensor B). Samples registered by these sensors were used to calculate the mean power of the signal which represents an evaluation of force applied by user during experiment. The value considered to compare the force applied in the two trials is an average between mean power of signal registered by sensor A and sensor B.

In the Table 2 it is possible to observe that the applied force is proportional to the sphere speed (Fig. 6).

In a hypothetical rehabilitation scenario a supervisor could set a game level suited to the physiological conditions of the user and then monitor the rehabilitation performance in terms of applied force.

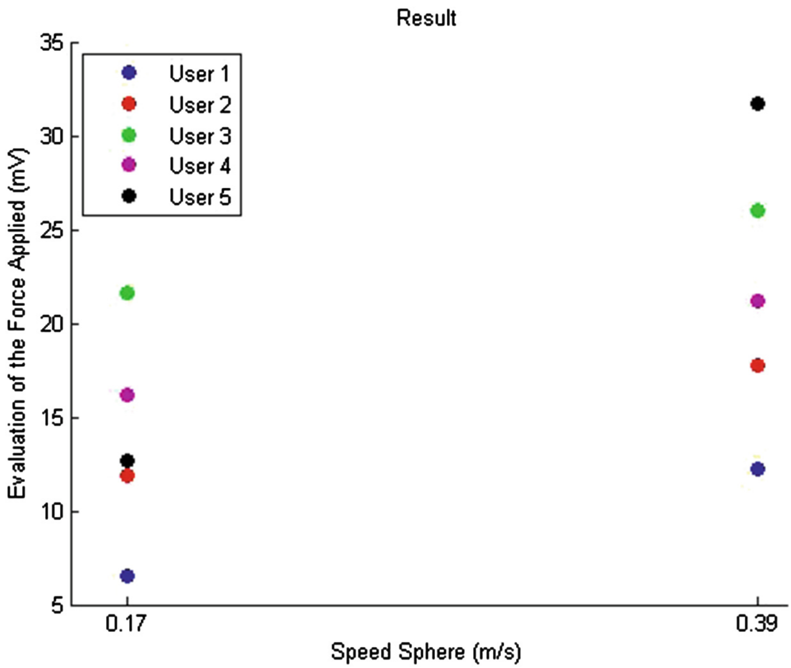


Fig. 6. Result

Table 3. Normalization

User	Attempt	Normalization
User 1	1	0,531699198
	2	1
User 2	1	0,668675935
	2	1
User 3	1	0,831360264
	2	1
User 4	1	0,76310549
	2	1
User 5	1	0,400208294
	2	1

6 Conclusion

In this work, we propose a system for forearm rehabilitation based on an AR serious game using a video see-through device.

We use a low cost and portable setup including a gesture controller device to monitor the rehabilitation task performances recording and processing sEMG signals. The samples are processed to find an evaluation of the applied force during the rehabilitation task related to level of difficulty of the game. In a rehabilitation scenario the results could be used to evaluate the improvements analysing the performance history.

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