# Scientific report BETER REHAB

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## Background

This is the scientific report for the UEFISCDI funded project 'BETER REHAB' (Biomechanically Enabled roboTic controlER for REstoring Human ABility). The project was officially started on the 1st of June 2018, and this report covers the progress made during the second year of the project until beginning of December 2019.

During this year we focused on the following aspects of the project:

- Communication channels with the partners of the project
- Developing and validating the prediction algorithm
- Testing the algorithm with a robotic arm
- Disseminating and distributing the work

In the following sections, we provide more specific details on each of these parts and our plans for the future work of the project.

## Deliverables

### Learning algorithm (D1.1 & D5.2 WP1)

The first working package of the project is related to the development of an algorithm that learns how to predict the intention of motion of patients while they are performing rehabilitation tasks. At the end of the first year of the project we had presented the experimental setup that we developed which would allow us to achieve this goal. This experimental setup included a reliable way to measure muscle activation for muscles involved in the motion of the upper-arm, and for a system to measure real-time kinematics of the upper-arm.

Starting from this setup, during the year we aimed at developing an algorithm that would predict resulting kinematics of the upper arm using the measured signals (EMG and kinematics). Initially, a musculoskeletal modelling approach was used, where a well known musculoskeletal model was used as a model of the arm. However, this approach proved to be cumbersome as the musculoskeletal model was not subject-specific and muscle parameters had to be tuned in order to provide realistic results. Therefore, we used machine learning techniques, based on the expertise of the research team, to develop subject and task specific models.

Two types of models were used for each subject and type of motion, both from the category of auto-regressive non-linear models. These models were implemented as neural networks and were trained using machine learning techniques. These models provided promising results from initial tests, and therefore a study with volunteers was constructed in order to validate the methodology. The study took place in the laboratory of our research group in April 2019.

The result of the study was trained models for seven volunteers and for three types of motion. The motion that was used for training and validation was discussed in advance with our medical partners to ensure that relevant motions for rehabilitation will be used. The algorithm that we designed was able to predict accurately in most cases the intention of motion in a horizon of 0.5 seconds, which we consider it long enough for controlling the end-effector of the robotic arm.

The preliminary results of these algorithms were presented in the 'Recent Advances in Artificial Intelligence' Conference in the end of June (https://beterrehab.eu/en/2019/07/03/raai-2019/). The methods were further refined and fine-tuned and were submitted as an article publication in the 'IEEE Transactions on Neural Systems and Rehabilitation Engineering', a Q1 ISI journal.

## Planning algorithm (D2.1 WP2)

The second Work Package of this project concerns the algorithm for planning the trajectory of the robot for assisting the patient in performing the rehabilitation tasks. The concept is to use the output of the prediction algorithm. This is a work package which runs on the second and last part of the project.

This work was initiated in Cluj-Napoca in a simulated environment, and was developed further using a real robot during a research visit of the Principal Investigator in Nara, Japan. The simulation environment was set to work with the same robot available at the visiting institution (KUKA LBR iiwa14), using a freely available toolbox for connecting and controlling the robot using a ROS environment (https://github.com/IFL-CAMP/iiwa_stack/). For the simulations, an environment was created using the Gazebo engine, which is well integrated with our setup in ROS. The nodes already developed by the principal investigator were made to communicate and drive a robotic arm in the simulated environment, in preparations for the research visit.

The research visit took place in the Robotics group of the Nara Institute of Technology (NAIST), located near Nara, Japan. The institution was chosen due to their excellent robotic background, but also due to their expertise in the field of human motion and rehabilitation. Finally, the institution agreed to put at the disposal of the Principal Investigator their robot for the whole duration of the visit (28 days). During the visit, the principal investigator attempted to implement the control algorithm using the actual robot from KUKA. Several steps had to be accomplished.

First of all, the PI had to connect all the different pieces of software written together and make the communicate with each other. Simple control routines for the robotic arms were implemented to ensure a predictable and safe operation of the robot.

Secondly, the frames of operation of the different devices, namely the depth camera and the robotic arm, had to be calculated with respect to each other. This would allow them to exchange information about the current and future positions of the arm of the patient during the rehabilitation scheme. Since the prediction is based on data from the depth camera (skeleton markers position), they are naturally calculated in the reference frame of the camera. These had to be translated to the reference frame of the robot to perform the control. After several attempts, this was achieved using computer vision techniques. A specific pattern was printed and mounted on the end-effector of the robotic arm, in a position visible by the depth camera. The camera could recognise the pose of the pattern with respect to itself, and with known joint coordinates for the robotic arm, the transformation from the pattern to the base of the robot could be calculated. Therefore, by combining the two transformations, the transformation between the camera and the base of the robot could be calculated. (https://beterrehab.eu/en/2019/09/11/extrinsic-calibration-of-the-depth-camera/).

Using this transformation, it was possible to transform the calculated intention of motion from the frame of the camera, to the frame of the robot, and feed it as a set-point to the robotic arm. In order to validate this procedure, some tests were performed by acquiring the muscle activation and kinematics, calculating the intention of motion, transforming it to the frame of the robot and feeding it as the set-point for the end-effector. All these were implemented to happen in real-time with success (https://beterrehab.eu/en/2019/09/17/real-time-intention-prediction/).

Finally, to implement a scheme that would apply a force in the direction of the intention of motion, we chose to use impedance control instead of directly controlling the position of the end-effector. Impedance control simulates a spring and damper attached at the end effector, applying a force proportional to the difference in position and speed between the actual position of the robot and the desired one. This approach was used both because it applies a force proportional to the error in position (therefore assisting the patient along the calculated trajectory), but also because it provides a safer environment for the patient in the vicinity of the robot.

# Dissemination

As mentioned in the project proposal, our goal is to disseminate the results of this project both to the broad public, but also to specialised audience. For the first, we chose to use and enrich the website of the project (www.beterrehab.eu). Special care is taken to update it frequently, and post news about the project and its developments. The language used is usually more accessible, and a lot of graphical material (pictures, animations, videos) are used in order to convey the concepts behind this project in an easier way to non-experts. The website and its posts are also included in the website of the community ‘Research in Cluj’, which brings together researchers active in the geographic region around Cluj-Napoca and promotes their work (https://www.clujresearch.eu).

For the scientific audience, this project has so far resulted in two conference presentations/publications and in one journal submission. Firstly, work of this project was presented in ‘Recent Advances in Artificial Intelligence’ (https://conferences.unibuc.ro/raai2019/) both as an oral and as a poster presentation. Secondly, work of this project will be presented in December in the 58th Conference on Decision and Control (https://cdc2019.ieeecss.org/index.php). This is an ISI indexed conference.

Finally, the work of the intention of motion algorithm was prepared and submitted as a article publication for the IEEE Transactions on Neural Systems and Rehabilitation Engineering (https://tnsre.embs.org/), a Q1 ISI journal. This is a journal in the cross section of rehabilitation and engineering, which is the target group mostly interested in our project results.

# Future work

For the remaining part of the project, we are aiming at completing the work package 2 by optimising the trajectories of the robot in order to follow the set-point calculated from the intention of motion. Even though, this is already working as planned, a better trajectory planning will ensure that we avoid singular confirmations of the robot, something which might become a problem when testing with more volunteers. Furthermore, we are already planning a validation study for the developed methodologies. Even if they study might not include patients as initially planned, due to the difficulty to move the robotic platform in the clinic, the developments of this project can still be demonstrated using healthy volunteers.

Finally, the results of the trajectory planning will be prepared as the second journal publication of this project and the results of the validation study will be submitted as a conference presentation towards the final months of the project.