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Research activities at LARM2 lab of the University of Rome Tor Vergata

M. Ceccarelli and M. Russo

Departamento de Ingeniería Industrial, Universidad de Roma Tor Vergata, marco.ceccarelli@uniroma2.it, matteo.russo@uniroma2.eu

In this paper, the activities of the Laboratory of Robot Mechatronics (LARM2) at the University of Rome Tor Vergata are reported. LARM2 has been established in 2019 to renew a lab with 3 decades of activity originally based at Cassino University, under the leadership of Prof. Marco Ceccarelli and together with Dr Matteo Russo. The structure and activities of LARM2 can be considered as distributed in several international locations, because of joint research projects, research visits, supervision of international students, and dual doctoral programs. LARM2 activities are mainly focused on education and research in topics related to Robotics and Mechatronics from a mechanical engineering viewpoint, referring to theory, design, practice and technological transfer. They are directed at collaborations in investigating, designing, planning, and improving mechanical and mechatronic systems, with traditional and innovative designs. The development of BSc, MSc and PhD theses on subjects and prototypes for innovation is oriented to form engineers capable to solve problems with new and traditional techniques. LARM2 activity is also carried out for applied research through formal and informal agreements with enterprises, with the aim both to apply research results and to solve problems in engineering practice in industrial and non-industrial applications. LARM2 research focuses on new designs for service robots and machinery, the analysis of solutions in robot-assisted processes and in robotized manipulations, and the enhancement of mechanical systems. LARM2 is available for joint projects within local, national, and international frames, particularly in the European framework not only within Erasmus program. LARM2 invites scholars and students for periods of study and collaborations in the subjects of common interest with academic and non-academic institutions within, but not only, signed international agreements for bilateral projects even with extra-European universities. Current activities focus on applied robotics issues to develop service robots, especially in healthcare. Specific attention is paid to the development of systems for the motion assistance of limbs with the peculiar vision referring to the assistance of elderly people. Furthermore, activity continues on LARMbot humanoid robot, used as research and experimental platform in the design of robotic parts for the development of a low-cost humanoid robot with high mechanical performance. This paper presents LARM2 to reenergize past collaborations with Spanish colleagues but also to activate new ones on topics that can be useful not only in the research field but also for training new generations of engineers with an international vision that is not just pro-European.

1. Introduction

Modern engineering research activity in academic frames is worked out in teams of members with different roles and expertise in multidisciplinary aspects both to get results that contribute to the state-of-art and to transfer developments in practical applications, forming new generations of engineers. The activities of research groups, tracked in their evolution over time, are very rarely recorded in publications, but they are instead summarized in the webpage and /or flyers of the laboratories or the teams. These websites and flyers are, however, subject to changes and could not be available in the same form even after a brief period of time, making the few written records available particularly valuable.

In this paper, a survey is presented on the activities that have been recently carried out at the LARM2 laboratory in Rome, with the aim to encourage future collaboration at different levels such as with student exchanges as well as PhD and postdoc periods of study within or out of established programs of collaboration.

2. LARM2 at the University of Rome Tor Vergata

The LARM2, Laboratory of Robot Mechatronics (RM2 also indicates Tor Vergata, known as the second University of Rome, Roma 2 in Italian, https://larm2.ing.uniroma2.it/) has been established in 2019 at the Department of Industrial Engineering at the University of Rome Tor Vergata as a renewal of a laboratory with three decades of activity at the University of Cassino under the leadership of Prof. Marco Ceccarelli, [1]. The current mission areas with significant activities refer to research, formation, dissemination, and other multidisciplinary or emerging topics, Fig.1.

The activity at LARM2 is worked out in research, formation, dissemination and other multidisciplinary aspects or emerging topics of interests, Fig.2, with developments in theory, design, prototyping, testing including dissemination and transfer plans in practical applications and in formation initiatives.

