MULTIBODY DYNAMICS 2011, ECCOMAS Thematic Conference
J.C. Samin, P. Fisette (eds.)
Brussels, Belgium, 4-7 July 2011

# DESIGN OF A REHABILITATION ROBOT FOR HEMIPLEGIC PATIENTS VIA MULTIBODY MODELING AND ANALYSIS

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**Keywords:** Rehabilitation Robot, Multibody modeling.

**Abstract.** *Multibody dynamics maturity presently allows engineers to deal with new families and applications for which there is still a lack of understanding of dynamical phenomena: this is obviously the case of biomechanics. By referring to the recent scientific literature, it is rather impressive — and this is a real source of motivation — to see how multibody dynamics has been rapidly and deeply involved in biomechanical and surgical issues. From about ten years now, the expertise of our team (UCL, Louvain-la-Neuve) in the field of multibody systems has been exploited in close collaboration with physiotherapists and surgeons of the Cliniques Saint-Luc (UCL, Brussels) for medical research projects in which dynamical issues have to be solved. The present application, namely a rehabilitation robot for upper limbs of hemiplegic patients, has been recently analysed via a multibody approach, thanks to kinematic and dynamic models symbolically generated by the ROBOTRAN program.*

# 1 Introduction

Multibody dynamics maturity presently allows engineers to deal with new families and applications for which there is still a lack of understanding of dynamical phenomena: this is obviously the case of biomechanics. By referring to the recent scientific literature, it is rather impressive — and this is a real source of motivation — to see how multibody dynamics has been rapidly and deeply involved in biomechanical and surgical issues. From about ten years now, the expertise of our team (UCL, Louvain-la-Neuve) in the field of multibody systems has been exploited in close collaboration with physiotherapists and surgeons of the Cliniques Saint-Luc (UCL, Brussels) for medical research projects in which dynamical issues have to be solved. The following application, namely a rehabilitation robot for upper limbs of hemiplegic patients, has been recently analysed via a multibody approach, thanks to kinematic and dynamic models symbolically generated by the ROBOTRAN program.

# 2 Rehabilitation robot

### *2.1 Upper limb rehabilitation*

Many areas of medicine perceive in the progress of robotics, data processing and multimedia, an opportunity of developing robotic assistance tools to improve the therapist working conditions and to provide more efficient and better care to patients. Physical and rehabilitation medicine, being aware of the above scientific advancement, has already proposed and developed with engineers various morphologies of upper limbs rehabilitation robots for hemiplegic patients. However, those existing solutions show significant gaps in terms of mobility, ergonomics and safety.

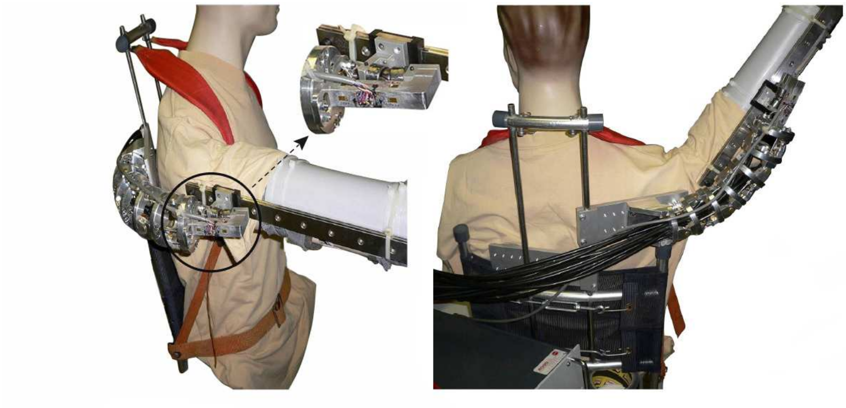
Based on this observation, we have developed in [1] a solution that meets these high level criteria and proposed a solution consisting of five modules governing the movements of the shoulder, the elbow and the wrist. It is worth mentioning that these modules have been designed to operate via an original action principle which, contrary to classical exoskeletons, can clearly disregard – and thus solve – the delicate problem related to the alignment of the robot and patient joint degrees of freedom: these developments are thoroughly detailed in ref. [1].

