# 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 first six months of the project until beginning of December 2018.

During this first six months of the projects we focused on the following aspects:

- Communication channels with the partners of the project
- Plans for disseminating the results and mitigating the risks for the project
- Measurement setup of the project
- Developed the initial stages of the algorithms

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

### Project website

The first deliverable planned was the creation of a website for the project. This helps in promoting the project and the results to the scientific community but also the general public. The website was designed with both of these target groups in mind and it was implemented in the form of a blog with some static pages. In the static pages, the project description, deliverables, team and partners are described, while in the blog part the specific progress is presented as it becomes available.

The website is offering also an RSS feed, so that interested parties can follow-up any progress that is posted. Finally, to address a bigger audience, the static part of the website is published both in English (main working language of the field) but also in Romanian (official language of the country). Currently, the blog posts are available only in English, as they cover mainly technical aspects and concern mainly the scientific community. The plan is however to translate in Romanian the posts that concern the general public (e.g. posts about the rehabilitation process and how can a robotic rehabilitator improve the process of rehabilitation).

Finally, all the publications, presentations, code that will result from this project, will be made available on the website. The website can be accessed on http://beterrehab.natsakis.com

## Dissemination plan

During the project, we foresee three journal publications to be generated, with a similar output of conference presentations expected. The three publications will be related to the three main working packages. The aim is to submit the two of them before the end of the project and complete the third one, right afterwards.

A more detailed explanation of the dissemination for this project was prepared in the form of a plan (with specific dates and target journals) and was published on the website of the project (http://beterrehab.natsakis.com/en/2018/07/29/dissemination-plan).

## Contingency plan

The third deliverable of this project was the creation of a contingency plan, where risks of the project would be identified and necessary contingency measures foreseen. We have identified five major risks for this project:

- On board planning is not feasible in real-time (moderate)
- Trajectory for all the tasks is difficult to predict (moderate)
- Robot arm cannot apply desired forces (low)
- Low number of participating patients (low)
- Safety of patients (moderate)

For each of these risks, contingency measures were foreseen and included in the contingency plan that was also published on the website of the project (http://beterrehab.natsakis.com/en/2018/08/06/contingency-plan).

## Learning algorithm (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. This is necessary for calculating later on the necessary actions of the robotic rehabilitator for assisting the patient in performing the intended motion. To perform this prediction, we need information about the state of the arm at every time-step, and a way to predict the muscle activation over a time horizon. If we have this information, we can then feed the muscle activation prediction into a musculoskeletal model of the arm and through forward dynamics calculations, calculate the trajectory of the arm over the horizon.

In this working package, we worked in setting up the necessary measurements for the EMG activation and state of the arm. We also included the musculoskeletal model in the workflow of the project, and started working on the prediction of the muscle activation over the horizon.

### *Measuring the EMG forces reliably*

The first task of WP1 was to arrange the measurement setup for the EMG activation of the muscles of the upper arm. We initially worked with the equipment available at our laboratory (Bangoli, Delsys, Natick, MA). Using this equipment we were able to measure simultaneously the EMG signal of four muscles of the arm (biceps, triceps, deltoid, flexor carpi). Even though this equipment does not allow the measurement of more than four muscles simultaneously, it was used for fine-tuning the filtering parameters of the acquisition.

After several trials and research on the literature, we identified that a butterworth filtering with a band-pass of 20Hz-450Hz was preserving the power of the signal corresponding to the muscle activation, filtering out the noise due to motion between the EMG sensor and the skin. The Root Mean Square (RMS) of the filtered signal was then calculated to reveal the muscle activation. This measure is widely used for quantifying the muscle activation.

Due to the limitations of the Delsys system (not enough muscles measured simultaneously), we sought another solution for the acquisition of the EMG signals. Through discussions with National Instruments (Austin, Texas) representatives in Cluj-Napoca, we obtained a NI 9025 module, which allows the simultaneous measurement of 32 signals at the necessary rate. To use this module for EMG acquisition we had to acquire reusable EMG patches and connector cables, which were obtained through the funds of the project (http://beterrehab.natsakis.com/en/2018/07/31/emg-processing/).

### *Measuring real-time the arm pose*

The second task of WP1 was to measure real-time the pose of the arm. The initial plan was to use a marker based optical measurement system (OptiTrack, NaturalPoint, Corvallis, OR), however due to the complexity of measurement setup (not mobile, markers need to be accurately attached on the patients), we decided to use a simpler approach. The preferred solution was to use a depth camera, which can distinguish the segments of the human arm and estimate their position and orientation in 3D space real-time. This approach has the advantage that the system is mobile and can be used without any markers or other preparation for the patients.

