Virtual Reality and Hand Rehabilitation.
Part I: Computer Aided Hand Function System.

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ABSTRACT

Rehabilitation Process could be enhanced through the use of computer simulation technology. The computer simulation was used in physical medicine and rehabilitation for both examination and training exactly those functions that are disturbed in specific disorders. The purpose of this study was to design and implement a computerized system for hand functions using simulation. The system consists of a hardware subsystem, software subsystem and accessory equipment. The hardware subsystem includes a personal computer, data acquisition system, preamplifier, force sensing resistor box, falling object detector, electrical muscle stimulator and an adaptor card. The software subsystem includes the simulation program and the database module. The accessory equipments are wooden objects with different geometrical shapes and different size and weights. The system was considered as a useful tool for training hand functions that can be impaired in many disorders like cerebral palsy, reconstruction of hypoplastic thumb and in case of crashed hand.

Key words: Computer, Virtual Reality, Hand Function, Hand Rehabilitation, Simulation Technology.

INTRODUCTION

The use of action perspective over the movement perspective in learning a different task was emphasized for cerebral palsy patients. Conventional biofeedback deals with the regulation of contraction in a single muscle group, or even a collection of muscles but this is far from functional goals. Therefore, it was suggested to replace biofeedback by action feedback, using the interactive computer environment [15,16].

Virtual reality (VR) refers to a range of computing technologies that present artificially generated sensory information in a form that people perceive as similar to real world objects and events. The basis of most VR systems is the simulation of a visual three-dimensional environment presented on a monitor, or projected on to a large screen, or viewed via one or two screens inside a helmet-mounted display. To make the subjective experience of exploration and interaction realistic, the computer must generate new images fast enough to give the impression of real-time movement and responsiveness [6,17].

The virtual environments can be experienced in two ways: Immersion VR and Desktop VR. In immersion VR the virtual environment is viewed via screens in a head mounted display; a tracking system slaves head movements to the image-generation system so that, for example, when the head is turned to the left, an appropriate update of the left hand view of the environment is displayed. Additional movements may be effected using a joystick or similar device such as space ball (a tennis-sized ball that responds to hand pressure in any direction), or a three-dimensional mouse [1,17].

In desktop VR the environment is viewed on a conventional computer monitor (or sometimes projected onto a larger screen). Typically image resolution is much better than in immersion VR. Sounds are usually presented via external loudspeakers. In order to interact with simulated objects, a range of interface technologies have been developed. This can be achieved by using a mouse or joystick-controlled pointer. More sophisticated methods include presenting a simulated hand with the virtual environment that is slaved to the movements of the u
fitted with position and stretch sensors [12,17].

VR can be applied for rehabilitation of specific disorders by training exactly those functions that are disturbed. Creating virtual scenarios, in which series of motor tasks are generated, can do this. This will produce a motivating effect for patients arising from the precise feedback of their success in real time [10,12].

It was theorized that the rehabilitation process could be enhanced through the use of VR technology. The use of VR in physical medicine and rehabilitation was outlined into two categories. The first is the use of VR for examination using the data glove as a means of collecting dynamic functional movement data. The second is the use of VR technology in rehabilitation [7].

A unified computerized system for hand diagnosis and rehabilitation was described [3]. The diagnosis subsystem consisted of an electronic dynamometer, an electronic pinch meter and a goniometer. A tactile glove- a device similar to data glove- supplied with a sensing component consisting of sixteen fiber optic sensors mounted on the back of the glove and a tactile component made of sixteen ultrasonic force sensors was used. The rehabilitation subsystem consisted of a virtual rubber ball and the first exercise was to squeeze the ball; the second exercise was a virtual version of the commercially available individual finger exercise, Digikey. The third exercise implemented a peg-in-hole insertion task. A virtual model of a board with nine holes and the corresponding number of pegs was created. Their clinical experiment for this system indicated that all patients liked the device. Qualities such as biofeedback and watching the virtual hand move on the screen were the main reasons regarding the positive impression of the device [13].

