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REMOTE SYSTEM FOR REHABILITATION OF A POST-FRACTURED HAND

BY

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Abstract. At present, the traditional “face to face” (physician and patient) pattern of diagnosis and treatment, which has been predominant before the exponential growth of the Internet and ITC, has a remote and affordable alternative. Persons with disabilities, who are hardly transportable or who live in faraway areas, may have much easier consultation and rehabilitation programs, with significant savings both in the time and financial budget of the patient and of the insurance company. In this way, the spatial distance and the possible psychological barrier between the disabled and the rehabilitation specialist are overcome. In the paper is presented a remote rehabilitation system of a fully functional post-fractured hand, based on very flexible software, developed in the LabVIEW graphic programming environment, running on a simple computer, the mouse being obviously attached.

Key words: virtual instrumentation; remote rehabilitation; kinetotherapy.

1. Introduction

Telemedicine is the remote assurance of health care services by transmitting medical data through communication technologies. Unquestionable challenges are associated with the widespread use of telemedicine, which may be an additional and potentially appropriate tool for diagnosis, treatment, rehabilitation and surveillance of patients. The wider and wider spread of

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chronic diseases, the quasi-limited health insurance budget, the increased demand of patients for a greater flexibility of treatment due to their working program and the expectations for high quality health services make telemedicine an interesting challenge for the present and the future. The concept of telemedicine could be also useful for patients living in isolated rural communities. They might access some specific health care services without having to leave their home (Jong *et al.*, 2004; Lewtas, 2001). At present, the telemedicine concept is being applied for chronic disease consultations, aiming to decrease the number of visits to the hospital, reducing travel time and associated stress, involving both financial and time savings (Davis *et al.*, 2001; Lewtas, 2001; Ward *et al.*, 2016). After a fracture of the hand there is a period in which the affected limb must be immobilized in gypsum or splint. Fracture and limb immobilization lead to muscular atrophy and/or limitation of movements. Each fracture may be different, as well as recovery procedures. It is essential to perform recovery exercises with the patient; removing gypsum does not mean that the fracture healing process is over.

Welding bone in the process of fracture healing involves four steps:

1. The first stage lasts for a week. It's called a pseudo-inflammatory phase; within this range the absorption of the blood clot formed by the trauma occurs.

2. The second stage takes two weeks. This stage mainly means the formation of fibrous callus (connective tissue that does not have bone strength but prevents fracture movement).

3. In the third stage, the "scarring" of the bone occurs. In the first three weeks of fracture, calcium is not deposited. Now the fibrous callus has to be transformed into bone tissue. In the upper limbs, this process lasts between three and five months, while for the lower limbs it lasts from five to eight months. During these two months a new biomechanically weak bone tissue is formed, the bone being soft and bulky. We can say that the body is trying to compensate by quantity the new bone tissue that is soft.

4. The fourth phase is the one in which the bone volume decreases but the bone itself strengthens. This is the very beginning of the recovery period.

The annoying gypsum sleeve is finally removed after 4 to 6 weeks of wearing. The patient is eager to return to normal life but it takes some time to resume his old habits. The doctor has to establish a mandatory program of motion and recovery. Due to the relatively long “idle” period of the arm, the muscles have been atrophied. In the first few hours after gypsum removing, the affected arm may swell up, being not recommended to force the movements. One should start with light exercises, under the close observation of a specialist in orthopedics or physiotherapy. There are also recommended baths with lukewarm, not hot water. Most of the time, in contact with water, the affected limb may change color. It may get a more reddish or violet hue to black color; this is due to a necessary recovery period for the neighboring tissues of the fractured bone, which were also indirectly affected.

Studies supervised by World Health Organization (WHO) have shown that repetitive movements training facilitated by virtual instruments could be an effective incentive to normalize the control of limb movements in moderate to severely impaired people who have difficulty in performing unassisted movements.

