DEUHR

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Executive summary

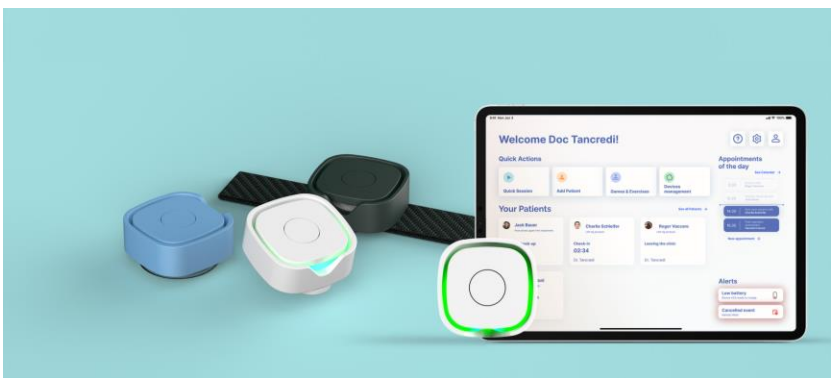
The increase of life expectancy, together with a greater occurrence of many illnesses (such as stroke), has caused a huge demand for rehabilitation of chronically ill patients. In this context, therapists have a limited amount of time and resources available, thus impacting on the quality of care. On top of this, many dismissed patients tend to give up follow-up therapies as they may lose confidence in the process and feel unmotivated or abandoned.
The project Digital Exergame for Upper limb and Hand Rehabilitation (DEUHR) aims at addressing the afore-mentioned issues by introducing exercise gamification and ICT technologies in the patient's treatment, either at home or in a rehabilitation facility. DEUHR is a telerehabilitation solution to treat post-stroke patients suffering from upper limb and hand motor chronic impairments. It has been developed together with Villa Beretta rehabilitation clinic, one of the leading actors in the rehabilitation panorama in Italy [1].
The DEUHR final product is composed of two main parts:

- A prototype composed of two mobile applications, one for the patients to perform therapy through the exergame and another for the therapists to customise the training and continuously monitor the patients' progress.
- A demonstrator of the project (DEUHR1.0) intended as a possible phygital - both physical and digital – configuration of the final product for the patient. The physical device hosts one single-sensor (an inertial mass unit) to interact with the game on the screen, which features a fastening mechanism adaptable to different physical tools, enhancing the flexibility of the service.

Both components have been tested: laboratory tests measured the correlation between the output signals of DEUHR and the ones of a reference system, which showed significantly high values. Both the app prototype and DEUHR 1.0 were successfully tested by presenting them to some therapists and post-stroke patients.
Through DEUHR, patients are monitored outside of the therapist office, reducing abandonment of the treatment and disengagement of the patient. As a matter of fact, the gamification of the rehabilitation process can actively engage the patients because they can exploit rehabilitative exercises embedded inside the videogame.
Furthermore, DEUHR allows treatment delivery in the patients' home, reducing the emissions due to physical transport and the congestion of healthcare facilities. The rehabilitation process becomes less time consuming also for the therapist, who can customise the treatment and monitor multiple patients by simply checking the app.
Another significant feature is that DEUHR applications are modular in their design, facilitating the addition of multiple exercise routines to the same patient (even from different medical specialists) and introduce brand new exercises in the app.
In the future, DEUHR could be extended to other body parts and other types of illnesses, both physical and cognitive, aiming at building a more inclusive social environment by inducing a faster reintegration of patients into the society.

