TRACCIA 1

1 – Tipologie di *Series Elastic Actuators* utilizzati nella progettazione di protesi di arto inferiore.

2 – Discutere il montaggio e dimensionamento dei cuscinetti nell'assieme allegato.

3 – Competenze e funzioni del Rettore.

4 – Lettura e traduzione dei primi due capoversi dell'articolo scientifico allegato.

5 – Descrivere la sintassi per produrre la media di una colonna di numeri in Excel.

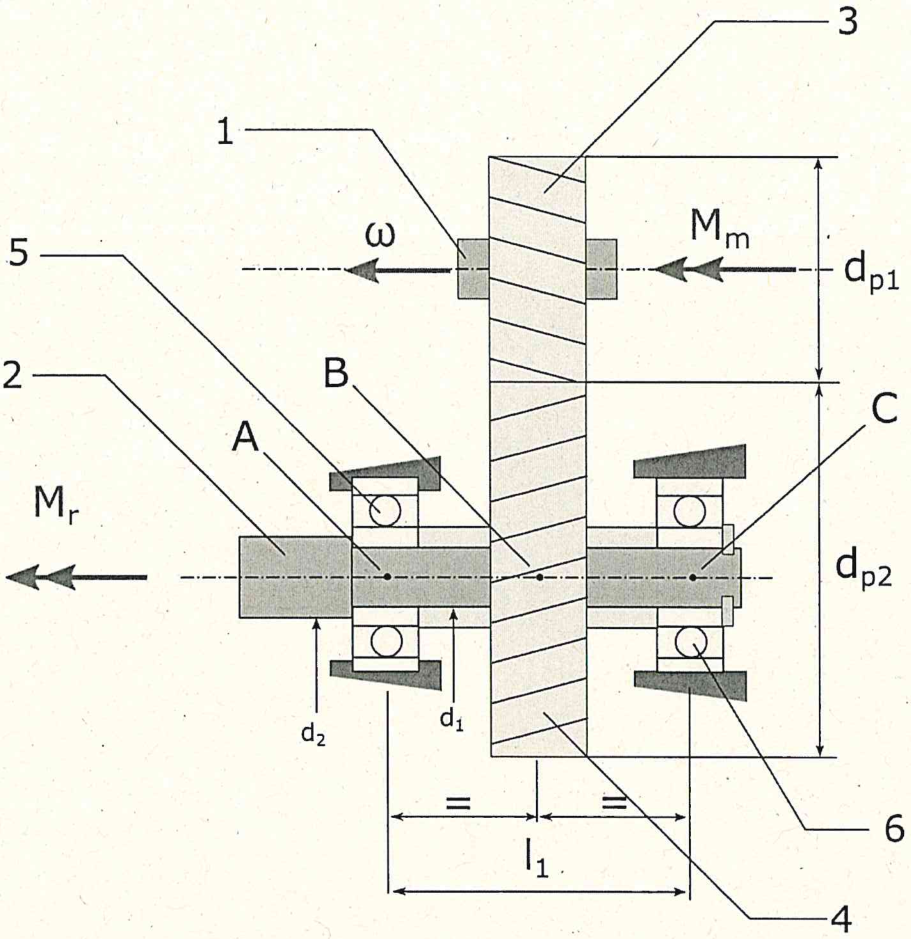


Figura 1

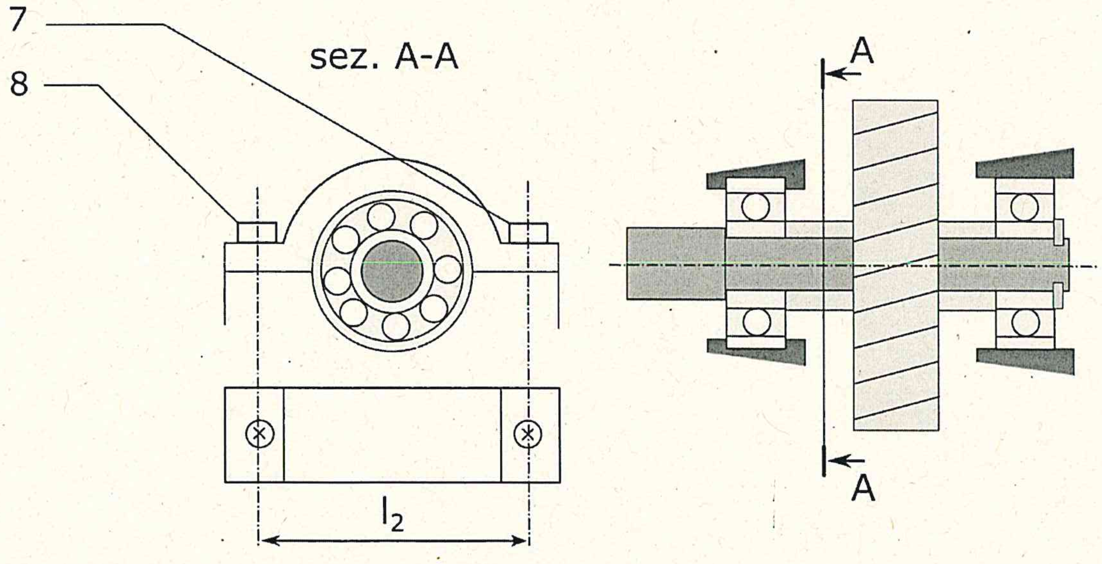


Figura 2

EMB IEEE TRANSACTIONS ON NEURAL SYSTEMS AND REHABILITATION ENGINEERING, VOL. 28, NO. 7, JULY 2020 1573

Performance Evaluation of Lower Limb Exoskeletons: A Systematic Review

David Pinto-Fernandez, Diego Torricelli, *Member, IEEE*, Maria del Carmen Sanchez-Villamanan, Felix Aller, Katja Mombaur, *Member, IEEE*, Roberto Conti, Nicola Vitiello, *Member, IEEE*, Juan C. Moreno, *Senior Member, IEEE*, and Jose Luis Pons, *Senior Member, IEEE*

Abstract—**Benchmarks have long been used to verify and compare the readiness level of different technologies in many application domains. In the field of wearable robots, the lack of a recognized benchmarking methodology is one important impediment that may hamper the efficient translation of research prototypes into actual products. At the same time, an exponentially growing number of research studies are addressing the problem of quantifying the performance of robotic exoskeletons, resulting in a rich and highly heterogeneous picture of methods, variables and protocols. This review aims to organize this information, and identify the most promising performance indicators that can be converted into practical benchmarks. We focus our analysis on lower limb functions, including a wide spectrum of motor skills and performance indicators. We found that, in general, the evaluation of lower limb exoskeletons is still largely focused on straight walking, with poor coverage of most of the basic motor skills that make up the activities of daily life. Our analysis also reveals a clear bias towards generic kinematics and kinetic indicators, in spite of the metrics of human-robot interaction. Based on these results, we identify and discuss a number of promising research directions that may help the community to attain a comprehensive benchmarking methodology for robot-assisted locomotion more efficiently.**

Index Terms—**Benchmarking, locomotion, walking, posture, assessment, wearable robots, orthoses.**

