Systems development for diagnostics and dexterity rehabilitation by means of touchscreen technology

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"La vertigine non è paura di cadere, ma voglia di volare"

Lorenzo Jovanotti

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1 Introduction

This thesis stems from the need to implement the existing technology in the rehabilitation. Smartphones, touch screen technology, apps, which are a common part of our daily life don't find an application in clinical practice.

The aim of this work is to verify the effectiveness of using this technology both in the hospital and outside.

The exergames we developed can be played on usual touchscreen devices, on personal computers and on the custom device built in our laboratory.

The device used during our experimentation is now installed in a medical facility with other latest generation medical devices like the Armeo and two different types of exoskeletons.

In the first part of this project we focused on developing some exergames oriented to the rehabilitation of persons affected by strokes and in the characterization of people affected by Parkinson.

In the second part, because of the strong correlation between physical activity and neurocognitive functions we decided to use the device since the very beginning of the rehabilitation process, developing some kind of exergames used also to monitor patients during this phase.

Thanks to the collaboration with the medical staff we analysed and summarized the macro areas and the neurocognitive functions involved during the rehabilitation process.

After that, we analysed some of the usual exercises given to the patients highlighting the neurocognitive functions involved, and for each exercise we defined some indicators, like touch precision and its standard deviation, mean of force and its standard deviation, total time to execute the test, number of errors, etc...

To develop the exergames based on what we decided with the medical staff we used the game engine called Unity3D and we wrote the code of the exergames in C#.

After a first test phase in which the medical staff tried the exergames and gave us a feedback, we fixed the bugs and decided to integrate all the exergames in a common platform.

Then, we defined an official procedure for the rehabilitation program based on this new method in order to submit it to the ethics committee.

In a second phase, the medical staff selected the group of patients to be assigned to the test program, and defined some useful indicators about the neurocognitive functions involved. Finally, to validate the efficiency of this protocol, patients need to executed the exergames for a certain time, after which the medical staff measured the indicators.

In this way we were able to validate the efficiency of the exergames and of the device installed.

By working in the European project NoTremor we developed two different type of test with the aim of characterize a model of people affected by Parkinson.

2   Problem definition

2.1   Rehabilitation and diagnostic in current society

According to (Clerici e Gherardi 2012/2013), rehabilitation is a problem solving and educational process in which the aim is to increase the quality of life of a person both in physical, functional, social and emotional aspect with less restriction on his operative choice. Physical therapy is a medical branch based on physical energy.

In the first half of last century with rehabilitation it was intended physical therapy, a method with proof evidence of efficacy and without specific indication on how to do it. Then with kinesitherapy and specific procedure for the diagnostic and prognosis the physical therapy became "physical medicine. (Bocacrdi, La riabilitazione oggi,che cosa,dove,chi 2010)

In an article written after Jesy conference about the impact of the new technology in the Governance Rehabilitation the author said that though the absence of valid results on technological point of view the application of this technological aspects by the medical staff validate the effectiveness of the this device in the rehabilitation area. The author assert that now it is the task of scientific research to identify the mechanism behind this functional therapy and to define which are the appropriate method of administration.

The article continue and said that in the conference it was affirmed that in according with this prospective of efficacy it is necessary that these procedures became a standard and all the people should be able to use that without any kind of discrimination also by money aspect.

It is necessary to find a way to a multi-lateral collaboration to reach right quantity of series in order to validate these models. (Zampolini 2015)

According to research by Andersson et al. (2003) the patient normally makes good progress during the beginning of the rehabilitation program when there are regular meetings and practice sessions with the physiotherapist/ occupational therapist (PT/OT). The problems often begin when the patient is supposed to continue their rehabilitation at home and on their own. Lack of motivation due to boredom and lack of support from family and friends can make the rehabilitation progress slow down. According to Broeren (2002) the use of meaningful and rewarding activities has been shown to improve the patient's motivation to practice. (Lövquist e Dreifaldt 2006).

In the article the authors said that According to (Carr e Shepherd 2003) computer games are likely to be increasingly used in training for various aspects of upper-limb movement. They state that the use of a game focuses attention on the outcome of the movement as opposed to the movement itself. The motivating effects of being an active participant on an interesting task may be powerful facilitators in the rehabilitative process.

In her article about phsicolgy of the handicap (Mottareale s.d.) said that diagnose a disability is not like diagnose an illness. So for the disability it is necessary to made a functional diagnosis in which the doctor analyse the deficit and the residual potential of the patient in order to design the right therapy.

The functional diagnosis is made by a staff composed by:

- A Doctor who made medical diagnosis to identify the causes of disability
- A Psychologist who made a diagnostic interview using some kind of test
- A social worker who investigate on personal relation between person affected by disease and his family

- Educators which carry out investigation in order to identify an educational plan for each person

2.2 Definition of the disease of the people involved in the project

In this party we speak about the possible diseases of the person involved in this project. I quote what one of the doctor who supported me during this project said when I asked him some advice on the disease that I'm going to explain.

"You ask me to give a neurology treaty…"

What I'm going to do here after is a brief introduction to the pathologies involved in the project.

Neurodegenerative diseases such as Alzheimer, Parkinson, Huntington's disease, Amyotrophic Lateral Sclerosis (SLA), are diseases characterized by a slow and progressive loss of one or more function of nervous system. This kind of disease until now are treated with poor results by using only symptomatic drugs.

The number of person affected by neurodegeneration it's dramatically high. The Alzheimer affects about 600,000 people in Italy and 5 million in the world. This number is expected to increase in absence of a valid therapy due to the increase of the elderly people which are the people mostly affected by this kind of disease. Person affected by Parkinson in Italy are more than 250,000 and like Alzheimer over 65 years of age the incidence increase significantly. (Di Pietro s.d.)

2.2.1 Parkinson

Parkinson's disease (PD) is a chronic and progressive movement disorder, meaning that symptoms continue and worsen over time. Nearly one million people in the US are living with Parkinson's disease. The cause is unknown, and although there is presently no cure, there are treatment options such as medication and surgery to manage its symptoms.

Parkinson's involves the malfunction and death of vital nerve cells in the brain, called neurons. Parkinson's primarily affects neurons in an area of the brain called the substantia nigra. Some of these dying neurons produce dopamine, a chemical that sends messages to the part of the brain that controls movement and coordination. As PD progresses, the amount of dopamine produced in the brain decreases, leaving a person unable to control movement normally. cit[http://www.pdf.org/about_pd]

The specific group of symptoms that an individual experiences varies from person to person. Primary motor signs of Parkinson's disease include the following.

- tremor of the hands, arms, legs, jaw and face. This type of tremor is noticeable if the person is at rest and it is reduced when he perform a specific task. This disease has been observed when the person affected by Stroke use the Force Panel, in fact while he performing the exercise like dragging some figure with the finger he tends to reduce the tremor in the hand.
- bradykinesia or slowness of movement
- rigidity or stiffness of the limbs and trunk
- postural instability or impaired balance and coordination
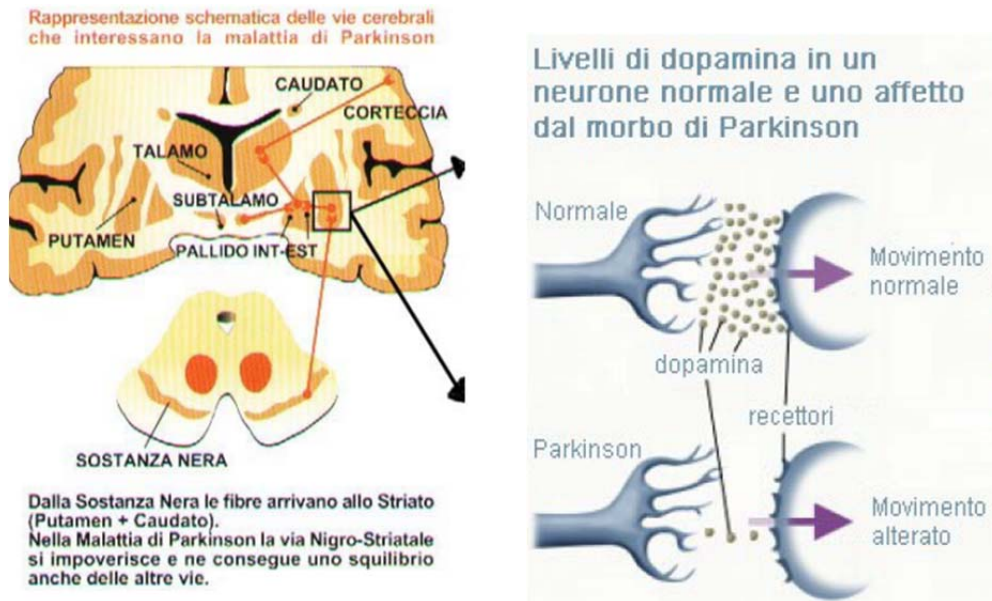
Both man and women could be affected by Parkinson disease

2.2.2 Right Hemiplegia
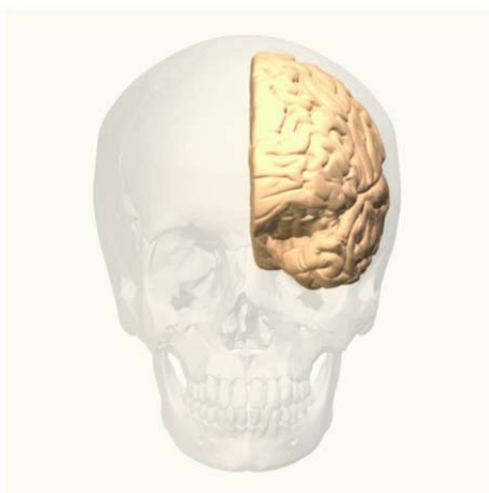
Hemiplegia is a condition that affect one side of the body and this is a results of the ictus. In this case the disease affect the left side of the brain.

Usually it cause disorders, paralysis or sensory disturbances on the right side of the body, vision on the right side of both eyes may have decreased (hemianopia). Other symptoms of hemiparesis are speech and language problems (aphasia), problems with object recognition (agnosia), problems with daily activities, routines which formerly went well (apraxia), memory for verbal (spoken) things, decreased

analytical skills, problems with chronology (in order of time, cause and effect), reduced timing and speed skills, left and right confusion, difficulty in dealing with numbers, understanding numbers and money, slow, shows some insecure, anxious and withdrawn behaviour, risk of depression, chance of changing moods, easily overwhelmed by emotions.

Is it impossible to associate one dysfunction to one side or the other of the brain but in most case there some problem associated to one side of the brain injured.

2.2.3 Left Hemiplegia
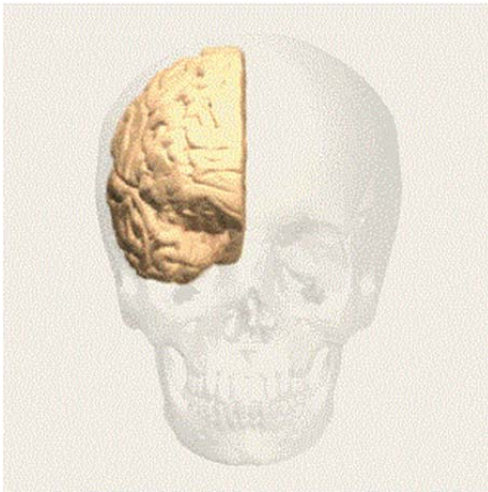
Like for the right Hemiplegia is a condition that affect one side of the body and this is a results of the ictus. In this case usually the person injured show this symptoms:

- movement disorders
- numbness or paralysis on the left side of the body
- impaired vision on the left side of both eyes. As if both glasses on the left side have been taped off (hemianopia)
- not realizing that the left side of the body or space exists (neglect)
- no attention to the cripple side of the body

- the sense of space and time can be bad giving someone depth, shape, colour and size cannot assess and lost. Spatial awareness problems
- visuospatial problems
- often someone has little insight into his own behaviour, problems and limitations (anosognosia)
- less understanding of (he or she does not 'understand') social situations
- language is often taken literally and jokes and underlying messages are not easily understood
- difficulty understanding humour
- difficult to estimate what the other emotion in the voice explains as anger,   relief, sadness, joy (prosody)
- recognizing faces can be bad (prosopagnosia)
- difficulty in seeing the whole
- do not know how one should dress in what order (apraxia)
- fast, impulsive behaviour, and sometimes inappropriate behaviour
- sometimes little consideration for others
- overestimating him / herself
- reduced self-control
- easily aroused
- reduced disease understanding

2.2.4 Injury to the peripheral nerves

Injury to the peripheral nerves can occur through a variety of trauma. The nerves originate at the spinal cord and innervate the muscles and skin of the upper limb. Brachial plexus injuries can occur as a result of shoulder trauma, tumors, or inflammation. The severity of a brachial plexus injury is determined by the type and amount of damage to the nerves.

The radial nerve runs down the underside of the arm and controls movement in the triceps (muscle located at the back of the upper arm), responsible for extending the wrist and fingers, and controls sensation in a portion of the hand.

Injuries to the radial nerve are called either radial neuropathy or radial nerve palsy. Injury can occur as a result of physical trauma, infection, or exposure to toxins.

2.2.5 Multiple Sclerosis

Multiple sclerosis (MS) is an unpredictable, often disabling disease of the central nervous system that disrupts the flow of information within the brain, and between the brain and body. (nationalmssociety s.d.)

We are increasingly cognizant that axonal destruction, as well as demyelination, proceeds together even early in the disease process . The responsible lesions that affect the mind are usually subcortical and pericallosal. Individually, these lesions are almost always asymptomatic. Over time, they may collectively degrade the highest intellectual functions, with special deficits in the ability to make complex decisions using multiple variables and to remember complex networks that tie together information. The personality may change subtly. Lesions that separate and disrupt the integration of neural systems can reproduce almost any psychiatric disorder. Depression, anxiety, paranoia, obsessions, loss of inhibition, and variants of neurosis may be encountered.

Main symptoms of
Multiple sclerosis

Central:
- Fatigue
- Cognitive impairment
- Depression
- Unstable mood

Visual:
- Nystagmus
- Optic neuritis
- Diplopia

Speech:
- Dysarthria

Throat:
- Dysphagia

Musculoskeletal:
- Weakness
- Spasms
- Ataxia

Sensation:
- Pain
- Hypoesthesias
- Paraesthesias

Bowel:
- Incontinence
- Diarrhea or constipation

Urinary:
- Incontinence
- Frequency or retention
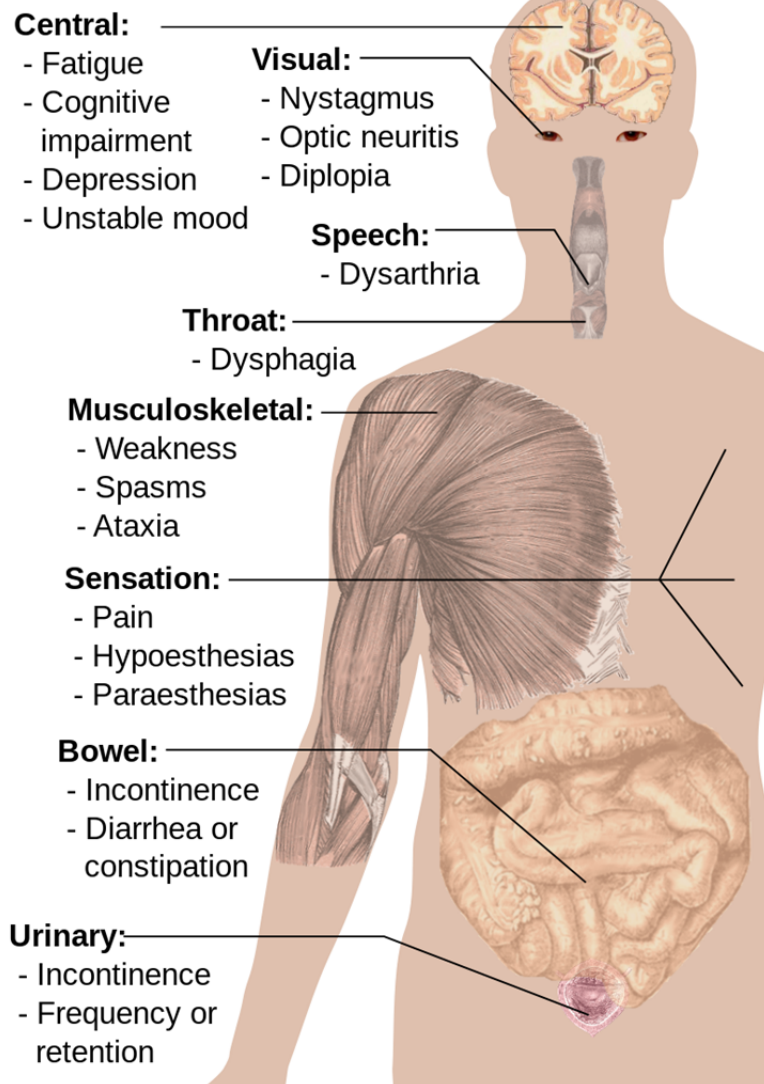
2.2.6 Ataxia

Cerebellar ataxia can occur as a result of many diseases and presents with symptoms of an inability to coordinate balance, gait, extremity and eye movements. Lesions to the cerebellum can cause dyssynergia, dysmetria, dysdiadochokinesia, dysarthria and ataxia of stance and gait. Deficits are observed with movements on the same side of the body as the lesion (ipsilateral). Clinicians often use visual observation of people performing motor tasks in order to look for signs of ataxia. (wikipedia, https://en.wikipedia.org/wiki/Cerebellar_ataxia s.d.)

2.2.7 Cognitive disorder

Cognitive disorders are a category of mental health disorders that primarily affect learning, memory, perception, and problem solving, and include amnesia, dementia, and delirium. While anxiety disorders, mood disorders, and psychotic disorders can also have an effect on cognitive and memory functions, the DSM-IV-TR does not consider these cognitive disorders, because loss of cognitive function is not the primary (causal) symptom.[1] Causes vary between the different types of disorders but most include damage to the memory portions of the brain.[2][3][4] Treatments depend on how the disorder is caused. Medication and therapies are the most common treatments; however, for some types of disorders such as certain types of amnesia, treatments can suppress the symptoms but there is currently no cure.