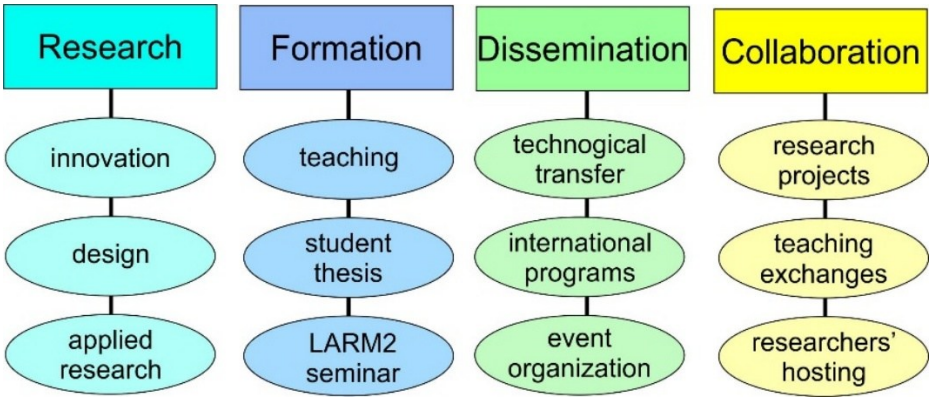


Figura 1: Areas of interest for the mission of LARM2 laboratory

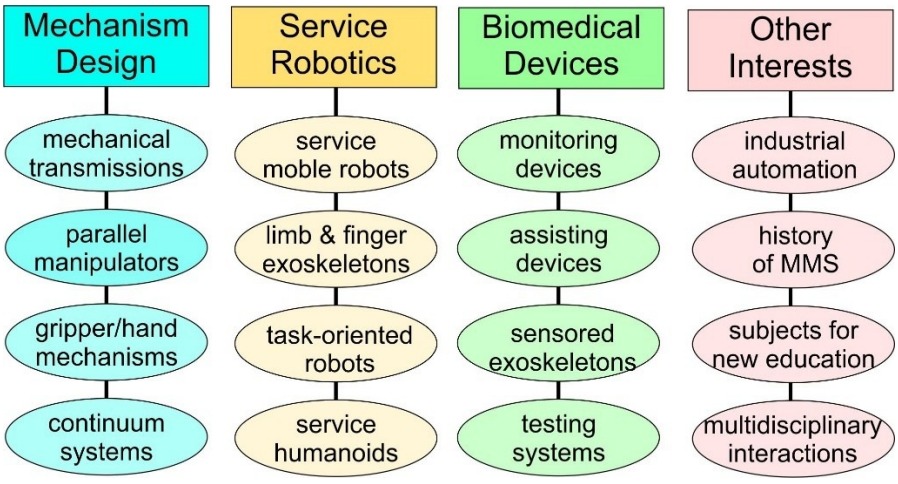


Figura 2: An overview of activity subjects at LARM2

The activities are directed and available for collaborations with the purpose to investigate, to design, to plan, and to improve mechanical and mechatronic systems, with traditional and innovative designs. The development of

theses on subjects and prototypes for innovation is orientated also to form engineers, who will be capable to solve new problems but still with interest on new disciplines and traditional techniques of Mechanical Engineering.

LARM2 activity is also available and carried out for applied research with and without research contracts with enterprises with the aim both to apply research results and to solve problems in engineering practice in industrial and non-industrial applications. In particular, the study can be focused on new designs of service robots and machinery, analysis for problem solutions in robot-assisted manufacturing processes ad motion assistance applications, robotized manipulations, and functionality enhancement of existing mechanical/mechatronic systems. LARM2 is available for joint projects within local, national, and international frames.

LARM2 invites scholars and students for periods of study and collaboration in the subjects of common interest with academic and non-academic institutions. Activity can be carried out within the Erasmus program and within, but not only, signed international agreements for bilateral projects even with extra-European universities. Theses for Bachelor, Master and PhD students are developed within LARM2 activities, both in their own projects and in co-tutorship with other institutions. PhD candidates are welcomed also for double degree PhD programs in collaboration with other Universities. Figure 2 shows the LARM2 team working during the fall 2024 with participation of students and research fellows from all around the world within different programs of exchanges.