I. INTRODUCTION

WEARABLE robots are experiencing an unprecedented era. Many research prototypes have been successfully turned into commercial products and are now facing a rapidly evolving market, characterized by diverse applications and needs. While the potential of wearable robotics technology is indisputable, demonstrating its value on a quantitative basis is challenging. Previous reviews have highlighted weaknesses and difficulties in providing reliable evidence of the clinical usefulness of these devices, possibly due to a lack of clear and rigorous evaluation methods [1], [2]. At the same time, the robotics community has demonstrated an increasing interest in benchmarking as a way to scientifically assess and compare the performance of exoskeletons [3]. However, no agreed methodology, best practices or standards have been made formally available so far [4]. Currently, the principal approach to compare exoskeletons has been through competitions, such as Cybathlon [5]. The major drawback of competitions is that scores are usually based on very simple metrics, for example accomplishment of a task and/or time to completion, which can hardly be used to characterize the multiple aspects of exoskeleton performance. Fortunately, the scientific literature has produced hundreds of studies that focused, directly or indirectly, on the evaluation of exoskeletons, which has resulted in a multitude of available methods and variables. However, the great variability in procedures, experimental settings and metrics, makes these methods difficult to apply to other devices and environments, which impedes an objective comparison across systems. A unified and broadly applicable benchmarking methodology for performance evaluation of wearable robotic systems is therefore eagerly anticipated. In line with this objective, this review aims to identify and bring together the most promising methods, metrics and experimental procedures available in the literature to assess robotic-assisted motor skills. We focused on lower limb exoskeletons for gait assistance and rehabilitation, following on our previous efforts in the field of benchmarking bipedal locomotion [6]. We screened more than nine hundred papers which, after a careful selection process, resulted in a total of 187 relevant publications. We structured our analysis to address two main research questions:

Manuscript received May 31, 2019; revised November 21, 2019; accepted January 3, 2020. Date of publication May 28, 2020; date of current version July 8, 2020. This work was supported in part by the H2020 Project EUROBENCH under Grant 779963, and in part by the COST Action under Grant CA16116. *(David Pinto-Fernandez and Diego Torricelli contributed equally to this work.) (Corresponding author: Diego Torricelli.)*

David Pinto-Fernandez, Diego Torricelli, Maria del Carmen Sanchez-Villamanan, and Juan C. Moreno are with the Neural Rehabilitation Group, Cajal Institute, Spanish Research Council, 28002 Madrid, Spain (e-mail: diego.torricelli@csic.es).

Felix Aller is with the Chair Optimization, Robotics and Biomechanics (ORB), Institute of Computer Engineering (ZITI), Heidelberg University, 69120 Heidelberg, Germany.

Katja Mombaur was with the Chair Optimization, Robotics and Biomechanics (ORB), Institute of Computer Engineering (ZITI), Heidelberg University, 69120 Heidelberg, Germany. She is now with the Canada Excellence Chair in Human-Centred Robotics and Machine Intelligence, University of Waterloo, Waterloo, ON N2L 3G1, Canada.

Roberto Conti is with IUVO S.R.L., 56025 Pontedera, Italy.

Nicola Vitiello is with The BioRobotics Institute, Scuola Superiore Sant'Anna, 56127 Pisa, Italy, also with the Department of Excellence in Robotics & AI, Piazza Martiri della Libertà, 33-56127 Pisa, Italy, and also with IRCCS Fondazione Don Carlo Gnocchi, 20148 Milan, Italy.

Jose Luis Pons is with the Scientific Chair, Legs & Walking AbilityLab, Shirley Ryan AbilityLab (formerly Rehabilitation Institute of Chicago), Chicago, IL 60611 USA, also with the Department of Physical Medicine and Rehabilitation, Feinberg School of Medicine, Chicago, IL 60611 USA, and also with the Department of Biomedical Engineering and the Department of Mechanical Engineering, McCormick School of Engineering, Northwestern University, Chicago, IL 60611 USA.

Digital Object Identifier 10.1109/TNSRE.2020.2989481

TRACCIA 2

1 – Classificazione delle protesi di arto inferiore.

2 – Discutere il montaggio e dimensionamento dei cuscinetti nell’assieme allegato.

3 – Competenze e funzioni del Consiglio di Amministrazione.

4 – Lettura e traduzione dei primi due capoversi dell’articolo scientifico allegato.

5 – Descrivere la sintassi per produrre la somma di una colonna di numeri in Excel.

The Long and Winding Road to Symbiotic Wearable Robotics

By Lorenzo Masia and Nicola Vitiello

If we close our eyes and try to extract the first image blinking in our mind when we think of robotics, we probably see a clean, aseptic space where multiple anthropomorphic mechanical arms dance in a coordinated action to assemble a car or an airplane. However, over the past decade, robotics has gradually undergone a metamorphosis and, like a giant growing tree, has dichotomously multiplied its roots and branches. Among the new frontiers of research, wearable robotics is increasingly prominent. Robots and humans have often represented two entities that exist without sharing common spaces (as in the industrial realm where humans and robots are separated by safety fences), but the road taken envisions a future where artificial and biological systems aim at a truly symbiotic interaction.

