Università di Roma Tor Vergata

UNIVERSITY OF ROME TOR VERGATA

LARM2: Laboratory of Robot Mechatronics
Department of Industrial Engineering

https://larm2.ing.uniroma2.it/

LaRM2 Tor Vergata

Challenges for Mechanism Design in Robotics

Marco Ceccarelli
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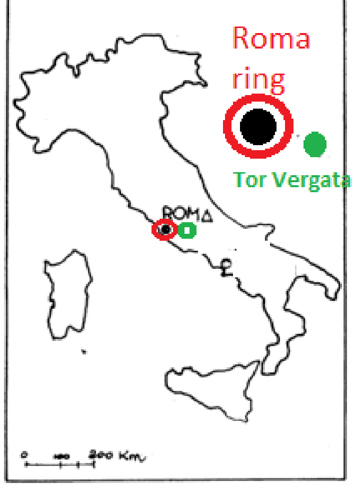
in technical aspects as connected with creativity
social aggregation in a well-identified technical-scientific community,
also thanks to the MEDER conference initiative.

central role of Mechanism Design
by considering purposes of assistance, support, or replacement of human operators with mechanical functional characteristics in motion and force.

in research activities in theory, design, application, and technology transfer



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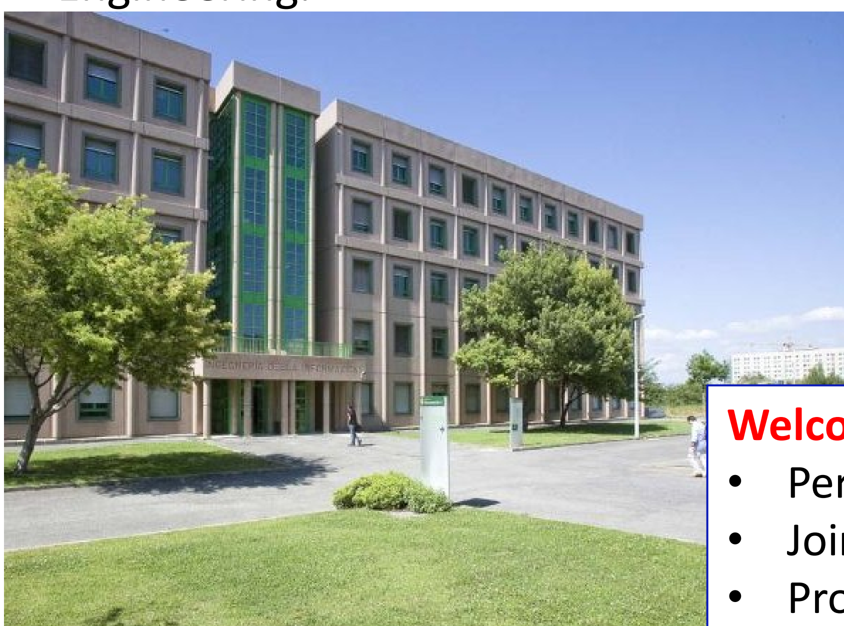
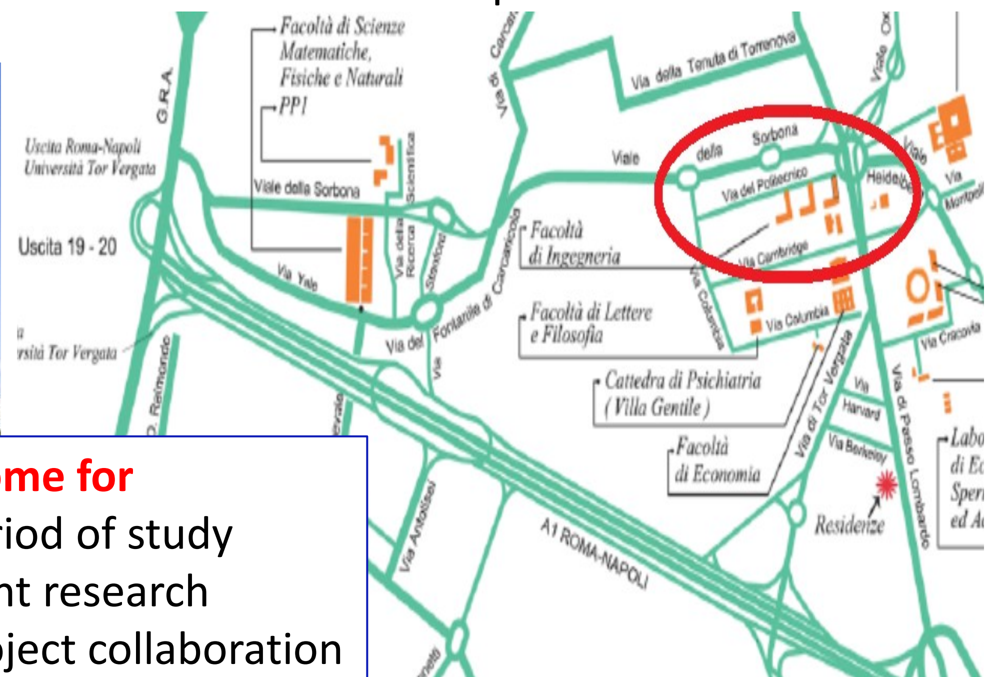
- The Laboratory of Robotics and Mechatronics (LARM) was founded in 1990 in Cassino
- Since March 2019 it is in Rome University Torvergata
- The aim of LARM2 is to develop experience, teaching, and research in the fields of Automation, Robotics and Mechatronics with main focus on aspects of Mechanical Engineering.





Welcome for

- Period of study
- Joint research
- Project collaboration

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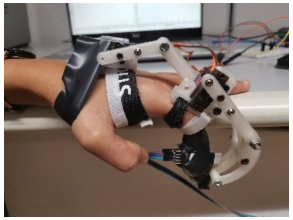
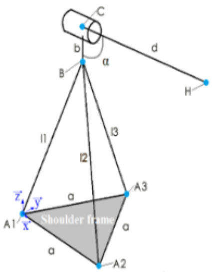
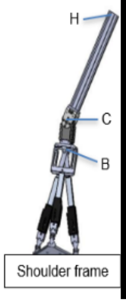
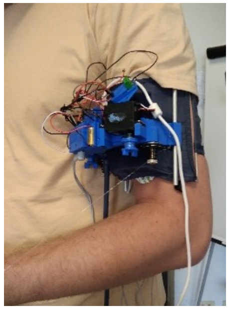


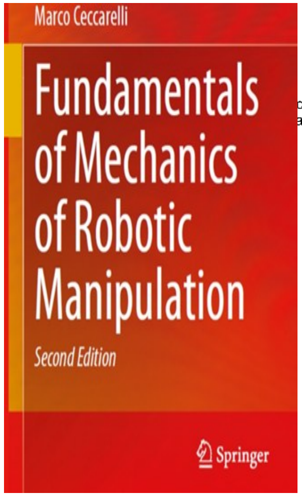


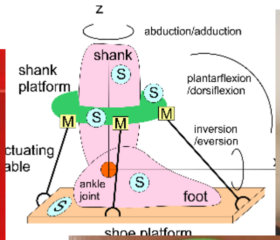


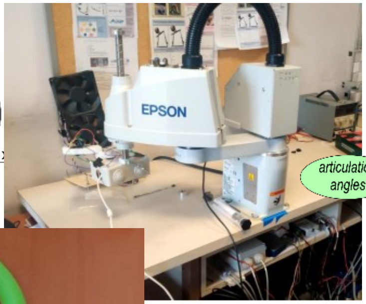
the activities at LARM2 in Rome are planned on topics and systems for collaborations in research and joint student formation

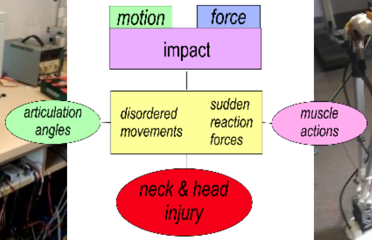
Special interests on Service Robotics, Medical Devices, Mechanism design, History of (mechanical) Engineering

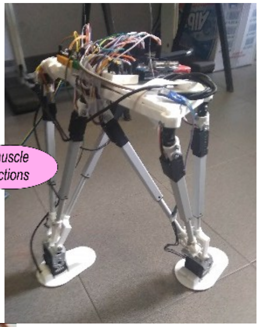












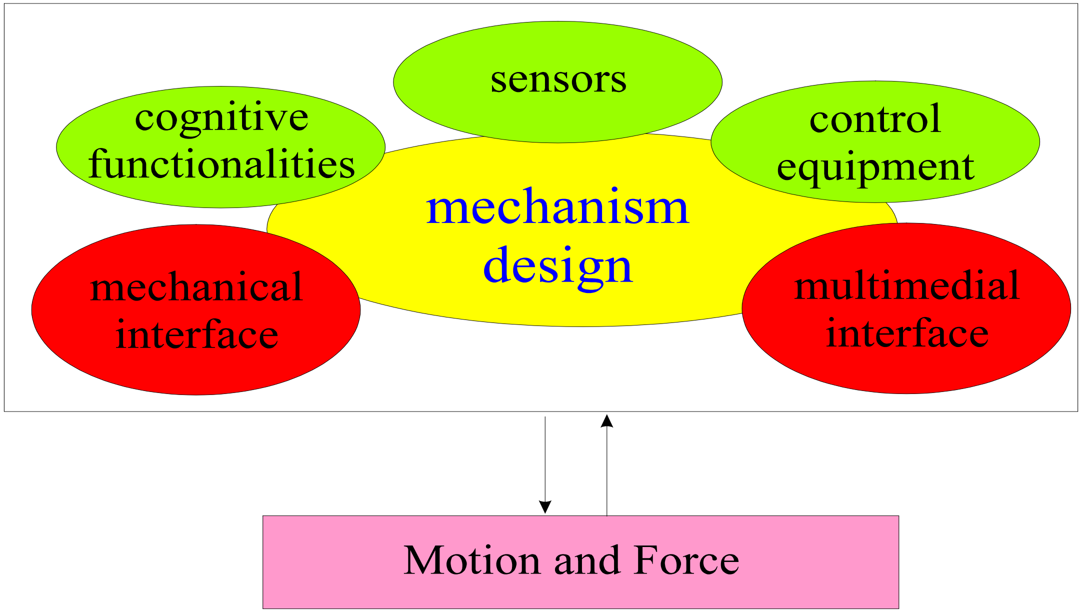
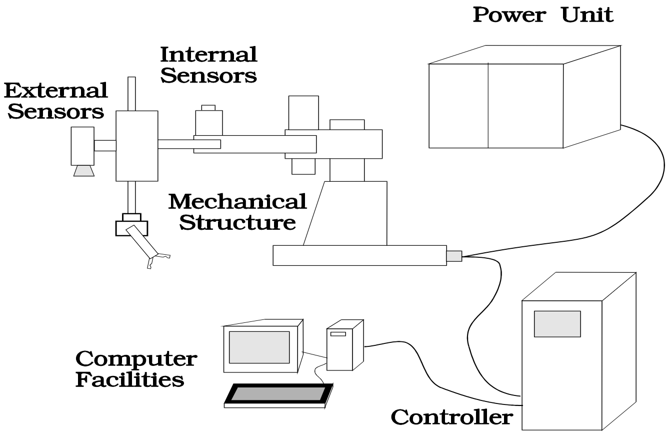


Fig. 1. General structure of modern mechatronic system



Mechanism: system of bodies designed to convert motions of, and forces on, one or several bodies into constrained motions of, and forces on, other bodies.

