# Towards a Myoelectric Prosthetic Wrist with Rigid and Compliant Behaviour

P. Capsi-Morales, C. Piazza, G. Grioli, A. Bicchi and M. G. Catalano,

*Abstract*— **The simple kinematics of commercial prosthetic wrists limits the individuals in performing a wide range of tasks and restore natural motor functions. We propose a functional prosthesis that improves grasping capabilities through the addition of a simple yet useful 3 DoF myoelectric wrist joint with compliant and rigid properties. Its locking capability enables the adjustment of hand configuration in pre-grasping phases and separates the hand motion from the wrist motion. The proposed wrist, combined with a prosthetic hand, was tested with 8 able-bodied subjects and 1 subject with limb loss. It was compared to a common commercial rotational wrist and to subjects' natural wrist. Results evidence the feasibility of the prototype, improved performance capabilities, and the subjects' first impression about the proposed system. Finally, a prosthesis user tested and compared systems during Activities of Daily Living (ADL).**

## I. INTRODUCTION

The human-machine interface and the mechanical features of robotic devices could limit the performance and development of arms prostheses. The lack of compact and reliable actuators and the difficulties to mimic human prehension capabilities result in a reduced set of practicable movements [1]. Prosthesis users are often forced to alter their strategy and perform unnatural compensatory movements to increase their range of motion [2], to apply larger forces on objects and to obtain acceptable levels of smoothness, accuracy and energy efficiency [3]. Compensatory movements increase the discomfort, often resulting in residual limb pain or overuse syndromes [4].

In [5], the authors demonstrate that a single DOF hand with wrist flex/extension allows functions comparable to a highly performing poly-articulated hand without wrist. Moreover, [6] suggests that an adaptive wrist with both compliant and rigid behaviours could benefit the user by alternating between its adaptative capacity for the approach, and stability once the object is grasped.

This work presents a preliminary design of an innovative and compact 3 DOFs prosthetic wrist. The wrist can switch behaviour between two states: compliant and rigid, through the actuation of one motor. Taking advantage from the environment, this prototype enables the setting up of the prosthetic hand orientation during the pre-grasping phase, and the adjustment of its stiffness through sEMG signals. We hypothesize that this design could reduce compensatory movements and facilitate the reach of objects while promoting stability in the transport and holding phases. We study the proposed system and compare it with the most common active wrist - a prono/supination rotator - using time-based metrics and biomechanical measures from 8 able-bodied subjects. Furthermore, one prosthesis user provides a qualitative evaluation during the performance of ADL (see the prototype implemented in a user's socket in Table I).

## II. MATERIAL AND METHODS

We propose a prosthetic wrist based on a spherical joint that can be friction-locked through the actuation of one motor. Moreover, a compliant stage provides adaptable behaviour when the joint is unlocked. 8 able-bodied subjects evaluated the system functionality versus one of the most common active wrist on the market (a prono/supination joint). Both robotic wrists were connected to the same under-actuated prosthetic hand, called SoftHand Pro (SHP) [7]. The whole system was controlled by two EMG channels, as common sockets for transradial amputees embed. In this case, they correspond to the FDS and EDC muscles. The selection of the actuator to command between the wrist and the hand is based on the velocity of the user's muscle activations through a Finite State Machine and a timer. A fast activation commands the wrist, while a slower activation commands the hand closure. Once wrist control is elicited, while the friction-lockable wrist requires an impulse to lock the joint, the rotational wrist requires continuous muscle activation to select the prono/supination angle. The experimental protocol is based on functional movements related to reaching, grasping and transport. It consists in the grasping and moving action of 3 different objects from 3 shelves at different heights. An Xsens was used to gather subjects' motion and to analyse their body posture. Finally, a survey was conducted after each wrist type experiment about systems usability and satisfaction. Furthermore, one prosthesis user performed purpose-oriented movements inspired by ADL with the 3 systems, focusing on the reaching phase. While the control system for unimpaired users was their left natural wrist, the prosthesis user used her unimpaired arm (right) during the experiments.