(wikipedia, https://en.wikipedia.org/wiki/Cognitive_disorder s.d.)

2.3 Correlation of neurocognitive and physical areas

Cognitive Rehabilitation Therapy (CRT) is the process of relearning cognitive skills that have been lost or altered as a result of damage to brain cells/chemistry. If skills cannot be relearned, then new ones have to be taught to enable the person to compensate for their lost cognitive functions. The process of CRT comprises 4 components:

- Education about cognitive weaknesses and strengths. The focus here is on developing awareness of the problem.
- Process Training. This refers to the development of skills through direct retraining or practicing the underlying cognitive skills. The focus here is on resolving the problem.
- Strategy Training. This involves the use of environmental, internal and external strategies. The focus here is on compensating rather than resolving the problem.

- Functional Activities Training. This involves the application of the other three components in everyday life. The focus here is on real life improvements.

The Brain Injury Interdisciplinary Special Interest Group (BI-ISIG) of the American Congress of Rehabilitation Medicine defines cognitive rehabilitation therapy to be a:

(ConnorB, et al. s.d.) "systematic, functionally-oriented service of therapeutic cognitive activities, based on an assessment and understanding of the person's brain-behaviour deficits." "Services are directed to achieve functional changes by (1) reinforcing, strengthening, or re-establishing previously learned patterns of behaviour, or (2) establishing new patterns of cognitive activity or compensatory mechanisms for impaired neurological systems" (Harley, et al., 1992, p.63).

(www.societyforcognitiverehab.org s.d.)

The pathology that could benefit from the cognitive rehabilitation therapy include Stroke, Multiple sclerosis, cognitive problems, etc.

In his book "Cognitive Rehabilitation Therapy for Traumatic Brain Injury" the autor said that tahnks to the evolution by the society could help to survive to alot of people affected from various type of disabilities, like injuried soldiers or people affected by stroke.

Clinicians and researchers develop a lot of therapy in order to recover the function affected by the disease. In his book he speak also about the relation with the physical and neurocognitive during the rehabilitation process. The clinicians and researchers saw the need to provide cognitive as well as physical rehabilitation.

Cognitive deficits are a well known problem associated with many disabling conditions, such a traumatic brain injury, stroke, and other neurological disorders. The incidence of cognitive deficits following stroke has been estimated to be greater than 35% (Connor, et al. 2002)

As shown in some studies, neurocognitive deficits, make less effective the rehabilitation process, it is important that the patient and doctor are able to communicate with each other and in particular it is essential that the patient is capable of understanding and interpreting the instructions of the doctor .

Stroke can cause impairments of comprehension, memory, visual recognition, attention, and sequencing of actions that can have profound effects on physical functioning. To benefit from physical rehabilitation patients must be able to understand the therapist's commands, remember instructions, recognize physical objects in the environment, attend equally to both sides of space, maintain arousal levels sufficiently to co-operate throughout a treatment session and continue to utilize what the therapist has taught in their everyday lives (Riddoch et al, 1995). If the aim of rehabilitation is to optimize treatment outcomes then all factors influencing these outcomes need to be addressed, including cognitive impairments, in designing effective systems for intervention. (ConnorB, et al. s.d.)

In recent study researcher try to use this technology also for neurocognitive rehabilitation, in this case we found great evidence of interaction of cognitive and physical area during rehabilitation programs.

In his work Connor use a joystick with force feedback associated with the errorless learning approach in order to demonstrate that the rehabilitation of the person affected by stroke.

He investigate investigated the effectiveness of haptic guided EL compared to trial and error (errorful: EF) learning on a perceptual motor task with twelve patients who had visuoperceptual deficits following stroke.

Already in 1991 were made experiments to demonstrate the effectiveness of physical rehabilitation neurocognitive, in fact, as highlighted in the article Krebs (Krebs, et al. 2007) a robot, MIT-

MANUS, for upper limb rehabilitation has been realized of people affected by stroke.

In this paper the author show the implementation of a new version of the previous device, but in our point of view what is interested is that already in 1991 the researcher evidentiate that the brain is able to

In his article the author presents a new version of the device, but what is interesting is that in 1991 it became evident that the human brain is capable of self-reorganization or plasticity. Afferent and efferent limb stimulation can lead to synaptogenesis and the re-establishment of the neural pathways that control volitional movement, potentially leading to impairment reduction, added functional capabilities, and reduced disabilities. (Krebs, et al. 2007).

In an article Brummel (Brummel, et al. 2012) proposes a new protocol with the intent to show how in a rehabilitation program is important to involve both the physical area that cognitive.

In a 2006 article, Smeets (Smeets et al. 2006), concludes that a rehabilitation protocol improves functions affected by disease. In his study, the group of patients waiting for a period of 10 weeks before starting a rehabilitation program shows less significant improvements compared to the other two groups that start immediately the rehabilitation. The author does not show differences instead by neurocognitive point of view and physical.

- Within the project are defined 4 groups of patients:
- WL: group of patients who have to wait 10 weeks before starting rehabilitation
- APT group of patients receiving a physical rehabilitation treatment
- CBT: group of patients who received a cognitive rehabilitation treatment
- CT: group of patients receiving a joint treatment of APT and CBT

At the end of the program are highlighted big differences between the first group and the other, while the other three groups do not present particular differences..

2.4 Force concept in the rehabilitation

The use of devices in which the parameter of the force exerted by the patient during the execution of the exercises is still an area of rehabilitation relatively unexplored.

While the spread of personal computers before, and touchscreen devices such as smartphones and tablet then, gave the opportunity for serious games to find increasing space in the field of rehabilitation, the force measurements and the development of interfaces based on this is still mostly in the experimental phase.

In literature we found device like robotic arm and joystick with force feedback used for the rehabilitation of neurocognitive and physical function of people affected mostly by Strokes.
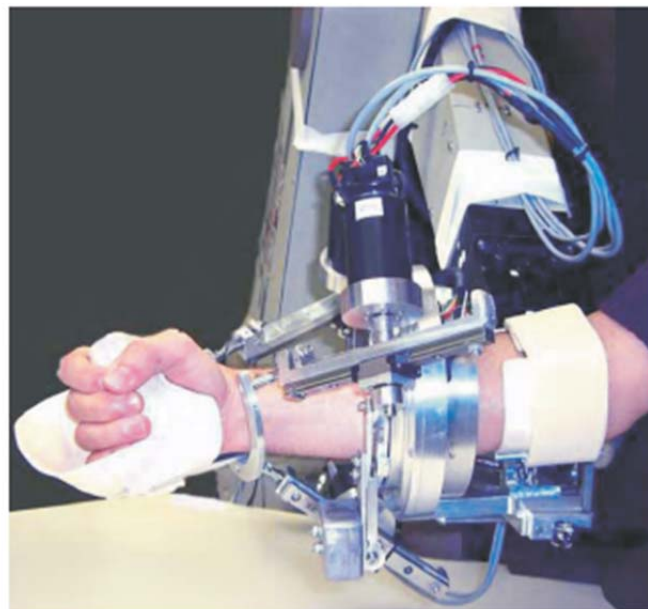
Fig. 27. Subject operating the integrated MIME-*RiceWrist* System.

(Gupta, et al. 2009)

Connor (Connor, et al. 2002) use an errorless learning therapy, he use an active force feedback joystick to guide the patients during the execution of the test.

Figure 1. *AFF Joystick and computer display.*

In another article the authors try out a device capable of generating a force feedback on the patient during the execution of exercises which simulate the activities of normal daily reality

(The Hong Kong Polytechnic University 2014)

A similar device is presented in this other article where a 3D joystick with force feedback is used to demonstrate the effects of feedback on the strength of healthy people while using this device.

Figure 1. Picture of the Novint Falcon.

From a theoretical point of view, this work seeks to test the following hypotheses: (i) force feedback regulates the smoothness, accuracy, and duration of the subject's movement and (ii) inclusion of science learning in the exercise increases participants' interest in the tasks. (Cappa, et al. 2013).

Interesting is also the case study presented by Stein (Stein, et al. 2004)] in which are compared two types of robotic devices used for post-stroke rehabilitation. One of the devices is equipped with a force control system. Both instruments used showed an increase of patients' performance at both the motor control level and at maximal strength level. however, no differences were detected using a device rather than the other.

Figure 1: InMotion2 robot: a subject is shown performing robot-aided exercises. A cursor on the display corresponds to the position of the hand, and each target is highlighted sequentially as a goal for the subject to reach toward.

In my opinion, in all the analysed article there is a .the number of people how participate to the test is no significantly large to validate the results.

3   Exergames introduction

In this chapter we are going to introduce the concept of exegaming. A great part of our work is about developing a new sets of exercise based on this type of tests.

3.1   Definition

At a glance, "Serious Games" appear to be a recent phenomenon. A market study shows that the worldwide Serious Games market is worth 1.5 billion € in 2010 (J. Alvarez, V. Alvarez, Djaouti, & Michaud, 2010). If we consider this statistic as an indicator of the success of "Serious Games", we can question whether they really represent the "first attempt" at using video games for serious purposes.

The terms evolved to designate "games that do not have entertainment, enjoyment or fun as their primary purpose" (Michael & Chen, 2005). (Djaouti, et al. s.d.)

The current definition of "Serious Games" appears to follow the lead set by Sawyer & Rejeski (2002).

- A serious game is an interactive computer application, with or without a significant hardware component, that has a challenging goal;
- is fun to play and/or engaging;
- incorporates some concept of scoring;
- imparts to the user a skill, knowledge, or attitude that can be applied in the real world.

Serious games have been used by the U.S. military, medical schools, and the general academic community long before the term was coined. For example, the programming language LOGO is arguably an early serious game. It was designed in the 1960s as a programming language that would encourage small children to grasp mathematical

principles and learn constructive principles [Papert80]. With LOGO, children can create complex geometric shapes by instructing a mechanical or on-screen turtle to move iteratively in specified directions for specific distances. See the LOGO foundation Web site, el.media.mit.edu/logo-foundation, for examples of games written in LOGO.

The genesis of the commercial video game industry was the development of simulators for the military. Initial accounts of serious gaming and the modern military date back to the late 1920s, when Edwin Link built the first flight simulator [Kelly70]. During WW II, approximately 10,000 Link Blue Boxes were produced and used to train a half-million Allied aviators. Following the war, Link's company continued to develop simulators for the military, NASA, and the commercial airline industry.

Medicine is second only to the military in directing the evolution of serious games. The reasons for this influence include a tradition of biomedical modeling and simulation, significant government funding for research into computer-based instruction for physicians, and the attractiveness of the lucrative medical market to hardware vendors and software developers (Bergeron 2006)

In his article Djaouti speak about seriousgame and healthcare, in 1992 Raya System design a game in order to teach to the kids how to manage the diabet.

So the term seriousgames is not so new in the vocabulary as showed now, but now the increase of new technology and the easy tool realized to give to the user the possibility to realize their own application increase the number of seriousgames.

Thanks to internet the people can upload their application and everyone in the world can try and play with that.

3.2 Application fields

For what concern our interested area the seriousgames are applied in a lot of different type of disease like Stroke, Multiple sclerosis, and many different type of cognitive disease.

In 2006 Lövquist and Dreifaldt presented an application based on an immersive workbench and a haptic device, designed to motivate stroke patients in their reha-bilitation of their arm. (Dömők, et al. s.d.)

During our project we analyse some seriousgames taken from the website http://www.retiaperte.it/eserciziperlamente/ in which a speech therapist collect a series of test used to rehabilitate person affected by affected by cognitive disease.

3.3 Some exemple

They developed a virtual labyrinth system. The Labyrinth contributes to an overall pleasant and encouraging exercise experience. The patients see this as a complement to the rehabilitation techniques used today and it gives them alternative exercises that are encouraging, challenging and fun to help ease their recovery [11] .[The design of a hapticexercise for post-stroke arm rehabilitation.].

"Break the Bricks" is a classic brick-breaker game. The aim of the game is to break all the bricks with a bouncing ball, while keeping the ball from falling down with a block. The user can control the block by moving the phone. These precise arm. (Dömők, et al. s.d.).

Another method used for post-stroke rehabilitation is "The Rutgers ankle" (Boian et al. (2002)).This involves controlling a computer game with a haptic device strapped to the foot. By moving the ankle, an airplane or boat is guided on-screen and the built-in-resistance helps rehabilitate the control mechanism of both the foot and the lower leg muscles. It is also worth noting that efforts have been made to create more engaging games by using force-feedback. For

example, when the airplane bumps into something, as part of the game previously mentioned, the device gives the user haptic feedback. (Lövquist e Dreifaldt 2006)

4 Clinical requirements

In this chapter we are going to define the needs of the medical staff and patients. Thanks to a series of meetings we went to analyze the current method used in rehabilitation.

We highlighted what are the advantage and disadvantage of these techniques. So we went to identify possible areas in which to apply the Force Panel.

4.1 Currently methods and device used

4.1.1 The initial situation in the hospital

The rehabilitation method used in the rehabilitation area of Villa Rosa's hospital in first two year of the project were based on physical medicine approach that the physiotherapist use with the patients.

Here there was a series of medical bed used by the patients that under the supervision of the physiotherapist performed a series of exercise in order to recover physical function affected by the disease.

There was also a structure that allows the patient to cover a short straight section using two handrails to download part of its own weight.

For what concerns the rehabilitation of the upper limbs in addition to the normal physical exercises were present a series of "simple games" like those used by children in kindergartens to allow the patient to easily and gradually regain some of their physical function affected by the disease.

In a dedicated area it was installed the ARMEO, a robotic arm, that the physiotherapist use with the patients to execute some interactive exergames.

The ARMEO is an exoskeleton with integrated springs with the adjustable arm support. It embraces the whole arm, from shoulder to hand, and counterbalances the weight of the patient's arm, enhancing any residual function and neuromuscular control, and assisting active movement across a large 3D workspace.

The pressure sensitive handgrip is not only an input device for exercises but is also a computer interface for the software and computer games, and can be removed for functional training of real life tasks.

In this area was placed also the previous version of the Force Panel used during the Veritas project.
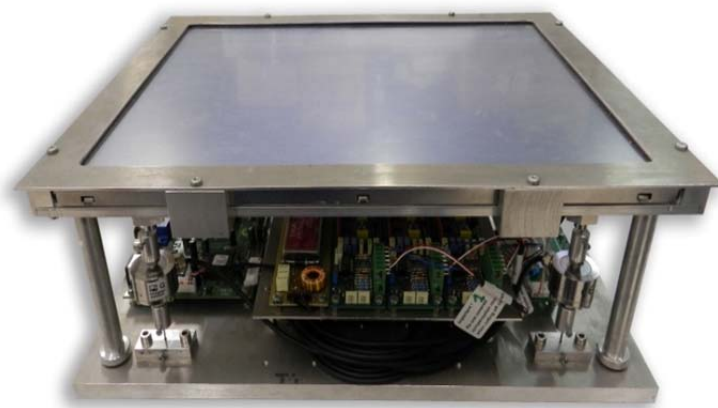
This is the situation in the rehabilitation area of Villa Rosa when we start with the project.

4.1.2 The new hospital

In the new Villa Rosa hospital's there is a complete area for the rehabilitation with the new technology.

Here are installed the Armeo two different kind of exoskeleton similar to the figure, a pneumatic glove like in picture and some different visual interaction device.

4.2 Description of the requirements of the medical staff and of the patients

An analysis of those that are the classical method used by the staff, the big drawback is the lack of patient motivation in performing this type of exercises. The patients are bored if they have to perform a test with toys such as cubes or wooden of different forms.

In accordance with Lövquist very often the patients show this kind of feeling. One patient said that she felt the exercises sometime were only to tell her that she was worse than before the stroke, worse than average, and left her with a feeling of being worthless. Another patient said that she didn't do her best, because the exercises were not motivating enough. (Lövquist e Dreifaldt 2006).

According with Carr e Shephard (Carr e Shepherd 2003) technological device are more interesting especially in the initial phase of the rehabilitation therapy. For example while using the first version of Force Panel I interact with a stroke patient who had participated in the past in shooting competitions. It was interesting and stimulating to see the patient's enthusiasm in telling me that with the ARMEO his shooter performances were still very good, in fact in a seriousgames inspired by the shooting it was still better.

With PHP instead it was motivated in trying to improve his dexterity by running a game based on Fitts' law.

Speaking with the medical staff it emerges that in general the seriousgames installed on the devices, are of poor quality both from the point of view of graphics and in terms of physical stimulus.

For example during the rehabilitation session with the exoskeleton there is a monitor in front of the patients that shows a road that runs, there is no interaction or changes on the screen. The quality of the graphics is old stile, like commodore64 games.

The medical staff needs a tool that is easy to use, many of them do not have a great familiarity with the computer and with programs like Excel, Word, etc.

Staff must not spend time to understand how to use the tool, he must be able to setup the option of the test in a few and simple steps.

One of the requirements is to create an archive where the doctor can save:

- The list of the patients with their data
- The standardized parameter of the patients

This specification is useful for the next step of the project. The doctor is able to monitor the patients during the rehabilitation therapy.

The exercises must be personalized according to the individual needs and preferences must be saved so that physiotherapist can

administer the test with the default settings determined by the selected patient.

The results obtained during the exercises should be saved in custom folders with a format as simple and intuitive as possible so that the physiotherapist can access and monitor the patient in the simplest possible way.

Patients who undertake the rehabilitation process are usually the person of a certain age, other times they are people who move with the aid of a wheelchair, is of fundamental importance that the instrument is designed by considering these issues.

Also many times this type of patients have visual difficulty due to age, and then the tool must be able to be oriented in order to improve the visibility of the screen.

5 Technical requirements and development environment

In this chapter we go to translate the needs highlighted in the previous chapter in a series of technical requirements.

We define a specification useful for develop the project in the right way.

Analyzing in depth the project will highlight two different categories of technical specifications; one based on a hardware and the other software-based.

Obviously these are intrinsically connected, in fact, the selecting a particular type of hardware will involve the use of a certain type of software, and vice versa.