Wearable robotics has been expanding in several areas, embracing the civilian and industrial domains. The adoption of smart spring-loaded mechanisms and new materials comprising polymers, carbon fibers, and textiles, complemented with novel smart sensing-actuation and human-in-the-loop control strategies, is opening a wide scenario where the exoskeletons and exosuits market is expected to grow to US$5.2 billion by 2025. Applications range from medicine and rehabilitation to industry and wellness, with new implications still unexplored in robotics subfields related to psychology, ergonomics, and biomechanics, in addition to mechanics and electronics. If robotics has been the bailiwick of engineers since its birth, the past two decades have been marked by the need to embrace new disciplines. Wearable robotics is transversally permeating science and its practical spheres.

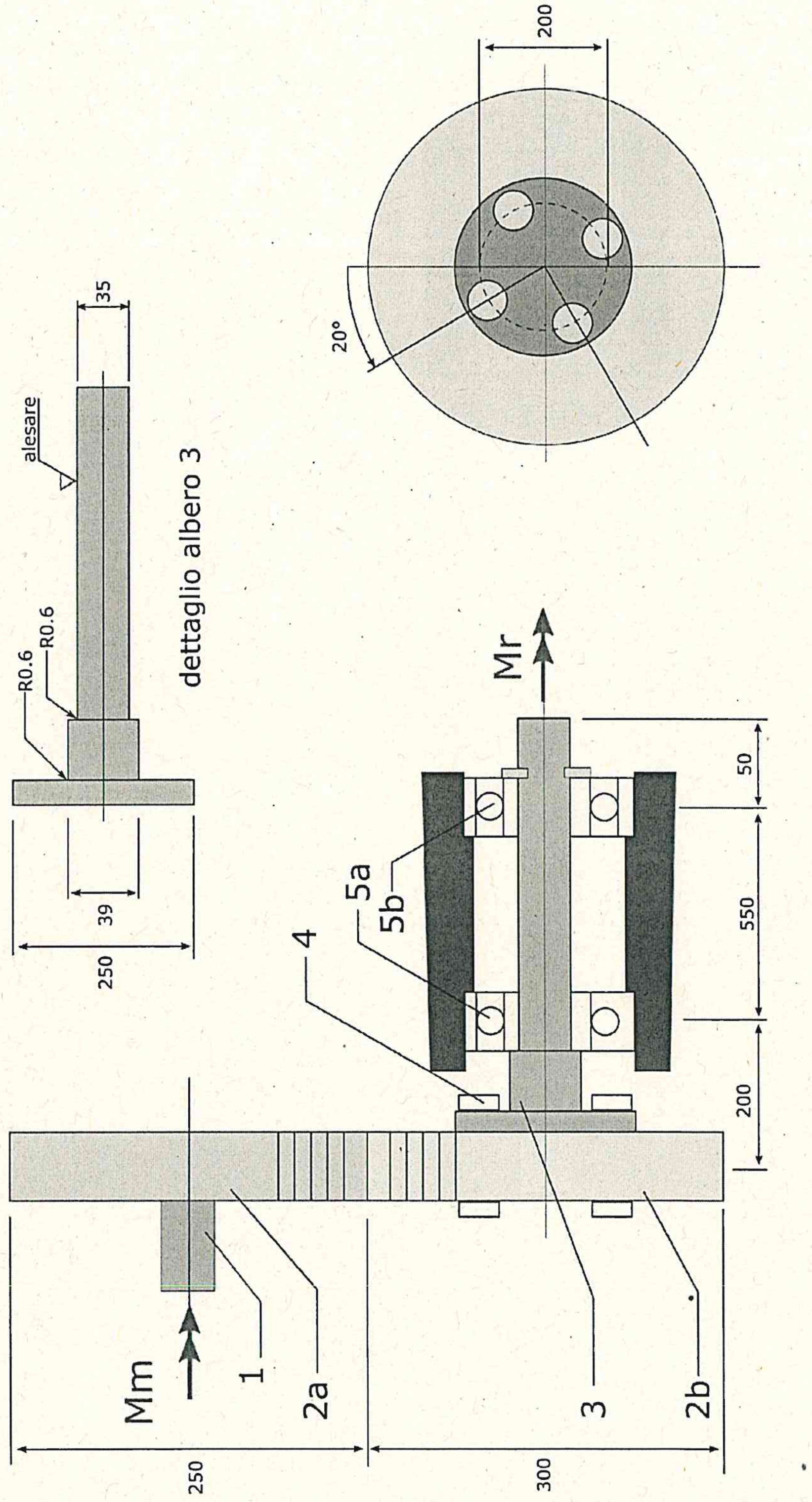
The new challenges are more like open calls for experts from different scientific backgrounds; if one wants to make the symbiosis between humans and wearable robots a reality, synergistic efforts from multiple actors are paramount. Design guidelines for exoskeletons and exosuits must have a common fulcrum around which multiple professional entities rotate: engineers, clinicians, psychologists, health-care managers, industry representatives, operational and line managers, and investment professionals. How can all this be acheived?