An important feature of virtual instruments used to rehabilitate hand movements is their ability to measure the kinematic and dynamic properties of a patient's movements. They can also supply the information needed to adjust the device, aiming to provide the required activity according to the patient's evolution.

The first generation of virtual appliances has allowed only unilateral gross movements; the present devices allow for very fine movements; their control being tailored to the needs of the patient. None of these systems do not allow for three-dimensional arm movements. These moves are possible only through the use of robots. By interfacing the robot with virtual instrumentation can be obtained systems that simulate virtual reality. For example, the movements of the arm undergoing rehabilitation can be controlled by using specialized “gloves”. These types of simulators are currently used in military applications, entertainment, surgical training, spatial training, and more recently as a therapeutic intervention for phobias (Stanney, 2002). Essentially, it might be about new, affordable and remote rehabilitation tools that can be used to exploit the capacity of the sensorimotor adaptation nerve systems.

2. Presentation of the Rehabilitation System

2.1. Brief Summary on the Use of Virtual Instruments in Medicine

Any practical activity is based on the measurement of some data or parameters, collecting them from environment and finally delivering to the user.

This process consists of three main parts:

1. Obtaining the measured data;
2. Conditioning and processing the previously acquired data;
3. Delivering data to a human or a machine.

It has become common for a measuring instrument to receive the signal, to condition the input and then to digitize the result. The speed and available resources of general purpose computers have exponentially increased, making them suitable for online applications needed for real-time measurement and control. So, general purpose computers, running interface-type software could become part of these tools Aiming to reduce the cost of such a system, the “end user” could use his own computer and its computing capability while the manufacturer must only supply what the user could not obtain on the market – the virtual instrument (Goldberg, 2000). So, virtual instrument is performing a particular function, but it does not exist in real form. Traditional instruments, such as oscilloscopes and waveform generators, are powerful but costly and are designed to perform one or more specific tasks. Buttons and controllers, embedded circuits and functions are specific to the functions of the instrument and have the advantage of benefiting from the latest technology. Because software development application installed on the PC and the wide range of hardware available on the market, they provide high flexibility without replacing the entire device depending on requirements and needs. With virtual instrumentation, engineers and scientists build measurement and automation systems that precisely fit the user-defined needs, instead of being limited by the traditional factory-defined functions (Spoedler, 1999).

Virtual instrumentation is increasingly used in biomedical domain, the effective applications being broadly categorized into four categories:

1. Examination, when the physician makes an on-line or offline examination of the patient's measurements, using an open-loop system. It can be directly done, in contact with the patient or indirectly, when the sensor is connected to the doctor via a telecommunications network. Nowadays, virtual instruments become part of standard medical examination procedures, with medical systems being implemented as virtual tools.

2. Monitoring used as basis for real time alerts and interactive alarms. These systems are also open-loop ones, the patient being just “monitored”. A certain process continuously monitors the measured data, performs the analysis and acts when a particular pattern is been detected. These systems are more autonomous than examination systems. Designing monitoring systems is a complex process because many requirements need to be met in real time. The monitoring and recognition of the biomedical signal pattern may also be used outside the biomedical domain, for example in affective computation (Allanson, 2002).

3. Training and education, where a virtual instrument simulates or reproduces previously measured signals useful for improving doctors' skills. Computer generated models allow the training and education of the operator without the effective use of sensors. The same virtual tool can work online; it can play the measured data in the first stage or simulate any clinical situation. Therefore, the training experience does not differ much from the real-world measurements. Virtual instrumentation can also be integrated with many applications based on virtual reality for education and training. For example, Hoffman has developed Anatomic Visualize, a virtual environment designed to support the teaching and learning of complex 3D structures such as human anatomy. These are closed-loop systems that detect biomedical changes to facilitate change of user status. For example, physical rehabilitation systems for biofeedback may amplify weak muscle signals, encouraging patients to persist when there is a physical response to therapy. Interfaces from existing biofeedback applications range from 2D interactive graphics tasks to real-world physical tasks. Healthcare providers are increasingly using biofeedback or neuro-feedback as part of treatment for a growing range of psychological or physiological dysfunctions, addictions, anxiety and depression. In these

applications, the resulting EEG is delivered in real-time as abstract images, helping to alleviate these disorders (Charles, 1999).