5.1 Definition of technical specification

If we analyse what described in the previous chapter, one of the fundamental requirements for the medical operators is that the device need to be easy to use also with people with have non confidence with personal computer.

The device is installed in the hospital where the accessibility by the external staff is not so easy. Another requirements is that the instrument should require the minimum of maintenance, so it need to be robust and protected by accidental bumps. In addition the electronics parts mounted in the device must be stable and also need to be calibrated only in the initial phase.

All equipment used must be capable of being handled by a single person and with the minimum possible operations, in fact, usually there is only one doctor with the patient during the rehabilitation session.

The session usually take one hour and so the time used to setting up the device should be as little as possible in order to dedicate as much time as possible for the rehabilitation exercises.

Summarizing the requirements:

To be easy to use
To be robust
Stable Electronics
Minimum number of calibration
Set-up of the entire system should be simple
Set-up of the entire system should take a little time

From the patient point of view the device must be accessible for people with reduced mobility.

The screen used must be large enough to be able to project images large enough, patients are often elderly people who have vision perceptual problems.

The screen should not be too large because person with reduced mobility cannot reach some screen region, this can strain patients before the end of the session.

The device must be oriented to increase screen visibility as a function of ambient light.

Summarizing all requirements of both patient and physiotherapist:

Requirement	Subject
To be available for patients with reduced mobility	Patient
Screen size nor too big nor too small	Patient
To be orientable	Patient
To be easy to use	Patient/ Doctor
To be robust	Doctor
Stable electronics	Doctor
Minimum number of calibration	Doctor
Set-up of the entire system should be simple	Doctor
Set-up of the entire system should take a little time	Doctor

5.2   Definition of software specification

We must distinguish between the part that is concerned to the archive management and the part focused on the design of the exergames.

The graphical interface for the patients data management need to be as easy as possible in fact one of the requisite is that the due to the poor familiarity of the medical staff with the computer the software interface need to be as easy as possible.

We decide to implement an archive based on subfolder. We have the parent one which is like "NameSurname". In this folder we save a .txt file with the data of the patient:

- Name
- Surname
- Birthday
- Disease

In a file .csv we save the data and all the standardized parameters measured by the doctor. So we have an history of the clinical evolution of the patient during the rehabilitation.

In the folder there are also subfolders with the name of the seriousgames in which we store the settings used in the last session and a file .csv with all the parameter measured during the test for each session.

After the first debugging phase we find out that the physiotherapists do not have the adequate knowledge of Excel so we now start to implement another program to visualize a report of the performance of each test for each patient.

As it regards the implementation of exergames is necessary to define with the medical staff those that are the exercises to implement.

5.3 Equipment's

5.3.1 Force Panel

The device used during the experimentation has been realized in the university laboratory. The main parts that make up the hardware are:

- An LCD screen 15 "
- A capacitive touchscreen sensor and its electronics hardware interface
- A load cell with the relative power supply and filtering modules
- The base plate, the cover of the screen and on the protective cover

5.3.2 LCD display

Thanks to the experience by using the first version of Force Panel with patients with different types of disabilities and after an analysis with medical staff we identified that the optimum size of the screen is 15 ".

In this way you have a good visibility during test execution, this si a very important factor since it often they work with olde people that may suffer from impaired in vision. An excessive size of the screen would require the patient to make too large movements and in some case some areas of the screen be inaccessible. In this way we avoids excessively fatigue for the patient's limb.

5.3.3 Touch screen sensor

The touch screen model used, ZYP15-1.0001D is a retina glass 3 mm thick with controller for 15"integrated USB. The Zytronic Projected Capacitive X-Y Controller Touchscreen is based on Projected Capacitive technology which enables the device to sense through a protective screen in front of the display. The touchscreen electronic controller effectively divides the screen into sensing cells using micro

fine wires which are embedded into a glass laminate construction. These wires are connected to the touchscreen controller circuitry, and an oscillation frequency is established for each wire. Touching the glass causes a change in frequency of the wires at that particular point, the position of which is calculated and identified by the controller. The controller then outputs the x-y touch coordinate via a USB communication link. Unlike other capacitive systems where the operator touches the actual conducting surface of the sensing panel, the active component of the Zytronic Projected Capacitive X-Y Controller touchscreen is embedded within the glass laminate construction ensuring long product life and stability.

Compared to the previous version that use a resistive touchscreen with the new version the touch is managed as a mouse. In this way we can develop the software and the exergames more easily and we can also use the touchscreen to manage all other applications such as Excel, Word, etc.

The technical specification of the touch screen are:

Power Requirements USB Controller powered from regulated VBUS 5V dc ±5% (max) tolerance external power supply
Resolution <1mm
Speed of Response <10ms
Positional Accuracy <1.5% of reported position in recommended viewing area.
Optical Resolution >4 lines/mm (NBS1963A)
Light Transmission ~90%
Sensor Thickness   <3mm
Stylus Type: Finger, gloved hand
Operation Force < 0.1g

5.3.4 Load cell

While performing the test we measure the force exerted by the patients by using a load cell type PW6CC3MR.

Here after dtasheet:

Maximum capacity (Emax)	5 kg
Minimum LC verification interval	0.5 g
Max. platform size	300x300 mm
Sensitivity (Cn)	2,2 ± 0,2 mV/V
Relative reversibility error (dhy)	± 0.0166 % di Cn
Non-linearity (dlin)	± 0.0166 % di Cn
Off-center load error	± 0.0233 % di Cn

This type of sensor has allowed us to create a robust system, more than the one used for the previous version of the Force Panel.

One of the problem of the previous device is the risk of damage the measure system.

The previous solution is composed of three U9B model of load cells capable of measuring the strength both in tension and compression that connected the lower base with the upper one with harmonic wires.

Load cell image with the harmonic wires which connect the lower base with the upper platform

This type of configuration allowed to measure with good accuracy the perpendicular force exerted by the user to the screen, but the entire device was very delicate and sensitive to impacts.
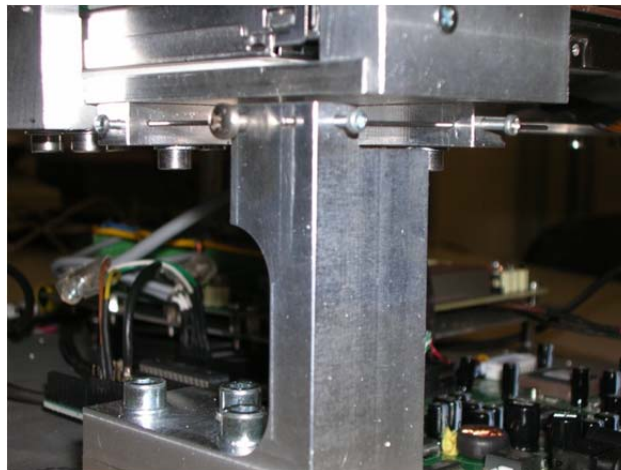
In this image it is evident the delicate harmonic wire system that constrain the device on the lateral side.

With the new configuration the upper part is firmly screwed to one end of the load cell, while the other end of the sensor is screwed to the lower base.
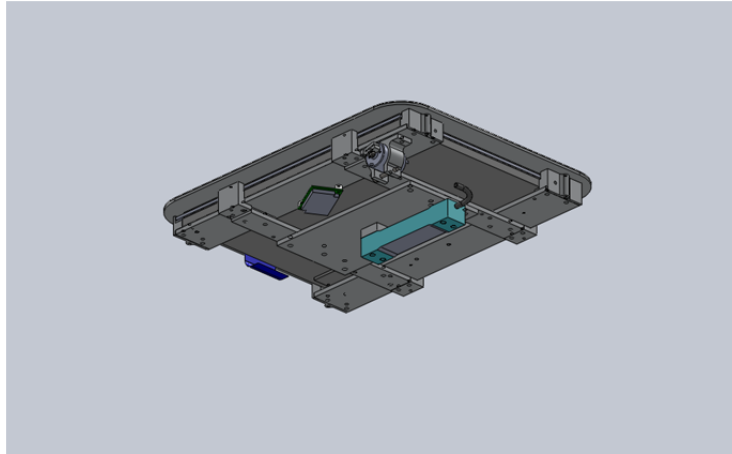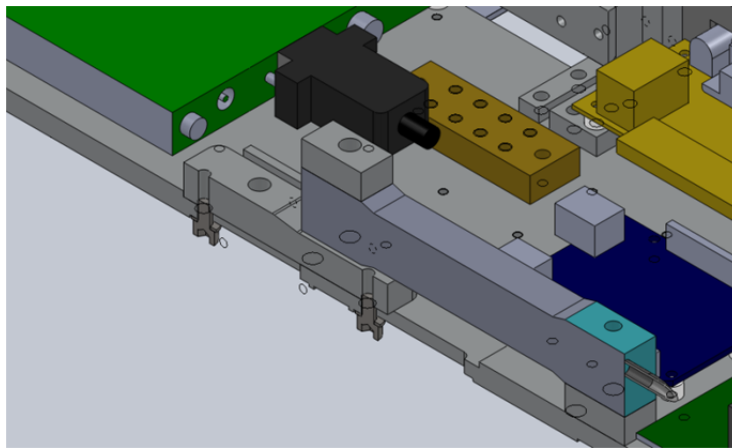
Image of the upper part with the load cell (blue part) fixed on the lower end

Section of the base with the load cell and the two spacing blocks.

As you can be seen from the datasheet, the load cell is capable of measuring a weight that is not in axis with the constraint point up to a distance of 300 mm along the x-axis and 300 mm along the y axis. The choice of a 15"screen has allowed us to use this type of sensor.

5.3.5 Amplification module

The amplification module used is designed and manufactured by Ing. Antonio Selmo. It is a module powered by an additional board that provides a dual voltage of 15 V (Figure 53). It is basically composed of a part of analog filtering, an amplification and a translation in order to conver all the values in terms of positive voltages, readable via the Arduino.
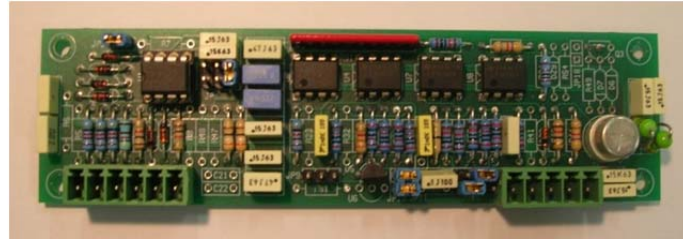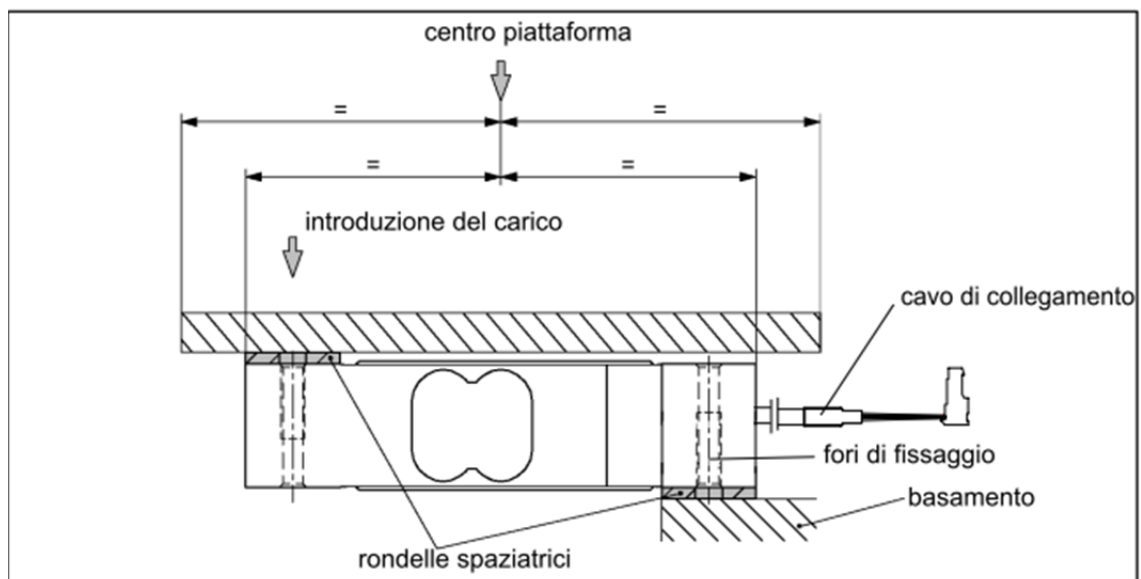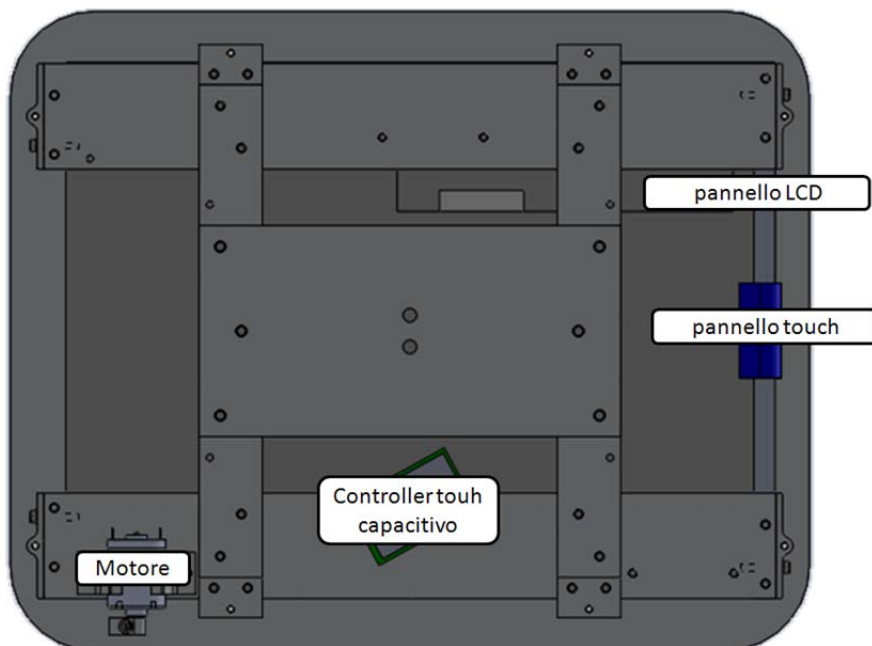
Figura 1 – Modulo di condizionamento.

Figura 2 – Convertitore DC/DC per alimentare
i circuiti di condizionamento.

5.3.6 Base plate, display case and carter

Most of the electronics mounted on the instrument is fixed to the base plate. This has been obtained from an aluminum plate so that the load cell fixed on it can be considered a fixed joint.

With Eng. Selmo we studied the layout of the various electric modules in order to try to eliminate any parasitic currents.

Keypad
Scheda con porte di interfaccia
Centro stella
Buzzer
Scheda LCD
Arduino
Cella di carico
Condiz. cella
DC/DC per condizionamento
Modulo pilotaggio motori
Inverter lampade LCD

pannello LCD
pannello touch
Controller touh capacitivo
Motore
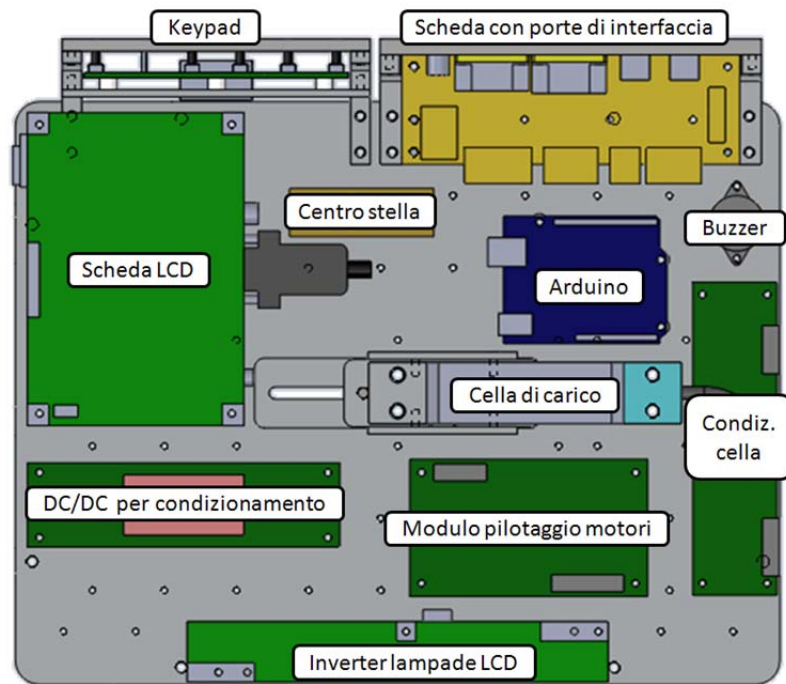
The case of the screen is fixed with two screw to the load cell. On the top of the case we fix the LCD screen and the touchscreen sensor by using a cover plate. Under the case we place we place the

alimentation board of the light of the LCD screen and the controller of the touch screen.
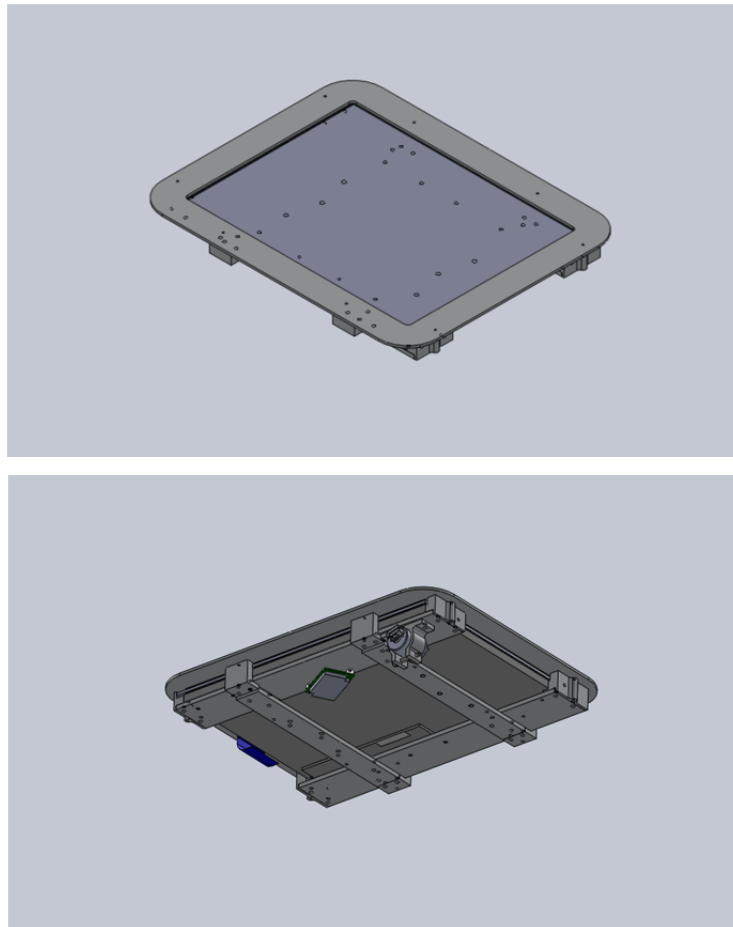

The spacing between the Display and the rear of the Touchscreen should be at least 3mm. This 3mm spacing should be created using a double sided adhesive gasket (i.e. VHB tape or some form of foam gasket). Layers of gasket may have to be built up to obtain the required spacing. The important point here is that even under compression the uniform spacing should remain at least 3mm.

