Examples of Assistive Robotic Solutions for Healthy Aging and Rehabilitation at University of Calabria

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Abstract

This manuscript describes a systematic design procedure and some examples of innovative assistive robotics solutions that have been developed at University of Calabria (UNICAL) to address various challenges for healthy ageing and rehabilitation. These solutions include advanced technologies such as exoskeletons, therapeutic robots and wearable devices, designed to improve mobility, strength and coordination. They are designed for use either at home or in the clinic. The main objective is to provide innovative and cost-oriented solutions for increasing users' independence, promote well-being and improve the overall quality of life of the elderly and recovering population. Furthermore, these technologies are designed to be intuitive and easy to use, thus ensuring easy adherence to prescribed exercises and improved effectiveness of rehabilitation programs.

Keywords

Assistive Robotics, Robotic Design, Healthy Aging, Rehabilitation

1. Introduction

The escalating global population of elderly individuals poses substantial challenges in promoting healthy aging and facilitating rehabilitation for individuals confronting diverse health conditions and injuries. As the number of individuals seeking rehabilitation continues to rise, there is a pressing need for innovative and effective assistive robotic solutions to enhance quality of life and independence [1].

The World Health Organization (WHO) defines assistive technologies as products, systems, and services designed to maintain or enhance functioning and promote well-being [2].

Assistive robots, therefore, are devices that leverage robotic capabilities such as sensing, processing, and mobility to achieve this goal. Assistive robotics offers a range of applications tailored to diverse needs, such as mobility assistance, communication aids, cognitive assistance, rehabilitation, and environmental control as reported, for example, in [3, 4, 5, 6, 7].

This paper explores some innovative examples of assistive robotic solutions. Each of these solutions deals with specific aspects of healthy aging and rehabilitation, providing significant benefits in terms of mobility support, healthcare monitoring, physical rehabilitation, and overall well-being. By showcasing these exemplary cases, it underscores the transformative impact that robot technologies can have on the lives of the aging population and individuals seeking to regain their independence and mobility.

The objective is to inspire further research and development in the field of assistive robotics, fostering the creation of cutting-edge solutions that effectively address the unique challenges faced by seniors and individuals in rehabilitation. Ultimately, these innovative devices play a pivotal role in enhancing independence, promoting well-being, and improving the overall quality of life for the aging population and individuals on the path to recovery.

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2. The Attached Problem

With advancing age, older adults face physical and cognitive decline, leading to reduced mobility, increased health risks, and potential social isolation. Exercising and rehabilitation of human limbs are critical for promoting healthy aging and aiding recovery from injuries or medical conditions [8].

For healthy aging, maintaining muscle strength, joint flexibility, and cardiovascular health is vital for an active lifestyle and independent living. Similarly, individuals undergoing rehabilitation require targeted, efficient exercises to regain motor function and mobility, highlighting the importance of incorporating robotic technologies, [9]. These devices must offer personalized exercises, real-time progress monitoring, and adaptability to various physical conditions. User-friendliness, portability, and compactness are essential for both home and clinic settings, with safety and precise control mechanisms crucial to prevent harm during unsupervised sessions. By integrating assistive solutions such as wearable devices, rehabilitation robotics, and innovative equipment can offer personalized exercise regimens, real-time monitoring, and tailored rehabilitation programs [10], empowering diverse needs and facilitating healthy aging and recovery. Moreover, continuous research and development in this field aim to enhance the effectiveness and accessibility of these technologies, ensuring they meet the evolving needs of seniors and individuals undergoing rehabilitation. Additional focus on interdisciplinary collaboration and user-centered design approaches can further improve the usability and acceptance of these devices among the target population, promoting their widespread adoption and impact in improving quality of life. This collective effort fosters innovation and addresses the unique challenges faced by older adults and individuals in rehabilitation, ultimately enhancing their overall well-being and independence.