Virtual instruments could be used to medical research applications, clinical applications, medical project development, medical information management systems and mathematical modeling of physiological systems. (Olansen & Rosow, 2001).

2.2. Adaptability of the System

The concept of "personalized health monitoring (PHM)" is the desideratum of having systems that can be individually adapted to the specific needs of the selected patient.

Various studies and different ideas, theories and practical suggestions for various physical-therapeutic exercises have been done lately, whereby a patient can fully or partially recover the functions of the fractured hand. For example, analyses were made regarding the correlation between the training intensity and the time elapsed since the accident.

Following these studies, it has been agreed that there are three key exercises given to patients for complete rehabilitation of wrist and hand movements (Woodson, 1995).

1. Fig. 1 *a* shows closing the hand from an open position to a fully closed position followed by the relaxation of the hand. This is usually the first exercise used for most patients with fractures that have initially got the hand blocked in a "claw" form. To measure the severity of this disability, the patient should try to perform the exercises without help, after which the physiotherapist manipulates the fingers in the correct position to fully close and open the hand. The patient will slowly progress in motion without help.

2. Fig. 1 *b* shows how applying the movement: tracking rehabilitation with the object kept in hand as in everyday life. The patient will progress slowly from the situation when feels pain and cannot complete the task. This movement adds difficulties to the patient, when trying to keep an object, using a finger different position depending on the used item. For example: fully opening the hand as much as possible before slow closing around a cylindrical object. Or bring your thumb and forefinger together in a pinch movement.

3. The main wrist movements, flexions and extension are suggested in Fig. 2. In a flexion movement, the patient assumes sitting in a neutral or flat wrist position and then tilts his hand as far as he can. The extension begins with the patient's hand in a neutral or flat wrist position and then the patient tilts his hand up as much as possible. This combination of moves helps the patient who had the wrist actually immobilized in the first few weeks after the accident. Due to the structure of the muscles in the human arm, if the extension or flexion movements are too large, there is the risk of poor results.

4. There are also other two movements, having lower priority that could be done during wrist rehabilitation, the abduction and adduction. Abduction and adduction describe the movement of the wrist from one side to the other with respect to alignment with the arm so that the hand rotates with the palm down.

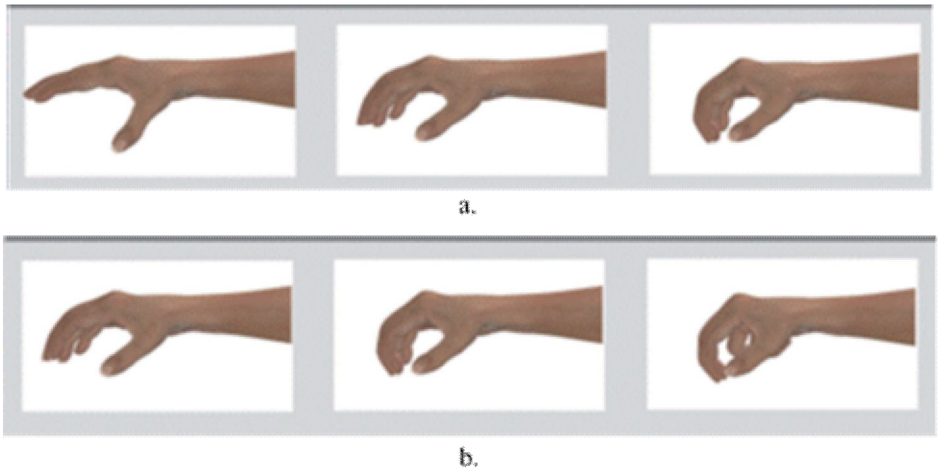


Fig. 1 – *a* – Closing the hand from an open position to a fully closed position
b – closing hand around a cylindrical object.