In our opinion, a first igniting spark results from an academic mind-set that values designing an approach to education with new classes, attracting students from different backgrounds, and creating cultural and gender diversity that allows us face the problems on different fronts. To ensure the dissemination of knowledge across disciplines, dedicated events, conferences, and websites must promote these integrations, and, ultimately, the job market must create new professional profiles that work as the glue across multiple backgrounds and application scenarios. This is the long and winding road that can lead to symbiotic wearable robotics being perceived as a part of our everyday life, just as prehistoric clothing was once our main protection from nature.

Wearable robotics is transversally permeating science and its practical spheres.

We live in an era where technology must provide the next step to our evolutionary path. The wearable robotics challenge is too broad to be faced by a single specialization but rather must be seen as a call for researchers and professionals who want to test themselves on unexplored grounds and accomplish technological wonders. The danger of failure is around the corner; the risks of running into a dead end are a possibility, as is the chance to become the starring actors, the dei ex machina, for the next technological–human revolution.

Digital Object Identifier 10.1109/MRA.2020.2967007
Date of current version: 18 March 2020



DISEGNO NON IN SCALA

Figura 1

TRACCIA 3

1 – Sensorizzazione delle protesi di arto inferiore: tipologie e benefici.

2 – Discutere il montaggio e dimensionamento dei cuscinetti nell'assieme allegato.

3 – Competenze e funzioni del Senato Accademico.

4 – Lettura e traduzione dei primi due capoversi dell'articolo scientifico allegato.

5 – Descrivere la sintassi per produrre la radice quadrata di un numero in Excel.