For this project, we used the Orbbec Astra Pro camera (Orbbec, Seattle, WA), which was available at our laboratory. The camera was chosen due to its open SDK and the available options for extracting the results of the skeleton tracking. A software was written to extract the position of the arm segments that are necessary for calculating the state for the musculoskeletal model.

(http://beterrehab.natsakis.com/en/2018/10/05/skeleton-tracking).

### *Controlling a musculoskeletal model based on EMG and position*

The third task of the WP1, is the development and control of a musculoskeletal model. The model should be able to be controlled using the EMG signals and the state of the human arm. For this, we used the open source platform OpenSim (https://simtk.org/projects/opensim/) for musculoskeletal modelling, and the previously developed dynamic model of the human arm (https://simtk.org/projects/das).

This model, is a full musculoskeletal model of the human arm, featuring of 13 joints and 29 muscles. However, due to the complexity of measuring the EMG forces from some small muscles, we reduced the amount to 16 muscles, considering only the most important ones. The muscles that were considered in our simplified version of the model were: Deltoid (anterior and posterior), Bisceps brachii (medial and lateral), Coracobrachialis, Triceps brachii (medial and lateral), Brachicardialis, Flexor carpi, Flexor digitorum, Extensor carpi, Extensor digitorum, Pectoralis major (proximal and distal), Infraspinatus, and Teres major.

Furthermore, we developed a C++ version of the model, so that we can evaluate it and run the forward dynamics programmatically, something that will be necessary during the next steps of the project.

### *Integration of measurement devices and musculoskeletal model*

The EMG signals acquisition, arm state calculation and forward dynamics of the musculoskeletal model are separate programs which can also run on different computers. This poses the necessity to gather all the signals on a central system, synchronise their acquisition and run everything in a parallel and programmatic fashion.

To achieve all these goals, we decided to use the ROS framework (http://ros.org), which is an Operating System widely used in robotic applications. A central ROS node is running on a system, and other nodes are communicating with each other via the central node. Each node receives information that is interested in and can transmit information back to the framework for other nodes.

The implementation we chose for the current project is to run each of the acquisitions as two separate nodes (EMG signals and Pose calculation) publishing their information on the framework, and a third node running the musculoskeletal model. The musculoskeletal node is reading the information of the EMG signal acquisition and pose calculation and is controlling the model, giving as an output the state of the human arm at every time-step.

Our plan is to continue integrating every part of this project in the ROS framework, as this will aid us greatly in controlling the robot in the final stages of the project.

# Partnerships

During the initial stages of the project we setup kick-off meetings with both our partners (Polaris medical and MIRA Rehab), to discuss and plan our actions for the duration of the project. MIRA Rehab is assisting us with the pose calculation and the depth camera technology, and the goal is to later on attempt to integrate our solution with their system.

Polaris medical has assisted us greatly with the last WP of this project (validation), by helping us obtain the ethical approval needed for this study. At the moment they have provided all the necessary documents for the ethical approval submission, and they will facilitate the process when we actually apply (planned for summary of 2019). Furthermore, they have been willing to allow the principal investigator of this project to attend rehabilitation sessions of their patients. This will greatly help the PI identify the tasks that are important during the rehabilitation process, and become more familiar with the patients and their particular issues. Finally, it also allows the patients to get more familiar with the PI and increase the chances of their participation in a validation study.

# Future work

The final part of WP1 is the development of a learning algorithm, that will be able to predict the muscle activation over a specific time horizon. We our current implementations, we are trying to introduce a new node that will do this calculation. We are investigating the use of a non-linear auto-regressive model (NARX), to perform this calculation. To do this, we will use the information gathered from the EMG acquisition and arm state for specific rehabilitation tasks. We will initially train the NARX model for each specific task separately, as this has higher chances of giving a longer horizon for the muscle activation prediction. The second step will be to design a classifier that will be able to understand independently what task is the patient trying to perform. We are aiming at completing this task at the beginning of 2019, completely the first working package.

In parallel, we are also investigating the use of our measurement setup for estimating more accurate muscle parameters for each subject. This is currently of great importance in the biomechanics community, as the estimation of muscle parameters is a complicated task. However, we believe that with our current approach and multiple trials, we will be able to estimate these parameters more accurately, and even monitor them through the rehabilitation process. If this proves to be possible, we might be able to quantify the progress of the rehabilitation process based on these estimated parameters, giving further feedback to the physiotherapists on the efficiency of the rehabilitation process.