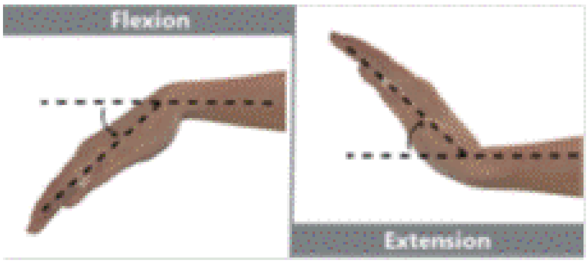


Fig. 2 – Hand flexion and extension movements.

Existing robotic devices for rehabilitation of hands and wrists can be divided into two categories based on the following criteria:

- technological readiness of the device (TRL);
- type of mechanism (final effector or exoskeleton system) used to achieve the desired movement. An example of a finite effector system is the haptic button at the Singapore National University and the Imperial College in London. Examples of the exoskeleton are the PMH system developed at the Heriot-Watt University. Fig. 3 illustrates the differences between end-effector and exo-skeleton systems.

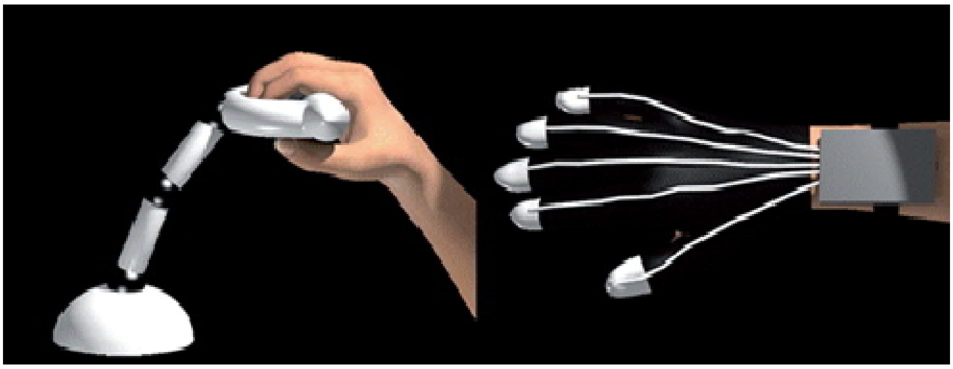


Fig. 3 − Differences between end-effector and exoskeleton systems.

2.3. Software Presentation

The developed system is end-effector type. These are devices that interact with the patient in a single point. This type of device is either attached to the patient's hand (Loureiro & Harwin, 2007) or caught by hand (Lambercy *et al*., 2007). This one-point interaction allows the patient to perform predefined system exercises in Cartezian XYZ 3D space, which can be plotted on a monitor, displaying the progress in a realistic mode (Guidali *et al*., 2011). These end-effector systems provide a limited range of movement of joints.

In the first stage they were developed (together with several kinetotherapist teams) various rehabilitation programs for broken hands. It must be possible to add new programs to the database or personalize them according to the specifics of the patient.

The here presented system does not require special components, just a simple PC mouse that should be moved and clicked.

Aiming to calibrate the instrument, 5 seconds after starting the application, in the middle of the screen is displayed the message "START".

Fig. 4 presents the flow code graphical programming of the hand rehabilitation device.

In Fig. 5 is presented the front panel of the rehabilitation device. On the left there is a selection button for the program to be executed. On the right, we have the horizontal, vertical and scrolling buttons. On the left, the coordinates of the mouse position at that time are displayed.

The patient must move the mouse so that the coordinates on the left are the same as those on the right. Moving the mouse so that the coordinates are identical must be done within 30 seconds. When the red LED is ON, the patient must press the corresponding mouse button.

If the right button is pressed within 5 seconds, the corresponding green LED will light up. At the end of these 30 seconds, it will be checked if the corresponding button has been pressed within 5 seconds.