Key Words

Telerehabilitation, Exergame, IMU, Upper-limb



The main components of DEUHR – sensing device and tablet application

Therapist App

From their personal and shared clinic devices,
therapists can manage all steps of therapy seamlessly

1. Therapy Setup

Targeted body areas,
Initial Ranges of Motion of joints
Training schedule and sessions

2. Monitoring

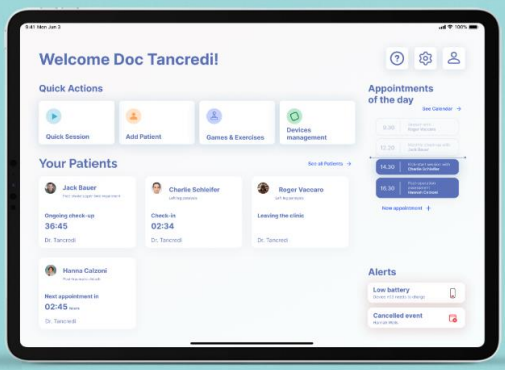
Real-time visualization of
- ROM reached,
- Time of reaction
- Completion rate of exercises

3. Planning

Diversify training schedule and frequency, modify intensity and typology of exercises

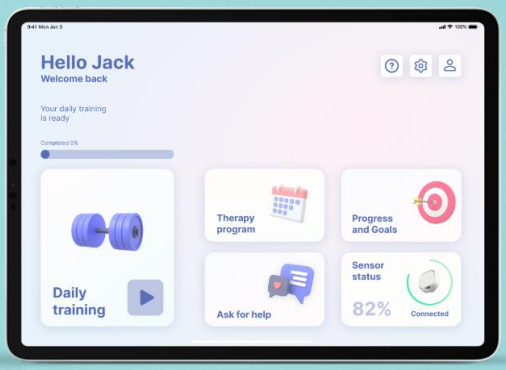
4. Quick session

Training feature for in-presence periodical check-ups



Patient App

Patient digital touchpoint allows users to perform their daily training exergames and be aware of their rehabilitation programs



1. Daily training

Day by day, the system sets up all the exercise that need to be done, for all the ongoing therapies

2. Monitoring

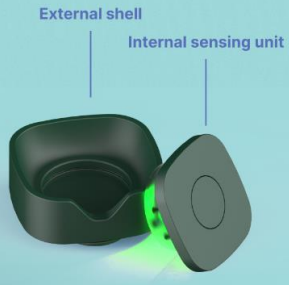
- Calendar of therapy
- Score and progress of exercises
- Feedback from the therapists

3. Direct contact

- Chatbot for exercise tutorials
- Direct contact with tech personnel in the clinic

Sensing device

Low power Inertial measurement unit designed to monitor the quality of movements in the space and control the therapy exergames



Different shells

Shells present different clipping mechanisms to adapt to every kind of gym tool at home

Light feedback

IMU functioning is communicated by chromatic light feedback

SCAN ME

Try out the app prototype from your device (PC or tablet recommended)

Project description written by the Principal Academic Tutor

Since the research group that proposed the project already has wide experience in the field of the impairments of the upper limbs and hands, DEUHR is supposed to be focused on patients that have undergone stroke and suffer from upper limb or hand issues, in order to minimize the development effort of analyzing the entire neuromuscular rehabilitation process.

The upper limb/hand is essential in many human activities; therefore, it is essential to regain most of its abilities as quickly as possible.

Often, after coming back from the hospital, patients tend to stop training as frequently as they were, because the frequency of their supervised session is decreasing. It sometimes implies stagnation in their rehabilitation or even regression. For this reason, the project's aim is related to design a product to help patients that have already regained some mobility but should continue to train regularly.

Developing an unobtrusive product that would motivate patients to train in any circumstances, whether it be at home or outside, is mandatory to improve the quality of the rehabilitation process. The product should be hybrid, which means usable with or without Virtual/Augmented Reality. Through this virtual application, patients will be connected to their therapists who will be able to adapt the level of their training, while also connecting users with each other to motivate them through challenges. Finally, ergonomics will be included in the development phase, adapting the system to different patients' conditions and environments.

The project aims to develop a system, designer on users' needs, which can improve the quality of care, involving the patient in the rehabilitation process. The system, by means of mobile applications and VR/AR games, helps patients to continue the treatment by engaging them, for instance with leader boards and digital rewards. At the same time, the system collects data from sensors, analyzing them to assess the quality of the exercise and, eventually, suggesting a new path of treatment if the exercise is too or not much difficult.