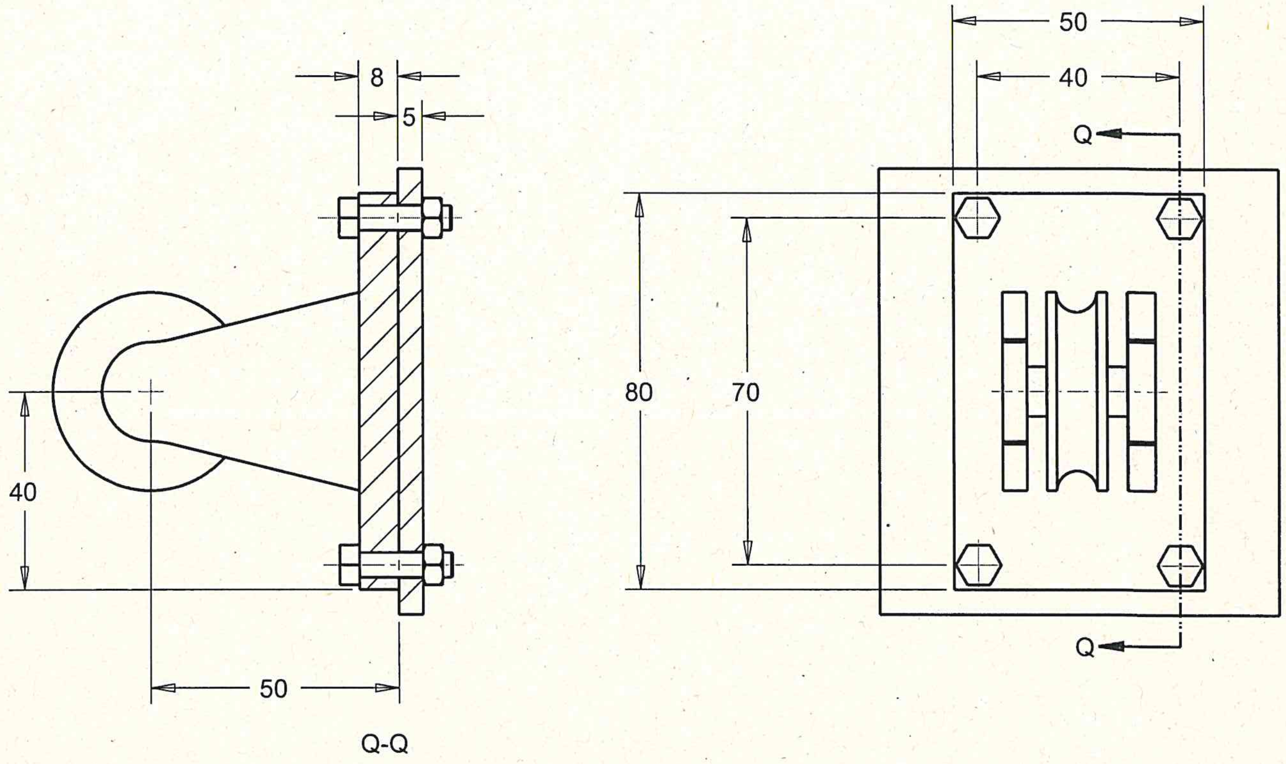


Figura 2

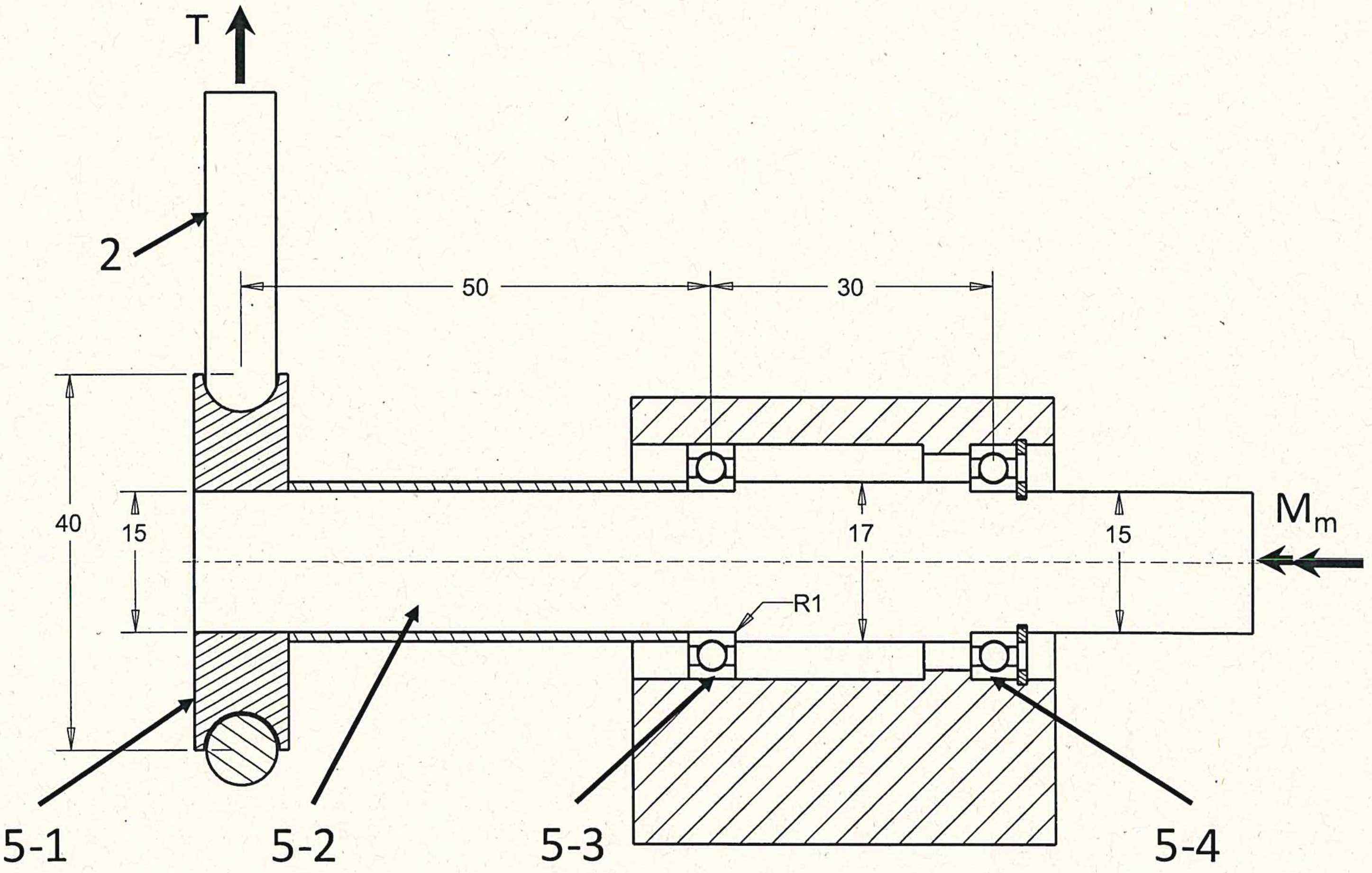


Figura 3

Robotica (2019) volume 37, pp. 2056–2072. © Cambridge University Press 2018
doi:10.1017/S0263574718001340

A Novel Generation of Ergonomic Upper-Limb Wearable Robots: Design Challenges and Solutions

Giorgia Ercolini†*, Emilio Trigili†, Andrea Baldoni†, Simona Crea†‡ and Nicola Vitiello†‡

† *The BioRobotics Institute, Scuola Superiore Sant'Anna, Pisa, Italy*
E-mails: e.trigili@santannapisa.it, a.baldoni@santannapisa.it, s.crea@santannapisa.it, n.vitiello@santannapisa.it
‡ *IRCCS Fondazione Don Carlo Gnocchi, Milan, Italy*

(Accepted November 25, 2018. First published online: December 26, 2018)

SUMMARY

In this work we present NEUROExos, a novel generation of upper-limb exoskeletons developed in recent years at The BioRobotics Institute of Scuola Superiore Sant'Anna (Italy). Specifically, we present our attempts to progressively (i) improve the ergonomics and safety, (ii) reduce the encumbrance and weight, and (iii) develop more intuitive human–robot cognitive interfaces. Our latest prototype, described here for the first time, extends the field of application to assistance in activities of daily living, thanks to its compact and portable design. The experimental studies carried out on these devices are summarized, and a perspective on future developments is presented.

KEYWORDS: Exoskeletons; Control of robotic systems; Mechatronic systems; Neurorehabilitation; Series elastic actuators.

1. Introduction