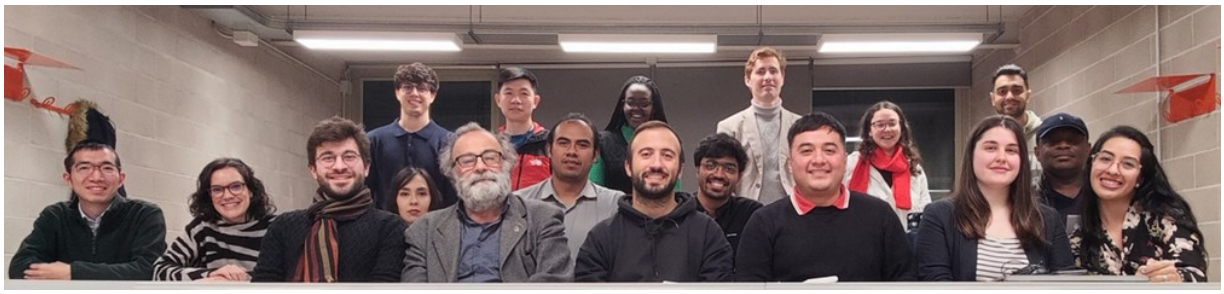


Figura 3: LARM2 team at LARM2 seminar on 28 November 2024 (from left to right) - first row: Dr Matteo Russo, Prof Marco Ceccarelli, Luca Quattrucci (PhD student), Luis Angel Gerrero (visiting PhD student), Miss Chloe Gabarren (visiting Master student), Karla Nayeli (visiting PhD student); second row: Takamaru Saito (visiting PhD student), Dr Maria Garrosa (visiting postdoc), Alexandra Leonova (Master student), Cuauthemoc Morales (research fellow), Janapareddy Sumanth (Bachelor student), Earnes Ofonaike (research fellow); third row: Alessandro Perini (PhD student), Bowen Yang (Master student), Olga Ishimwe (Master student), Sergey Kotov (PhD student), Clara Kierbel (PhD student), Mohammadmehdi Lari (Master student).

LARM2 activity is carried out by researchers and students from Bachelor, Master, and PhD programs under the supervision and guidance of prof Marco Ceccarelli and Dr Matteo Russo. The structure and activities of LARM2 can be rather considered as distributed in several locations in Italy and abroad as per the collaborations which is based on. International sections can be considered with the laboratories and team units with or without official agreements for joint frames with existing collaborations. Two rooms are allocated for LARM2 laboratory at the Department of Industrial Engineering of Rome University Tor Vergata, namely one for prototype construction and testing activities, Fig.4a), and one for desk area of team members, Fig.4b).

. a) b)

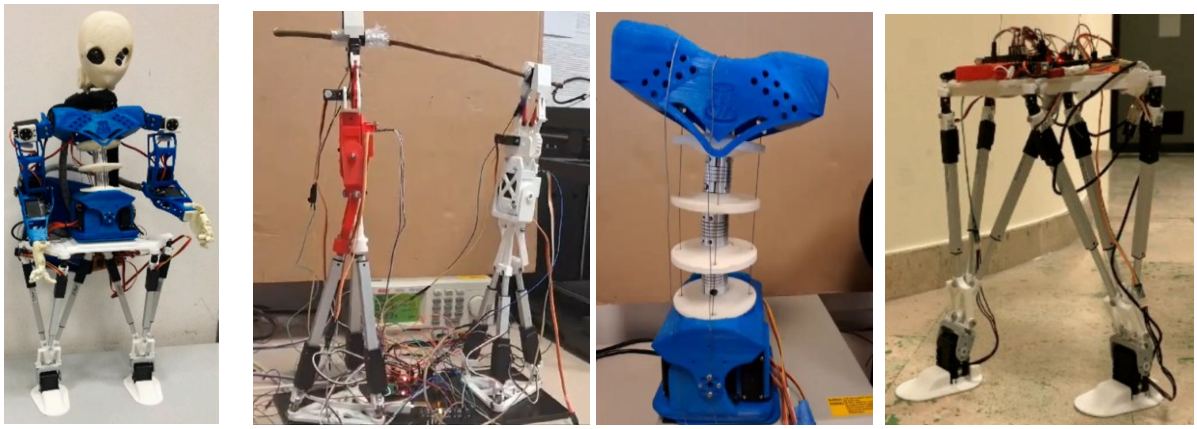
Figura 4: Rooms of the LARM2 laboratory: a) for prototype construction and testing activities; b) one for desk area of team members

3. Main research topics

The research activities at LARM2 are carried out with a mechatronic approach, developing systems in design and prototyping considering the mechatronic structure that integrates the mechanical and mechanism design aspects with adequate sensors, actuations, controls, and software supports. The main activities are carried out on the topics of robotics and service robotics with particular recent attention in applications in the biomedical fields as illustrated below with reference to the main topics currently under development.