After that we need to verify that the active area of the touchscreen is aligned with the viewable area of the display and that there is no excessive flexing or mechanical movement between the touchscreen and the Display. We have a front bezel and this also must be spaced off the front of the touchscreen using a 3mm double sided adhesive gasket. This 3mm gasket can be applied directly to the edges of the touchscreen and the spacing must be maintained even under compression.
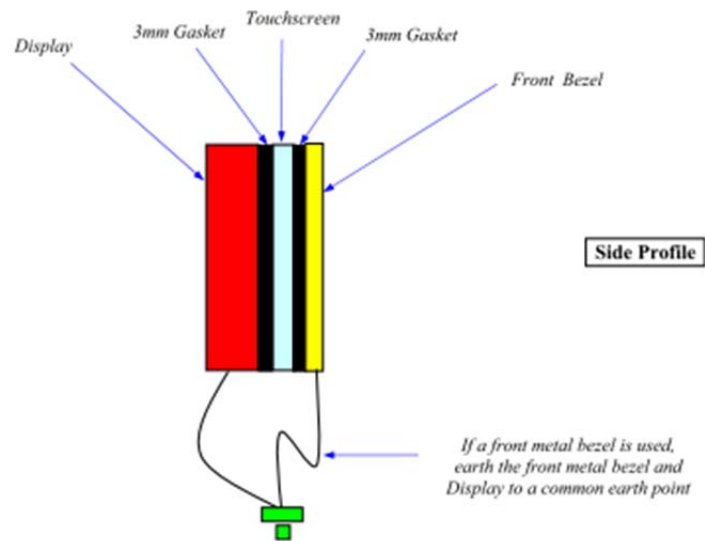
Figure 1: *Direct Touch integration with a typical front bezel which can be made from either plastic or metal*

To protect from dust and possible damage the electronics of the system on the sides four metal plates were fixed.
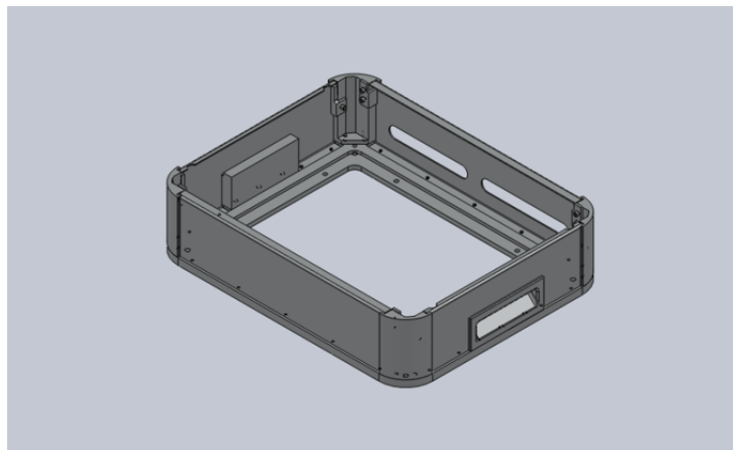
5.3.7 User accessibility

In section 4.1 concerning the definition of technical specifications it has highlighted the need to make the instrument usable by people with specific physical and motor deficits, such as people who have to use wheelchairs or people with vision problems.

As a solution it was decided to use an adjustable table both in height and in inclination of the type used by architects, in this way it is

possible to easily adjust the height position and the orientation of the instrument and thus the visibility of the screen.

On the table it was made a hole in size of the Force Panel, in this way the FP has been fixed to the lower part of the table leaving the screen on the same plane of the table.

In this way it is possible to increase the difficulty level of the exercise by putting the orientation of the table near the vertical. In this case the patients need to perform the test without resting his elbow on the table.
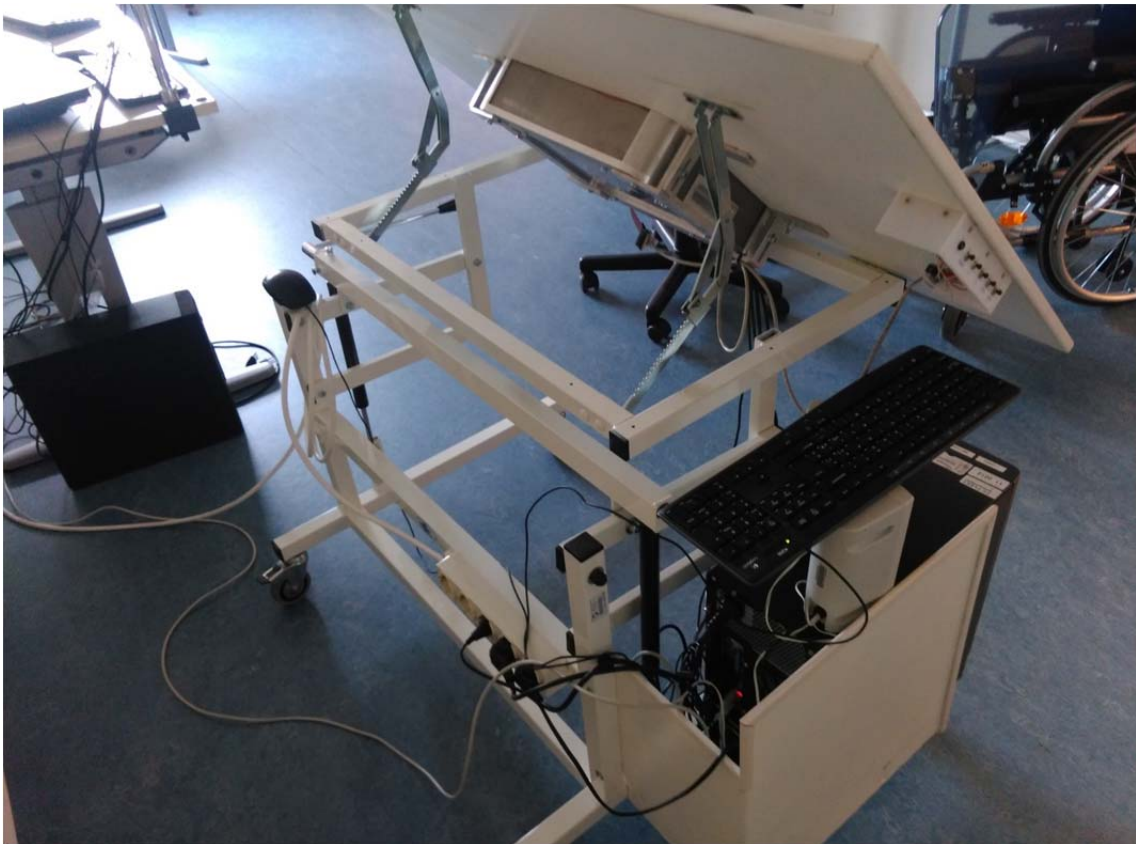
5.3.8 Definition of the development environment

As regards the implementation of exergames we were evaluated several possibilities:

1. Implementing exergames working directly with OPENGL delegating part of window management to Qt and then writing the code directly in C ++.
2. Use the Ide of Processing for the management of the GUI and also for the tests implementation.
3. Make the GUI with Qt and the seriousgame with a game engine dedicated as Unity3D.

Each of these three approaches has advantages and disadvantages. The main advantage of using Qt is the possibility to compile code for different platforms including Windows and Mac.

The disadvantage is the need for a dedicated class for the serial communication management with Arduino. In this way we also need to write a program to run separately before each session to ensure that communication between Arduino and PC is synchronized, otherwise we cannot acquire the force values.

Another difficulty writing interface with Qt is absence of useful libraries that are able to realize the plot of results and saving files in a format compatible with other software such as Excel.

The Processing IDE is a great tool fully compatible with Arduino and which is based on java. With this tool simple applications can be realized with an attractive graphics and in very short amount of time.

One of the main disadvantage of this tool is the lack of a library for GUI interface generation. Also the plotting of the results requires quite complicated libraries. As for the graphics part of the exergames it was initially evaluated the ability to directly use the library of OPENGL for programming. The main advantage is that it works at low level and then you have a direct management of the code. The main

problem is that in this case we the need to write many lines of code just to load the two-dimensional images to be used in tests.

The alternative is to use part of the Qt libraries that allow management of the highest level of the graphics with certain limitations, or use a game engine dedicated. In our case, we are focused on a Unity3D game engine, a semiprofessional game engine where the freeware version is already quite full and the supporting literature is very wide. The main advantage of a game engine is the ease of implementation of what in technical terms is called the scene and that once the code is compiled generate the game environment.

This game engine give us the possibility to write the code both in C# and in Java. The main advantage of the C# is that it is very similar to C++ the code used with the Qt and they are easily interfaced.

C# and .NET have a lot of library and default classes that helps programmer during his work. In our case it was easily implement a class in order to open a serial communication between the PC and Arduino.

With this game engine like with Qt it's possible to compile the code with different platform like Windows, MAC and Android.

We decide to take the advantage of the Qt for what concerned the graphical interface and the archive management. For the serious game implementation we decide to use the Unity3D game engine.

In accordance with E Lövquist and U Dreifaldt (Lövquist e Dreifaldt 2006) another advantage of developing a system like this is the easiest way to include new test in the Rehabilitation platform.

5.3.9 Calibration of the Force Panel

The Zytronic Projected Capacitive X-Y Controller Touchscreen is connected to a host computer via USB connection. The Zytronic Projected Capacitive X-Y Controller Touchscreen Driver software is called the Universal Pointing Device Driver (UPDD). The UPDD allows the touchscreen to interface with the host computer's operating

system and is the main interface to allow calibration to take place and the settings of the touchscreen to be altered.

Figure 27: *Calibration targets appear on the screen. Apply and hold a touch in the centre of each displayed target in the sequence they are displayed on the screen*

Una volta installato il driver del dispositivo touchscreen è possibile utilizzare un programma dedicato per calibrare la lettura del tocco con lo schermo.

We write a dedicated software in order to calibrate the load cell mounted on the Force Panel. We need to calculate calibration parameter to convert the Arduino data output in the respective real value of force.

For the Force Panel calibration we need:

- Force Panel
- A personal computer with Arduino driver installed
- The Ide Processing
- A series of weights between 100 g and 2 kg. The load cell is able to measure from 1 g to 5 kg but the weight of the integrated system (LCD, touchscreen and case) it's about 2 kg. The shape of the weights must be used to exert pressure on

a circular area with a diameter about 1 cm. For the calibration we use a series of 200 g of weights

- Matlab, for the data analysis and to find out the calibration value.

The software is written using Processing because it's very easy to interface this IDE with Arduino and to create a simple interface in order to acquire the data.

The calibration procedure shall be as follows:

1. To set:
   a. the value of the weight used
   b. the discretization of the grid (the number of rows and columns in which it intends to split the screen)
   c. the index of the row and column in which it will place the weight.

   In the Ide.

2. To start the program
3. To place the weight in the right position. The screen is projected a grid of horizontal and vertical lines as a function of the values settled in step 1. To the Index of the row and column set in step 1 a circle of radius approximately 5 mm diameter is projected to indicate the acquired position.
4. To press ENTER key once to start the PC recording data that Arduino receives from the load cell.
5. To press the ENTER key to terminates the acquisition and store data in a .txt files. It is important to wait a few seconds before you begin recording data after placing the weight because the value read from the load cell need to be settle to a constant value.

6. Returns to point 1, settings new position or weight value until all the grid point and all the weight value are inserted.

7. To run Matlab calibration software to extract the calibration value.

During the preliminary analysis of the data acquired we try to correlate these three variable:

- The x coordinate of the point
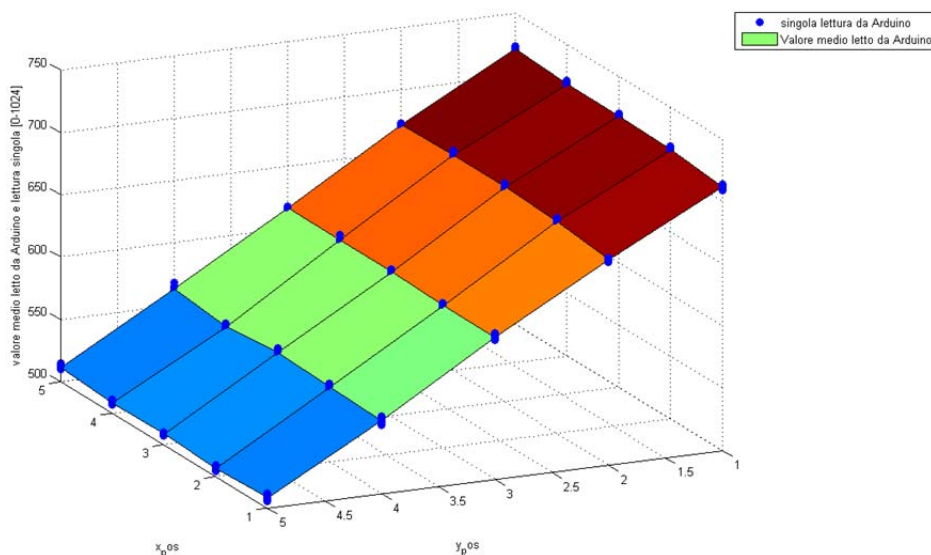- The y coordinate of the point
- The weight value

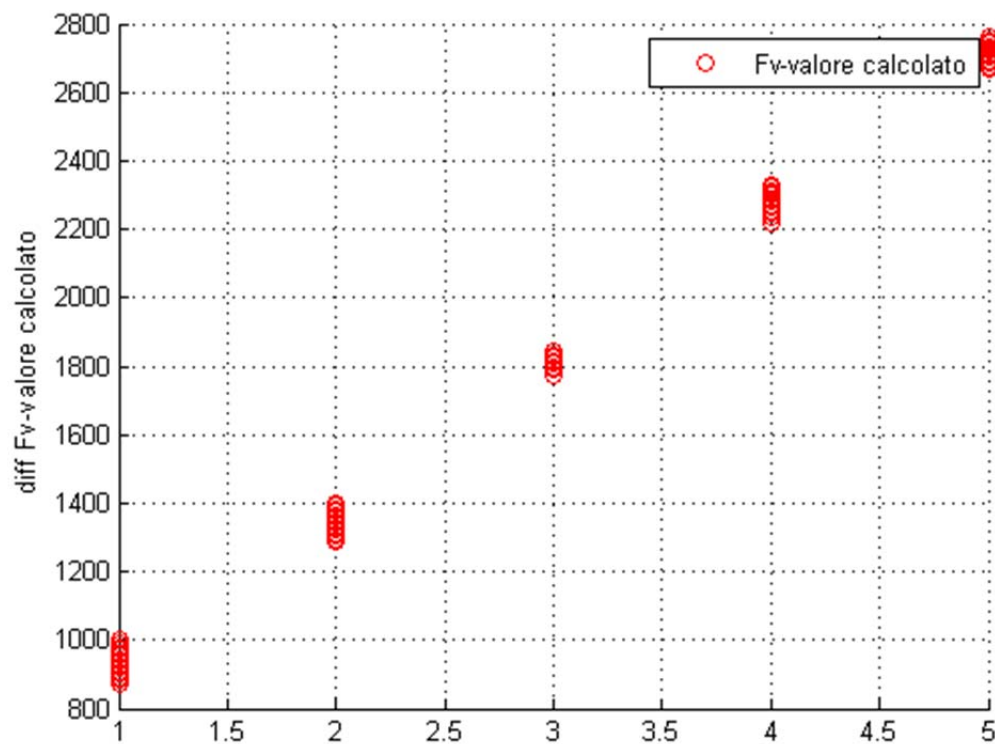We consider a fourth order polynomial to calculate the coefficients.

$$F_s = a + bx_s + cy_s + dx_s^2 + ex_sy_s + fy_s^2 + gF_m + hF_mx_s + iF_my_s + jF_mx_sy_s$$

Analyzing the results, it was verified that the formula used can be simplified as follows.

$$F_s = a + cy_s + iF_my_s$$

In the figure below it si evident that along x direction the value acquired it is constant.

The only two variables of interest are the y coordinate and the weight value. By analysing the data we find a linear dependencies of the two variable considered.

Once we terminate the calibration phase, the calculated coefficients are stored in a file that will be used during the implementation of the serious games in order to convert the values acquired from the load cell in the pressure exerted by the user in terms of grams.

6 Tests development

In this chapter we describe the implementation of some of the exergames used in this project.

In the first part we are going to define how it is managed the archive of the patients and the Rehabilitation platform used for the selection of patients. With this tool it is also possible to setting up the personalization of the test in accordance with the needs of the individual

The second part is focused on the design of the exergames. We start by analysing existing test already used in rehabilitation therapy. For what concern this kind of test we find a lot of material in the web site http://www.retiaperte.it/eserciziperlamente/ and a great support by the medical staff involved in the project.