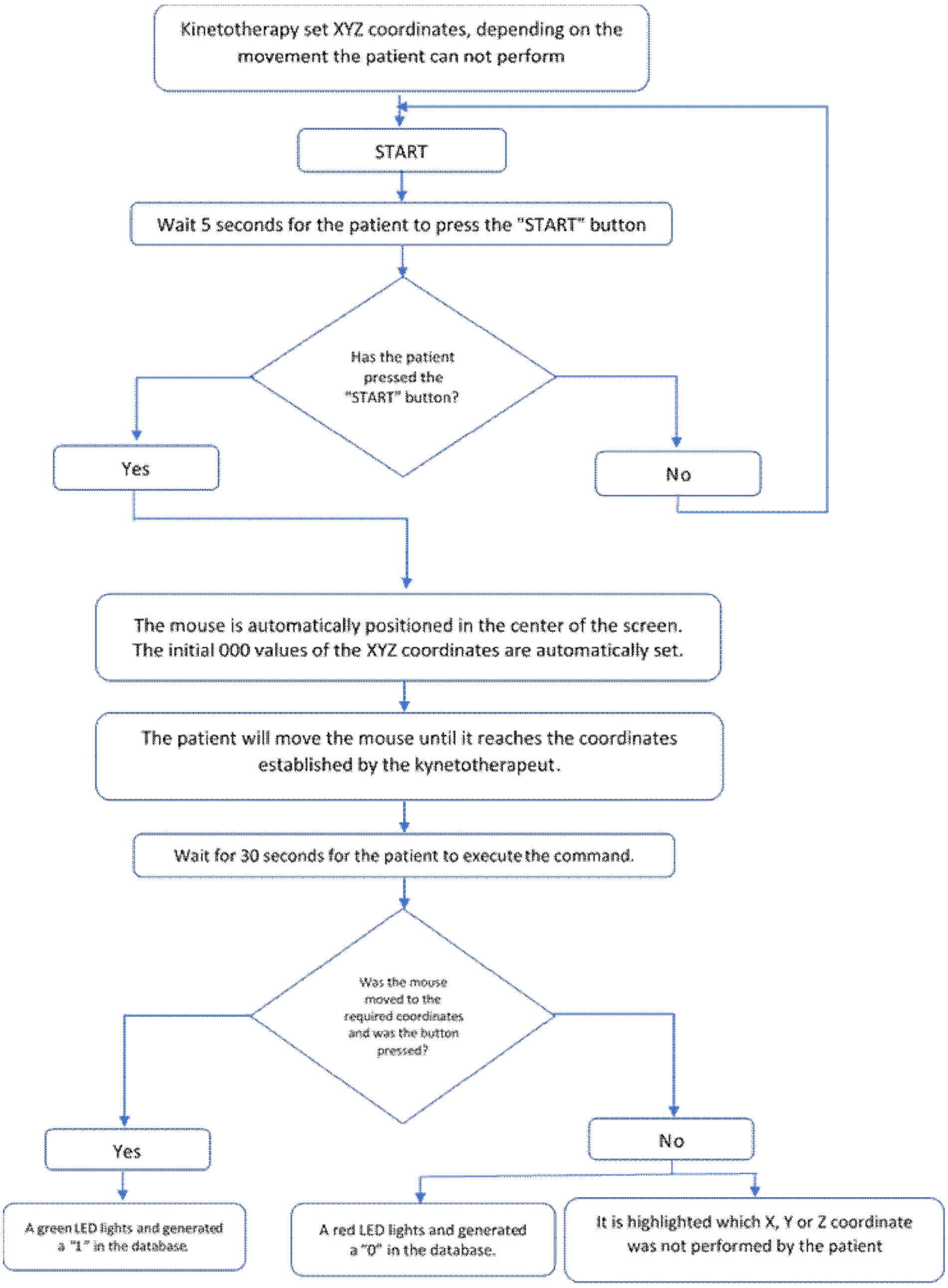
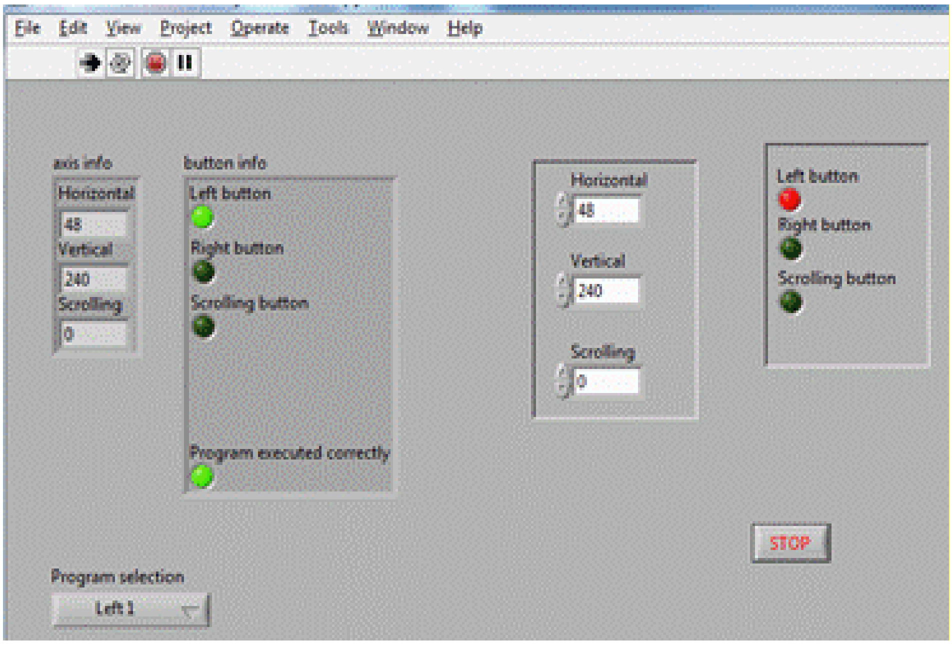