3.1. LARMbot humanoid robot

The most important topic of activities in the field of Robotics is the development of the low-cost LARMbot humanoid, which began in 2014 with the first prototype in 2016, Fig. 5 a), [2] and has recently continued with a program of improvements structural and functional substructures as summarized in the prototypes of Fig.5 b). The LARMbot humanoid robot is characterized by a structure of parallel architecture mechanisms with low-cost design solutions using commercial components and parts made through 3D printing as pointed out in [3]. These characteristics allow a user-oriented solution based on the use of Arduino-type microcontrollers and programming that allows the operation of the individual substructures separately and in a coordinated manner. Furthermore, as with the 2016 prototype of less than 3,000 euro, the new version is expected to be a prototype that will cost less than 5,000 euro. Current activities may require further in-depth analysis and expansion and are centered mainly on expanding the performance of the mechanisms used to achieve even more efficient solutions of the manipulation system with two arms with a parallel structure similar to that of the legs, of the locomotion system with structural configurations more compact, and of the trunk system with an elongated torso still mixed serial-parallel with larger movement and load capacity.



. a) b)

Figura 5: LARMbot humanoid robot: a) 2016 prototype, [2]; b) new substructures under development for dual arm unit, torso unit, and leg unit

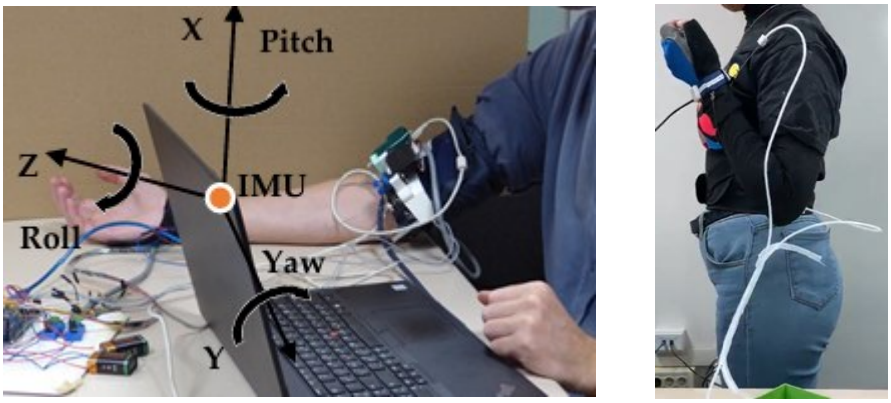
3.2. Motion assisting devices

The development of motion assisting devices has recently focused on solutions based on mechanisms that with their action help in the natural motion of the assisted limb using a light and compact structure of little weight. Figure 6 shows the prototypes aimed at motion assistance of the fingers of a hand with alternative solutions such as that of the ExoFinger exoskeleton in Fig.6 a) based on articulated mechanisms and that of the system actuated by cables, [4] and a textile-based glove for post-stroke rehabilitation in Fig.6 b), [5], tailored to be fully washable and easy to sterilize and reuse with different patients while limiting cost to less than 20€ per glove. In both cases the solutions were also developed with the contribution of students during their activities for their final thesis.

The interest in biomedical motion assisting systems has become a topic of current interest considering the progressive aging of the Italian and European populations so that the activities usually directed at the development of robotic rehabilitation systems in physiotherapy are evolving towards the development of suitable systems for motion exercise of elderly people. This renewed attention to the development of motion assisting devices has been funded in a project of the Italian PRIN 2022 program with the aim of expanding the experience of recent years with the L-CADEL cable system, [6] for the elbow up to the design of cable-actuated devices for the motion exercise of the human arm of elderly people. A last prototype of the L-CADEL is shown in Fig. 7 b) still in the improvement phase with research and design activities, while in Fig. 7 b) a first new prototype ASSIST-FEEv3 is shown, [7] as developed during the ongoing activities of the ASSIST project of the PRIN2022 PNRR program.

