

# A NOVEL PASSIVE COMPLIANT WRIST WITH AUTOMATIC SWITCHABLE STIFFNESS

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## ABSTRACT

State of art upper limb prostheses lack several degrees of freedom (DoF) and force amputees to compensate for them by changing the motion of their arms and body. Such movements often yield to articulation injuries and in general represent a discomfort; nonetheless these could be prevented by adding DoFs, for instance, to an articulated passive wrist. Available stiff or compliant wrists with passive flexion/extension and/or radial/ulnar deviation are sub-optimal solutions. Indeed, stiff wrists induce the individuals wearing them to perform exaggerated compensatory movements during the reaching phase while compliant wrists proved to be impractical while manipulating heavy objects. Here we present the concept of a wrist capable of combining the benefits of both stiff and compliant wrists. It is provided with two switchable levels of passive compliance that are automatically selected depending on the grasp phase.

## INTRODUCTION

The development of a natural hand prosthesis as a substitute of the biological limb, after amputation, is one of the most fascinating and open challenges in rehabilitation engineering. The limits that prevent the advent of next generation prostheses are well known and pertain to both the human machine interface and the physical features of the device. Among the latter, the most crucial is probably the lack of compact and reliable actuators with power densities similar to the human muscles. This deficit, combined with design trade-offs pertaining to desired performance, control inputs, prehension capabilities and anthropomorphism, implies that a hand prosthesis can perform a reduced set of movements only with respect to the natural counterpart [1].

The design of currently available prosthetic wrists represents a striking example of such a simplification. With its three degrees of freedom (DoFs), the natural wrist contributes to the execution of a grasping and manipulation task, by orienting the hand in space. However, in modern upper limb prostheses, such elegance is synthetized within a single DoF; myoelectric wrists are primitive, albeit useful, rotators that enable to pronate/supinate the hand [2]. Wrists with passive flexion/extension and/or radial/ulnar deviation were also demonstrated and made commercially available; these can be classified into *stiff* and *compliant* wrists. Stiff wrists enable the user to manually orient and

lock the hand in a desired and firm position [3]. Compliant wrists can also be manually locked in a certain position, but when unlocked they exhibit an elastic behavior. Hence, as their name suggests, they allow for adaptation of the prosthesis during reaching and grasping, as well as other Activities of Daily Living (ADLs), e.g. bike-riding [4].

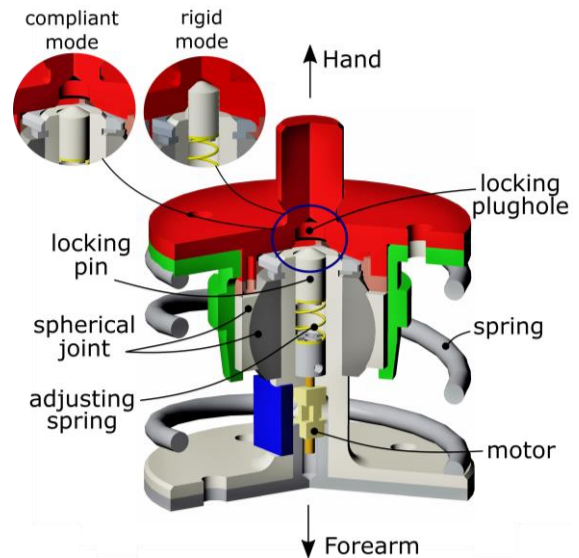


Fig. 1 Cross section of the wrist.

A number of studies compared the performance of stiff versus compliant wrists during ADLs [4]-[6]. All of them revealed improved functionality for most of the ADLs (in particular: bimanual tasks and tool manipulation) when using the compliant wrist, with the exception of those tasks which involved the manipulation of heavy objects; these tasks were performed better using a stiff wrist. These studies highlighted the limitations of both kinds of passive wrists. In particular, stiff wrists force the amputees to perform exaggerated compensatory movements during the reaching phase [7] (which are known to cause discomfort and secondary injuries in the long run [8]). Compliant wrists proved impractical while manipulating objects, particularly heavy ones.

In the light of these findings, we developed a concept of a novel compliant wrist with automatically selectable stiffness. The concept is aimed at combining the benefits of a compliant wrist (i.e. dexterity during the reaching phase of objects limiting compensatory movements) with the benefits of a rigid wrist (i.e. precision and safety while manipulating heavy objects).