We try to find a way to introduce the force concept in the seriousgame that we design for the rehabilitation therapy.

In accordance with E Lövquist and U Dreifaldt (Lövquist e Dreifaldt 2006), to make an exercise encouraging, stimulating, engaging and playable for a stroke patient several design aspects have to be considered. These aspects are the result of literature studies, informal interviews with medical doctors, physiotherapists, occupational therapists and a study with stroke patients.

Here in the table we summarize there requirements

Reward system, by using some type of feedback like a scoring system, audio feedback, etc.
Difficulty. The degree of the disease it is different for each patients. It's important to vary the difficulty level of the game in order to keep the engagement of the patient
Real time feedback
Environment design. Take care in the graphical aspects of the game in order to capture the interest of the patient

Intuitive task
New possibilities. Take care to the patients requirements and try to introduce in the exergames real life situations in order to rehabilitate the patients from the social point of view.

Graphical interface appeal it is necessary not only to increment the interest of the patients but also because usually people affected by disease have visuo spatial problem, it's really important to take care on this aspect.

In the first debugging phase we verify the importance of instruction of the tests. The game implemented in fact can be used with some different objective but the data acquired system is designed to evaluate some specific tasks.

It is very important to explain not only to the patients the objective of the test but also to therapist. Not all the therapist are involved in all the steps of the project and so they don't now in depth the aim of each seriousgame. During the implementation of the test we need to write an instruction page for each test after a discussion with the doctor to find the right word to use.

6.1 Patients' data management

The device installed in Villa Rosa hospital is linked to a personal computer with Windows 7 installed.

We realize a software to create a database of the patients, so the physiotherapists are able to manage the patients' data directly by using the Force Panel as user interface.

The GUI is based on Qt libraries and it is implemented using C++ programming language.

Here we describe the graphical interface and we start to analyse the function implemented in the software in order to satisfy the requirements of the doctors.

On the left side of the GUI we have one icon for each exergames implemented in the Force Panel. The physiotherapist selects from this menu the test that he want to administrate to the patient.

In the right side of the Rehabilitation platform you can see the list of patients just been added to the database. Also in this case the physiotherapist need to select the patients when he start the session. When the patients is selected on the top of the screen is displayed the name and surname of the person.

In the centre of the screen is showed the option for each serious game. The value settled depends on the patients selected and the physiotherapist can change and save this value during the session. When the patients start a new session the Rehabilitation platform reload the configuration of the previous one.

At the bottom of the screen there are a number of buttons which have the following features:

- Run the exergames
- Save the current options
- Add new user
- Modify user data

6.1.1 Tests managements

We now start describing the normal procedure performed by the physiotherapist at the beginning of the session. We explain each function that can be used during the session. In the last part we understand how we can change the user data.

The first time a patients start using Force Panel there is no data about him in the database. The physiotherapist need to insert the data in the archive.

In specific he need to insert:

- Name
- Last name
- Date of birth
- Treatment initiation date
- Type of disability
- Any notes
- If necessary, a number of standard medical indicators

In the bottom part of the interface there is a button to add a new user. The doctor press the button and is opened a second window like the one below.

In this second interface, you must enter the details of the patient and to be able to save the new patient you must enter at least the name, surname, date of birth and type of disability. Once you have filled out all necessary fields physiotherapist goes to save the new patient. In the event that the person has already been inserted displays an error message.

After this procedure the window is closed and you return to the home page. If the patient is not selected by default, the physical therapist can select it from the side menu and then the top of the interface displays the selected user.

Now physiotherapist select the exergame to be executed by the patient by selecting the test in the left side of the interface.

If the patient has never performed the tests in previous sessions in the central part the options for the test are set by default with the defined settings with the medical staff.

In general terms all the exergames have common settings for what concern the settings of the force parameters and for the audio feedback.

When we start the Rehabilitation platform the software verify USB device connected, if it identify the Force Panel in the option page of each test the force modality check box is checked by default.

With these option active it is possible setting up the upper and lower threshold value; the range value that the patients need to use during the exercise. It is possible to set the permanence time in the force range, in fact during the test in order to activate the target the user usually need to maintain the pressure in the range for a certain time.

To give a practical example if the patients need to select a number of object with the force modality selected, he need to place the finger on the target and exert a pressure in the range value for the time previous settled, after that time the object is selected.

With regard to the audio feedback we have two different type independently selectable.

- Background music, this type of feedback could be a positive stimulus for some kind of patients, but with some other could be a distractor.
- Audio feedback, a sound to indicate to the patient if complete the task in the right way. For example when the user select the target the program emit two different sound one if he select the right ones the other if he select the wrong target. This type of feedback could be helpful for the patient during test execution.

Once defined the method for test execution physiotherapist can choose to save the current settings or he can decide to start the test. We implement this option because the doctor can decide to set up the option of all test before starting the session.

Another interesting feature it is related to the modification of the user data. At the bottom of the screen there is a button that open the

patient data interface, in this page physiotherapist can update the standardized indicators in to monitoring the evolution of the patient during the therapy. New data are saved in a specific file for each patients, in this file are save all the parameter with the data of evaluation.

So it is possible to evaluate the effectiveness of the rehabilitation therapy.

6.2 Test implementation

In this part we are going to illustrate two of the seven exergames designed during the project, we are going to define the neurocgonitive and physical area involved.

During the meetings with the medical staff we analyse the specific function involved during the rehabilitation therapy. We start from the physical exercise that the physiotherapist do with the patients and we also analyse some seriousgames already implemented.

We found a lot of seriousgame for neurocognitive rehabilitation in the site www.retiaperte.it/eserciziperlamente/. In this game the interaction of the player is made by the keypad or mouse.

We find a way to reimplement that in order to play with touchscreen device. We also define some physical function that can be rehabilitated with this seriousgames. In order to use the tests with the Force Panel we also figure out a way to introduce the force feedback in this exercise.

Macrofunction	Specific function	Specification	Environmental correlations	For example
Orientation	Spatial Orientation	Ability to organize the self-perception in the space and in in the time	Orient oneself of "where and when" in specific situations	What time is it? Where are you?
	Temporal Orientation			
Attention	Vigilance/Alertness	Activations level of arousal	Physiological quickness in	Atlete that wait the start in the race

			stimulus responses
	Selectiv attention	Selection of one attention target and inhibition of distractors	Ability of to take the interested stimoulus out of contest and to ignore the distractors, in a span of time	Try to listen to a conversation while as other conversations are in progress
	Sustained attention	To preserve attention in a long time		Speak on the telephone while you are cooking
	Divided attention			
		Division of attentive resources between many simultaneous stimulus/tasks	Pay attention to more informations or more tasks	
Memory	Short Term Memory (MBT) and Working memory (WM)	Temporary retention system, elaboration and selection of visuo-spatial information, verbal and write, finalized to make a cognitive task	MBT: memory and recall of just presented informations WM: ability of keep in memory the informations for the all time necessary for finalize the task	Ability to repeat the last expression that you have hear For solve algebrical calculation, I must remember many prior changeovers
	Long Term Memory (MLT)	Permanent or part time retention system, in the memory stock	Capacity to organize events, situation, learnings, in order to render available this informations if necessary	Serf-memory, memory of events, learning knowledges
Executive functions	Planning Attention Control – To inhibit inappropriat e responses Set Shifting – Cognitive flexibility Abstraction Motivation	Include this capacities To planning action's strategies To inhibit automated behaviours To planning strategies for problem solving Abstaction and classification of stimulus and events Willingness to begin many actions	To be able to organize own actions and behaviours, in relation of the enviromental requests, social relations, even in non-ordinary situations	Write the shopping list: to planning what you want to buy. To find the motivation for leave home. Go in the supermarket, according to necessity, but having the flexibility to put down in the shopping trolley one economic product, for example. Go in checkout counter having patience, standing in line and having willingness

				to pay
Language	Verbal production	Ability to produce understandable verbal messages	Ability to interact in the usual comunications	To interact through the word and listening in a conversation between 2 or more persons
	Oral comprehension	Ability to understand verbal messages		
Visual perception	Object	Ability to recognize the objects, through the visual channel	To recognize the objects	To distinguish between a pen and a pencil
	Space	Ability to elaborate the surronding space	To recognize the places and environments	Distance between me and an object
Motion	Executive	Patterns of finalized motor behaviour	Programmation of motor actions, in relation of space into take place the action and in relation with the around subjects	To climb a mountain
	Strategical			

6.3 "Apprendimento Immagini" test development

6.3.1 Objective

The game, realized using Unity Game Engine, is characterized by an advanced graphical interface. This game engine allows us to develop high level applications, in particular from the graphical point of view.

The game consists of different levels and scenes. This is important in order to give to the patient an increasing impact, but also to help the users with particular pathology (like hemiparesis).

In the first scene it's showed the target (food) that the user need to select in the second step of the test. The aim of the game is to choose the right path showed in the first scene, when the right target it's clicked it fall down from the shelf and it disappear, unless a sound feedback it's given to the player.

6.3.2 Neurocognitive and physical areas involved

The macro area, from a neurological point of view, involved in this exercise is the long term memory.

In particular this game requires some capabilities:

- Permanent or part time retention system, in the memory stock
- Capacity to organize events, situation, learning's, in order to make available this information if necessary

6.3.3 Settings

At the beginning of the game the application loads the appropriate settings. This information is stored in a file with a common format.
In particular, the user can set:

- Number of targets to be selected
- Total number of target in the scene
- The time to memorize the targets
- Upper and lower force thresholds
- The permanence time in the target

- The constant force value

The game has four different level, from very easy to hard, in terms of the total number of objects in the scene. It also possible to set the number of targets to be memorized, from 1 to 5. The doctor can also set the time to memorize the targets, two five or ten. Before the play scene start the targets will be showed for certain time. In order to select the object in the force mode, the user has to apply a force between a lower and a higher threshold for a certain time set in the menu. To start the timer the user need to apply a constant force and in order to evaluate it the doctor can set the standard deviation limit of force.
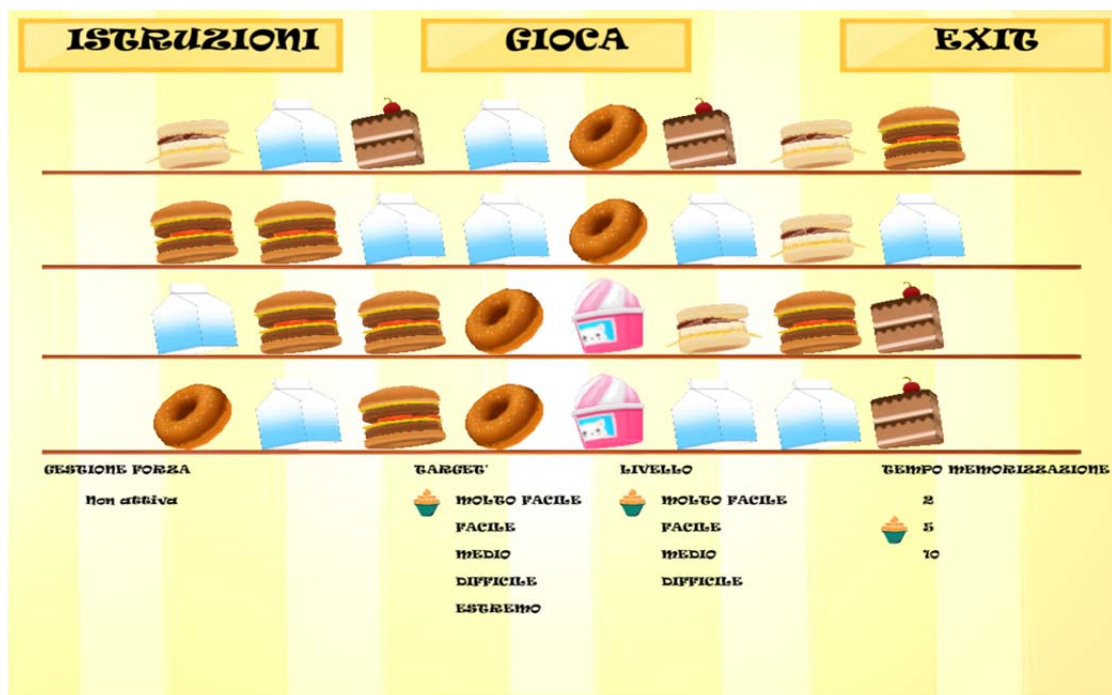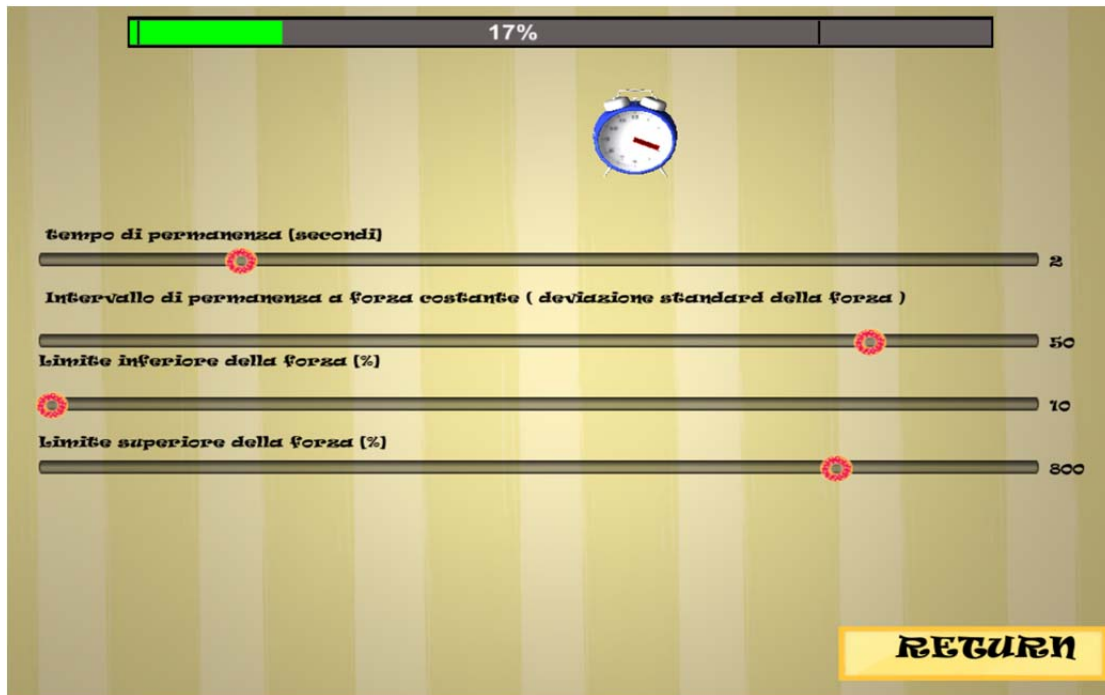
6.3.4 Game environment

The game consist in two different scenes. When doctor press the play button the targets to be selected are showed in the middle of the screen for a certain time settled in the menu. The number of targets to be selected is also defined in the menu and it could be a value from 1 to 5. After this time the scene switch in the game scene, here in function of the selected level (Very easy, Easy, Medium and Hard) the scene is fulfilled with the objects placed on fixed shelves. The number of objects increase with the difficulty of the level and the dimension of them decrease with it.
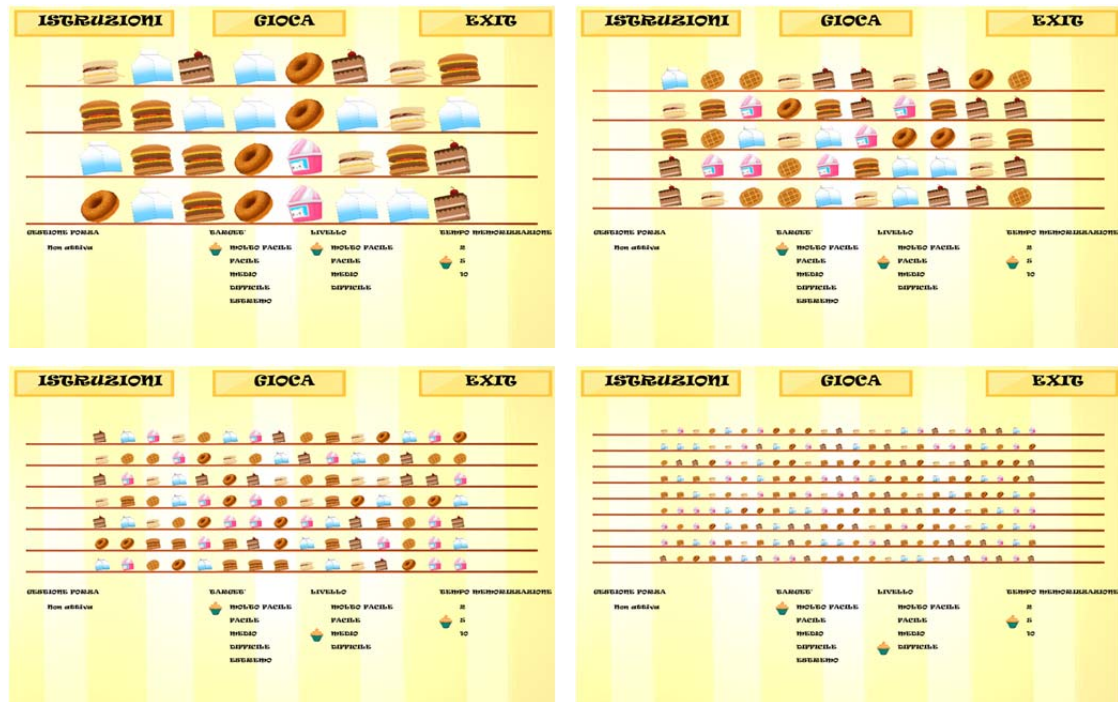
The user has to select the correct targets in order to complete the level. The objects are randomly placed in a grid in which the rows and columns depends from the selected level.

If force mode is disabled when the user click on the right target it fall down from the shelf and disappear, otherwise a sound feedback it's given to the user.

If the force mode is enabled in order to select the right object the user needs to press on it in a certain range of force. He need to maintain a constant pressure for a certain time previously settled.