. a) b)

Figura 6: Finger exoskeletons: a) ExoFinger.v3, [4]; b) cable-driven fingered glove, [5] PERINI



a) b)

Figura 7: Prototypes of motion assisting devices: a) L-CADELr.v3, [6]; b) ASSIST-FEE.v3, [7]

3.3. Biomedical devices

The proximity of the Tor Vergata Polyclinic with colleagues also affiliated with Tor Vergata University has allowed multidisciplinary collaborations for the development of biomedical systems that respond to specific needs. Fig. 8 shows the prototypes that are designed within this research and design activity in an active collaboration with the thoracic unit group of prof Vicenzo Ambrogi at the Tor Vergata Polyclinic aimed at improving current clinical and surgical techniques. In particular, Fig. 8 a) shows an innovative breathing monitoring apparatus [8], based on data acquisition from an IMU which, with its lightness and portability, is implemented in the post-operative clinic of thoracic operations. Fig. 8) shows a laboratory test of a sensorization of the Finocchietto surgical instrument [9] for the retraction of the ribs that is still under development for a forthcoming implementation in the operating room.

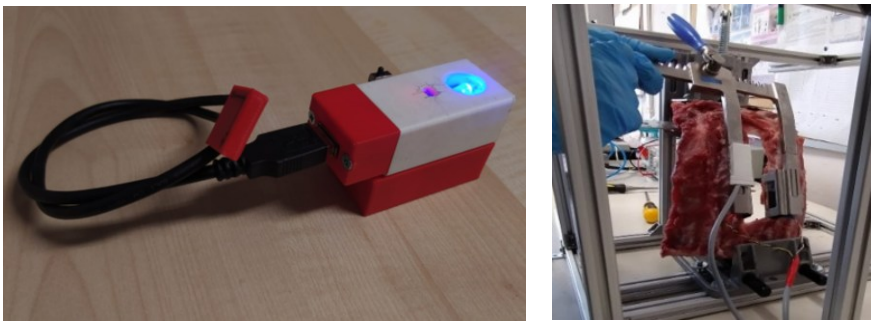


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Figura 8: Prototypes of biomedical devices: a) RESPIRHOLTER device, [8]; b) a lab test with sensored Finochietto surgery too,[9].

3.4. Continuum Robotics

Continuum and soft robots are bioinspired systems that leverage compliance and flexibility to adapt to complex environments and objects. Particularly successful in inspection and maintenance of complex systems (e.g., turbines, pipelines), robotic minimally invasive surgery, and grasping of fragile or unstructured objects (e.g., eggs or vegetables), these robots have enabled automation and teleoperation in fields inaccessible to conventional rigid manipulators and mobile robots. Dr Russo's research on continuum robots, stemming from a successful collaboration with Rolls-Royce for the inspection and repair of their aircraft engine blades and nuclear plants, has developed towards low-cost, 3D printable prototypes and endoscopic surgery at LARM2, also with the collaboration of surgeons from Roman hospitals and universities. In the example in Fig. 9a, a monolithic design for continuum robots has been developed and 3D printed in a single part without any support material as part of Mr Nicola Perugini's BSc thesis work [10]. In Fig. 9b, Ms Clara Kierbel's PhD research on gynecologic intervention with continuum robots to minimize the invasiveness and pain of uterine intervention is shown.