- Whatever Electronics, Informatics, Telecommunications and so on, will be enhanced and expanded in Mechatronics Technology, Mechanical Design will be always needed
- since a woman/man always lives and interacts with the environment on the basis of mechanical phenomena of the human nature

today machines with mechatronic design and operation that
it is often believed with performance not depending on mechanical aspects

It is indeed true that

- **mechanical components can be less and less**
- **even with reduced influence on the overall mechatronic design.**

Fundamental role of Mechanism Design in robotic devices

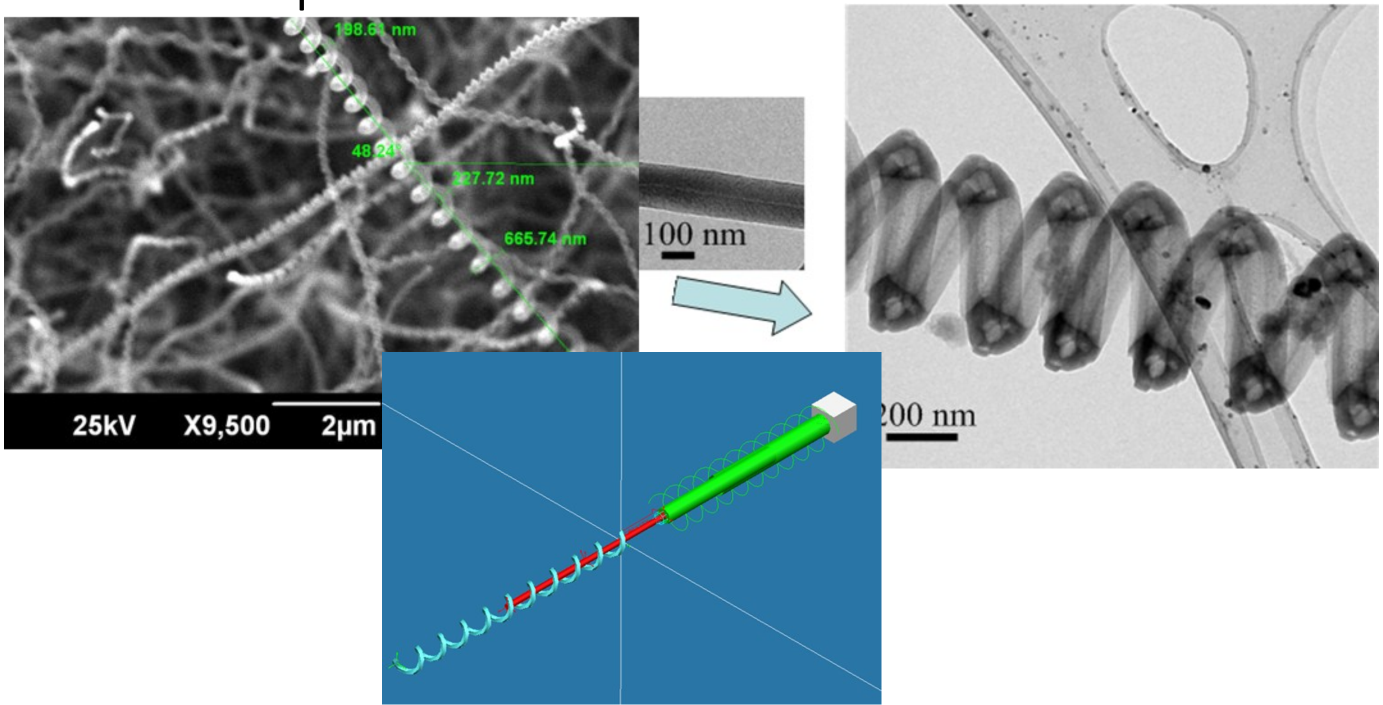
An example: photocamera

1960-2000	Mechanics %	Electronics/ Infcs %
CAR	90 - 50	10 - 50
CALCULATOR	100 - 10	0 - 90
CAMERA	100 - 30	0 - 70

Future: voice commands & digital zoom
But focus depends on distance and
shoot time depends on image velocity

Mechanism Design (even with ergonomic features)
- Handling the camera (also mechanism structure for fixed positioning)
- Operating the camera (push buttons)

An example: a nanosolenoid drive

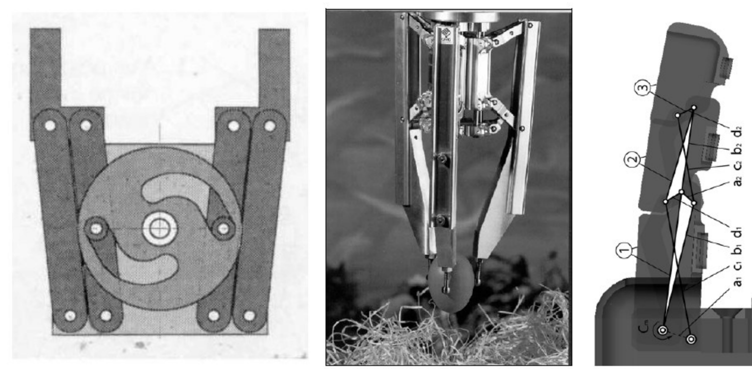


description	application
Constant-velocity one direction displacement	Constructing a nano-solenoid
Static action (pulling and pushing) in steady configuration	Inserting nano-parts
Continuous pushing (or pulling) while moving in one direction with constant velocity	Transporting parts
Alternate motion	for vibration generation
Alternate pulling and pushing	Force transmission to nano-arts

An example: industrial robots

Fig. 2. Examples of mechanisms in the structure of serial manipulator robots.

Fig. 3. Examples of parallel architectures in industrial robots



Examples of mechanism designs in grippers and fingers for artificial hands

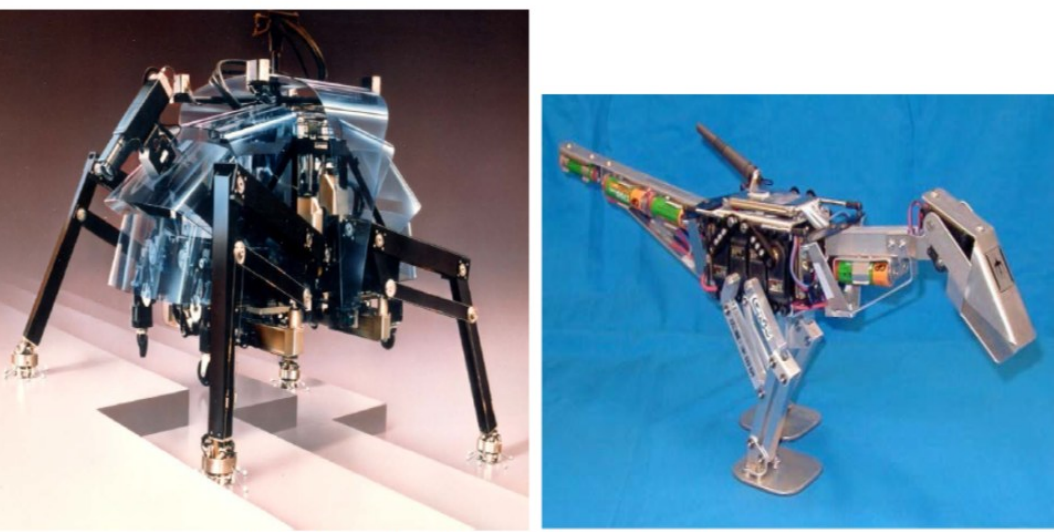


Fig. 5. Examples of leg mechanisms in walking robots

•Innovation can be started when a **technical idea or solution has potential** contents.

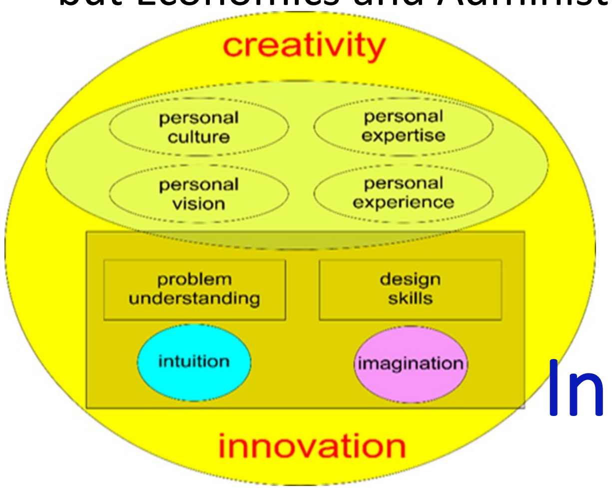
- initiators of innovation are designers or scientists with engineering skills,
- main exploiters are business experts or enterprise leaders, for market valorisation and users' acceptance.

•novel ideas but mainly when the knowledge transfer **reaches successfully the real world with users' acceptance**.

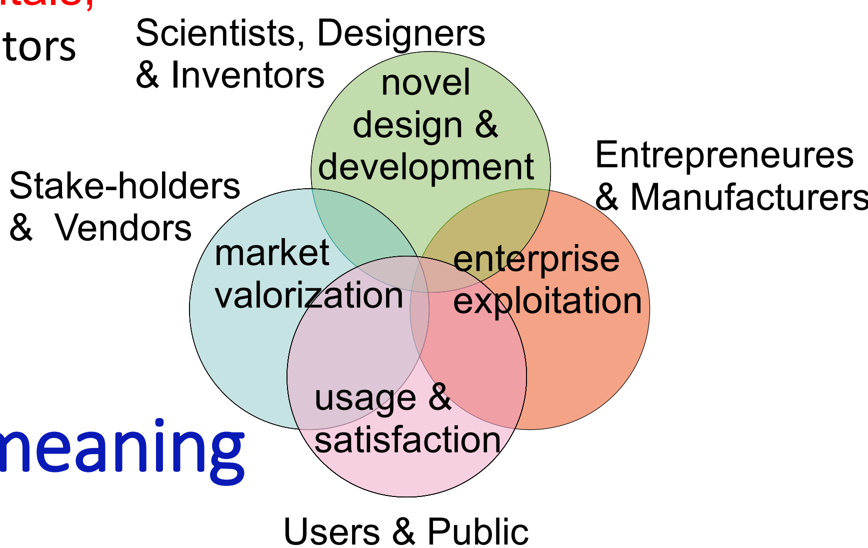
•a sequence of skills: when just one is weak or fails, the whole transfer process will fail.

•Science and Technology are the fundamentals,

•but Economics and Administration are the motors



Innovation meaning



•and Education and Publicity are final tools of Innovation.

•University frames in fundamentals and final tools

Education and Formation are essential areas both for conceiving new ideas and preparing users to the acceptance of those new ideas.