The drawbacks of VR was Considered, which include nausea and vomiting following the use of the head-mounted display. They also noted that these problems are not reported following desktop VR use. An area of ethical concern, particularly for children who have difficulty in negotiating real environments, such as children with physical disabilities, is that they may find virtual environment too attractive. There is always the possibility that a few children may become addicted to VR experience and withdraw from real world interactions [14,17].

The purpose of this study was to design and implement a computerized system using simulation for training of hand functions that can be useful for those with hand functions impairment.

The Hardware System

The simulation was run on an IBM compatible personal computer (PC) system (Pentium 100), with 16 MB RAM. The components of the hardware were Data Acquisition System (DAS), a preamplifier, force sensing resistors (FSR's) box, a falling object detector, an Electrical Muscle Stimulator (EMS), and an adaptor card.

The Data Acquisition System

The PC is equipped with DAS, which is one channel analog-to-digital (A/D) converter (fig.1), with the following characteristics: 8 bit (2^8) resolution and maximum input voltage of 5 volts, that leads to measurement resolution of 20 millivolts (step value= 5 volts/2^8 = 0.0195312 v ≈ 20 mV). The sampling rate of the A/D was 4.5 KHz (the band width of the EMG was 1 KHz).

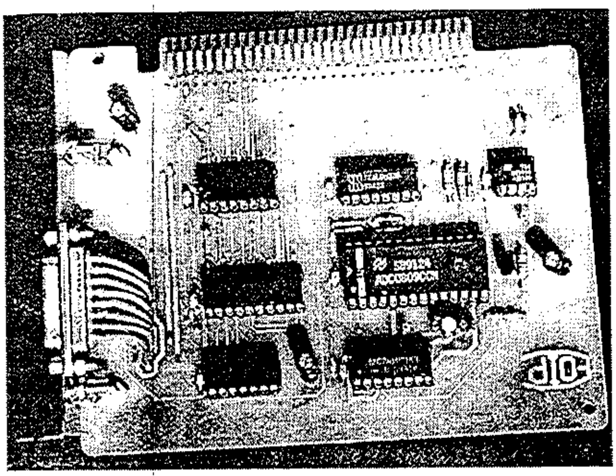

Fig. (1): Analog-to-digital converter.

The preamplifier

The DAS is interfaced with a two channels preamplifier (fig.2), to amplify the EMG signal and the force sensors signal. The bandwidth of the preamplifier channel used for the EMG signal was 1 KHz, while the preamplifier channel used for the force sensors had very low bandwidth (100 Hz), as the force signal is not varying with time. The EMG preamplifier channel had a voltage gain up to 5000 volts and a maximum input of one millivolt peak-to-peak (VP-P). An isolated direct current (DC) power supply was used to protect the patient from any direct connections with the main supply. Surface EMG electrodes (Silver-Silver-Chloride) with high sensitivity <5mm active area were used, from Medisana Germany.

Non-isolated direct current power (5 volts) supply was used in the force sensor channel, as there was no direct electrical connection between the patient and FSR preamplifier channel.

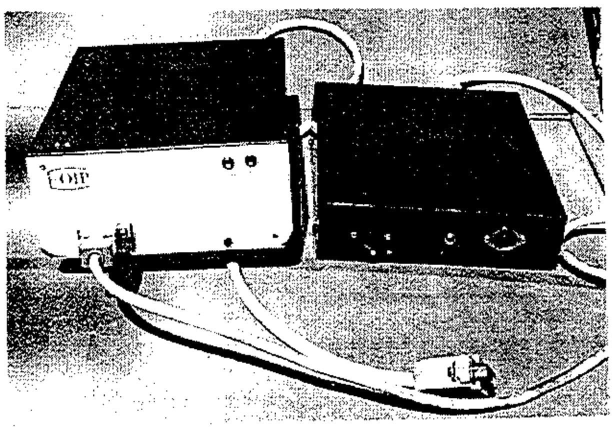

Fig.(2): The preamplifier and the adaptor.