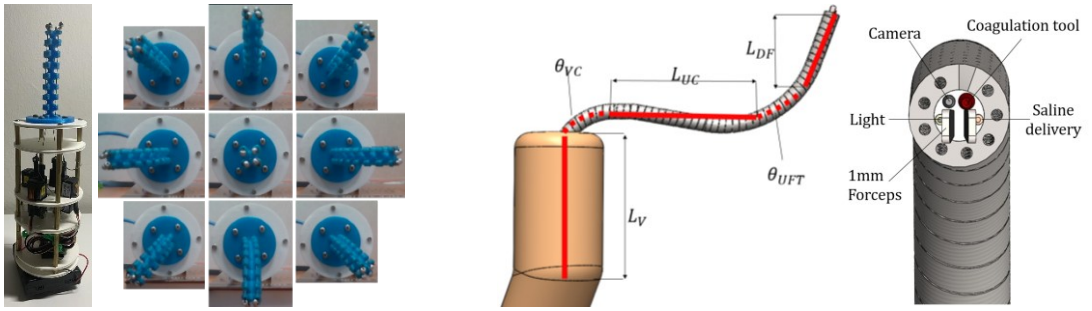

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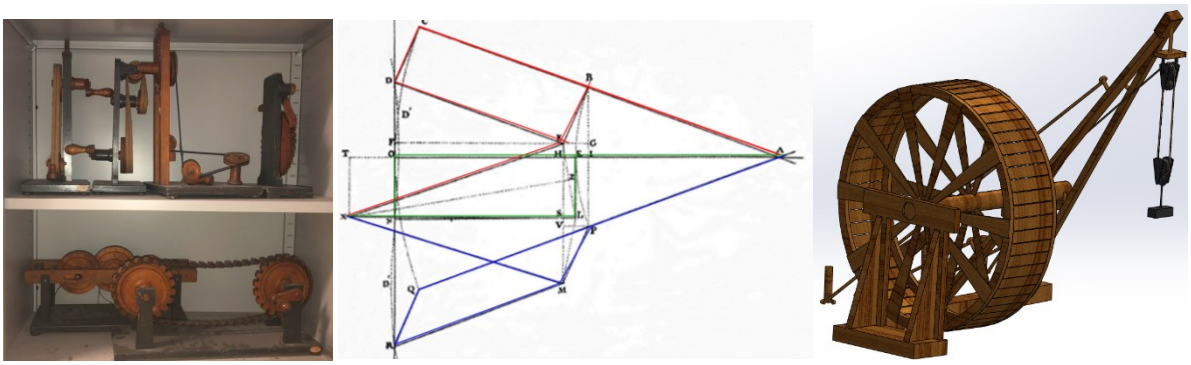
Figura 9: Continuum prototypes: a) 3D printed monolithic continuum robot, [10]; b) a conceptual design for gynecological tissue sampling, [11]

3.5. History of Mechanical Engineering

The activity on the analysis of the history of mechanical engineering and machines in general is carried out with the aim of developing a knowledge on the history of engineering but also for a useful background for other research and teaching activities. In fact, in general the addressed topics are linked to historical insights of past interest on topics of current interest for research and teaching. Subjects are explored in terms of historical research with technical contents in, topics referring to significant personalities with their results and the development of scientific and technical achievements in the field of machinery and mechanisms looking at theory, design and practical implementations. This interest and activity are documented not only in publications but also in the Springer series http://www.springer.com/series/7481 of which Professor Ceccarelli is scientific editor. This background interest is also addressed in teaching activities, especially with the preparation of bachelor's and master's theses which have the aim of explaining the development of specific machines by personalities whose professional development is also analyzed. Examples of this activity with results worthy of publications are shown in Fig. 10. In particular, Fig. 10 a) shows a recent result obtained in collaboration with Prof Marco Cocconcelli of the University of Modena in Reggio Emilia on the use of mechanism models in teaching [12], in Fig.10 b) a historical analysis in collaboration with prof Juan Ignacio Cuadrado of the Polytechnic of Valencia on a first modern synthesis of mechanisms by Agustin de Betancourt in 1789, [13], and Fig. 10 c) shows the work in a Bacheleor thesis in the CAD reconstruction and functional evaluation of a Vitruvian crane from the Roman era, [14].



a) b) c

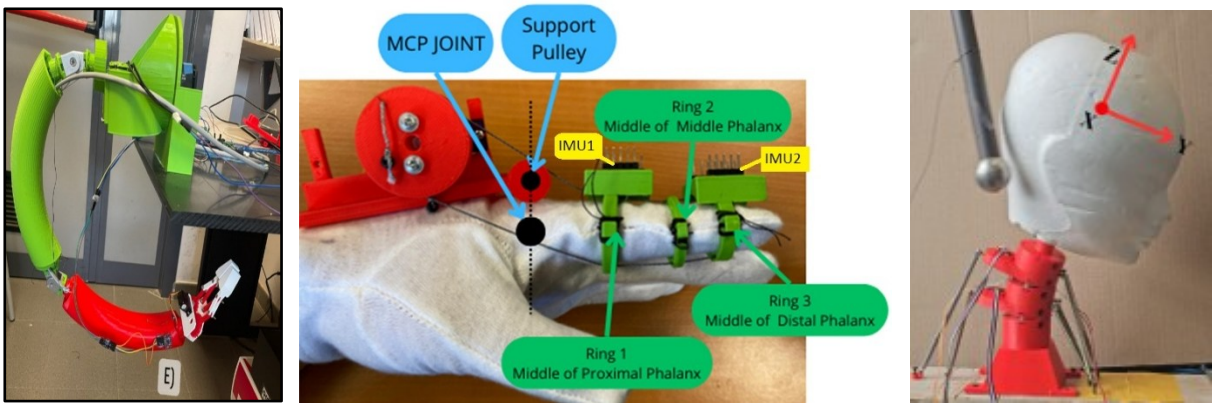
Figura 10: Examples of findings in history of MMS: a) stored mechanism models in Bologna, [12]; b) a scheme of the Betacourt mechanism synthesis in 1789, [13], a CAD reconstruction of a Vitruvian crane, [14]