Challenges in Mechanism Design for Robotics

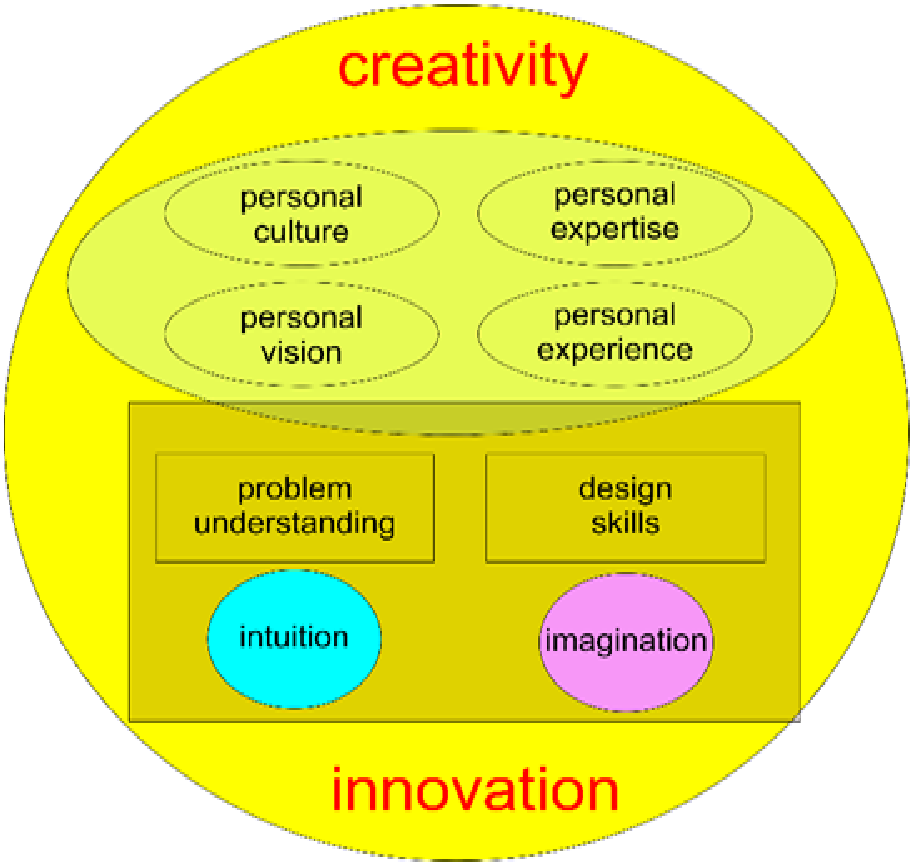


Fig. 2. Concepts for creativity producing new solutions (innovation)

mainly in the following topics:

- 3D Kinematics and its application in practical new systems and design methodologies
- Modelling and its mathematization
- Multi-d.o.f. multibody systems
- Spatial mechanisms and manipulators
- Unconventional mechanisms
- Solutions for new service applications
- Mechanisms at different sizes (from nano scale up to large platforms)
- Mechatronic designs with well integration and synergy of all components of different nature
- **Reconsideration and reformulation of theories and mechanism solutions**

- …

4. Trends for Mechanism Design in Robots

new problems can be identified for new solutions in :

- **topological mechanism structures, for new enhanced designs**
- **materials, for better mechanical design and environment interaction**
- **tribology issues, for reduction of wear and longer accurate functioning with limited friction**
- **energy sustainable solutions, for better attention to energy saving and recycling of wasted components**
- **contamination free conditions, for considering environment influence of operation and manufacturing of mechanisms**
- **….**

The short above lists want to indicate that

both new issues and reconsideration of existing solution and past experiences,
even with more subjects,
will be the focus for the challenges in the future mechanism design for robots
within increased mechatronic evolutions

Mechanism Design for mechatronic systems

Robotics has shown Innovation challenges and potentialities since the early days and nowadays is well recognized the impact that any further achievement in Robotics can have on the society improvements both in production aspects and in diary life quality.

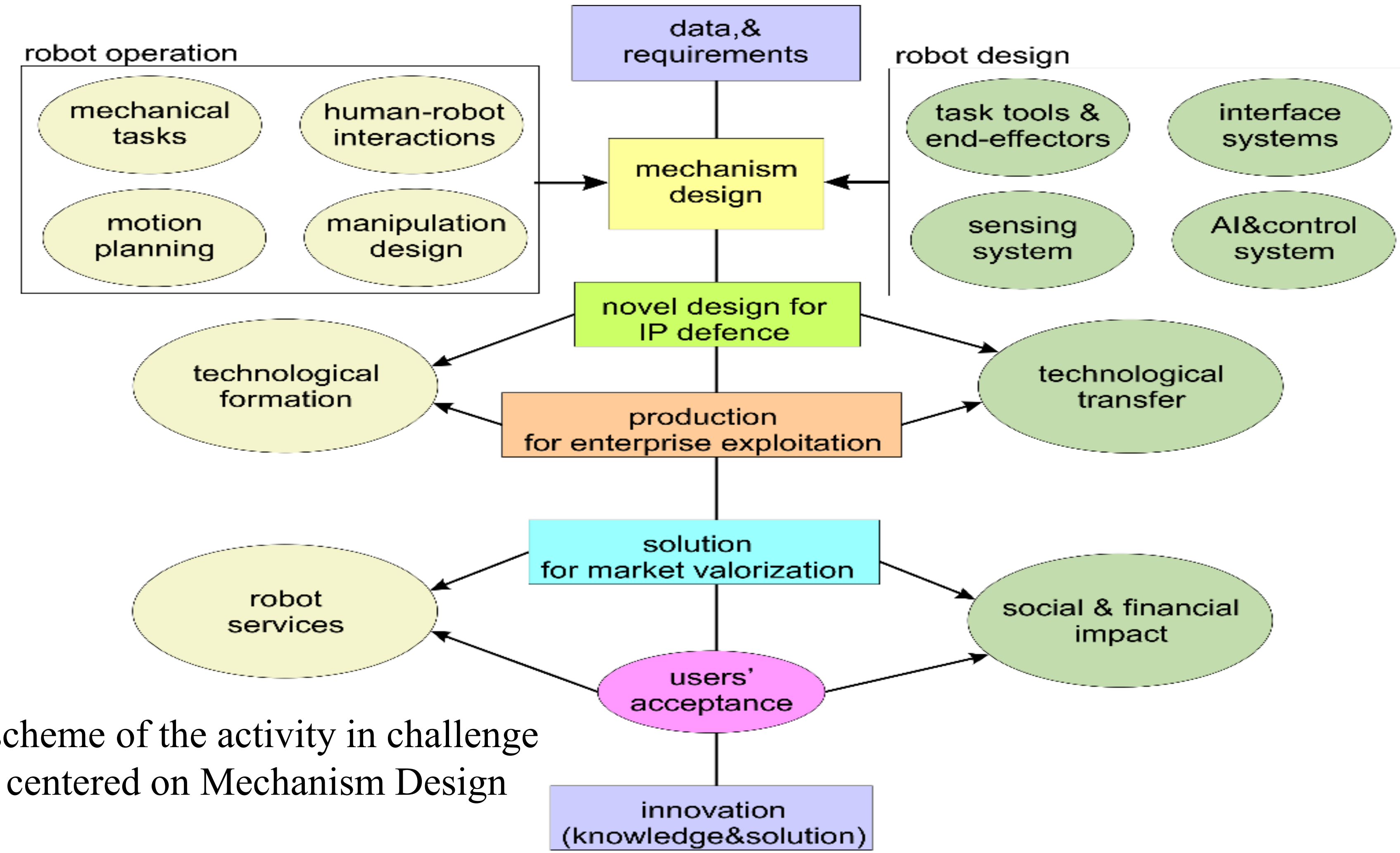
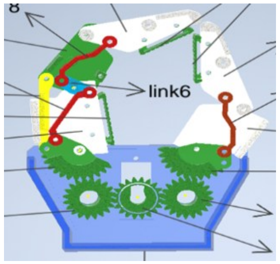


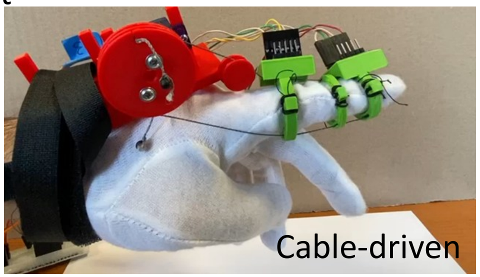
Fig. 2 A scheme of the activity in challenge activity centered on Mechanism Design

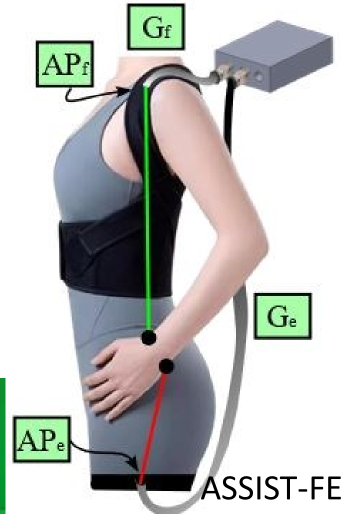
Research Activity– prototypes at LARM2

Mechanism Design, Robotics, medical devices, History of MMS

Underact&compliant







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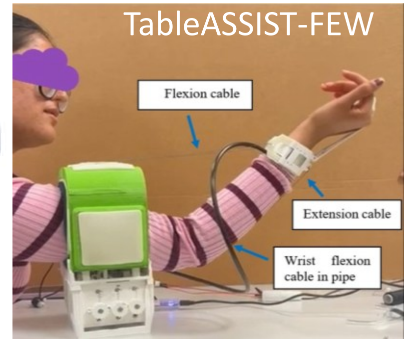
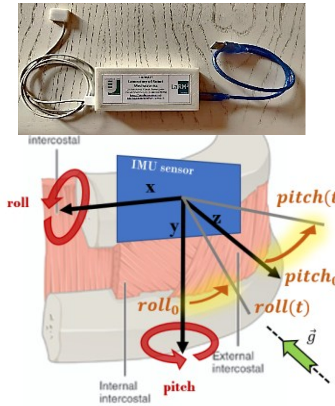




SENSIRIB &RESPIRholter

LARMbot

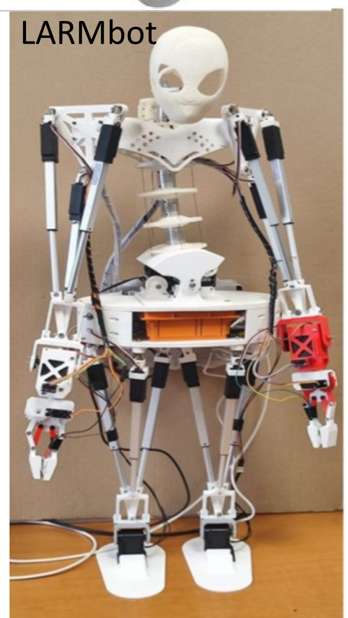
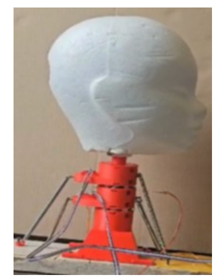
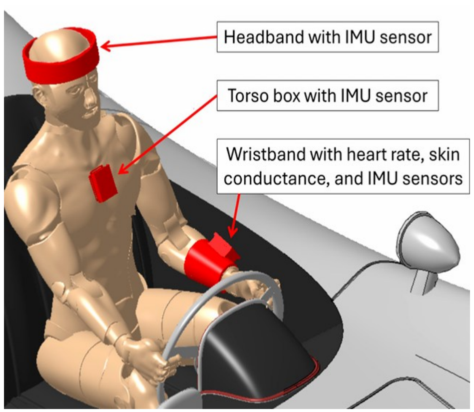


Figure 4.19: The LARMBOT humanoid robot V3.