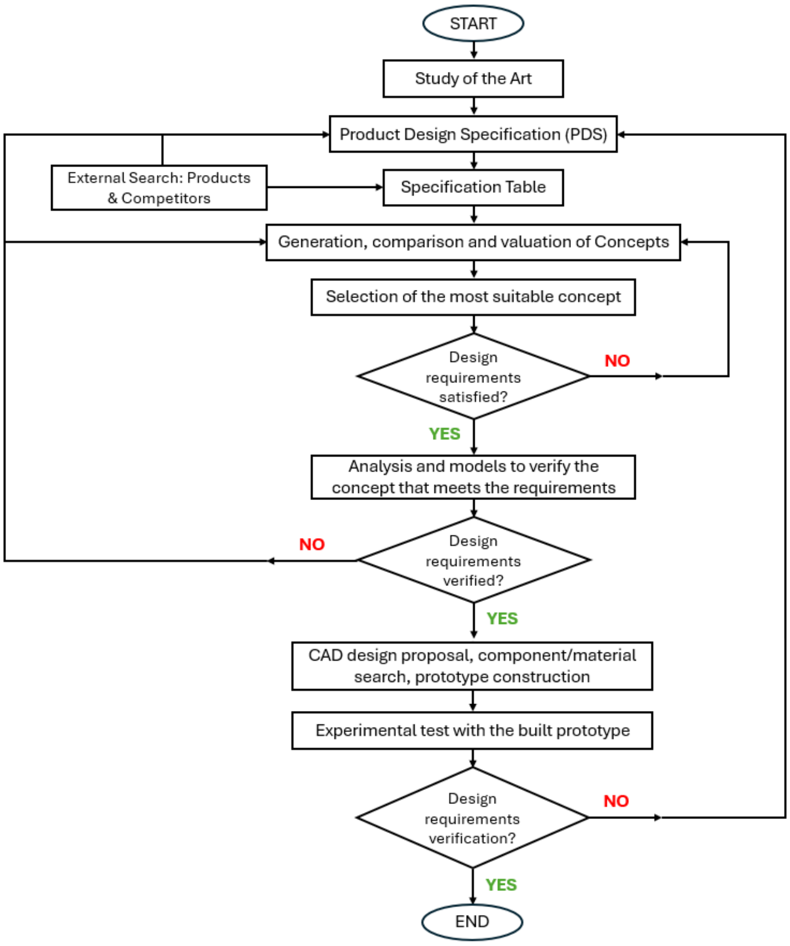


Figure 1: Methodological process.

3. A General Design Procedure

We propose a general design procedure to address any innovative robotic design that can concurrently consider multifaceted green-aware design requirements and constraints. A diagram representing the entire proposed methodological process is shown in Figure 1.

The process of designing a robotic device aims to achieve the optimal solution, starting from the definition of the product requirements, known as the Product Design Specification (PDS). The PDS phase involves compiling a table outlining the project's performance and key features using objective data and sources, including competitor analysis, regulatory references and conditions of use to form a product profile. Design begins with defining specifications while researching competitors and regulations. Specifications should be justified, flexible, and relevant, covering aspects like performance, materials, ergonomics, production costs, and sustainability. Market analysis helps estimate the new product's potential, while radical innovations require hypothesis testing. Subsequently, concepts are generated and evaluated using techniques such as brainstorming and mind mapping. These concepts are then compared with the specification table to identify any unattainable targets, allowing for necessary adjustments. Specifically, brainstorming generates ideas without criticism, which are then organized and refined, while other techniques explore innovative solutions by identifying key product functions and proposing creative alternatives. Concepts are assessed for technical feasibility using both qualitative (Datum Method) and quantitative (Optimum Rating Method) methods. Simplified models are created to analyse system behaviour, often with the help of simulation software. This iterative process ensures a robotic system design that meets technical, economic, and environmental specifications, resulting in an innovative solution.

4. Devices for Rehabilitation and Motion Assistance

Our research group, led by Prof. Giuseppe Carbone at the University of Calabria, has developed advanced mechatronic solutions for rehabilitation and movement support, in collaboration with several international partners. These innovative devices aim to enhance mobility and motor function of both upper and lower limbs, marking a significant advance in assistive robotics. The following sub-chapters detail some of these solutions, each featuring original designs and protected by proprietary patents.

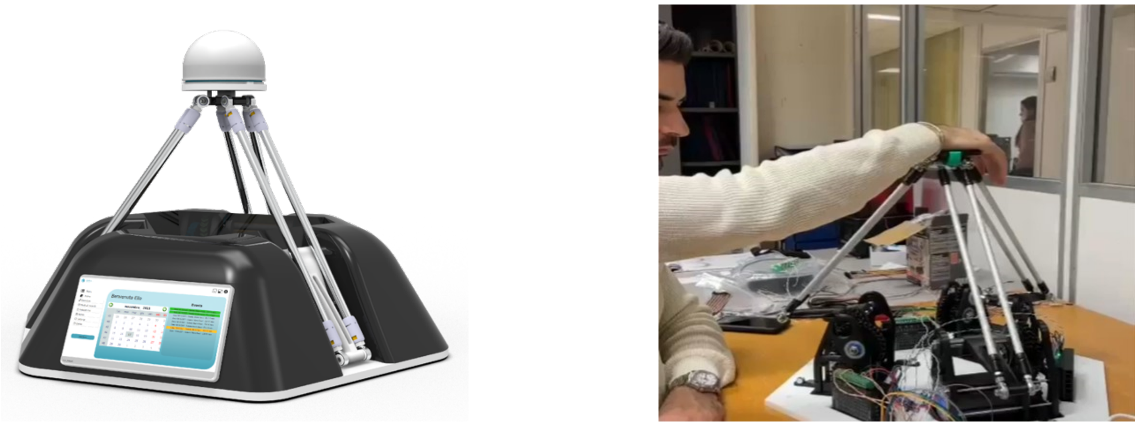
4.1. The Adiutor upper limb device

The Adiutor upper limb rehabilitation device is an advanced assistive mechatronic solution designed for home-based exercising and rehabilitation of the upper limb, Figure 2, [11]. Based on a delta architecture, it is designed to offer a wide range of rehabilitation modalities, supporting functional recovery in a targeted and effective manner.