Data gathered from the system can be used both as feedback for therapists and as a mean of continuous improvement for the quality of the exercises. This dataset, alongside with new data from sensors, by means of ad-hoc algorithms developed during this project, help to predict the progress of rehabilitation.

Team description by skill

The DEUHR team is composed of 6 students, 5 engineers and 1 designer:

- **Fedele** studies Digital and Interaction Design at Politecnico di Milano.
- **Alessandro** is a Biomedical Engineer student at Politecnico di Torino specialised in Biomechanics.
- **Chiara G.** is a Biomedical Engineer student at Politecnico di Milano specialised in Technologies for Electronics.
- **Chiara N.** is a Biomedical Engineer student at Politecnico di Torino specialised in Biomedical Instrumentation.
- **Paolo** is a Biomedical Engineer student at Politecnico di Torino specialised in Biomedical Instrumentation.
- **Riccardo** is a Mechanical Engineer student at Politecnico di Torino specialised in Automation.

In the first stages of the project, Fedele and Chiara G. carried out the desk research, collecting knowledge from the state of the art, and the field research, interviewing patients and therapists of Villa Beretta to collect information about their needs and expectations.

Fedele designed the UX/UI of the apps and the graphical assets that were employed also in the DEUHR Demo. Riccardo took confidence with Unity in order to develop the game and carried on some research on clinical trials. Chiara G. started the actual development of the app in Flutter and created the game environment using Flame. Alessandro was assigned to the Bluetooth connection between the sensor and the Android device. Paolo and Chiara N. worked on the sensor and its firmware, through the Simplicity Studio IDE.

Afterwards, Paolo and Chiara N. joined Alessandro to work on the connection of the sensor to the app and on how to use the data collected by the sensor to control the exergame's playable character.

Once the App demo was completed by Alessandro, Chiara G., Chiara N. and Paolo, the system was tested: Fedele, Alessandro, Paolo and Riccardo travelled to Lecco to test both the accuracy of the sensor and the usability of the app and the exergame.

Goal

The purpose of the project is the design and development of a telerehabilitation solution to treat post-stroke patients that suffer from upper limb and hand motor impairments. To reduce the risk of abandonment of the treatment and disengagement of the patients, the final product features an exergame that patients can perform during the rehabilitation sessions. The adoption of DEUHR into the rehabilitation routine should reduce the currently excessive pressure on therapists and increase the quality of treatment of outpatients outside of the clinical settings.

Typically, patients are asked to travel or move to the clinic to attend the rehabilitation plan. The challenge for DEUHR is to allow patients to perform it easily at home on their own: the team's goal is to design a real-time connected telerehabilitation tool to increase the patient's independence from the therapist.

Moreover, Villa Beretta clinic was interested in a portable and wearable device to be employed in different rehabilitative exercises on patients with various anthropometric measures (height, weight, length of the arms, etc.). The rehabilitative tool should be also intuitive and easy-to-use also for patients less familiar with technology.

The team is supposed to combine existing electronic and physical components, provided by the academic tutor, which represent a constraint for the design process. Nonetheless, innovation can happen in terms of enhancement of patient's experience and accuracy of monitoring, also by providing through DEUHR a new framework for various therapists to assist in parallel the same patient through one single service. In addition, there's a high degree of freedom in the design of the exergame and an improvement in terms of UI, accessibility and user flows, to achieve a higher level of engagement and novelty for the patient and a better outcome of the whole therapy.

Understanding the problem

In the last few decades, the world has seen an increase in life expectancy which has not been matched by an equal increase in the quality of life: now many are facing the last years of their life dealing with the long-term consequences of life-changing illnesses. Particular attention is devoted to stroke, which is estimated to be the main cause of disability worldwide.