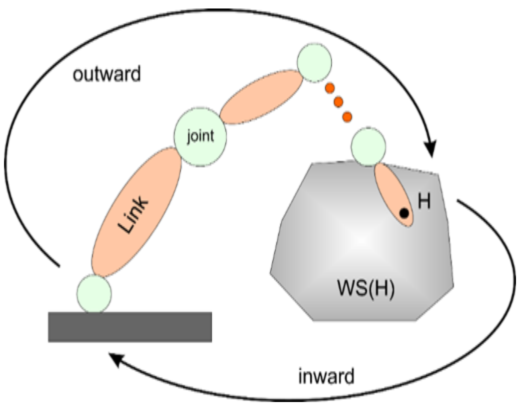
TORVEASTRO astronaut

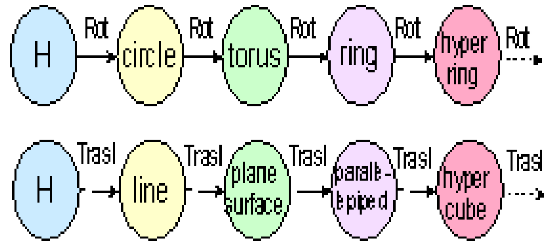


and much more ....

with students and international collaborations

workspace of manipulators





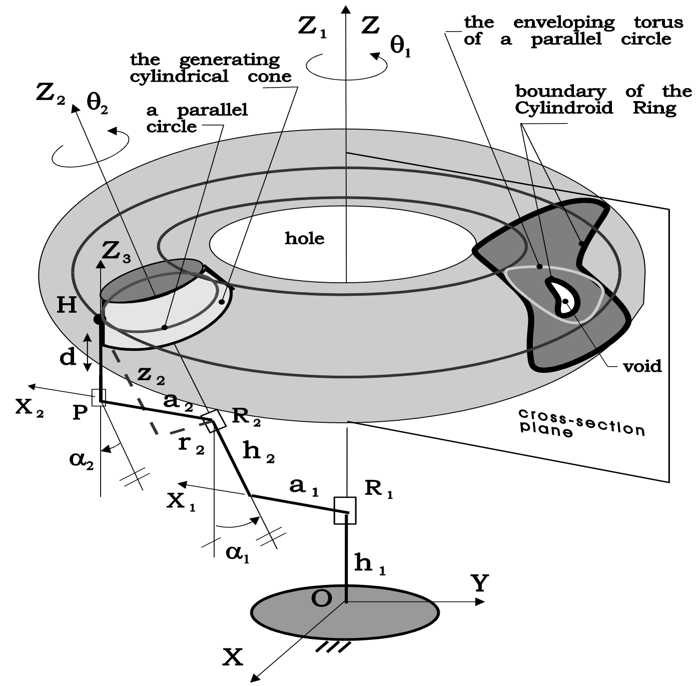


Fig. 4. A scheme for generation of the workspace of manipulators: a) using Direct Kinematics in outward and in-ward algorithms; b) from generating loci in Descriptive Geometry based approach

$$W_{3R}(H) = \bigcup_{\vartheta_3=0}^{2\pi} T_{R_1R_2}(H)$$

$$W_{3R}(H) = \bigcup_{\vartheta_3=0}^{2\pi} T_{R_1R_2}(H)$$

$$z = \frac{-B'D' \pm A'\sqrt{-\left[B'^2 + B\left(A'^2 + D'^2\right)\right]}}{\left(A'^2 + D'^2\right)C} - \frac{D}{C} \qquad r = \sqrt{\frac{B' + (Cz + D)\,D'}{A'} + A - z^2}$$

$$A' = 2\,(d + h_2 \cos\alpha_2); \quad B' = -4\, a_1^2\, d \sin^2\alpha_2 \;\; ; \quad D' = -2\, a_1 \cos\alpha_2 \frac{\cos\alpha_1}{\sin\alpha_1}$$

workspace of parallel manipulators

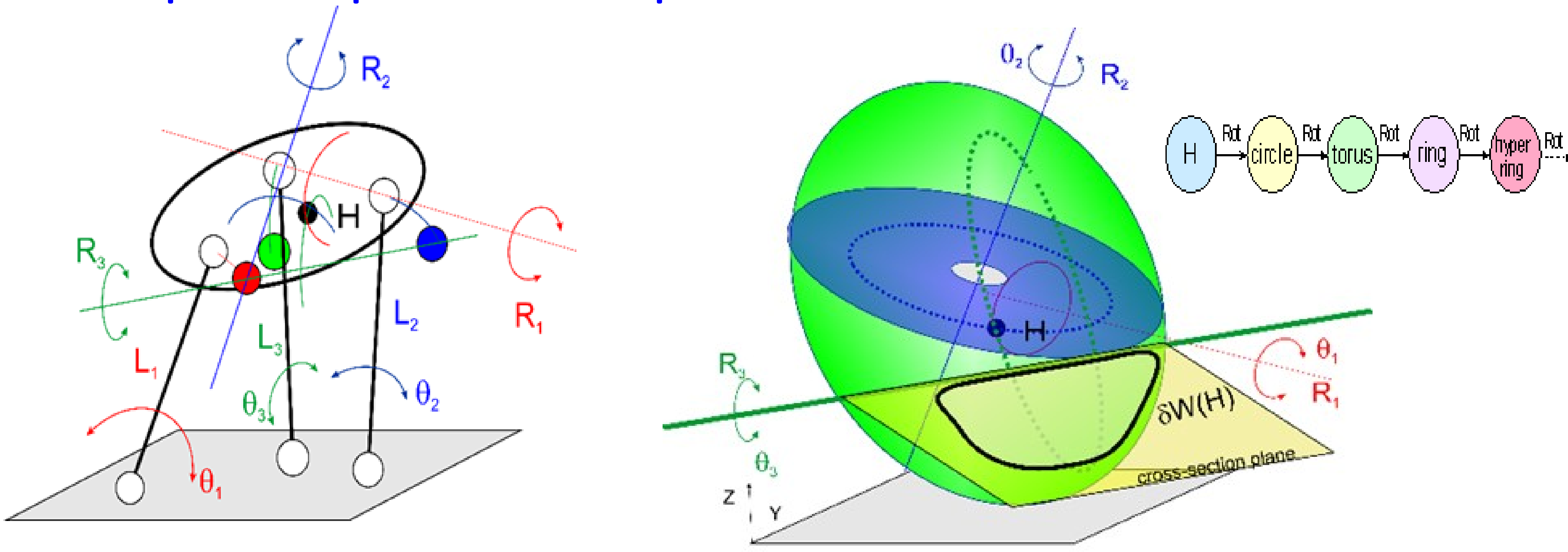
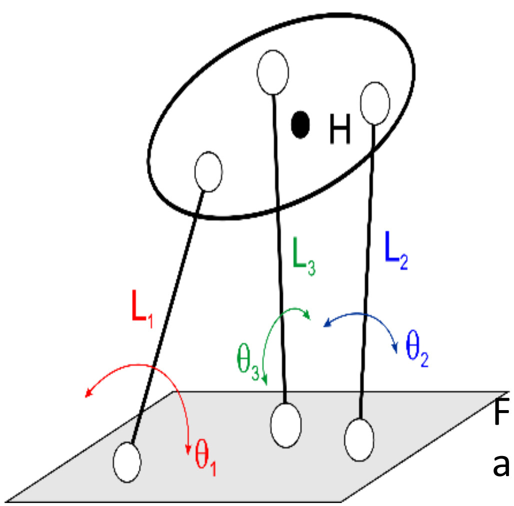
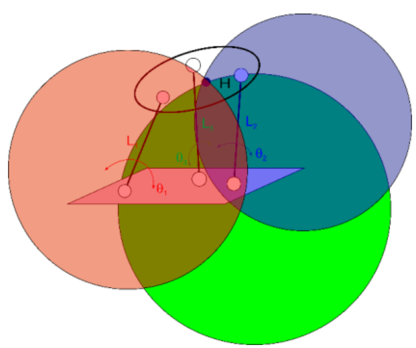


Fig. 5. A scheme for workspace generation of a 3RS parallel manipulator: a) the sequence of limb motions; b) a general topology of the generated workspace





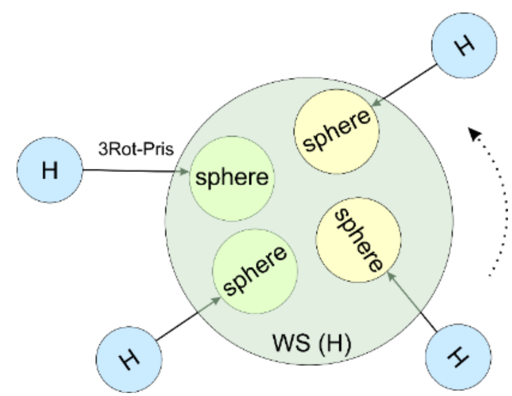


Fig. 4. A scheme for workspace generation of a 3RS parallel manipulator: a) the simultane-ous limb motions; b) general topology of the generated workspace as intersection of spheres