The Adiutor device not only allows users to perform a series of pre-programmed exercises, but also offers the possibility to record and replicate specific movements. These movements can be created and set by the therapist, who can customise the exercises to the patient's individual needs. After recording a movement, the device allows the patient to repeat it, providing a score based on execution time and comparison with a healthy person's time. This scoring system helps monitor the patient's progress and motivate them, making the rehabilitation experience more engaging and goal-oriented.

In addition, the Adiutor device features an intuitive interface that facilitates patient interaction with the system and increases engagement during rehabilitation sessions. The integrated telemonitoring functionality allows health professionals to remotely follow and assess patients' progress, thus ensuring personalised care and effective remote support.

This integrated approach, combining user interface and telemonitoring, makes the Adiutor a valuable tool for efficient upper limb rehabilitation, all from the comfort of one's own home.



(a) (b)

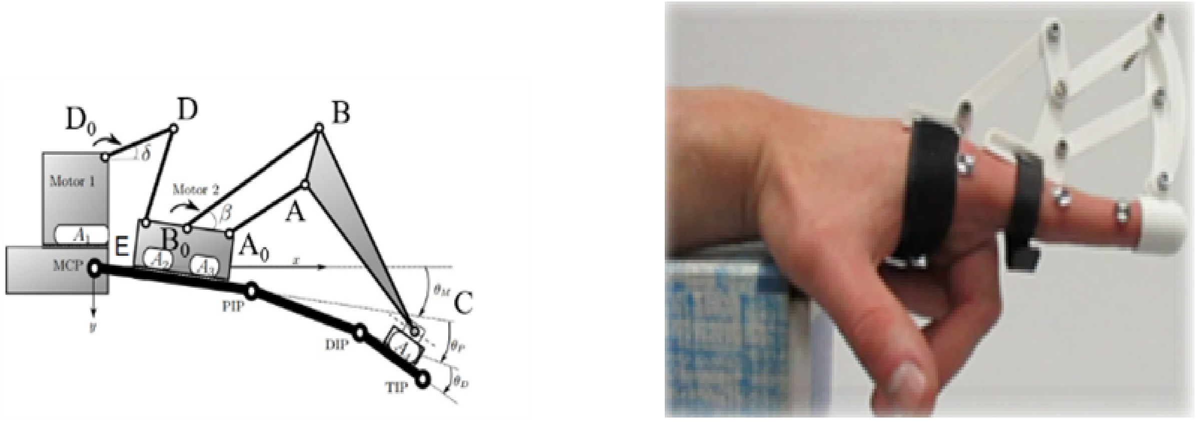
Figure 2: Adiutor home assitive device: a) concept; b) prototype at UNICAL.

4.2. A finger assistive exercising device

The two degrees of freedom finger assistive exercising device stands as a mechatronic solution meticulously crafted to facilitate finger exercising and rehabilitation with exceptional precision and effectiveness, Figure 3, [12].

By harnessing its ring design, operating architecture and adjustable resistance levels, the device empowers users to engage in a diverse range of finger movements and exercises, purposefully promoting flexibility and strengthening of the fingers.

This targeted and specialized support is particularly advantageous for individuals grappling with finger impairments or injuries, offering them the opportunity to partake in customized exercises tailored to their distinct needs and capabilities, ultimately fostering their rehabilitation success, and enhancing their overall hand dexterity and quality of life.



(a) (b)

Figure 3: Finger exercising device: a) concept; b) prototype at UNICAL.

4.3. A cable-driven lower-limb device

The cable device for bedridden patients allows specific exercises for the knee and ankle joints, such as flexion and extension, without having to leave the bed, Figure 4, [13].

Designed with strategically placed cables, the device ensures controlled and risk-free movements, while the resistance, range and maximum force adjustments allow it to be adapted to the type of injury and the specific needs of the patient, providing a safe and personalized workout. The device's compact and lightweight design facilitates its use in hospitals and nursing homes without compromising effectiveness, while its versatility is highlighted by its ability to adapt to rehabilitation needs, adjusting exercises based on patient response and therapeutic goals.

This device not only facilitates the recovery of bedridden patients through targeted and customised exercises, but also stands out for its practicality and adaptability in various healthcare settings.

Figure 4: A prototype of a cable-driven lower limb device at UNICAL.