4. Main teaching activities

The teaching activities carried out with reference to the LARM2 laboratory can be summarized in programs referring to the carrying out of bachelor's, master's and doctoral thesis projects in the design, construction and testing of prototypes, in topics usually related but not only to the above-mentioned interests of research. In particular, the teaching and application activities for the courses refer to the curriculum of Curriculum in Engineering Sciences (Bachelor) and Curriculum in Mechatronics (Master) in English. The main topics are oriented towards the development of mechanisms and prototypes in the fields of mechanical engineering, robotics, service robotics, and biomechanical systems for motion assistance, giving students the opportunity to have direct experience in design and development issues, and experimental validation of prototypes, including newly developed ones. The teaching activity is also carried out in collaboration with students hosted at the laboratory as part of exchange programs not only Erasmus for thesis activities or in internship periods aimed at experiences with existing prototypes or even developing new ones.

The expected results include not only the achievement of the expected educational experiences for the students but also the achievement of useful results for further development and activities at the laboratory with the possibility of publications that can recognize the merit and can contribute to the dissemination of the results at LARM2.

An example of good results of thesis work can be cited in the development of tests with TORVEASTRO arm in the bachelor thesis of Kaytare Shine, Fig.11a), [15]. Recent examples worthful of publication can be cited in the development of a new prototype cable-actuated finger exoskeleton mechanism, [16] during the internship of the French student Thibault Vaisson, Fif.11 b), and in the development of a cervical spine model for neck dummy, [17] during the internship of the Mexican student Jose Antonio Perez Valdez, Fig.11c).



. a) b) c)

Figura 11: Examples of Results from teaching activities: a) tests with TORVEASTRO arm from thesis work,[15]; b) new prototype cable-actuated finger exoskeleton mechanism, [16]; c) cervical spine model for neck dummy, [17]

5. Collaborations

Collaboration activity is an important part of the LARM2 laboratory's activities due to its academic mission in sharing problems and solutions. The ongoing collaborations available for further developments concern both research and teaching activities in institutional projects and bilateral exchanges. Examples of this activity can be cited in the recent results of a project financed by the Lazio Region on the development of the TORVEASTRO astronaut robot in collaboration with the ENEA Casaccia institution in Rome, [18]. Examples of international collaboration can refer to activities with the Institute of Mechanical Engineering of the Kazakhstan Academy of Sciences through cooperation in research projects, supervision of doctoral students, and organization of international congresses, [19].

6. Conclusions

The mission of LARM2 in the field of Robotics and Mechatronics is developed by activities referring to research projects and training programs within the academic offering at the three levels, also with collaborations at both a personal and institutional levels. The current activities available for future collaborations are briefly illustrated in the topics of Humanoid Robotics and Service Robotics, especially in the biomedical and motion assistance fields. What is presented is intended to be an overview of the willingness to strengthen and expand collaborations in the Italy-Spain context in a program that involves institutions and individuals in long-term agreements and relationships.

7. References

[1] Ceccarelli M., An Illustrated History of LARM in Cassino, Proceedings of RAAD 2012 international Workshop on Robotics in Ale-Adria-Danube Region, Napoli, Ed.i Scientifiche e Artistiche, pp. 35-42. (2012)

[2] Ceccarelli M., A History of LARMbot Humanoid. In: Ceccarelli, M., Aslan Seyhan, I. (eds) Explorations in the History and Heritage of Machines and Mechanisms. HMM 2024. Springer, Cham. pp. 360–370. (2024). https://doi.org/10.1007/978-3-031-54876-5_27

[3] Ceccarelli, M.; Russo, M.; Morales-Cruz, C. Parallel Architectures for Humanoid Robots. Robotics 2020, 9, 75. (2020) https://doi.org/10.3390/robotics9040075

[4] Ceccarelli M. and Morales-Cruz C., A prototype characterization of ExoFinger, a finger exoskeleton, International Journal of Advanced Robotic Systems, May-June 2021: 1–8. DOI: 10.1177/17298814211024880

[5] Perini A. and Russo M. Design of an adaptive tendon-driven hand exoskeleton for stroke rehabilitation. In 8th IEEE-RAS International Conference on Soft Robotics (RoboSoft 2025), 23-26 April 2025, Lausanne, Switzerland (2025) (in print).