Fig. 4 – Flow code graphical programming of the hand rehabilitation device.

If the times have been respected, the LED on the left (Program executed correctly) will light up and “1” will be generated in the database. If the times have not been respected, this LED will remain off and “0” will automatically be generated in the database. The occurrence of this zero will automatically generate a word file with the corresponding date and time; consequently, the kinetotherapist is able to see which coordinates or buttons have not been correctly executed.



axis info: Horizontal 48, Vertical 240, Scrolling 0

Horizontal 48
Vertical 240
Scrolling 0

Program selection: Left 1

Fig. 5 – Front panel of the rehabilitation device.

This program sequence should be repeated and if the same unexecuted coordinates appear, a conclusion can be drawn about the axis on which there are difficulties. Thereupon, a new customized program can be “tailored” for the identified problem; the system can be adapted to the needs of each patient.

Particular importance should be given to the parameters set for the mouse from the Windows operating system, namely: the reaction speed of the mouse and the number of dots per inch (dpi).

By setting a too high reaction speed, it will be harder to move the mouse on the required coordinates by people who are less familiar with using a computer. Another problem that might be encountered when using this hand rehabilitation device is the number of dots per inch (dpi); if more than one point are set, it will be harder to reach the required coordinates.

If changes are made to these parameters, it is desirable that the times, the 5 seconds and the 30 seconds, to be changed. The simplest way to correctly calibrate the tool is to leave the default settings.

2.4. Experimental Data

The device was tested in a kinetotherapy department for 2 months on a group of 34 people who had one or both of their broken hands. Each patient received a standard treatment for 10 days. Every day the patient ran the program for 2 hours. The average daily results are given in the table. There were 6 children, 17 males and 11 women. As was the case with children, the recovery rate was total (100%), the rate of bones-brazing is higher.