On the top part of the screen, a slider indicates the actual force intensity and the two thresholds.

When the patient achieves the target score the game stops and return to the setting page. At the end of the game the application writes the performance data in a specific file.

6.3.5 Measured parameters

To realize the evaluation of the performances, the game stores information about:

- Time to complete the game.
- Total number of error
- Number of error to select each target.
- Precision for each target:

- o In the modality without force it is the distance from the centre point of the target and the click position.
- o In the force modality it is the mean of the distance from the centre point of the target and the click position during all the permanence time.
- RMS (root mean square) of the force applied to the force panel.
- RMS (root mean square) of the distance between the release position and the vertical line passing to the center of the nearest pipe entrance.
- Kind of food

In order to calculate the RMS of the force it is necessary to determine the average value of the samples and then the variance of the measure.
Starting from the average of the force calculated after N sample (m_N):

$$m_N = \frac{1}{N} \sum_{i=1}^{N} u_i$$

Where u_i is the current sample.
It is possible to simplify the equation in order to obtain an on-line recursion:

$$m_N = \frac{N-1}{N} * m_{N-1} + \frac{u_N}{N}$$

The variance of the measure, defined by:

$$\sigma_N^2 = \frac{1}{N-1} * \sum_{i=1}^{N} (u_i - m_N)^2$$

can be simplified:

$$\sigma_N^2 = \frac{1}{N-1} * \sum_{i=1}^{N} u_i^2 - \frac{N}{N-1} * m_N^2$$

It is possible to use the same approach in order to calculate the RMS of the distance between the target position and the touch position.

6.4 "Giu dal tubo" test development

6.4.1 Objective

In each scene, there are paths that start from the top of the screen and end in the lower part. The aim of the game is to choose the right

path to bring the game object to its goal. The user has to bring an object (ball, fruit) and drag it at the beginning of the right path. At this time the object, thanks to the gravity force, falls following the selected path and then it reaches the target

6.4.2 Neurocognitive and physical areas involved

The macro areas, from a neurological point of view, involved in this exercise are the executive functions and the visual perceptions.

In particular this game requires some capabilities:

- Planning of action's strategy
- Inhibition of automatic behaviors
- Planning strategy for problem solving
- Abstraction and classification of stimulus and events
- Ability to recognize the objects through the visual channel
- Ability to elaborate the surrounding space

6.4.3 Settings

At the beginning of the game the application loads the appropriate settings. This information is stored in a file with a common format.
In particular, the user can set:

- Game Mode
- Low and high threshold of the force
- Maximum target score reachable from each goal
- Game level

The game has three degrees of difficulty, in term of number of paths and goals. Moreover, the doctor can select the game mode and so, if the patient has to perform the associations between colors or figures. In order to drag the game object, the user has to apply a force between a lower and a higher threshold set in the menu
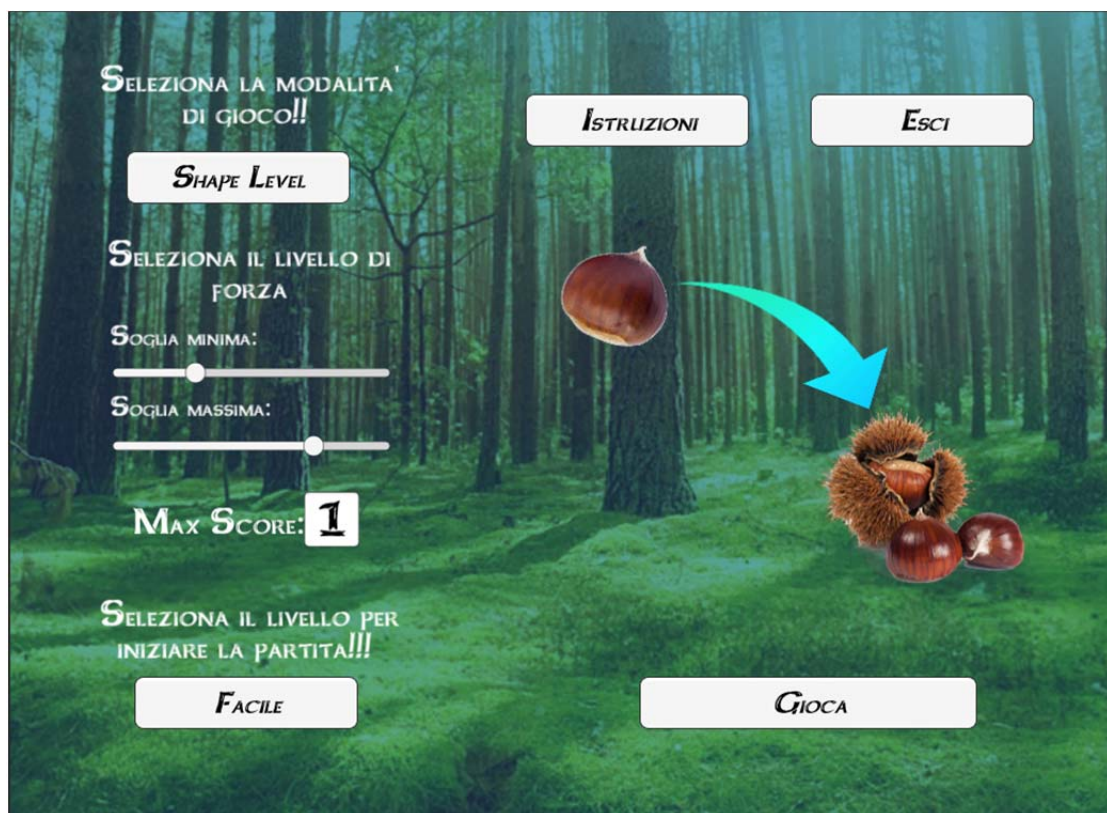
6.4.4 Game environment

The game is made mainly of many concatenated paths placed in the middle of the page. There are two game modes: color and shape. In the first case the user has to associate the color of a ball with the fluid inside the cauldron (target). The second mode implicates the coupling of the fruits. In this second case the game involves the capability to recognize the shape of the objects. Each game mode is characterized by three levels of difficulty. The number of paths increases with the level, starting from three (easiest) until nine (hardest).
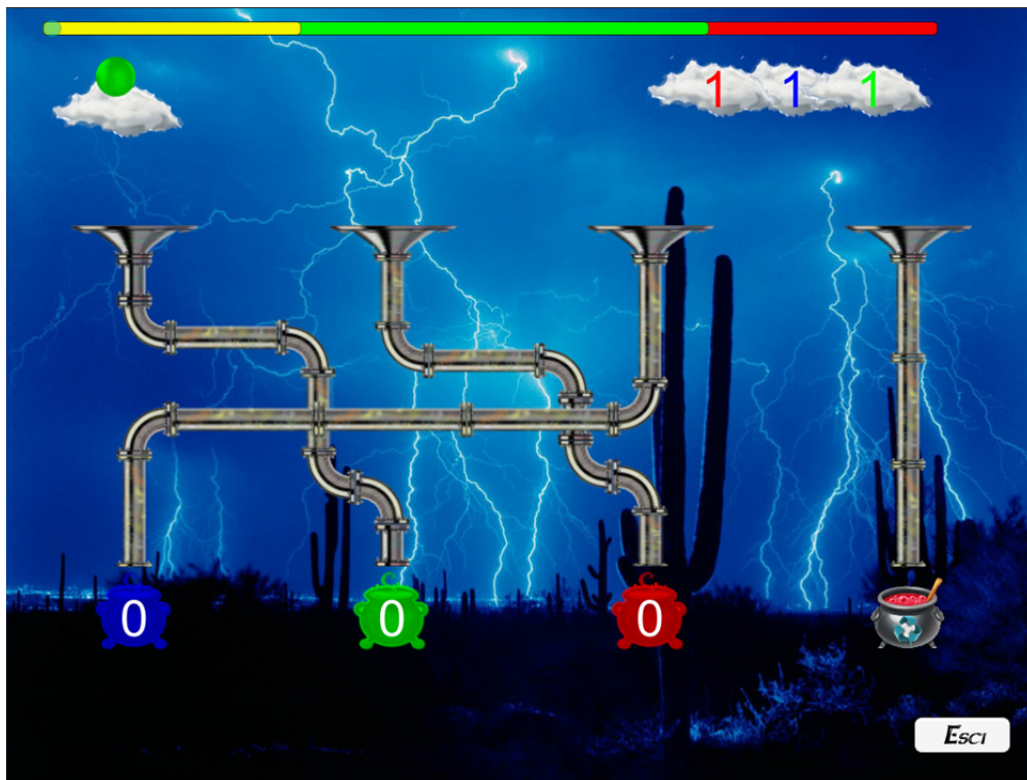
The game object during the path in the pipes follows the gravity force by falling from the upper part of the page to the lower. Below the end part of each path is randomly located a target object. The user has to select the correct pipe in order to put the game object to the

corresponding target. The software selects a game object randomly and it put it on a cloud in the top left part of the page. After the selection of the path, the patient can drag the game object above to the correct pipe. The dragging is enabled when the force applied to the display remains between the two thresholds. On the top part of the screen, a slider indicates the actual force intensity and the two thresholds. The user has to reach the target score placed in the top right part of the screen. If a specific target has been already achieved, the patient has to reject its using the trash path on the right. When the patient achieves the target score the game stops and the user can select to restart the level or return to the setting page. At the end of the game the application writes the performance data in a specific file.

6.4.5 Measured parameters

To realize the evaluation of the performances, the game stores information about:

- Time to complete the game.
- Position error.
- Planning error.
- RMS (root mean square) of the force applied to the force panel.
- RMS (root mean square) of the distance between the release position and the vertical line passing to the center of the nearest pipe entrance.

The game counts a planning error when the user reaches a wrong path. Instead, a positioning error occurs when the patient misses completely a pipe (correct or wrong).

7 Rehabilitation program definition

In this chapter we describe the protocol designed with the medical staff in order to evaluate the effectiveness of the device Force Panel and of the seriousgame used with the patients during the rehabilitation therapy.

7.1 Standardized tests for the patients evaluation

In our project the doctor decide to use two type of test in order to evaluate the patients.

The first one is the Fuegl-Meyer test. Lisa Zeltzer in StrokEngine define that the Fugl-Meyer Assessment (FMA) is a stroke-specific, performance-based impairment index. It is designed to assess motor functioning, balance, sensation and joint functioning in patients with post-stroke hemiplegia (Fugl-Meyer, Jaasko, Leyman, Olsson, & Steglind, 1975; Gladstone, Danells, & Black, 2002). It is applied clinically and in research to determine disease severity, describe motor recovery, and to plan and assess treatment.

According to (Fugl-Meyer, et al. 1975) they present a numerical cumulative score system for assessment of the development of score function and balance in patients who have sustained a cerebrovascular injury leading to hemiparesis/hemiparalysis.

The evaluation comprises three different but interdependent part:

1. Motor function and balance
2. Some sensation qualities
3. Passive range of motion and occurrence of joint pain

The measurement are focused on the daily live activity, on the functional mobility and on the pain.

The score procedure is based on a 3 point ordinal scale starting from 0 and it include five domain:

- Motor function (UE maximum score = 66; LE maximum score = 34)
- Sensory function (maximum score = 24)
- Balance (maximum score = 14)
- Joint range of motion (maximum score = 44)
- Joint pain (maximum score = 44)

Here a table in which we summarize the advantage and disadvantage of this test.

Advantage	Disadvantage
Gives a good over view of the patients motor and sensory function	The Sensation, Balance, Joint Range of Motion and Joint Pain domains have been criticized as less well suited for this instrument given its intended purpose
Can be used in a variety of settings	Joint Range of Motion may be a measured differently depending on the administrator, so the inclusion of the Joint Pain domain may be unnecessary
With a stroke patient it will give a good idea of the function of the affected limb.	Distal fine motor functions may be underrepresented (finger movement not assessed)
Can be used as a pre and posttest. You can see if changes have happened due to intervention or more motor and sensory is coming back to the client.	Arm scores are more heavily weighted than the leg scores
	Better measures of balance are now available
	Inclusion of subjective items on the Sensation and Joint Pain domains may reduce the measures reliability

The second one it's the Nine Hole peg test which is used to measure the finger dexterity in patients with Stroke, Parkinson, Multiple Sclerosis and other neurocognitive disease.

It is wide used because it's relatively inexpensive, very easy and brief to administrate. It requires:

- Board (wood or plastic): with 9 holes (10 mm diameter, 15 mm depth), placed apart by 32 mm (Mathiowetz et al, 1985; Sommerfeld et al., 2004) or 50 mm (Heller, Wade, Wood, Sunderland, Hewer, & Ward, 1987)
- A container for the pegs: square box (100 x 100 x 10 mm) apart from the board or a shallow round dish at the end of the board (Grice et al, 2003)
- pegs (7 mm diameter, 32 mm length) (Mathiowetz et al, 1985)
- A stopwatch

This test is useful to evaluate the fine motor coordination, to test the hand and eye coordination and to test the ability to follow simple direction. Here we summarize the advantage and disadvantage of this test taken from (http://www.health.utah.edu/occupational-therapy/files/evalreviews/nhpt.pdf):

Advantage	Disadvantage
Written and verbal standardized instructions.	Only tests a small area of function; therefore, should not be used in isolation
Can be administered by wide variety of trained examiners.	Performance may be sensitive to practice effects (improved performance after practice trials
Norms are available	Patients often display poorer performance

	when first tested due to lack of familiarity with the task
Relatively inexpensive construction cost and brief administration time	Should not be used to test normal subjects (i.e. for job placement). Other tests are more suitable or appropriate(i.e. Purdue Pegboard)
Used with wide range of populations	While it was said that "faster time generally indicates better function" (Rehabilitations Measures Database, 2010), there is no other mention of whether or not this test gives a good idea of how someone might function in daily tasks that require fine motor skills
Easily portable	

The directions/instructions given by Mathiowetz et al. (1985) are very straightforward and easy to follow.

Here after we report the administration protocol:

Setup(Mathiowetz et al, 1985):

- A square board with 9 holes,
    - holes are spaced 3.2 cm (1.25 inches) apart
    - each hole is 1.3 cm (.5 inches) deep
- wooden pegs should be .64 cm (.25 inches) in diameter and 3.2 cm (1.25 inches) long
- A container that is constructed from .7 cm (.25 inches) of plywood, sides are attached (13 cm x 13 cm) using nails and glue
- The peg board should have a mechanism to decrease slippage. Self-adhesive bathtub appliqués were used in the study.
- The pegboard should be placed in front of the patient, with the container holding the pegs on the side of the dominant hand.

Patient Instructions (Mathiowetz et al, 1985):

- The instructions should be provided while the activity is demonstrated.

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- The patient's dominant arm is tested first.
- Instruct the patient to:
  - "Pick up the pegs one at a time, using your right (or left) hand only and put them into the holes in any order until the holes are all filled. Then remove the pegs one at a time and return them to the container. Stabilize the peg board with your left (or right) hand. This is a practice test. See how fast you can put all the pegs in and take them out again. Are you ready? Go!"
- After the patient performs the practice trial, instruct the patient:
  - "This will be the actual test. The instructions are the same. Work as
  - quickly as you can. Are you ready? Go!"(Start the stop watch when the patient touches the first peg.)
  - While the patient is performing the test say "Faster"
  - When the patient places the last peg on the board, instruct the patient
  - "Out again...faster."
  - Stop the stop watch when the last peg hits the container.
- Place the container on the opposite side of the pegboard and repeat the instructions with the non-dominant hand

7.2 Procedure description

Doctors define a standardized procedure in order to evaluate the effectiveness of the exergames and the Force Panel.
They define three different steps for this protocol and called them T0,T1,T2:

- T0 = start of the administration program
- T1 = evaluation step after 10 session

- T2 = eventually after other 10 session there is another evaluation by the doctors

At each of these steps the doctors evaluate the parameters of the patients by the use of standardized scales explained in the previous chapter.

They use the Fuegl-Meyer test to evaluate the active sensibility and motricity of the patients. For the dexterity performances is used the Nine Hole Peg test and there is also a third point where both patient and doctor write the clinical global impression.

During each session the doctor use the Force Panel with the patients and in function of patients' disability, he decide which exergames need to be used.

In order to find the right exercise for each patients the doctor can use the table with the neurocognitive and physical functions involved for each test. in fact for each test before to start with the implementation we identified the functions involved.

At the end, for each serious game we have a paper where we describe:

1. General concept, an introduction to the specific exergame implemented
2. Cognitive and physical functions involved
3. Game setting, in which we describe the options that the doctor can set before to start, like the upper and lower limit of the force or the level of difficulty, etc.
4. Structure of the environment, a detailed description of the test
5. Animation, in which we explain which are the visual and sound feedback given to the player during the test execution
6. Measurement of the performance, a description of the output parameters stored for each test like the maximum of the force, the time to complete the test, etc.

7. In the evaluation sheet there is a table for each session with the list of the exergames. here the doctor check in the raw of the serious game in the column with the F if the patients execute the test with the force modality active, otherwise he need to check the T's column.