[6] Ceccarelli, M.; Kotov, S.; Ofonaike, E.; Russo, M. Test Results and Considerations for Design Improvements of L-CADEL v.3 Elbow-Assisting Device. Machines 2024, 12, 808. https://doi.org/10.3390/machines12110808

[7] Morales-Cruz, C; Ceccarelli, M.; Ofonaike, E. Problems and conceptual design of a cable-actuated device for shoulder, elbow and wrist assitance. XXV Congreso Nacional de Ingeniería Mecánica en Anales de Ingeniería Mecánica, Santander, España. Code B-01 (Submitted 15-10-2024)

[8] Ceccarelli M., D'Onofrio M., Ambrogi V., Russo M., A numerical analysis of ventilation motion after chest surgery with a RESPIRholter device, Respiratory Medicine Case Reports, Volume 49, 2024, 102005, ISSN 2213-0071,https://doi.org/10.1016/j.rmcr.2024.102005.

[9] Ceccarelli, M., Patirelis, A., Ambrogi, V., Tacconi, F., Russo, M. (2024). A Laboratory Experimental Characterization of Surgical Rib Retraction. In: Montanari, R., Richetta, M., Febbi, M., Staderini, E.M. (eds) Engineering Methodologies for Medicine and Sports. EMMS 2024. pp. 63–74. Springer, Cham. https://doi.org/10.1007/978-3-031-63755-1_5

[10] Perugini N. and Russo M., "A monolithic tendon-driven continuum robot design for easy 3D printing and assembly," in IFToMM Italy 2024, Mechanisms and Machine Science, vol 163, Cham: Springer, 2024, pp.215-223. https://doi.org/10.1007/978-3-031-64553-2_25

[11] Kierbel C. G., Russo M., Mappa I., Rizzo G., and Ceccarelli M., "Requirements for robotic gynecologic surgery," in New Trends in Mechanism and Machine Science, Mechanisms and Machine Science, vol. 165, Cham: Springer, 2024, pp. 28-36. https://doi.org/10.1007/978-3-031-67295-8_4

[12] Cocconcelli, M., Ceccarelli, M. (2024). Italian Mechanism Models from Blotto Catalogue in Late XIX Century. Advances in Historical Studies, 2025 (inprint)

[13] Cuadrado Iglesias, J.I., Ceccarelli, M. (2024). Betancourt Synthesis for Three-Position Problem in Mechanism Design. In: Ceccarelli, M., Aslan Seyhan, I. (eds) Explorations in the History and Heritage of Machines and Mechanisms.. Springer, Cham. pp. 289–302. https://doi.org/10.1007/978-3-031-54876-5_21

[14] Gurramkonda H.S., Reconstruction of A Roman Vitruvius Crane, Bachelor Thesis in Engineering Sciences, Tor Vergata Rome, 19/07/2024

[15] Shine,K.I., Ceccarelli M., Experimental Performance Characterization of Torveastro Limb. In: Quaglia, G., Boschetti, G., Carbone, G. (eds) Advances in Italian Mechanism Science. IFToMM Italy 2024. Springer, Cham, pp.201-208. (2024). https://doi.org/10.1007/978-3-031-64553-2_23

[16] Ceccarelli M., Vaisson T., Russo M., Design and testing of a Cable-driven Finger Exoskeleton, MADPOI Applied Sciences, applsci-3273736, 2024 (in review)

[17] Torres San Miguel, C.R.; Perez Valdez, J.A.; Ceccarelli, M.; Russo, M. The Problems and Design of a Neck Dummy. Biomimetics 2024, 9, 661. https://doi.org/10.3390/biomimetics9110661

[18] Ceccarelli M., Santo L., Paoloni M., and Cupertino G: (editors), Design Advances in Aerospace Robotics – TORVEASTRO 2023, Springer Cham, 2023. https://doi.org/10.1007/978-3-031-28447-2

[19] Tuleshov, A., Jomartov, A., Ceccarelli, M. (eds) Advances in Asian Mechanism and Machine Science. Asian MMS 2024. Mechanisms and Machine Science, vol 167, pp.1-8. Springer, Cham. https://doi.org/10.1007/978-3-031-67569-0_0