The force sensing resistors box

FSR's (part # 400) from interlink electronic (546 Flynn Road. Camarillo, CA 93012) were used to measure the force exerted by the thumb. Three FSR were used to measure the force exerted by the thumb, index and middle fingers in a specially designed box (fig.3). Its dimensions are 7cm length, 4cm width and 5cm height, supplied internally by the electronic circuit for the FSR. The sensors were numbered 1, 2 and 3 and fixed in a way that the span between the sensor corresponding to the thumb at one side and the index- middle fingers sensors in the opposite side is the width of the box (4 cm). At the right side of the box there is a switch that can be shifted into three positions to activate a single sensor one at a time. This enabled the patient to press on the force sensor properly.

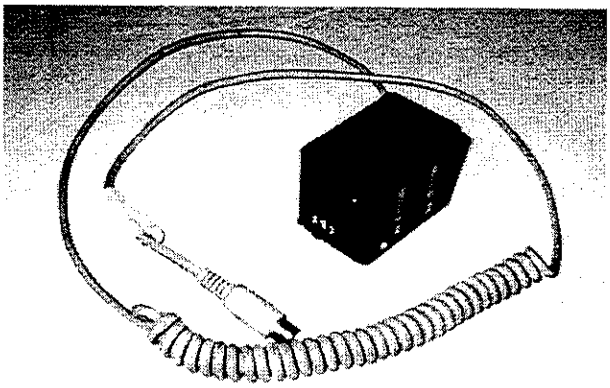

Fig. (3): The force measuring box with three FSR'S.

The Falling Object Detector (FOD)

A box, with a bank of five light source transmitters and a bank of five light detectors, is specially designed to detect any falling object. When an object is dropped into the box, the light beam is interrupted and the detector sends a signal to the computer indicating that an object has successfully fallen in (fig.4).

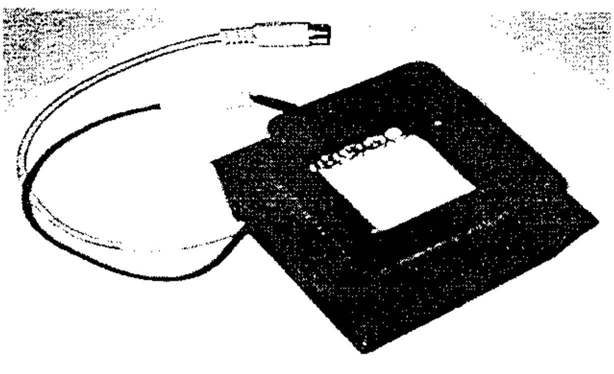

Fig. (4): The falling object detector.

The electrical muscle stimulator (fig.5)

A portable EMS, with two channels was used to stimulate the thenar muscles. A model 400 Bauartzugelassen, from Medisana Medizinalberdarfs-Gmbh, Bergerweisenstrafe 19-5309 Meckenheim, Germany. The two channels have two modes of operation, simultaneous and alternating. In the simultaneous mode, the two channels are totally synchronized with each other. This means that they are on and off at the same time. In the alternating mode, one channel is activated and the other is remaining inactive and vise versa. The latter mode was used in the study where one channel was used to stimulate the patient's thenar muscles while the other was connected to the computer to synchronize the operation of the software program. The intensity, frequency, and duration are adjustable parameters.

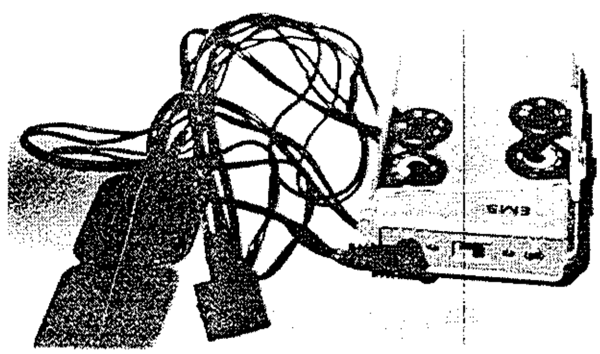

Fig. (5): The electrical Muscle Stimulator (EMS).