8. Here after I attach the table used during the rehabilitation protocol.

Protocollo di valutazione AS per la sperimentazione di
SERIOUS GAMES

Parte anagrafica

Cognome	Nome	Data nascita
Telefono		Data diagnosi malattia
		Data evento acuto/recidiva

Regime   ambulatoriale ☐   degente ☐   day hospital ☐

Riepilogo trattamento

Fisioterapista _____   Data valutazione T0 ____

Data valutazione T1 ____

Data valutazione T2 ____

Medico referente _____

Numero sedute _____   Frequenza sedute _____

Parte clinica: diagnosi

Emiplegia sx		Lesione midollare	7.3
Emiplegia dx		Lesione nervosa periferica	
Grave cerebro lesione acquisita		Sclerosi Multipla	
Atassia			7.4

Altro:

Serious Games

	data																			
Memory Food	T	F	T	F	T	F	T	F	T	F	T	F	T	F	T	F	T	F	T	F
Scoppia Le Bolle Test	T	F	T	F	T	F	T	F	T	F	T	F	T	F	T	F	T	F	T	F
Magma In The Box	T	F	T	F	T	F	T	F	T	F	T	F	T	F	T	F	T	F	T	F
Biliardo	T	F	T	F	T	F	T	F	T	F	T	F	T	F	T	F	T	F	T	F
Memory Card Test	T	F	T	F	T	F	T	F	T	F	T	F	T	F	T	F	T	F	T	F
Ape E Miele	T	F	T	F	T	F	T	F	T	F	T	F	T	F	T	F	T	F	T	F
Tubo	T	F	T	F	T	F	T	F	T	F	T	F	T	F	T	F	T	F	T	F

Note sui giochi

Protocollo di valutazione

FUGLE MEYER SCALE		T0		T1		T2	
Sensibilità		**destra**	**sinistra**	**destra**	**sinistra**	**destra**	**sinistra**
Sensibilità tattile superficiale	**Braccio**	/2	/2	/2	/2	/2	/2
	Palmo della mano	/2	/2	/2	/2	/2	/2
Senso di posizione articolare	**Spalla**	/2	/2	/2	/2	/2	/2
	Gomito	/2	/2	/2	/2	/2	/2
	Polso	/2	/2	/2	/2	/2	/2
	Dita	/2	/2	/2	/2	/2	/2
	Pollice	/2	/2	/2	/2	/2	/2
TOTALE		/14	/14	/14	/14	/14	/14

SENSIBILITÀ TATTILE SUPERFICIALE		
	0	Anestesia
	1	Ipoestesia/disestesia
	2	Normoestesia

SENSO DI POSIZIONE ARTICOLARE		
	0	il paziente non riesce a indicare o a riferire la posizione in esame
	1	soltanto i 3/4 delle risposte sono corretti
	2	riferisce la posizione in esame correttamente

FUGLE MEYER SCALE			T0		T1		T2	
Motricità attiva Arto Superiore			**destra**	**sinistra**	**destra**	**sinistra**	**destra**	**sinistra**
Sinergia flessori	**Spalla**	Elevazione	/2	/2	/2	/2	/2	/2
		Abduzione	/2	/2	/2	/2	/2	/2
		Extrarotazione	/2	/2	/2	/2	/2	/2
	Gomito	Flessione	/2	/2	/2	/2	/2	/2
	Avambraccio	Supinazione	/2	/2	/2	/2	/2	/2
Sinergia estensori	**Spalla**	Add/Rot int	/2	/2	/2	/2	/2	/2
	Gomito	Estensione	/2	/2	/2	/2	/2	/2
	Avambraccio	Pronazione	/2	/2	/2	/2	/2	/2
Mano alla colonna lombare			/2	/2	/2	/2	/2	/2
Spalla	**Flessione di 90°**		/2	/2	/2	/2	/2	/2
	Abduzione a 90°		/2	/2	/2	/2	/2	/2
	Flessione da 90° a 180°		/2	/2	/2	/2	/2	/2
Avambraccio	**Pronosupinazione**		/2	/2	/2	/2	/2	/2
Polso	**Stabilità**		/2	/2	/2	/2	/2	/2
	Flesso estensione		/2	/2	/2	/2	/2	/2
	Circonduzione		/2	/2	/2	/2	/2	/2
Mano	Flessione dita		/2	/2	/2	/2	/2	/2
	Estensione dita		/2	/2	/2	/2	/2	/2
	Opposizione pollice punta 2°dito		/2	/2	/2	/2	/2	/2
	PRESA UNCINO: bastone con MCF estese e IF flesse		/2	/2	/2	/2	/2	/2
	PRESA LATERALE: foglio tra 1° e parte lat 2°dito		/2	/2	/2	/2	/2	/2
	PRESA A PINZA: penna tra pollice e 2° dito		/2	/2	/2	/2	/2	/2
	PRESA CILINDRICA: bicchiere con pollice e 2° dito		/2	/2	/2	/2	/2	/2
	PRESA SFERICA: palla da tennis con dita abdotte e flesse		/2	/2	/2	/2	/2	/2
TOTALE			/48	/48	/48	/48	/48	/48

ESECUZIONE DI "SINERGIA FLESSORI": Il pz da seduto deve toccare l'orecchio del lato colpito; la spalla deve essere abdotta di almeno 90°, extraruota, ritirata indietro e alzata. Il gomito deve essere fisso, l'avambraccio supinato.

ESECUZIONE DI "SINERGIA ESTENSORI": Il pz da seduto deve estendere l'avambraccio verso il ginocchio con la spalla intraruotata e l'avambraccio pronato. La posizione di partenza potrebbe essere quella della completa sinergia dei flessori (attiva o, se non in grado, indotta dall'operatore). Il movimento deve essere ottenuto senza l'aiuto della forza di gravità. Il paziente non deve compensare il deficit di movimento con la rotazione del tronco o l'oscillazione del braccio.

punteggi

0 la prova descritta non può essere assolutamente eseguita

1 la prova descritta può essere eseguita solo in parte

2 la prova descritta può essere eseguita completamente

ESECUZIONE DI "MANO ALLA COLONNA LOMBARE": il pz da seduto raggiunge con mano le apofisi spinose lombari

punteggi

0 la prova descritta non può essere descritta

1 la mano oltrepassa la SIAS senza nessun espediente dovuto alla gravità

2 la prova può essere eseguita completamente

ESECUZIONE DI "FLESSIONE SPALLA DI 90°": Flettere spalla in un puro atto di flessione; gomito esteso durante tutta l'esecuzione dell'azione con avambraccio a mezza via tra pronazione e supinazione

punteggi

0 se all'inizio dell'azione il braccio è subito abdotto o subito flesso

1 se nelle fasi successive del movimento si verifica l'abduzione di spalla o la flessione di gomito

2 se la prova può essere eseguita correttamente

ESECUZIONE DI "ABDUZIONE SPALLA": Il pz deve abdurre la spalla di 90° con il gomito a 0° e l'avambraccio pronato

punteggi

0 se c'è un'iniziale flessione del gomito e/o una deviazione della posizione pronata dell'avambraccio

1 se l'azione può essere eseguita solo in parte, se durante l'azione il gomito viene flesso o l'avambraccio non si mantiene pronato

2 prova può essere eseguita correttamente

ESECUZIONE DI "FLESSIONE SPALLA": Flettere la spalla in un puro atto di flessione 90° e 180

punteggi

0 se all'inizio dell'azione il braccio è subito abdotto o subito flesso

1 se nelle successive fasi di movimento si verifica l'abduzione di spalla e la flessione di gomito

2 prova può essere eseguita correttamente

ESECUZIONE DI "PRONO SUPINAZIONE AVAMBRACCIO": Prono supinare l'avambraccio col gomito a 0° e la spalla mantenuta in una posizione tra un minimo di 30° e un massimo di 90° di flessione

punteggi

0 se il paziente non può assumere la corretta posizione della spalla e del gomito e/o eseguire la prova

1 se la prova può essere eseguita senza spalla e gomito correttamente posizionati

2 la prova può essere eseguita correttamente

ESECUZIONE DI "STABILITA' POLSO": La stabilità del polso ha circa 15 gradi di flessione dorsale e flesso-estensione sono provate con: spalla 0°, gomito 90° e avambraccio pronato. Spalla un po' flessa e abdotta, gomito esteso e avambraccio pronato. Se il gomito non può essere portato e mantenuto attivamente nella posizione richiesta, l'esaminatore può aiutare il pz.

punteggi

0 prova il paziente non può dorsi flettere il polso nella posizione richiesta

1 la dorsi flessione può essere eseguita ma non può essere applicata nessuna resistenza

2 la posizione può essere mantenuta contro una leggera resistenza

ESECUZIONE DI "FLESSO ESTENSIONE POLSO": La spalla, il gomito e l'avambraccio devono essere mantenuti nella posizione del test precedente. Il pz deve eseguire ripetutamente movimenti di flesso-estensione di polso, passando da un massimo di flessione palmare ad un massimo di flessione dorsale, mantenendo le dita leggermente flesse

punteggi

0 non ci sono movimenti volontari

1 la prestazione può essere eseguita solo in parte

2 sono presenti la completa flessione ed estensione anche con una certa resistenza

ESECUZIONE DI " CIRCONDUZIONE POLSO": La posizione di partenza è a spalla leggermente flessa e abdotta, gomito esteso, avambraccio pronato; l'esaminatore può aiutare il pz a mantenere il braccio in tale posizione. Si chiede al pz di eseguire i movimenti completi di circonduzione del polso.

punteggi

0 la circonduzione non può essere eseguita

1 durante il movimento si rilevano dei movimenti a scatti o la circonduzione è incompleta

2 la circonduzione può essere eseguita in modo completo

MANO
0 la presa richiesta non può essere eseguita
1 parziale
2 normale

Nine Hole Peg Test (NHPT)	T0		T1		T2	
	destra	sinistra	destra	sinistra	destra	sinistra
Numero bastoncini						
	Media:	Media:	Media:	Media:	Media:	Media:
7.4.1.1.1.1.1.1.1 Tempo (sec)						
7.4.1.1.1.1.1.1.2	Media:	Media:	Media:	Media:	Media:	Media:

ESECUZIONE DEL TEST: paziente seduto a un tavolo. Chiedere al pz di collocare i 9 bastoncini negli appositi fori. Registrare il tempo impiegato a collocare i nove bastoncini o il numero di bastoncini collocati in 50 secondi.

Clinical Global Impression (GCI)	T1	T2
Impressione clinica globale terapista	/7	/7
Impressione clinica globale paziente	/7	/7

	Impressione clinica globale terapista		Impressione clinica globale paziente
1	è migliorato molto dall'inizio del trattamento	1	è migliorato molto dall'inizio del trattamento
2	E' migliorato	2	E' migliorato
3	E' migliorato minimamente	3	E' migliorato minimamente
4	Non è migliorato niente dall'inizio del trattamento	4	Non è migliorato niente dall'inizio del trattamento
5	E' minimamente peggiorato	5	E' minimamente peggiorato
6	E' peggiorato molto	6	E' peggiorato molto
7	E' peggiorato moltissimo dall'inizio del trattamento	7	E' peggiorato moltissimo dall'inizio del trattamento

**Obiettivi terapeutici/Diario/Osservazioni**

7.5 Structure of data for the analysis

Once the rehabilitation program was approved we start the acquisition of the data of some patients. Unfortunately the procedure is not so easy and the debugging phase take a lot of time, it is very important that when the rehabilitators start working with the patients the Force Panel and all the test works well. In fact we are working with people with some kind of disease and during the session the need to be calm and concentrate.

Here after we define the data acquired for each one of the exergames realized.

We have a brief description of what the patient need to do to complete the test and after that we list all the parameter.

7.5.1 Bouncing bubble
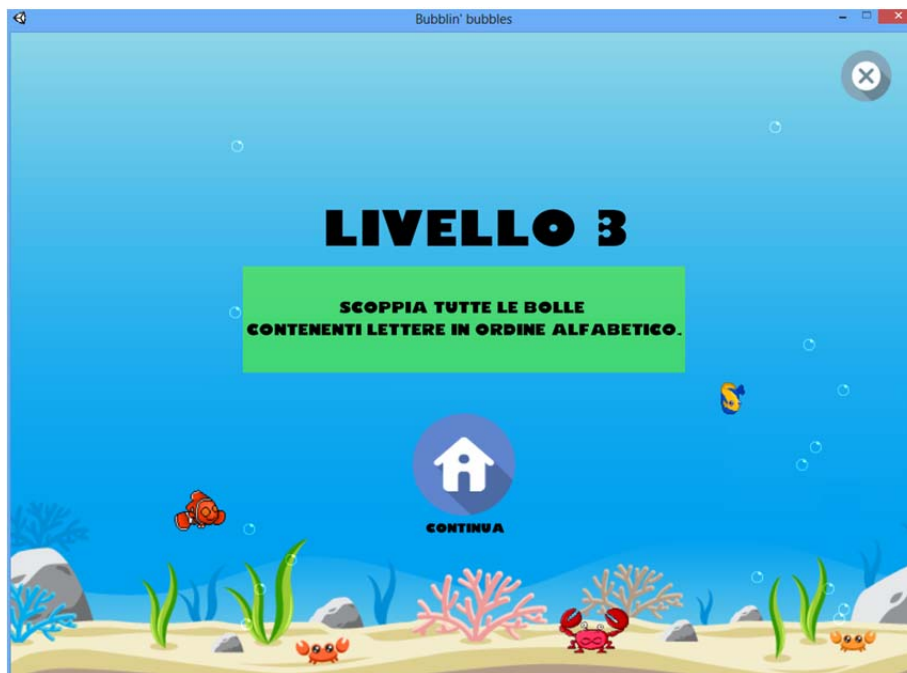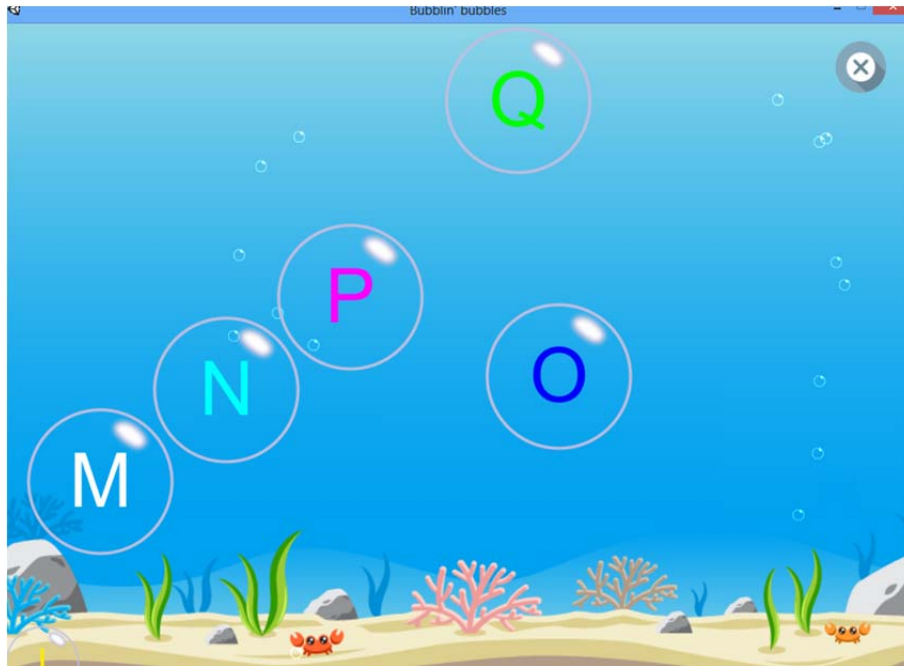
during the test the patient need to burst the bubble in the right order in function of the level selected.

- Level 1: Bursts all the bubbles
- Level 2: Bursting bubbles containing all the numbers in ascending order.
- Level 3: Bursting bubbles containing all the letters in alphabetical order.
- Level 4: Bursts all the bubbles that contain numbers in ascending order.
- Level 5: Bursts all the bubbles containing letters in alphabetical order.
- Level 6: Pop the bubbles alternating numbers and letters, respectively, maintaining and increasing alphabetical order.

In the file the following parameters are saved:

- Date
- Active Force[bool]
- Lower Force limit [0-1000]
- Higher Force Limit [0-1000]

- Permanence time[s]

- Sound [bool]

- Audio Feedback [bool]

- Level

- Speed

- Total time [s]

- Errors In / Out [num]: if it enters and exits without bursting the correct bubble or if it exceeds the upper threshold

- Order Error [num]: if you enter the wrong bubble

- Score

- Average force during the drag [g]

- Standard deviation of force while dragging [grams]

7.5.2 Magma in the Box:

The aim of the game is to collect inside a box the objects of form and color corrected. The shape and the right color are specified by the command at the top of the screen. The correct color is the one with which it is written the word and not the meaning of the word itself.

The doctor can decide if the patients need to differentiate the object only by the color or also by the shape.

In the file the following parameters are saved:

- Date
- Active Force[bool]
- Lower Force limit [0-1000]
- Higher Force Limit [0-1000]
- Score
- Sound [bool]
- Audio Feedback [bool]
- Target taken [num]
- Target lost [num]
- Wrong target taken [num]
- Total taget taken [num]
- Total target to be taken [num]
- Total time [s]
- Average force during the drag [g]
- Standard deviation of force while dragging [grams]
- Number of color[num]
- Shape active [bool]
- Number of shape[num]
- Speed

7.5.3 Biliard ball:
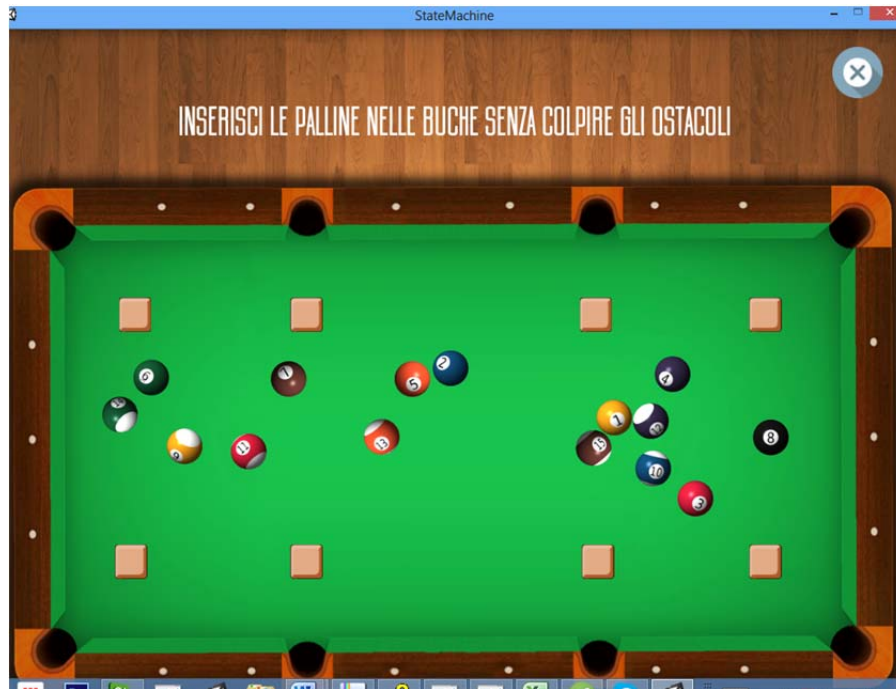
the aim of the game is to drag all the ball in the right hole by following the instruction showed on the top of the screen.