Complementary, younger subjects have a higher dexterity in handling a mouse. The LabVIEW program can be saved as a WEB page, saved on a server, being remotely accessible. The patient can do his/her "home exercises"; his/her real-time assessment can be done in real time by an authorized medical practitioner. Depending on the evolution of the recovery program, immediate medical follow-up may be adopted.

In Fig. 6 green color represents the success rate and the red color represents the failure rate according to the data saved in the virtual instrument database.

From this chart one can see that the Success Rate is significantly higher. This is normal; a higher failure rate might be a question mark about how the software application was designed or only about the parameters set by kinetotherapist.

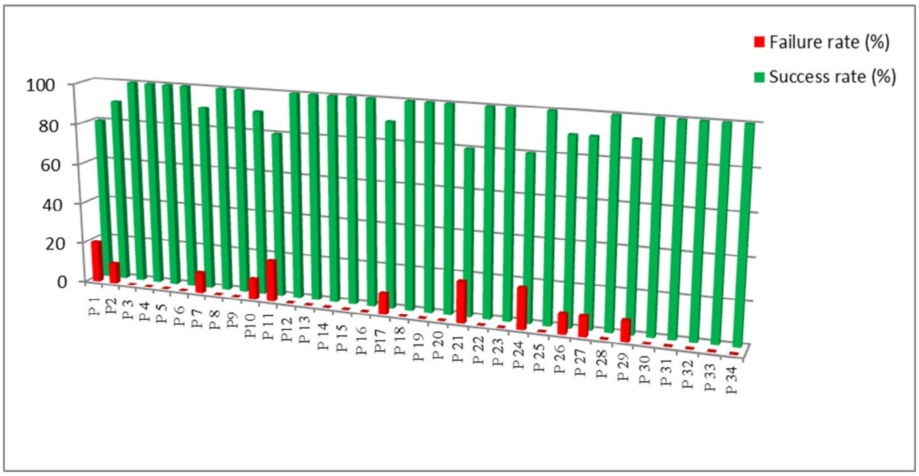


Fig. 6 – Success versus failure rate.

3. Conclusions

Data processing from 34 subjects who followed an arm fracture recovery program has demonstrated that using this modern type of treatment facilitated by the virtual environment could be a valuable solution. The here proposed device is made from elementary and affordable tools: a usual laptop or personal computer, the associated mouse and simple software developed in LabVIEW graphical programming environment. The resulting device is easy to use and has been tested in a recovery cabinet with encouraging results.

The system is very flexible, leaving the kineto-therapist's freedom to adapt the usage parameters to the patient's specificity.

A problem that might be approached in the near future would be the situation where the affected hand differs from the hand with which the subject ordinarily uses the mouse. We believe that a software solution could significantly reduce the adaptation period, benefiting from a reduction in the actual rehabilitation period.

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SISTEM LA DISTANȚĂ PENTRU REABILITAREA POST-FRACTURĂ A MÂINII

(Rezumat)

În prezent există tendința de dezvoltare a unor alternative „la distanță” pentru modelul tradițional de diagnostic şi tratament „față în față”, între medici şi pacienți; acesta era net predominant până la dezvoltarea exponențială a internetului şi a tehnicii de calcul. Persoanele cu dizabilități, greu transportabile sau care locuiesc în zone izolate au astfel acees la consultații şi programe de reabilitare mult mai usor, realizându-se economii însemnate, atât în bugetul de timp cât şi în cel financiar, al pacientului dar şi al Casei de asigurări de sănătate. Se surmontează astfel atât distanța spațială cât şi posibila barieră psihologică dintre persoanele cu dizabilități şi specialistul în reabilitare. În lucrare este prezentat un sistem de reabilitare la distanță a unei mâini post-fractură, complet funcțional, pe baza unui software foarte flexibil, dezvoltat în mediului de programare grafic LabVIEW, care rulează pe un simplu calculator, prevăzut bineînțeles cu mouse.