The adaptor card

It is an electronic card responsible for translating the signal generated from the EMS into a form suitable for PC handling. It further isolates the patient from electric shock that may be produced from the EMG preamplifier channel. Another function is to provide the required level of voltage correction received from the falling object detector (fig.2).

The Software System

The software system includes the simulation program and the database module.

The simulation program

The simulation program for the rehabilitation of hand function was written in C++ version 4.0 and visual basic version 5.0 while the database module was developed using Microsoft Access version 7.0 (Microsoft Corporation-Redmond, WA 98052-6399, U.S.A). There are three components of the program, corresponding to the hardware subsystem: The trial with EMS, the training with the EMG signal, and the force measurement. In addition -there is a demo and database module.

The main screen of the program shows the different options of the system: Trial, Demo, EMG and Pressure tests, Final results, patient data, and Exit (fig. 6).

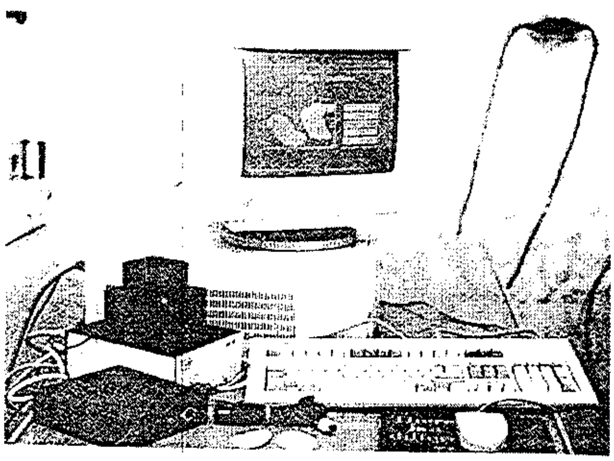

Fig. (6): The system with main screen of the program.

Trial

This option allows the therapist to choose the pattern of grasp, which he wishes to train the patient with the EMS. To start any grasp trial, one channel of the EMS is used to stimulate the patient's thenar muscles through its carbon adhesive electrodes. The other channel is connected directly to the computer for the sake of synchronization. This screen allows the therapist to select the patient's name, the pattern of grasp, the object shape, color and size (fig.7) When the therapist clicks start, the computer begin to detect the stimulation signal. As the stimulation starts, a movie of a hand corresponding to the selected parameters of grasp pattern appears on the screen. At the same time, the patient must grasp with the same pattern and same object parameters. The displayed hand grasps the object for the selected time of stimulation. If the patient successfully releases the object into the FOD within three seconds after the stimulation period, the movie continues its trajectory, to simulate the patient hand, and release the object. A congratulation message pops up on the screen with a clapping sound as a kind of reward. Otherwise, if the patient fails to release the object within the three seconds, the movie stops and a message indicating failure pops up with a breaking glass sound. The trial screen also displays the total number of trials taken, the percentage of successful and failed trials. At the bottom of the trial screen, a table containing all the details of the trials is presented. In case of erroneous trial, the therapist can easily select this record from the table and delete it.

The EMG and pressure

This option allows the therapist to conduct a training session by recording the EMG signal of the thenar muscle. Calibration of the system is performed to cancel the effect of the background noise so that the system actually records only the activity of the muscle. This calibration process is done automatically when the calibration button is clicked.

The recording time of the EMG signal can be selected from 1 to 8 sec. The software also provides an option to record the instantaneous value of the EMG during the recording period. Clicking on the "Save Samples" Button does this. The sampling rate used to record the EMG signal is 4400 samples/second.

After selecting the required parameters to represent a certain grasping pattern. The movie of the hand appears after clicking on the start button presenting all parameters chosen (grasp pattern, object shape, color and size). If the patient successfully releases the object within three seconds after the recording period, the movie continues its trajectory to simulate the patient hand and release the object. A congratulation message pops up on the screen with a clapping sound as a kind of reward. If the patient fails to release the object within the three seconds the movie stops and a message indicating failure pops with a breaking glass sound.