The doctor can choose 5 different level:

- Level 1: drag the ball in the hole avoiding the obstacles
- Level 2: drag the even ball on the right side and the odd ones on the left side
- Level 3: drag only the filled ball in the hole
- Level 4 : drag the ball in the increasing order
- Level 5 : drag the not filled ball in the top holes

In the file the following parameters are saved:

- Date
- Active Force[bool]
- Lower Force limit [0-1000]
- Higher Force Limit [0-1000]
- Permanence time[s]
- Sound [bool]

- Audio Feedback [bool]
- Level
- Total number of error
- Number of right error in level 2 [num]
- Number of left error in level 2 [num]
- Total time [s]
- Average force during the drag [g]
- Standard deviation of force while dragging [grams]

7.5.4 Memory Card Test
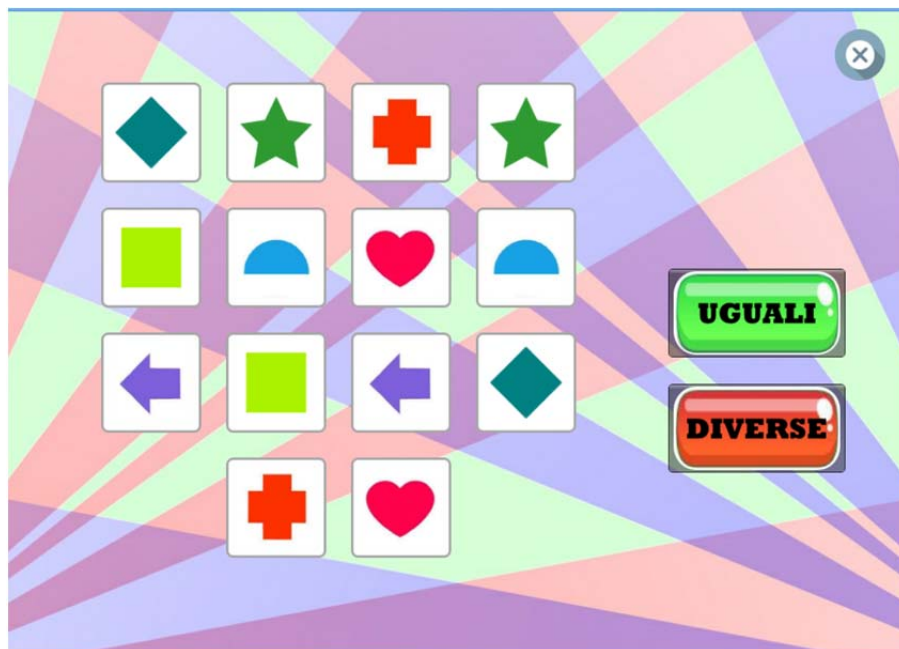
The purpose of the game is to guess the pairs of cards having the same image in the shortest time possible and with the minimum number of attempts. The player must select two cards at a time, if they are equal they are eliminated from the game, while if they are different they are turned over. You can play cards up front, this case is useful for learning the dynamics of the game and how the game works. On interesting option is the possibility to use two buttons that can be used with or without a minimum force value. If the option is active the user must confirm the equality or not.

In the file the following parameters are saved:

- Date
- Active Force[bool]
- Lower Force limit [0-1000]
- Higher Force Limit [0-1000]
- Score
- Sound [bool]
- Audio Feedback [bool]
- Number of pair of cards [num]
- Deck type [num]
- Type of background [num]
- Confirmed button [bool]
- Card showed [bool]
- Pair finded [num]
- Total time [s]
- Cards equal and confirmed [num]
- Cards equal but confirmed different [num]
- Cards different and confirmed different [num]
- Cards different but confirmed equal [num]
- Average force during the drag [g]
- Standard deviation of force while dragging [grams]

7.6 Exemple of elaboration of data

During this preliminary test we have no enough data to evaluate our protocol of rehabilitation therapy. Here after I show the data acquired during one month of acquisition. The patient play with all the exergames during each session.

For what concern the settings of the force the upper and lower threshold value it's the same for all the test during all the period of administration of the exergames.

Here in table we summarize the mean value and the standard deviation of the lower and upper limit.

	Memory card		Apprendimento immagini		Bouncing bubbles	
	lower	upper	lower	upper	lower	upper
Mean value [g]	10	234.9375	27.10045	244.6196	41.73303	281.9287
Std_Dev[g]	0	15.93947	21.72502	47.87272	16.58244	35.13711

If we are going to look at value of the force applied during the exercise we see that for the test "Apprendimento immagini" and "Bouncing bubbles" the value is similar. For the Memory card test it is higer then the other two ones.

	Memory card	Apprendimento immagini	Bouncing bubbles
Mean Value [g]	70.68062	35.10637	52.30903
Std_Dev [g]	8.830866	14.17638	16.64301

8 Future works

In this chapter we are going to introduce the possibility due to the use of Augmented Reality in future works. In last years has been significant increase of new technology that could be have a great impact in the rehabilitation tools for clinical practice
Below illustrates just some of the tools available on the market today.

8.1 Leapmotion

The first device that we present is the Leap Motion, a USB device that can identify the fingers of the hand within a specified range.

From a hardware perspective the device consists of two cameras and three infrared LEDs. These track infrared light with a wavelength of 850 nanometres, which is outside the visible light spectrum. Thanks to its wide angle lenses, the device has a large interaction space of eight cubic feet, which takes the shape of an inverted pyramid – the intersection of the binocular cameras' fields of view. Previously, the Leap Motion Controller's viewing range was limited to roughly 2 feet (60 cm) above the device (blog.leapmotion.com s.d.).
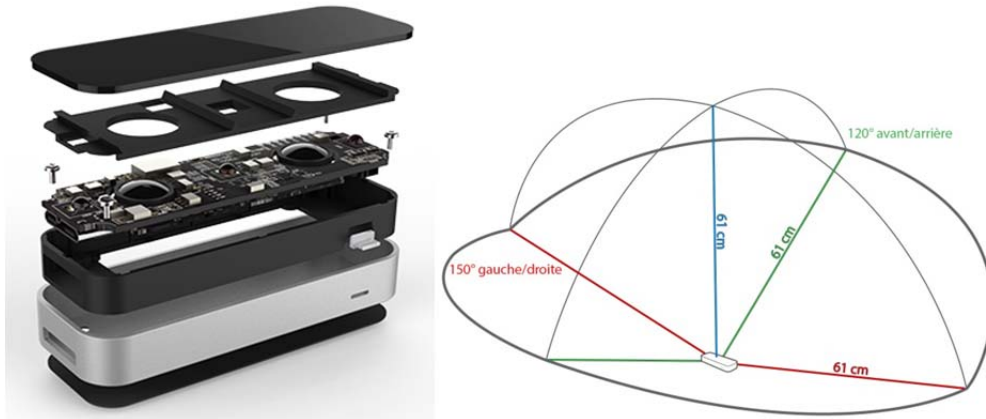
Immagine di come è composto il dispositivo a sx e del campo di azione a dx

This range is limited by LED light propagation through space, since it becomes much harder to infer your hand's position in 3D beyond a certain distance. LED light intensity is ultimately limited by the maximum current that can be drawn over the USB connection.

There are already some application developed with this device applied in medical rehabilitation. (virtualrehab s.d.)

Another interesting project is the UAV, a well chair with leap motion integrated not only to move the vehicle but also to interact with the electronic device used in the hose, like turn on and off the light, etc. (developer.leapmotion.com s.d.)

8.2   Oculus & Google cardboard

The Oculus is one of the famous device used in the Virtual and Agumented Reality application. It is a device to be worn on the face that thanks to a screen project a series of image in order to create a 3D world. Similar to the Oculus, Google realize the Google card board a cheaper version of the Oculus.

The Rift uses an OLED panel for each eye, each having a resolution of 1080×1200. These panels have a refresh rate of 90 Hz and globally refresh, rather than scanning out in lines. They also use low persistence, meaning that they only display an image for 2 milliseconds of each frame. This combination of the high refresh rate,

global refresh and low persistence means that the user experiences none of the motion blurring or judder that is experienced on a regular monitor.[39]

It uses lenses that allow for a wide field of view.[3] The separation of the lenses is adjustable by a dial on the bottom of the device, in order to accommodate a wide range of interpupillary distances. The same pair of lenses are used for all users, however there are multiple facial interfaces so that the user's eyes can be positioned at a different distance. This also allows for users wearing glasses to use the Rift, as well as users with widely varying facial shapes.

Headphones are integrated, which provide real time 3D audio effect. This was developed from technology licensed from RealSpace 3D Audio, by Visisonics.[40]

The Rift has full 6 degree of freedom rotational and positional tracking. This tracking is performed by Oculus's Constellation tracking system, and is precise, low-latency, and sub-millimetre accurate.[6]

Similar to Oculus works Google cardboard, this device can be used with a lot of smartphones models and it is possible to recreate an

immersive world. Google give you a cardboard, lenses, magnets, Velcro and a rubber band.
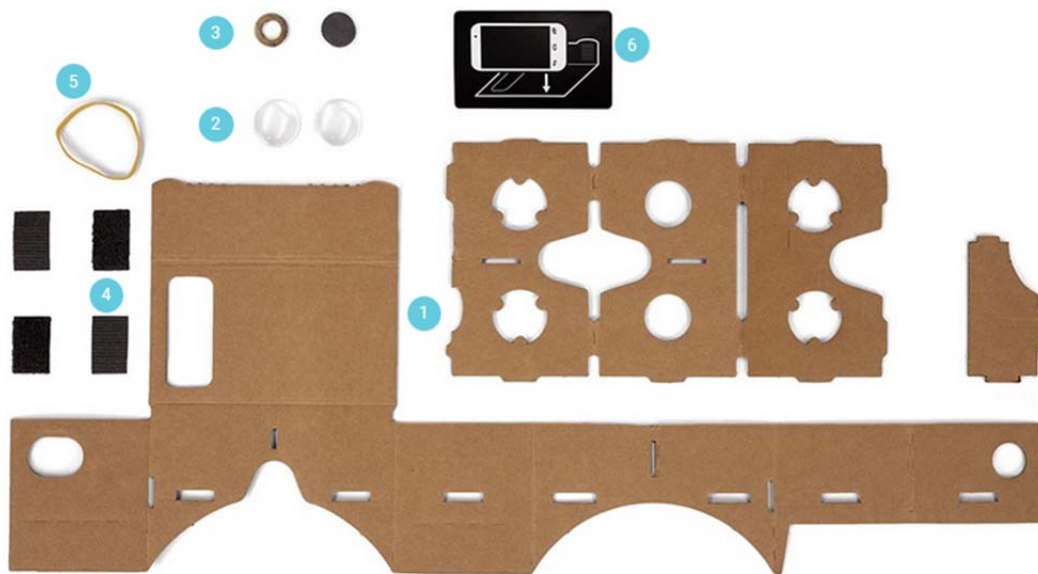
Installing the dedicated apps on your phones it works like Oculus, in fact also in these case two different image are projected on the screen that thanks to the lenses recreate the 3D effect.

Both these device are integrable with Leapmotion and so it is possible to interact with the environment.

8.3 Intel RealSense

The last technology that we investigate is the Intel RealSense.

RealSense camera uses multiple sensors to add depth to images, allowing a host of applications, from adjusting the focal point of an image to gesture recognition and augmented reality.

The RealSense camera has a CMOS sensor as well as an infrared one, plus a MEMs (micro-electro-mechanical) device that projects an invisible pattern of light across a scene, to help measure depth. The system also includes a new chip from Intel.

The rear-facing version is what Dr Bhowmik calls "world facing". It's used more like a standard camera, to take photos where the focal point can be edited after the fact, make measurements or be used for augmented reality. (alphr s.d.)

8.4 Augmented reality in the medical rehabilitation

Before starting introducing the augmented reality in the rehabilitation we need to define what is the augmented reality.

In his book (Furht 2011) define Augmented Reality as a real-time direct or indirect view of a physical real-world environment that has been enhanced/augmented by adding virtual computer-generated information to it [1]. AR is both interactive and registered in 3D as well as combines real and virtual objects.

Augmented Reality aims at simplifying the user's life by bringing virtual information not only to his immediate surroundings, but also to any indirect view of the real-world environment, such as live-video stream. AR enhances the user's perception of and interaction with the real world. While Virtual Reality (VR) technology or Virtual Environment as called by Milgram, completely immerses users in a synthetic world without seeing the real world, AR technology augments the sense of reality by superimposing virtual objects and cues upon the real world in real time.

Fig. 1.1 Milgram's reality-virtuality continuum [1]

According to (Azuma 2001) AR can potentially apply to all senses, including touch, hearing, etc. Certain AR applications also require removing real objects from the environment, in addition to adding virtual objects.

Leapmotion and all the other device described in the previous part could be used to implement application and software based on AR.

In Ulster university Dr. Darry Charles present an integrated toll kit with Oculus and Leapmotion focused in the rehabilitation areas. They map the clinical requirements for the exercise in order to first find existing game that have similar movement in their control design. The aim of their project is to design this rehabilitation exergames.

Another example of the application of the augmented reality is the research project supported by iMinds from Belgium and Agency for Innovation by Science and Technology in which the aim is to stimulate children during their physical rehabilitation or in their fitness program.

In their project (Gargantini s.d.) used the Google card board to realize an application in which the display the same image for the two eyes but with some difference that stimulate the lazy eye than the normal one.
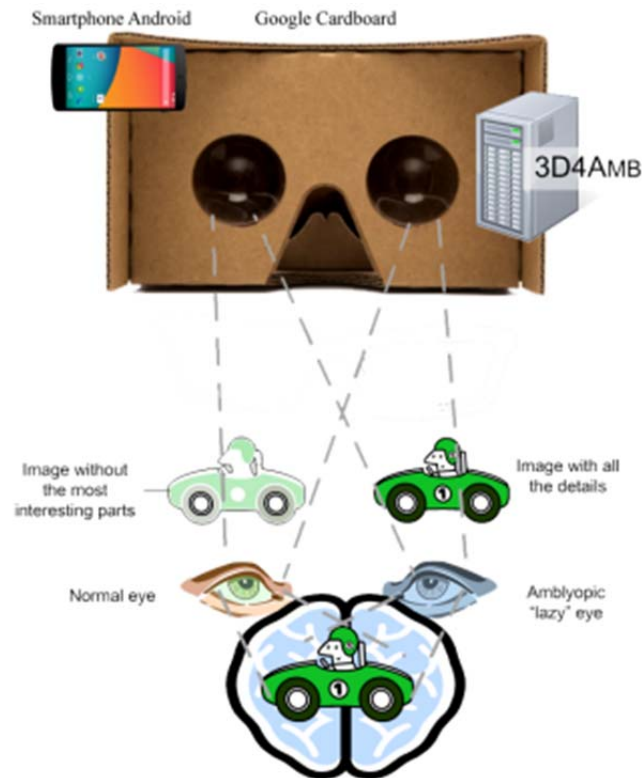
Figure 1: 3D4Amb system with Google Cardboard

Until now there are poor results to validate the efficacy of the exergames and AR applied in rehabilitation, in my opinion this is the real limit of the application of this new technology in the modern rehabilitation program.

Fortunately something moving now, in her research project (Kizony 2004) examine the relationship between cognitive and motor ability and performance within virtual environments.

In this work like in many other the evidence is an interest by the patients during the session, in fact enjoyed the experience and felt high levels of presence.

Figure 2a. *A participant within the Birds & Balls environment*

Figure 2b. *A participant within the Soccer environment*

In her work after each session the doctor evaluate the parameter of the patients by using standardized scale like Borg's scale. The results reveal some moderate relation between the cognitive abilities and the VR performances. In contrast, the motor abilities and VR performance were inversely correlated.

This type of relation is demonstrated also in some other research project, and this is why it is necessary work a lot in this sense and investigate to find which is the best way to implement the exergames in order to rehabilitate the person not only under the cognitive aspect but also from the physical point of view.

9 Conclusion

In this work we show the results of a collaboration between an engineering department and a rehabilitation hospital.

We start analysing the disease of the patients of the hospital both on physical and cognitive point of view. Thanks to the medical staff we define a pattern table with the neurocognitive and physical function involved in order to best satisfy the needs of rehabilitator and patients.

Thanks to the previous experience with the first version of the Force Panel we decide to try to integrate the force concept in a rehabilitation protocol. The device is used within the Hospital Villa Rosa in order to aid the physiotherapist in rehabilitation and to facilitate the rehabilitation of fine motor skills with exercises based on the control of digital pressure and visuo-motor coordination.

We define the hardware and software requirements in order to design the best useful device with the best set of seriousgames installed.

As described in chapter 5 we realize the new version of the Force Panel by using technology based on a capacitive touchscreen and a single load cell. The software is developed written in C++ and C# by using Qt and the game engine Unity3D. So we can integrate the advantage of the two tools; the graphical quality of the game engine and the powerful of the Qt IDE for the implementation of the GUI interface. Another advantage by using these two tolls is the portability of the code, in fact both of them can be compiled for different platform.

At the end of these project we define with the medical staff an administration protocol in order to validate the effectiveness of : a) the exergames in neuropsychological rehabilitation, b) the Force Panel technology compared to more traditional methods.

All the data that we are going to acquire are saved in a database where the rehabilitator can visualize the evolution of the patients

during the rehabilitation therapy. In these protocol we identify three different steps: T0, where the doctor measure the standardized data of the patients.

T1; after 10 session of exergaming the doctor use the standard evaluation test to verify the effectiveness of the therapy.

T2; eventually after other 10 session the doctor can measure the newest parameter.

In conclusion now we have develop a systems for diagnostics and rehabilitation by means of touchscreen technology associated with the integration of the force. The acquisition of the data is now possible thanks to the approval of the ethics committee.

In the future works the aim is to validate the efficacy, a) of the device installed in Villa Rosa hospital, b) the exergames developed, c) the administration protocol.

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