4.4. An interactive mechatronic approach for upper limb rehabilitation

The ReHArm prototype, a variable stiffness device, and the A.R.M.S. (Arms Rehabilitation Management System) user interface, Figure 5, provide an innovative solution for optimising upper limb rehabilitation [14]. Developed at Pprime University in Poitiers (France) with the UNICAL team, this system offers reliable and constant support, adapting to the specific needs of patients.

(a) (b)

Figure 5: ReHArm device and A.R.M.S. interface: a) concept; b) built prototype.

The compact and lightweight ReHArm prototype is easily transportable and can be installed on different work surfaces. Composed of five modules with different hardware components, it is versatile and effective. The presence of sensors integrated into the handle allows the device to adjust its stiffness in real time, providing personalized support during recovery and dynamically adapting to the severity of the patient's injury. The A.R.M.S. user interface provides an interactive and progressive path for patients, guiding them through exercises that increase in difficulty while providing immediate feedback. By continuously monitoring patient progress, it allows therapists to adapt the rehabilitation plan in real time based on individual needs and progress, improving the overall experience, engagement and effectiveness of treatment.

The innovation comes from the synergy between the device and the interface, which, by combining their functionalities, provides a highly personalized rehabilitation experience, significantly improving treatment adherence and overall effectiveness. Preliminary results indicate a promising efficacy of the system, which creates an immersive environment that promotes treatment adherence, patient autonomy and recovery of upper limb motor functions, making it a comprehensive, versatile and accessible option to enhance the rehabilitation process.

5. Assistive Devices for Daily Activities and Learning

In the context of our research, we have also developed assistive devices to improve the autonomy of people with disabilities and support learning in children with motor difficulties. In collaboration with international partners, we have designed solutions to help with daily activities such as eating and writing. The following subchapters describe these devices, which address the specific needs of users with motor difficulties, with the aim of improving their quality of life and education.

5.1. The Pick&Eat wheel-chair mounted robotic arm

The Pick&Eat device, Figure 6, is a wheel-chair mounted robotic arm (WMRA), a mechatronic assistive solution designed to support patients with paresthesia, paresis or paralysis of the upper limbs during the act of eating [15].

The optimised, modular design allows for easy installation, adaptability to different wheelchairs and autonomous operation without requiring specific professional skills.

Designed to the average anthropometric specifications of an adult male, the robotic arm features an interchangeable modular end-effector, allowing the use of a fork or spoon depending on the meal. The device is equipped with strategically placed sensors to increase safety during human-machine interaction, thanks to a unified control logic that executes tasks and monitors positions.

Tests have shown that the Pick&Eat device is a safe, reliable and low-cost solution, improving the quality of life and psychological well-being of patients and reducing the workload of healthcare staff.

(a) (b)

Figure 6: Wheelchair mounted robotic arm: a) proposed concept; b) a prototype.

5.2. Pyramidal cable driven robot for child writing assitance

An innovative pyramidal cable-driven robot has been designed to assist primary school children with difficulties in learning or regaining writing skills, as shown in Figure 7, [16]. This work is a collaboration with the University of Skidda, Algeria.

The robot's design features a pyramid-shaped structure with cables attached to the top point, which control a writing instrument held at the base. The child interacts with the robot by moving a stylus or using a modified pen grip. As the child moves the stylus, the robot translates those movements into precise and controlled writing actions.

This technology aims to provide personalised and adaptive support to children with fine motor difficulties, helping them develop and recover writing skills in a fun and engaging way. Personalisation is key as the system selects specific tasks for the child, which are then translated into executable trajectories by the robot, thereby tailoring the writing experience to their individual needs and therapeutic goals.

Through this assistive robotic solution, children can experience a positive and rewarding writing learning experience, enhancing their overall educational journey.

(a) (b)

Figure 7: Pyramidal cable driven robot: (a) concept; (b) prototype at UNICAL.

6. Conclusions

In conclusion, the showcased robotic solutions from the team at University of Calabria underscore remarkable potential for effective care, healthy aging, and rehabilitation. Technologies like exoskeletons, therapeutic robots, and wearable devices provide more accessible, tailored assistance, enhancing quality of life for rehabilitation and care recipients.

These solutions promote mobility, strength, and independence recovery, crucial for aging well. They address challenges of aging and rehabilitation, offering vital support for autonomy and fulfillment. Additionally, intuitive and user-friendly design ensures greater exercise adherence and rehabilitation program effectiveness in both domestic and clinical setting. These innovations offer personalized care, improving quality of life for those regaining mobility and independence.

Continued research will yield more advanced solutions, benefiting society with targeted care.

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Declaration on Generative AI

During the preparation of this work, the authors used X-GPT-4 and Gemini in order to: Grammar and spelling check. After using these tools, the authors reviewed and edited the content as needed and takes full responsibility for the publication's content.

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