The EMG and pressure screen also displays the total number of trials done, the percentage of successful and failed trials. At the bottom of this screen, a table presenting all the details of the EMG training session is presented. In case of erroneous trial the therapist can simply select that record from the table and delete it.

To measure the force exerted by the thumb, the therapist selects the "start pressure" button, while the patient presses on the appropriate sensor. The recording time of the pressure signal can be selected from 1 to 8 seconds. When the recording time has elapsed, a dialog box presenting the force in gram and the corresponding voltage measured by the FSR will be displayed. To save any data of the EMG training or pressure test, the "save data" button has to be clicked.

Demo

This option is used in order to explain to the patient the method needed to grasp certain object.

Database module

Using different Microsoft access tools (forms and, report) final results and patients' data are designed. It allows the therapist to manipulate patients' data through a user friendly, icon-based, interface.

There is a module responsible for storing all the data of rehabilitation training generated by applying the different operations of the program (trial, EMG, and pressure tests). When selecting an operation, the corresponding routine is activated by the module as a procedure specific to the operation. When the operation is completed, the procedure passes all the data on to the database, which stores it under the patient's name.

In the main menu, the therapist can click on the "final results" button to display and print selected patient results report. This report

his\her progress without actually having the patient to be present. A complete report will contain all the data relevant to a particular patient, including all trials, EMG and pressure tests and any comments or observations made by the therapist.

The last option on the main menu is the patient's data. The therapist can add new patient, and display or update data of an existing patient in both English and Arabic languages. The patient's data contain all information about the patient concerning his name, age, sex, address, operative data, history and remarks.

Accessory Equipment

The following tools were used as accessory equipment (fig.7) to complement the use of the software system:

1- A set of wooden objects were designed and made by a carpenter. This consists of four objects (cylinder, cube, prism and flattened ball), with four different sizes (4cm, 3cm, 2cm and 1cm). Each size had four colors (red, green, yellow, and blue).
2- Colored paper clips.
3- Tennis Ball and Table Tennis Ball.
4- Two hollow plastic eggs.
5- Different jewelry copper weights (5, 10, 20, 50 gm).

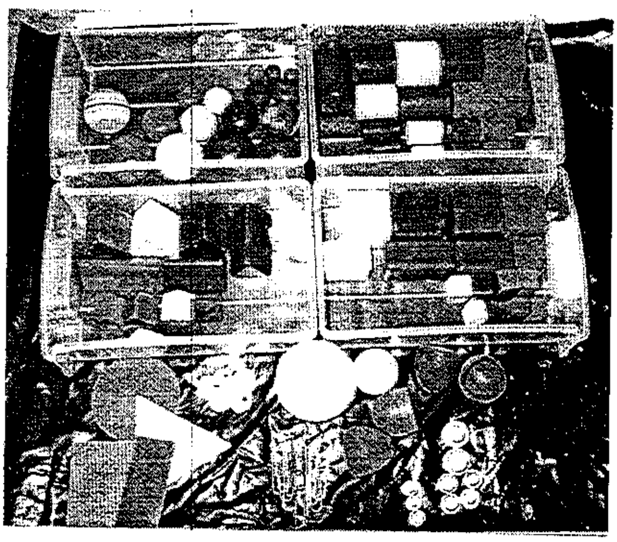

Fig. (7) Accessories used to train on different grasps.

System Testing

The system was recalibrated to output 5 volts maximum voltage and tests were performed to measure subsystem components accuracy and repeatability. It was found that all the subsystems have a very good linearity, small hysteresis, and excellent repeatability. The software worked exactly as it was designed to do.

Limited clinical trail

Ten normal volunteers agreed to participate in the project. Their ages ranged from 5 to 7 years, their parents signed an informed consent. Each subject was given the opportunity to be familiar with the system. The subjects performed two sets of testing for palmar pinch three points, palmar pinch two points, tip pinch, and lateral pinch using their right hands (all were right handed).