humanoid robot as based on mechanism design

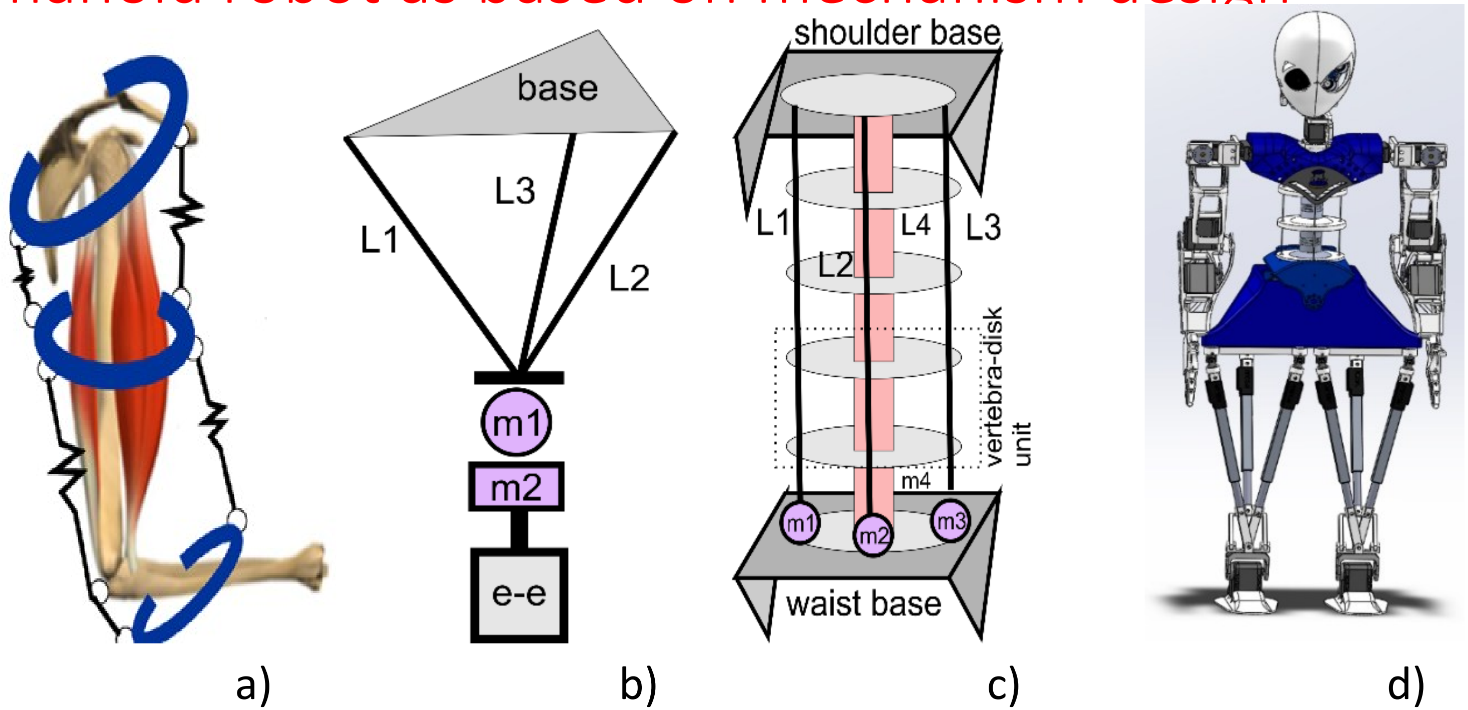
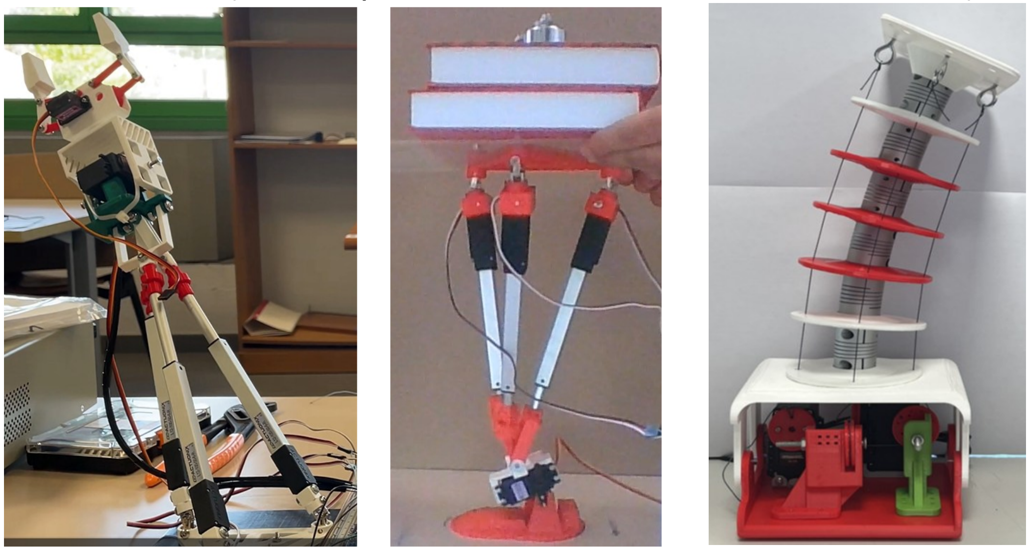
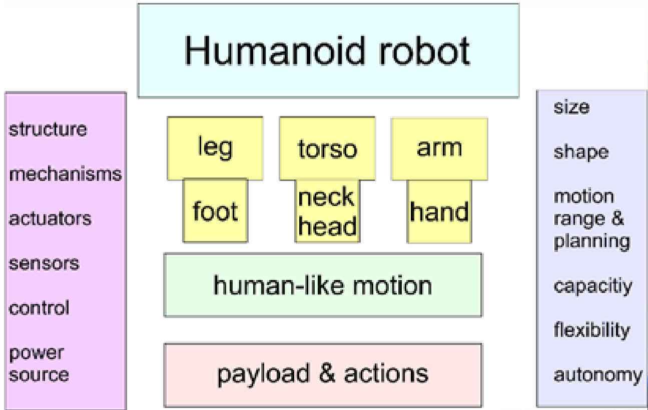
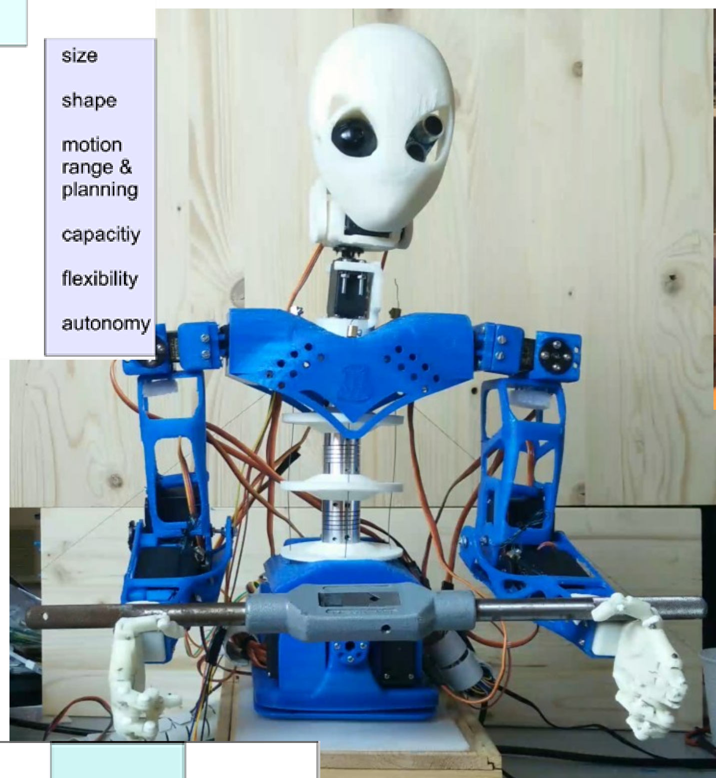


Fig.6. LARMbot humanoid design, [16-18]: a) inspiration from the human musculoskeletal anatomy; b) tripod architecture for limbs; c) serial-parallel mechanism for the torso; d) a CAD design of the full assembly



LARMbot Humanoid





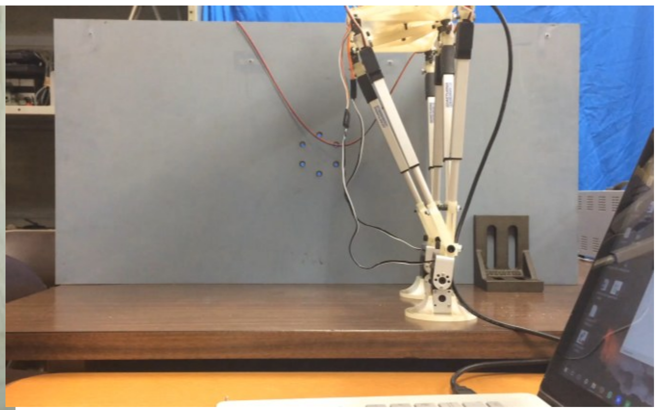
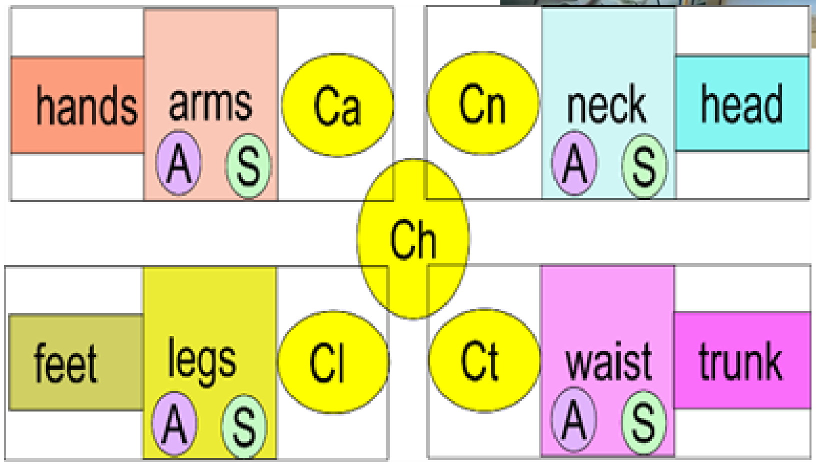
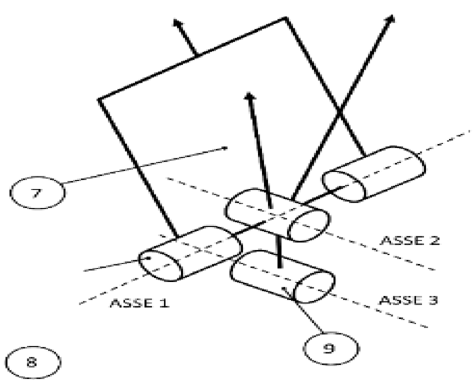
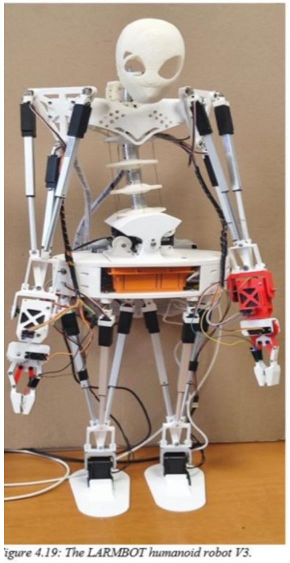


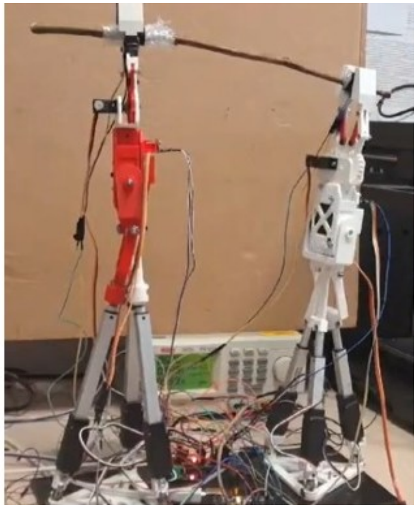
Fig. 7. A scheme for modular design of LARMbot humanoid: a) general functionality; b) mechatronics solution