Stroke incidence, increasing because of ageing population [2], has caused a huge demand for rehabilitative procedures to guarantee stable health conditions and fast recovery of lost/impaired functions.

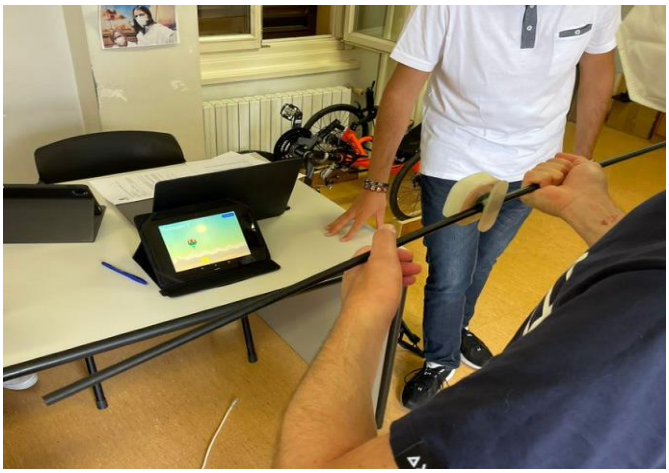
Furthermore, the Covid-19 pandemic has severely reduced the accessibility of patients to health-care facilities, where most physiotherapy treatments for chronic patients have been suspended in favor of urgent cases.

The patients may need to travel long distances to reach the clinic or the treatment center, because of inadequate connections of public transportation to health care facilities. This often implies that a family member/caregiver should take the patient to the therapy session. Moreover, therapists have limited resources available to reply to the huge demand for rehabilitation.

Patients may feel abandoned by the clinic or their therapist, or they may lose motivation, leading to a possible abandonment of follow-up therapy. This trend is rather dangerous, since patients may stop the treatment without full recovery.

With the surge in technological advances over the past 10 years, innovative methods and devices will be used to pursue new therapeutic approaches and augment the existing ones. Indeed, rehabilitation treatments could exploit information and communication technologies (ICT) and the related infrastructures (whose progress has been prematurely accelerated by the pandemic) for continuous monitoring and treatment after discharge.

Within this framework, home telerehabilitation is a promising opportunity as an alternative to in-site rehabilitation. Telerehabilitation proposes new solutions for treatment of the patient (at home or in a rehabilitation facility) through the employment of technological tools such as non-invasive sensors, low power transmission modules and mobile devices. These programs allow for a greater flexibility in therapy tuning and allow patients to perform rehabilitative exercises in the context of their own living environment [3]. These solutions stimulate higher engagement of the patients since they can exploit either exergames or serious games.



A post-stroke patient testing DEUHR 1.0

DEUHR 1.0 comparison with the reference system

Exploring the opportunities

A great effort was made to explore the main existing technologies in order to eventually find a source of inspiration or possibly find a hole in the market.

Rehabilitation robotics is a branch of robotics focused on enhancement of rehabilitation therapy by use of suitable devices and therapy protocols. It employs (wearable) sensors to track limbs motion through several parameters and possibly give a feedback to the patient or for closed-loop control. In this context, Inertial Measurement Units (IMU) are an interesting solution: thanks to their affordability and ease of use, inertial sensors are particularly suitable to motion analysis thanks to their non-invasiveness, wearability and possibility of integration with other sensors.

The control can be achieved in many ways: one can opt for a single actuator governing each finger motion, more desirable when implementing a simpler control strategy and targeting recovery of functions such as grasping and hand opening. Alternatively, it is possible to use multiple actuators for each finger, allowing for finer motor control of the fingers, with the additional challenges of higher number of degrees of freedom and complex kinematics.

Wearable gloves are also part of the opportunities explored: they are in general ergonomic, portable, and lightweight. Some of them can also interface with a custom app to stimulate competition and engagement of the patient [4], combining two very interesting aspects of rehabilitation: portability and gamification.