The results showed high level of repeatability of test results between test retest. All subjects liked the device and all enjoyed working with the system.

DISCUSSION

It has been suggested, that action feedback should replace conventional biofeedback, using the interactive computer environment [16]. Encouraged by their suggestion and their results of interactive computer environment for cerebral palsy patients, a computer simulation program was designed and implemented in this study.

Virtual environment can be experienced in two ways: Immersion VR and desktop VR [5,12,17]. But it was found that there were some drawbacks for the use of the head-mounted display, not present in the desktop display [17]. In this study, the virtual environment was displayed on a simple computer monitor in order to avoid the head-mounted display drawbacks (nausea and vomiting), and to use available and low cost facilities.

For a three dimensional model of a right hand appears on the screen, a high speed, high-resolution workstation is required which is expensive[2]. Hence, in this study, a video camera and video card were used to take a film of the right hand performing the different grasp patterns. Thus a realistic, three dimensional hand could be obtained. On the other hand the high speed and high resolution couldn't be achieved at a high level.

The success of VR training is to transfer what is learned in VR to the real life situation[11]. Therefore, a set of objects exactly the same to that appearing in the monitor was used to connect the virtual environment to the real situation. This solution gives the program another feature than that of VR, as the patient actually grasps the object seen on the monitor. So, it is more realistic to give it the name of computer simulation or computer interaction environment[8].

With respect to the FSR used to measure the force exerted by the thumb. Three FSR were used to assess the participation of the thumb and the other two fingers (middle, and ring) during three-point palmar pinch. It was not possible to measure the force exerted by the thumb and the other two fingers simultaneously due to hardware limitation (the A\D card has only one channel). Therefore, maximum pressure exerted by the thumb can be measured independently from the other two fingers. These FSR's were used because they are light, small and easily mountable[4]. These advantages were debated because of the claims of non-linearity force resistance characteristics, and poor repeatability caused by the rapid oxidation of the foil conductors[9]
were found to be linear and force measurements repeatability were obtained in this study.

CONCLUSION AND RECOMMENDATIONS

The system was considered as a useful tool for training different types of grasp patterns. It is recommended to be used in different disorders in which there is impairment of hand functions like CP, crashed hand, after tendon transfer and after reconstruction of hypoplastic thumb (a study described in part II).

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الملخص العربي

الفضاء التخيلي وتأهيل اليد

الجزء الأول : برنامج وظائف اليد بالمساعدة الكمبيوترية

عمليات التأهيل يمكن تحسينها باستخدام تكنولوجيا المحاكاة الكمبيوترية . ولقد استخدمت المحاكاة الكمبيوترية في التأهيل لاختبارات وتدريبات الوظائف التي تختل نتيجة للإصابة أو المرض . ويهدف هذا البحث إلى تصميم واستخدام نظام محاكاة كمبيوترية لوظائف اليد . ويتكون الجهاز من كمبيوتر ونظام لإدخال المعلومات ، مكبر ، صندوق مقاومات لقياس القوة ، مكتشف للأجسام الساقطة ، جهاز تنبيه كهربائي للعضلات وكارت المُهايئة . وتتكون حزمة برامج التشغيل من برنامج المحاكاة الكمبيوترية لوظائف اليد وقاعدة البيانات . وهناك مجموعة من الأدوات المساعدة تشمل أشكالاً هندسية ذات أحجاماً وأوزاناً وألواناً مختلفة . وقد تم اختبار جميع أجزاء الجهاز وتجربته على عينة من الأطفال الأصحاء .

وقد ثبت أن النظام يعمل بصورة ممتازة ودرجة ثبات عالية ، ويوصى باستخدامه في عمليات تأهيل واستعادة وظائف اليد التي تفقد نتيجة للإصابات المختلفة مثل الشلل التشنجي في الأطفال وإعادة بناء الإبهام الناقص وكذلك في حالات اليد المحطمة .