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 for the whole duration of the project until June 2020. The end date of the project was postponed by 60 days, due to inability to perform the experimental tests during the state of emergency of CoVID-19.

The following aspects of the project will be presented:

- Deliverables and details
- Development of necessary algorithms
- Final testing of the proposed solution
- Communication with the stakeholders of the project
- Closing remarks

In the following sections, we provide more specific details on each of these parts.

Deliverables

Project website (D5.1)

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.

During the two years of the project there have been 13 plog post publications on the website, at regular intervals. This was meant to keep the audience engaged and disseminate results in a timely manner. A further enrichment of the website is planned right after the final reporting, with the latest developments and publications.

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). The blog posts are available only in English, as they cover mainly technical aspects and concern primarily the scientific community.

Finally, all the publications, presentations, code that resulted from this project, are available on the website. The website can be accessed on https://beterrehab.eu

Dissemination and contigency plans

The second and third deliverable of the project were a Dissemination and Contingency plan. During the early stages of the project, the PI and mentor discussed and identified possible journals and conferences where the work would be presented. Furthermore, they discussed the potential risks that can be encountered during the project and came up with realistic mitigation strategies.

Both of these documents were made public and are available on the project website, under Progress (https://beterrehab.eu/en/progress/).

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 second year of the project we developed an algorithm that would predict resulting kinematics of the upper arm using the measured signals (muscle activation 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.

The algorithm was further refined during the final year of the project, and using the knowledge from the first iteration we improved on two aspects of it: a) Speed, b) universality.

To optimize the training duration, we firsty used the dedicated computational server that was acquired during the project. The server is equiped with a powerful GPU which speeds up a lot the training of the models for the intention of motion. Furthremore, we also re-wrote the code in Python instead of MATLAB and used a compltely new structure for the neural networks. The switch of language allowed us to train the network using a script (instead of a graphical interface), and therefore automate the process. This was very important during the experimentation phase of the project.

Furthremore, we improved upon the universality of the algorithm. In the first iteration, the intention prediction was subject-specific and we had to re-train the model with data from each volunteer. Besides being time consuming, this approach would not be realistic when trying to perform measurements with patients that are unable to perform the required movements. To alleviate this problem, we developed a generic version of the intention prediction that does not need training data from each individual. A model was trained for each type of motion performed and it was demonstrated that it can correctly predict the intention of volunteers that did not participate in its training.

The final version of the algorithm was submitted as an article publication to the 8th IEEE EMBS Conference on Biomedical Engineering and Sciences, that will take place on the 1st-3rd March 2021 (https://www.iecbes.org). The conference proceedings are published and are ISI indexed. The date of the conference is delayed due to the current situation with the CoVID-19 pandemic.

Planning algorithm (D2.1 WP2)

The second Work Package of this project concerned 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 was a work package which run 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.

The work that was initiated in Nara was continued at the Technical University of Cluj-Napoca. An almost identical robot was used (KUKA LBR iiwa7), provided by the Department of Mechanical Engineering. The solutions developed during the visit were re-implemented on the laboratory in Cluj and an experimental session was planned. The experiments were initially planed for March, however they had to be delayed due to the restrictions of the emergency state of the CoVID-19 pandemic. The experiments eventually took place in June 2020, followed by the processing of the data. Unfortunately, we were only able to recruit healthy volunteers and we did not manage to recruit patients, mainly due to the state of emergency.

The results of the experiments were writen in the form of a scientific article and were submitted for publication to 'IEEE Transactions on Biomedical Engineering'. This is a Q1 ISI journal, gathering experts both from the fields of engineering but also medicine, our primary two target groups. Furthremore, videos from the experimentation was published on the project website (https://beterrehab.eu/en/2020/03/06/trajectory-planning/).

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 three conference presentations/publications and in two 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 was presented in December 2019 in the 58th Conference on Decision and Control (https://cdc2019.ieeecss.org/index.php). This is an ISI indexed conference. Thirdly, the generic intention prediction model was submitted to the IEEE EMBS Conference on Biomedical Engineering and Sciences, that is scheduled to take place in March 2021. This is also an ISI indexed conference.

In terms of journal publications, 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/). The experimental setup, combining the intention of motion and trajectory algorithms, and the results from the study, were submitted as a journal article to the IEEE Transactions on Biomedical Engineering. Both of these journals are in Q1 and are in the cross section of rehabilitation and engineering, which is the target group mostly interested in our project results.

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 was tasked to assist us with the last WP of this project (validation), by helping us obtain the ethical approval needed for this study. They provided all the necessary documents for the ethical approval submission, and they provided feedback on the experimental protocol including the patients. Eventually, ethical approval for the experiements was obtained by the Ethics committee of the Technical University of Cluj-Napoca, as the experimentation was to take place there.

Futhermore, they have been willing to allow the principal investigator of this project to attend rehabilitation sessions of their patients. This did help grealy 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. Unfortunately though, we have not managed to collaborate on the recruitement of the patients, due to the state of emergency during the CoVID-19 pandemic.

Our second partner, MIRA rehab, provided a lot of valuable feedback for the whole duration of the project. This was mainly on the technical aspects of the project (such as the kinematics analysis required for the intention prediction algorithm.

Closing remarks

Almost four years have passed since the conception of this project until it's completion. During it, we have managed to maintain an excellent collaboration between the Principal Investigator and the mentor of the project. Furthermore, we kept our partners involved and always had in mind to keep the stakeholders infomed. We aimed at performing excellent research but also promote the project to the broad public, so that the merits of research become more apparent. Additionally, we managed to develop software, acquire technical equipment, and build skills that will remain as inheritance at the University and Research group where the research was performed. Overall, this project has managed to produce the expected results that were envisioned during the application, and we hope that it managed to make relevant contributions in the scientific community of rehabilitation science.