In terms of control, the proposed solution uses an admittance virtual system to reproduce a compliant behaviour, like a real therapist, through different operating modes.

Functional prototypes of these modules have been designed in our Laboratory; the one dedicated to the shoulder, the more complex kinematically speaking, is the purpose of the present work.

### *2.2 Shoulder module description*

This module aims to assist 2 movements of the shoulder – antepulsion/retropulsion and abduction/adduction – of stroke patients during their rehabilitation process. This robot has the general form of an exoskeleton whose action principle on the patient does not any longer require a tedious and accurate alignment of the robot and patient's joints. It is constituted of a poly-articulated structure whose actuation is deported and whose transmission is ensured by so-called Bowden cables. It manages two of the three rotational degrees of freedom (DOFs) of the shoulder. Quite light and compact, its proximal end can be rigidly fixed to the patient's back on a rucksack-type structure. As regards its distal end, it is connected to the arm through passive joints and a splint guaranteeing the robot action principle, i.e. exert a force perpendicular to the patient's arm, whatever its configuration (Fig. 1).



(a) (b)

**Fig. 1 - Robot configuration in an antepulsion (a) and an abduction (b) movement**

# 3 Multibody model

To design and study this new rehabilitation robot, a ROBOTRAN [2] multibody model of the shoulder module (Fig. 1) has been developed for both kinematic and dynamic reasons as explained hereafter.

### *3.1 Kinematic analysis*

The complexity of the robot structure – i.e. a sequence of revolute joints in quadrature – make the system rather complex from the kinematic point of view. In particular, for obvious physiological reasons, some relative degrees of freedom (DOFs ) between the robot and the arm must be preserved to avoid any pain or physical injury during any motion.

For this purpose, a 3D multibody model of the arm and the robot has been developed. This model has 25 DOFs and the kinematic loop (shoulder – poly-articulated robot – arm – shoulder) is classically solved via a so-called cutting procedure [3]: the shoulder has thus been split in two parts respectively denoted as the original body and its shadow which is added to the original MBS. This leads to 6 kinematic constraints (3 in translation and 3 in rotation) iteratively solved by the Newton/Raphson algorithm.

The ROBOTRAN multibody model has revealed that there was a lack of 2 revolute DOFs at the distal extremity of the first version of the robot. For illustration purpose, one of them (along a arm transverse axis) is clearly visible in the virtual multibody model of Fig. $2_{Left}$, in which it has been added. From a design point of view, these DOFs have been materialized via a universal joint as depicted in the virtual prototype of Fig. $2_{right}$ (and in Fig. $1_a$ for the real one).

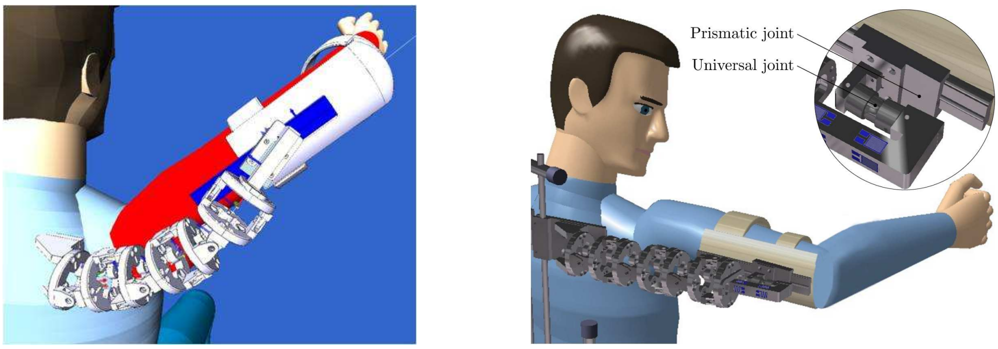



**Fig. 2 - Left : Multibody kinematic model – robot/arm distal rotation - Right : Updated version of the robot structure including a distal universal joint**

### *3.2 Control issue*

In addition to the previous kinematic results, the previous multibody model allows us to control the deflection angles of the patient's shoulder in relation with the robot joint deflection and conversely.