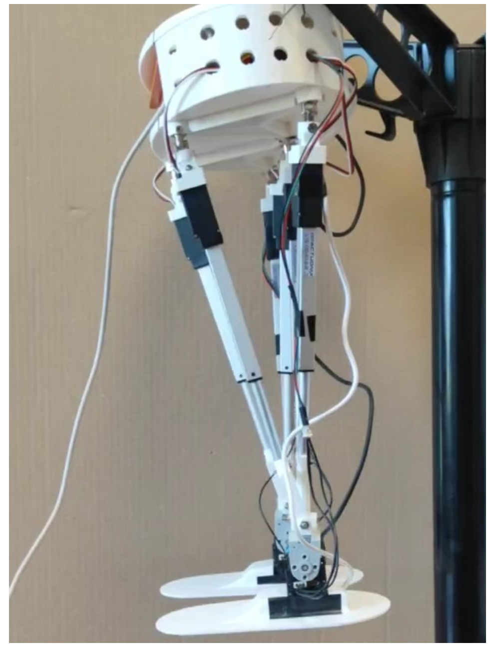


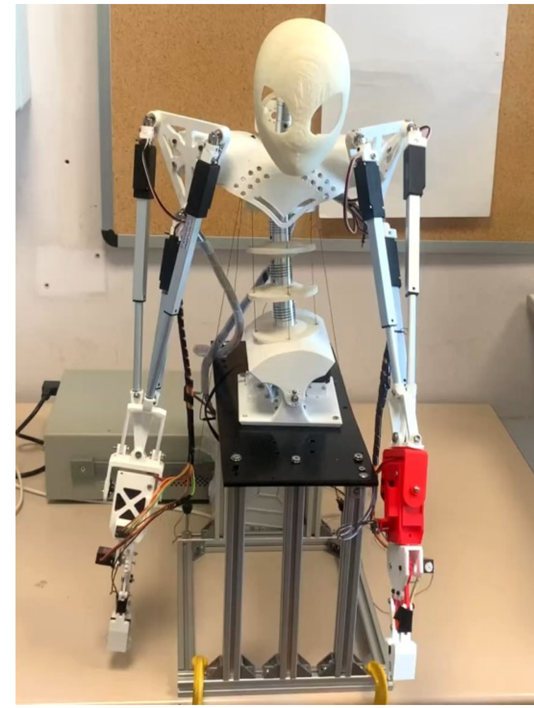


LARMbot humanoid robot









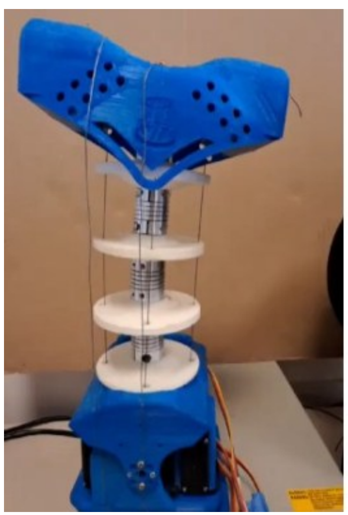
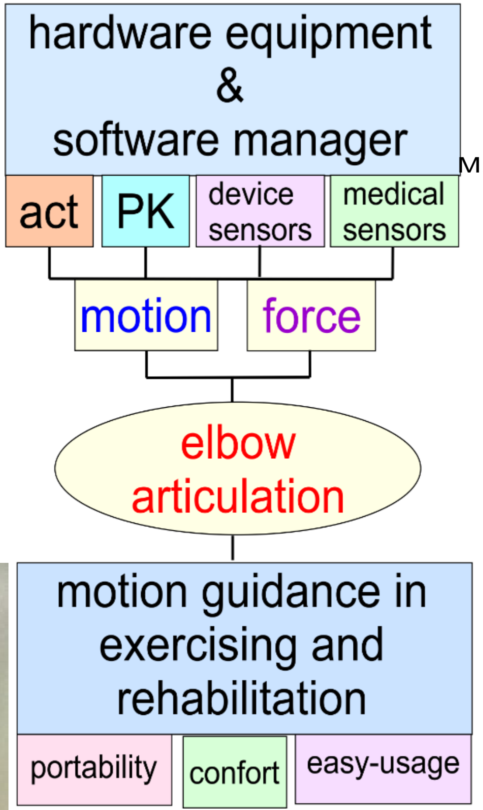
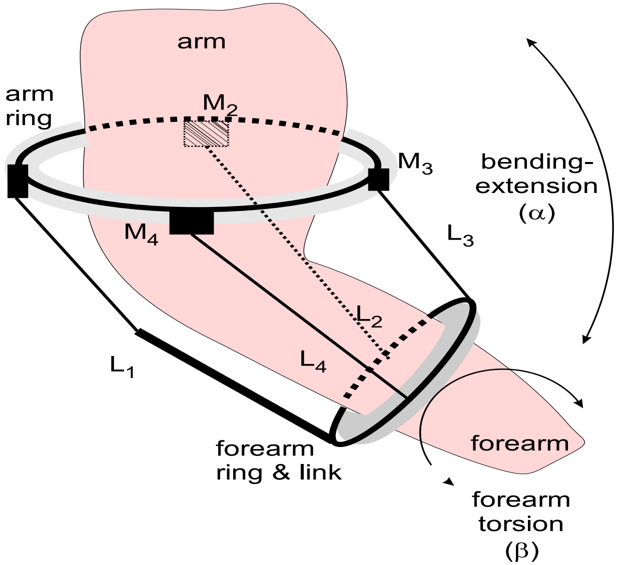


Figura 5: LARMbot humanoid robot:
substructures under development for dual arm unit, torso unit, and leg unit

CADEL design for elbow motion assistance Original design in 2017

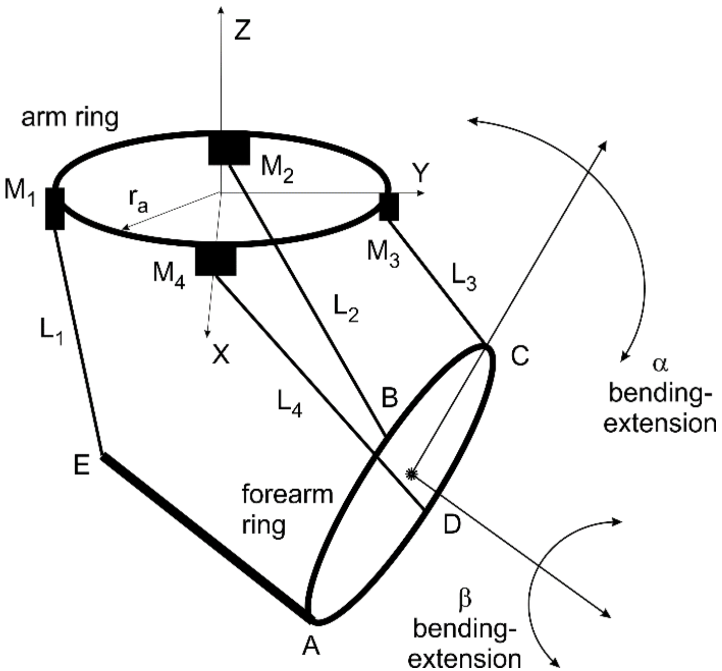
low-cost, easy wearable, low power consumption, user-orented operation…





Iarco Ceccarelli, Lucia Ferrara and Victor Petuya, Design of a cable-driven device for elbow rehabilitation and xercise,)In: Interdisciplinary Applications of Kinematics, pp. 61-68, Springer AG 2019, Cham 2019, https://doi.org/10.1007/978-3-030-16423-2_6

Modelling and computations - for motion planning



The cable length L_1 is given by the norm of vector $\mathbf{M_1E}$ as

$$\mathbf{M_1E} = \mathbf{M_1O} + \mathbf{OE}$$

$$\mathbf{M_1E} = \begin{bmatrix} 0 \\ -r_a \\ h_a \end{bmatrix} + \mathbf{R}(\alpha, \mathbf{x})\mathbf{R}(\beta, \mathbf{y}) \begin{bmatrix} 0 \\ -r_a \\ -r_b \end{bmatrix}$$

where, $\mathbf{R}(\alpha,\mathbf{x}) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\alpha & -\sin\alpha \\ 0 & \sin\alpha & \cos\alpha \end{bmatrix}$ and $\mathbf{R}(\beta,\mathbf{y}) = \begin{bmatrix} \cos\beta & 0 & \sin\beta \\ 0 & 1 & 0 \\ -\sin\beta & 0 & \cos\alpha \end{bmatrix}$ are the rotation matrices around $\mathbf{x}$ and $\mathbf{y}$ axes, respectively.

$$L_1 = \sqrt{(r_a + r_a\cos\alpha - r_b\sin\alpha)^2 + (r_b\cos\alpha - h_a + r_a\sin\alpha)^2}$$

$$L_2 = \sqrt{\left(h_a + h_f\sin\alpha - r_a\sin\alpha\right)^2 + (\cos\alpha)^2\left(h_f - r_a\right)^2 + (r_a + r_b)^2}$$

$$L_3 = \sqrt{\left(h_a + r_b\cos\alpha + h_f\sin\alpha - r_a\sin\alpha\right)^2 + \left(r_a + h_f\cos\alpha - r_a\cos\alpha - r_b\sin\alpha\right)^2}$$

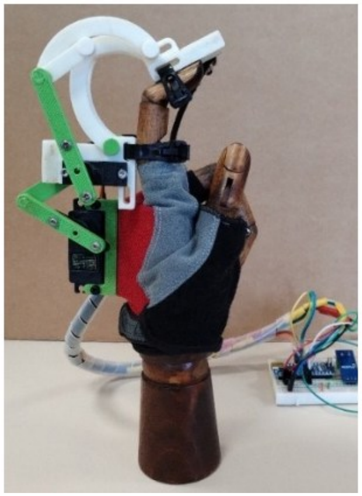
$$L_4 = \sqrt{\left(h_a + h_f\sin\alpha - r_a\sin\alpha\right)^2 + (\cos\alpha)^2(h_f - r_a)^2 + (r_a + r_b)^2}$$

- for cable tension

$$\mathbf{w}_e = \mathbf{J}^T\mathbf{T}$$

$$\mathbf{J}^T = \begin{bmatrix} \mathbf{u}_1 & \mathbf{u}_2 & \mathbf{u}_3 & \mathbf{u}_4 \\ \mathbf{R}_o \cdot \mathbf{O}_b\mathbf{E} \times \mathbf{u}_1 & \mathbf{R}_o \cdot \mathbf{O}_b\mathbf{B} \times \mathbf{u}_2 & \mathbf{R}_o \cdot \mathbf{O}_b\mathbf{C} \times \mathbf{u}_3 & \mathbf{R}_o \cdot \mathbf{O}_b\mathbf{D} \times \mathbf{u}_4 \end{bmatrix}$$