## SYSTEM ARCHITECTURE

The compliant wrist presents two automatically selectable levels of stiffness. The device (Fig. 1) consists of a spherical joint (range of motion  $\pm 30$  degrees) with its two sides connected by means of a compression spring. This spring is responsible for the compliant behavior of the wrist. To switch from *compliant mode* to *stiff mode*, the spherical joint can be locked using a linear actuation system based on a squiggle motor (New Scale Technologies, Inc., NY, USA) that drives a locking pin into a plughole. In compliant mode, the spherical joint is free to move under tangential forces applied to the prosthesis. Within this configuration, the bending of the spring is responsible for the elastic response of the wrist. When switched to *stiff mode* the locking pin is driven forward by means of the actuation mechanism and inserted in the plughole of the frame when the wrist is in its rest position (i.e. plughole centered with respect to the pin, Fig. 1). In the case of switching from compliant mode to stiff mode while the mechanism is not in this rest position, the adjusting spring ensures that the locking pin enters the plughole as soon as the two get aligned.

## OPERATION OF THE WRIST

The wrist was designed to aid amputees in manipulation using a myoelectric prosthesis. The typical manipulation starts from a rest position and consists of reaching, grasping and holding phases (Fig. 2). During reaching, the arm transfers the hand towards the target and the hand is preshaped according to the dimensions of the manipulandum. The reaching phase ends with the enclosing of the manipulandum (grasping phase). The wrist is compliant during reaching to facilitate the positioning of the hand with respect to the manipulandum. This is obtained by pushing the hand against constraints in the environment (e.g. a vertical wall, a horizontal shelf, etc.) or the manipulandum itself (Fig. 2). Once the hand encloses the manipulandum, the wrist automatically switches from compliant to stiff mode in order to make the amputee able to safely manipulate heavy objects. Thus the actuation of the stiffness switching was thought to be synchronous with the hand opening/closing DoF and controlled by means the same control channel used by the amputee to control the myoelectric hand.

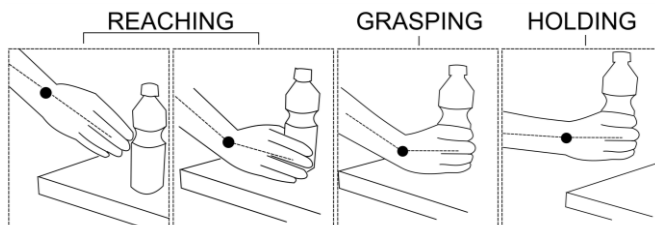


Fig. 2 Typical manipulation sequence.

## CONCLUSION

This paper presents the concept of a novel of passive wrist with automatically selectable stiffness. The developed prototype (Fig. 3) weighs only 80 g and its dimensions (diameter = 38 mm, length = 42mm) making the wrist suitable for transradial prostheses at every level of amputation.



Fig. 3 The wrist prototype developed.

## ACKNOWLEDGEMENTS

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## REFERENCES

- [1] M. Controzzi, C. Cipriani, M. C. Carrozza, "Design of artificial hands: a review." The Human Hand as an Inspiration for Robot Hand Development 1st edn, Vol 95 (eds Balasubramanian R. & Santos V. J.) Ch. 11 219–246 (Springer International Publishing, 2014).
- [2] H. H. Sears and J. Shaperman, "Electric Wrist Rotation in Proportional-Controlled Systems," *JPO J. Prosthetics Orthot.*, vol. 10, no. 4, p. 92-98, 2008.
- [3] Sears, Harold H., et al. "Evaluation Studies of New Electric Terminal Devices." in proc. of Myoelectric Controls Symposium, Fredericton, CA, 2005.
- [4] B. Petersen, "Preliminary feedback from field trial users of the motion control multi-flex wrist," in proc. of Myoelectric Controls Symposium, Fredericton, CA, 2008.
- [5] P. Kyberd, "The influence of passive wrist joints on the functionality of prosthetic hands," *Prosthet Orthot Int*, vol. 36, no. 1, pp. 33-38, 2012.
- [6] M. Deijis, R. M. Bongers, N. D. M. Ringeling-van Leusen and C. K. van der Sluis, "Flexible and static wrist units in upper limb prosthesis users: functionality scores, user satisfaction and compensatory movements," *J. Neuroeng. Rehabil.*, vol. 13, no. 1, p. 26, 2016.
- [7] F. Montagnani, M. Controzzi, C. Cipriani, "Is it finger or wrist dexterity that is missing in current hand prostheses?" *IEEE Trans Neural Syst Rehabil Eng*, vol. 23, pp. 600–609, 2015.
- [8] P. S. Kidd, C. McCoy and L. Steenberg, "Repetitive strain injuries in youths," *J Am Acad Nurse Pract*, vol.12, no. 10, pp. 413-26, 2000.