To assist the controller in estimating the necessary forces to be provided, we first compute the system kinematics for any given robot/arm trajectory. Then, by the way of an inverse dynamic model, we can artificially introduce the resistance of the patient, which is measured by force sensors located at the distal extremity of the structure. This inverse dynamic model provides an image of the torques (and also of the power) needed by the robot to guide the arm of the patient, as well as the equivalent net torques in the biomechanical joints.

These sensor measurements give a misconception because they were not always correctly oriented and the distance between the shoulder articulation and the sensor changes continually during the motion.

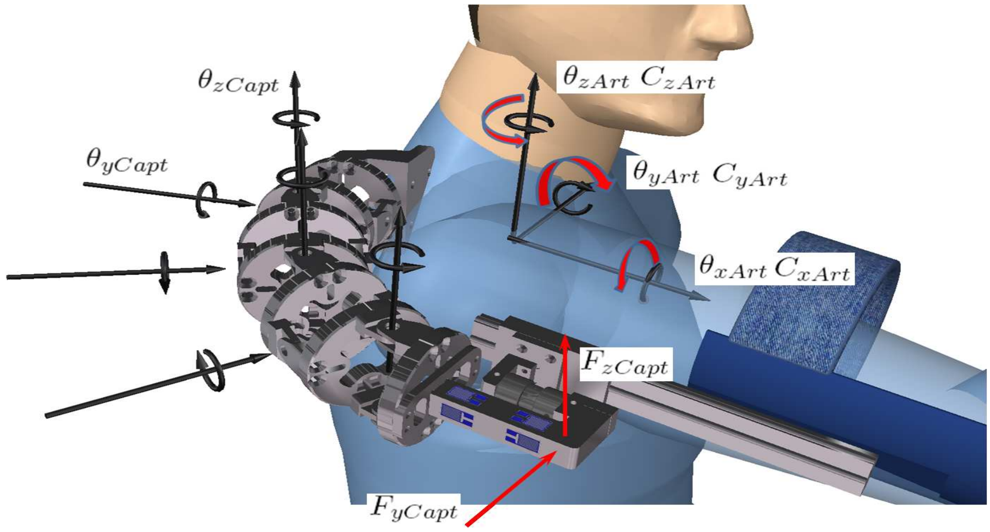



**Fig. 3 - Angles and forces measured at the sensors. Angles and joint torques should be calculated.**

This shows that it is preferable to convert the sensor forces $F_{zCapt}$ and $F_{yCapt}$ into joint torques $C_{zArt}$ and $C_{yArt}$, so that the compliance is introduced at the shoulder articulation rather than at the sensor location. To achieve this performance, we have developed in [4] a model based controller which uses, as input, the sensors force and angular displacement of the robot modules and convert them into shoulder torque and rotation.

This control scheme allows us to manage the compliance of the robot according to the choosen rehabilitation mode – passive, semi-active of active – depending on the patient capabilities [1]. Additionally, the system verifies that the robot configuration always remain compatible with the patient shoulder mobility.

# 4 Conclusion

In this contribution, we have shown that multibody dynamics can be advantageously exploited to help in designing an original morphology of rehabilitation robot for upper limbs. First, for pure kinematic design issues, a multibody model of the closed-loop system (i.e. including the shoulder, the robot and the patient arm), has revealed some failure in the design process – namely the omission of two important degrees of freedom – which has obviously resulted from the complexity of the robot poly-articulated structure.

Secondly, for control purpose and considering once again the morphology of the articulated structure, a multibody dynamic model has been helpful to compute sensored force / torques shoulder equivalencies. The latter is introduced in the controller scheme designed to generate shoulder motion and to perform the rehabilitation exercises, in a passive, semi-active or active way, depending on the physiotherapist expertise.

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