Motion assisting devices



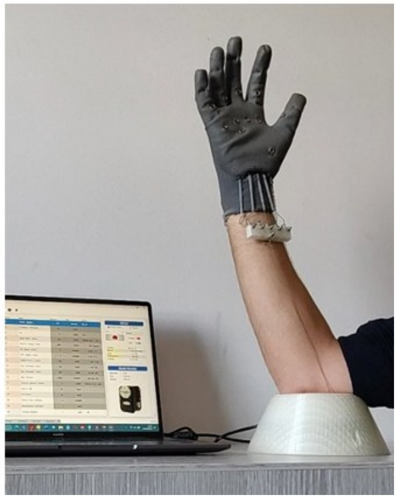
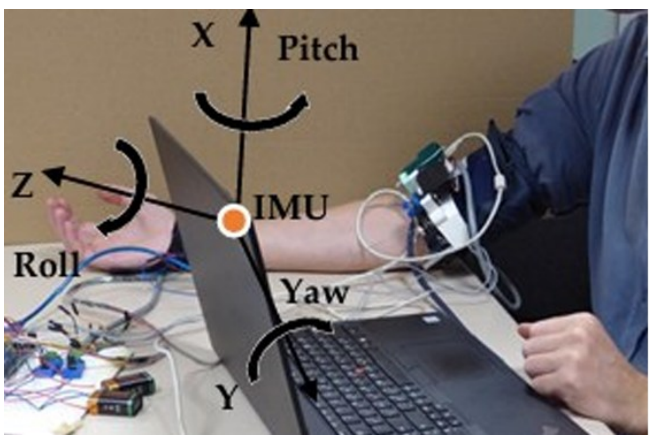


Figura 6: Finger exoskeletons



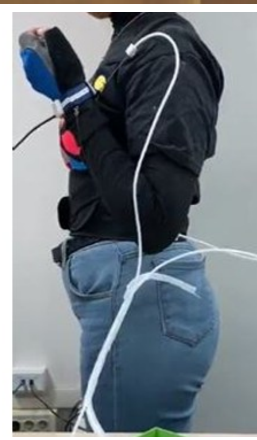


Figura 7: Prototypes of motion assisting devices: a) L-CADELr.v3, [6]; b) ASSIST-FEE.v3, [7]

Continuum mechanisms

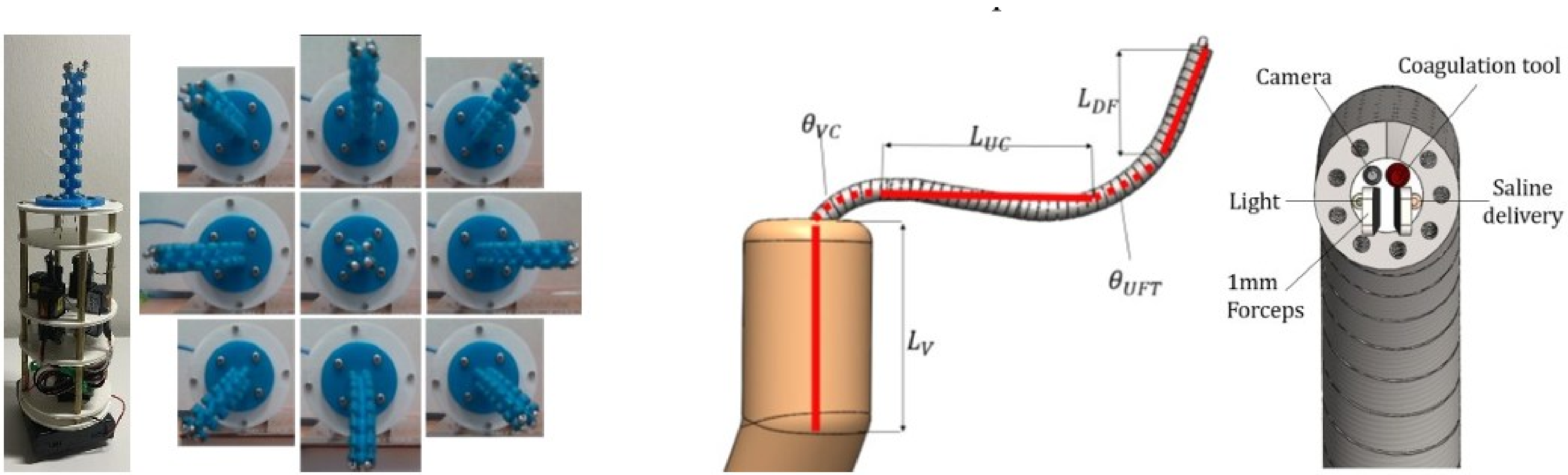


Figura 9: Continuum prototypes: a) 3D printed monolithic continuum robot, [10]; b) a conceptual design for gynecological tissue sampling, [11]

Mechanisms in past designs and procedures

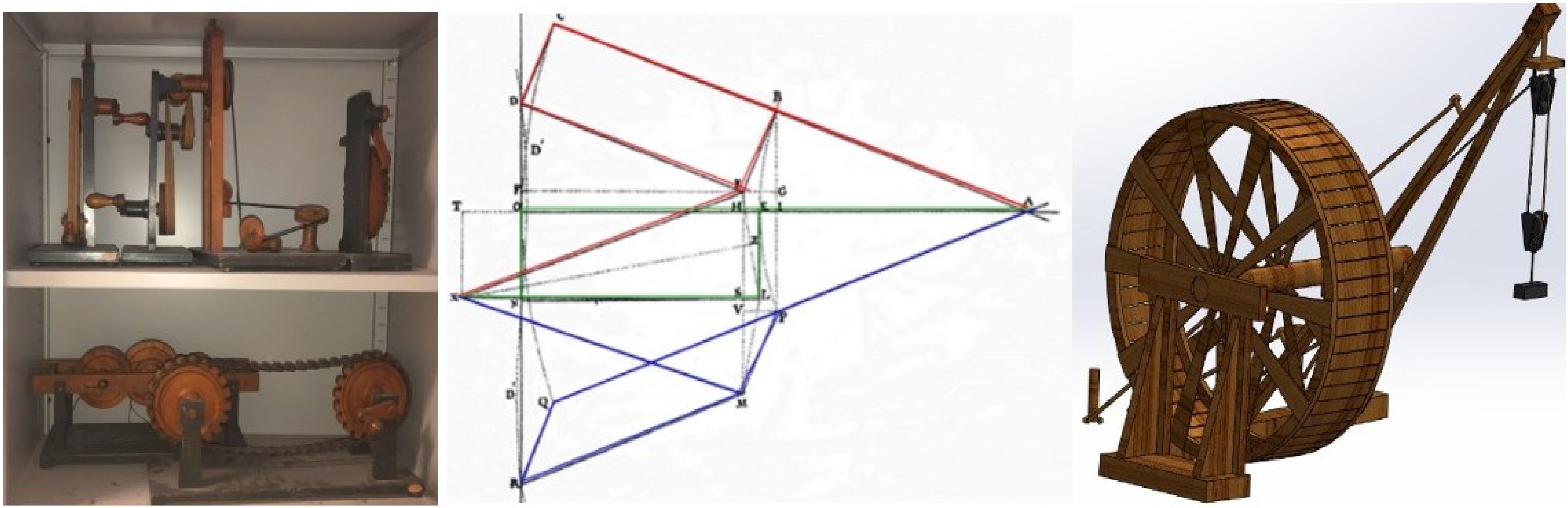
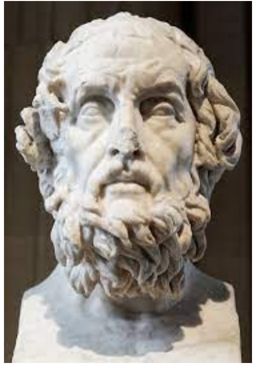


Figura 10: Examples of findings in history of MMS:

a) stored mechanism models in Bologna, [12];
b) a scheme of the Betacourt mechanism synthesis in 1789, [13],
c) a CAD reconstruction of a Vitruvian crane, [14]

First robots



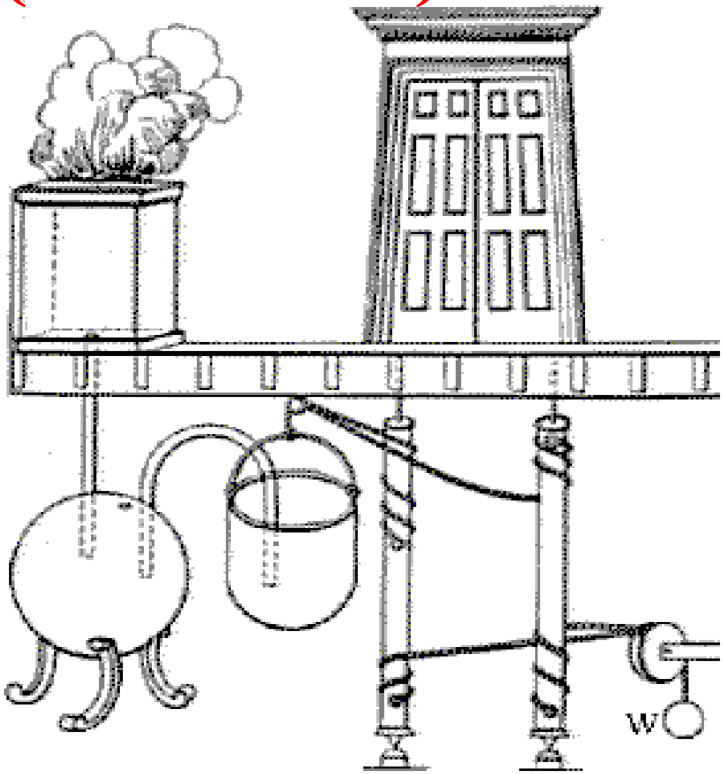
Concepts

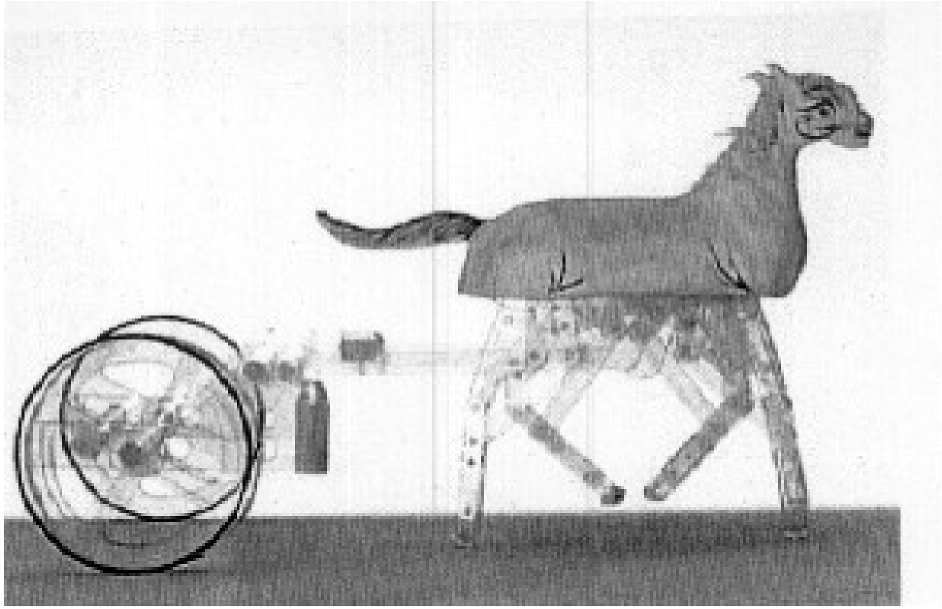
- In the Iliad, (*Il. 18.369–377*). Hephaestus building a number of **wheeled tripods capable of moving by themselves back and forward** serving food to the gods (*Il. 18.369–377*).