Robotic rehabilitation was proposed in the early 1990s as a tool for providing intensive and repetitive treatments to promote the recovery of the motor functions and movement coordination compromised by neurological disorders.[1] After a stroke, improving arm function is a core element of the rehabilitation, with the final goal of enabling the patient to recover motor functions and perform activities of daily living (ADL) independently.[2]

Compared to traditional physical therapy, rehabilitation robotics hold the potential to reduce the physical effort required of the therapist (enabling him/her to treat more than one patient at a time), to provide more objective and precise measurements of the patient's performance and progress, to adapt to different users' individual needs and abilities, and to maintain a high level of patient engagement.[3]

Robotic devices for upper-limb rehabilitation can be classified into two main categories according to their mechanical structure: end effector robots and exoskeletons. End effectors are characterized by a single interaction point with the patient (typically the hand or the forearm), which holds the arm and generates forces to guide or resist the movement. This connection makes the device easily adaptable to a wide range of patient anatomies and clinical conditions, but on the other hand, the lack of a tight coupling between the robot and the user can lead to undesirable forces and uncomfortable positions of the human arm. Examples of end effector devices are the MIT-MANUS,[4] which allows passive and active mobilization of the wrist and elbow in the horizontal plane, the GENTLE/s,[5] a

---

Giorgia Ercolini and Emilio Trigili have contributed equally to this work.

* Corresponding author. E-mail: giorgiaercolini7@gmail.com