## III. RESULTS

Xsens provides the angles between upper subject's body segments. We select 5 different angles to evaluate the level of

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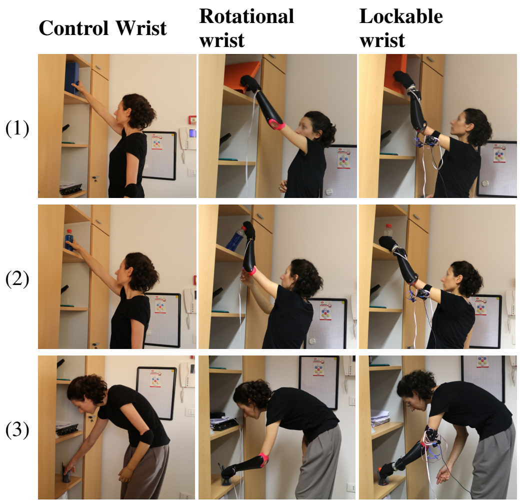
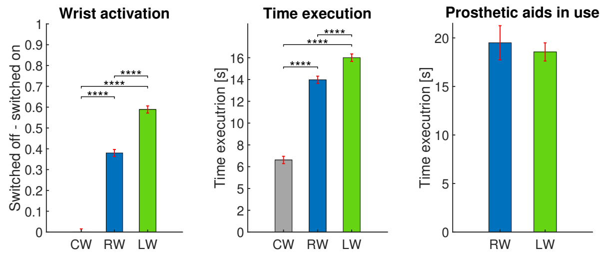
P. C-M., G.G, A.B. and M. G. C. are with Istituto Italiano di Tecnologia, Via Morego 30, 16163, Genova

P.C-M., C.P. and A.B. are with Centro "E. Piaggio" and Dipartimento di Ingegneria dell'Informazione, University of Pisa, Largo Lucio Lazzarino 1, 56127 Pisa, Italy. Correspond to: patri.capsi@gmail.com

TABLE I

ADL: GRASPING OBJECT FROM EXTREME HEIGHT CONDITIONS.




(a) $p < 0.0000$ (b) $p < 0.0000$ (c) $p = 0.6407$

Fig. 1. Frequency of activation (a) and time execution (b) for able-bodied subjects ($n = 8$). Panel (c) shows the time execution when the prosthetic wrists (RW - rotational wrist, LW - lockable wrist) has been voluntarily used for the execution of a task. CW refers to the control wrist. The p-values from a N-way ANOVA test are detailed in their caption. Tukey-kramer test significance is detailed with asterisks in the upper part of each graph with **** for $p \leq 0.0001$. The estimated means for each wrist of study are presented with a bar plot and the red errorbar refers to their standard error.

compensation when executing a task. Moreover, we analyse the time required to perform a task successfully and the frequency of wrists control elicitation usage. All experiments were video recorded to evaluate which DOFs are more used, and depending on which parameter (object or height).

The percentage of active usage and time execution for all able-bodied subjects are presented in Fig. 1. A larger frequency of activation implies a larger desired use of the robotic device. A shorter time implies a faster execution of the task, which is related to an easier use. Fig. 1(c) shows results from the time execution when both prosthetic wrists are actively used. Moreover, an example of a qualitative comparison for the prosthesis user is shown in Table I.

## IV. Discussion

Results from functional tasks proved a significantly larger frequency of active usage of the lockable wrist compared to the rotational wrist. Moreover, although Fig. 1(b) shows that the lockable wrist is 2 s slower in performance than the rotational, the fact that users voluntary activate the lockable wrist in 20% more of the occasions could be affecting to the total execution time. Indeed, looking at Fig. 1(c), where both robotic aids are voluntarily used, we realize that the lockable wrist use did not compromise the time execution of the overall prosthesis, increasing only the prosthetic arm functionality. Furthermore, users appear to show preference and acceptance of the proposed system, which will be evaluated though surveys results.

Regarding the completion of ADL, Table I shows that with the lockable wrist, the user not only presents a more natural body posture, but also a safer grasp is observed in extreme cases, where the stability of the object can be compromised when using the rotational wrist. Overall, ADL results of the lockable wrist suggest a decrease in the time to complete the task (usually related to cognitive load), an increase in intuitiveness and a softer interaction.

## V. Conclusions

Results prove the interest of able-bodied subjects in active use of the proposed system. Experiments with the prosthesis user suggest enlarged capabilities to adapt to different requirements. Although a preliminary evaluation of Xsens data seems to favour the proposed system in presenting a more natural body posture, further analysis of compensatory movements is needed. Future work points towards a more compact and light design with a larger range of motion, and the study of a variable stiffness system, that will allow the user to control the joint level of rigidity with a more intuitive control strategy.

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