Nevertheless, remote monitoring requires to consider telerehabilitation and mHealth (mobile Health, delivered via the patient's smartphone) seems promising to achieve improvements in care delivery with chronic conditions – with an existing body comprehensive of various solutions.

In general, none of the examined devices/services provides a comprehensive framework to address all the issues related to stroke rehabilitation. Furthermore, the services are rarely able to fully engage the patient and, on the therapists' side, the application is still designed only as a tool for performing rehabilitation, while the directional aspects of therapy must be managed in another way.

Generating a solution

The final solution developed by the team managed to include existing electronic and physical components and to fulfill the needs neglected by the existing technology and the client requests, in three sub-components:

- A material component, including a IMU sensor and its respective case
- An exergame
- A mobile app for patients and therapists to manage data

A stick with an inertial wireless sensor, placed in its medial point, represents the tool through which the user plays an endless-runner exergame, embedded in a tablet app. By lifting and lowering the stick, the user manages to elevate and drop an object on screen in order to collect target objects and avoid obstacles. Orientation data of the sensor are transmitted in real-time to the app in order to play the game; moreover, sensor orientation data and scores are saved and downloaded to a local folder, enabling post-processing.

The physical core of DEUHR is represented by a wireless single sensor featuring an IMU. The hardware configuration consists in a thin PCB that hosts measurement, logical and transmission modules within an edgeless plastic case. The main components of the sensor are:

- Power button: Sensor is switched on and off by pushing the button placed above a transparent window on the front side of the sensor.
- Micro Controller Unit: The MCU controls the several modules of the sensor.
- Inertial Measurement Unit: It is a low power 9-axis motion tracking device.
- Power supply: The power circuit includes agile modules and components for managing and supplying power to all the elements of the device.
- LED lights: The MCU determines the status of three LEDs (red, green and blue). According to the status of the sensor, LEDs' lights are combined in order to generate colors,

Exergames, as the word suggests, are videogames intended to let a user practice with a given motor task, typically inside the contest of a rehabilitation program.

DEUHR 1.0 exergame represents one possible implementation of an exergame for the rehabilitation and training of elbow flexion-extension. The game scenario is represented by a side-scrolling desert landscape where a balloon is controlled by the sensors to glide and collect coins and avoid flocks of birds, pyramids and palm trees.

The goal of the game consists in collecting a pre-defined number of coins, which represent the target and contemporaneously, the patient should avoid the obstacles. Moreover, auditory feedbacks to actions are reproduced during the game.

The exergame focuses on the kinematic analysis of the flexion-extension gesture. The typical outcome of such an analysis is represented by joint angles. The inertial sensor allows for the estimation of the sensor orientation with respect to a reference position. DEUHR 1.0 is designed to be a ready-to-use system, without the need of positioning any sensor on the user's body: then, the estimation of the flexion-extension elbow angle relies on the fact that the arm is aligned on the vertical axis. In the end, **the application** developed for Android/iOs device can be downloaded and then played when necessary.

On the therapist's side, once he enters the app, it is possible to directly set the language, log-in with the user credentials, remotely configure the therapy parameters and see progresses for each patient he is following.

On the patient's side, after that the session parameters have been set, the sensing unit is connected and the user enters the home page, which redirects him/her to the daily training session. After a quick home boarding, the user proceeds to the exergame: at every moment, the user can stop the game by touching a button on the top right corner of the screen; in addition, a few-seconds-pause is awaited between a repetition and the following one to prevent user's strain.

At the end of the last repetition, the user is asked to exit the game and rate their pain during the session. Finally, the user can visualize a summary of results.

In order to enable the patient to cover the whole screen of the tablet with the balloon, the range over which the balloon can span is adjusted according to the ROM indicated by the therapist. Specifically, the balloon will reach the top margin and the bottom margin of the screen respectively when the specified maximum flexion and maximum extension angles are achieved. In this way, patients with a small ROM can achieve also wide movements on the screen.

Main bibliographic references

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