- In the Odyssey, (Od. 7.78–94)., **two guardian-mastiffs** made of gold and silver, by Hephaestus, were the doorkeepers of the magnificent palace of King Alcinous in Phaeacia. invulnerable against assaults

- In the Iliad, (Il. 18.410–422)., Hephaestus was using **two "female" robots as personal assistants**, who supported him with his work in the forge and 'had voice and sense'

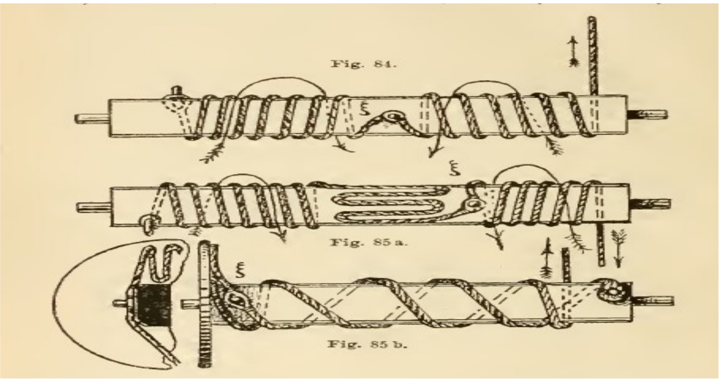
Examples of ancient robot designs (automata)





a) Chinese mechanical cow from the 5th century BC;

b) b) automatic opening system of Heron of Alexandria doors of the 3rd century c.;



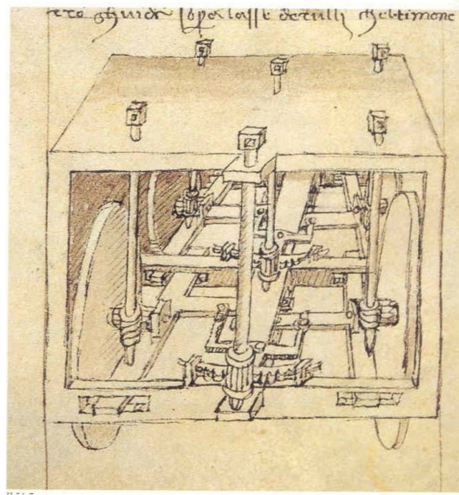
Heron

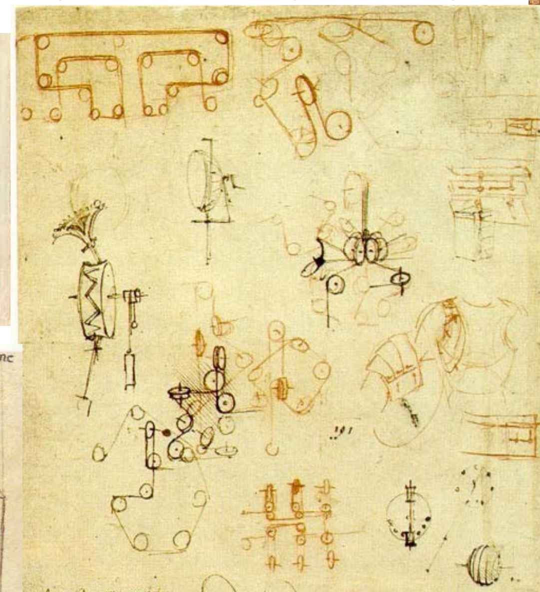
Examples of robot designs & their inventors

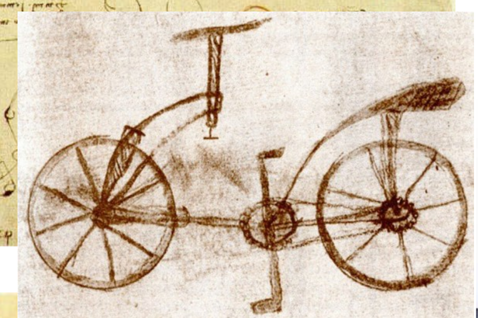
Mariano di Jacopo (il Taccola) (1381? - 1458)

Francesco di Giorgio (1439-1501)

Leonardo da Vinci (1452-1519)





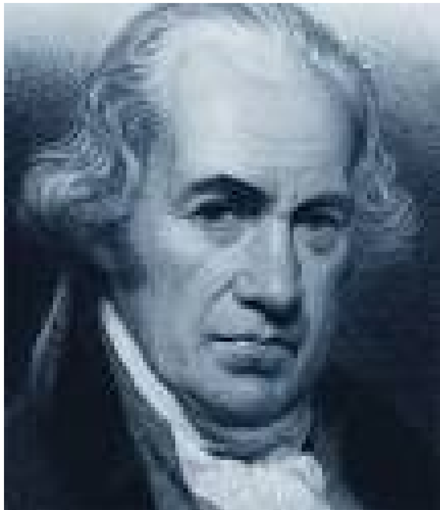


Theory: machine/robot elements

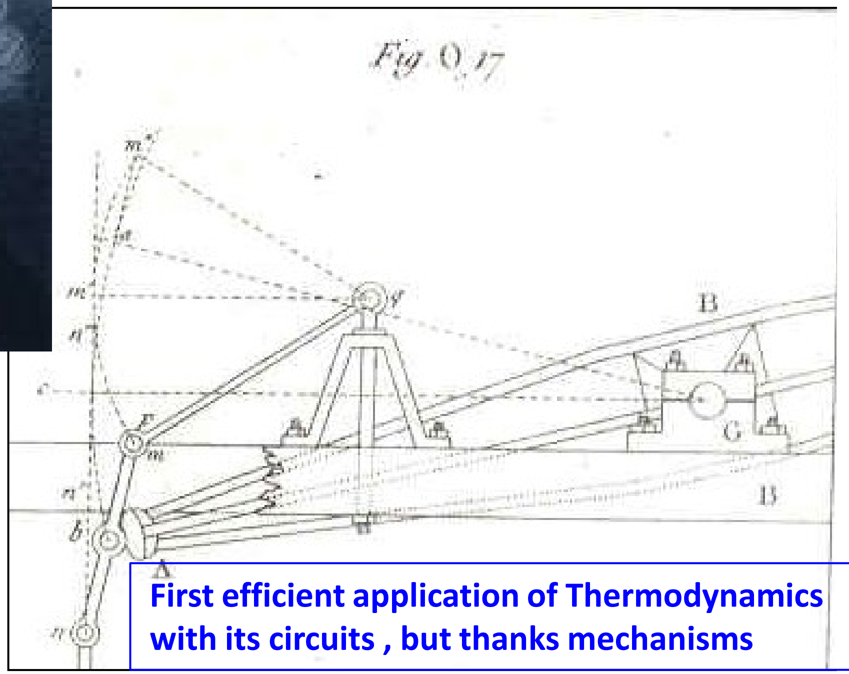
prominent Renaissance figure

- **for polyhedral activity**
- **showing a modern character of scientist**
- **in accumulating experience and dissemination knowledge.**

Examples of machines and their inventors



James Watt



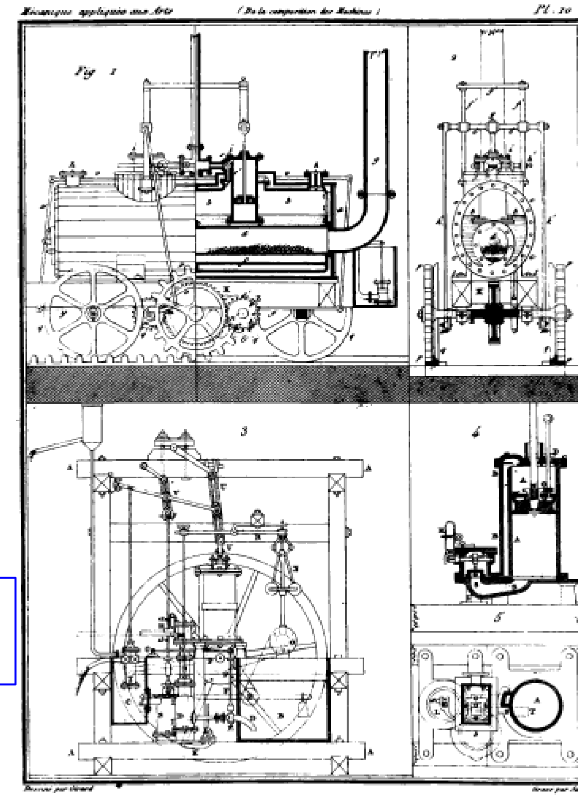
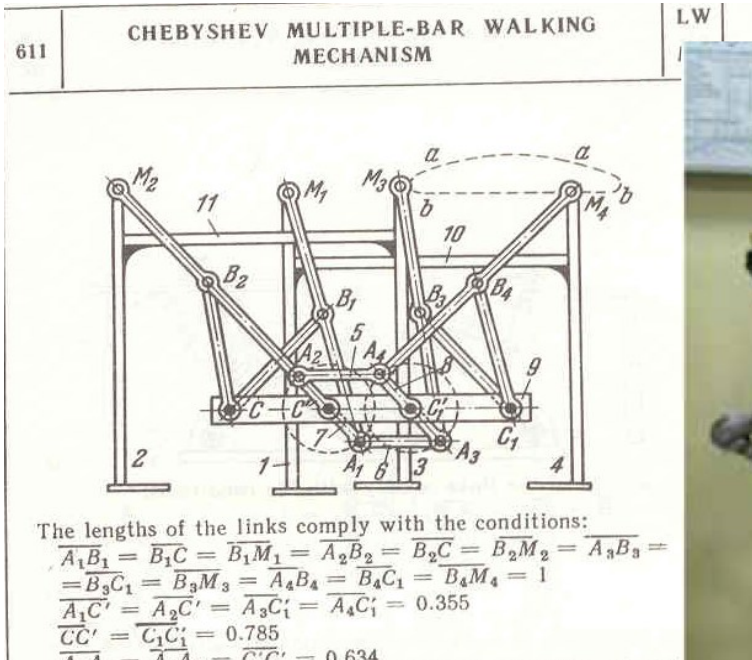


Fig. 2 Past innovation with Watt mechanism:

a) early kinematic study of kinematic properties in the book by Lanz and Betancourt in 1808;

b) applications for locomotives (top) and industrial plants (bottom) in the book on Composition of Machines by G.A. Borgnis in 1818.

xamples of machines & their inventors



611 | CHEBYSHEV MULTIPLE-BAR WALKING MECHANISM | LW

The lengths of the links comply with the conditions:

$$\overline{A_1B_1} = \overline{B_1C} = \overline{B_1M_1} = \overline{A_2B_2} = \overline{B_2C} = \overline{B_2M_2} = \overline{A_3B_3} = \overline{B_3C_1} = \overline{B_3M_3} = \overline{A_4B_4} = \overline{B_4C_1} = \overline{B_4M_4} = 1$$

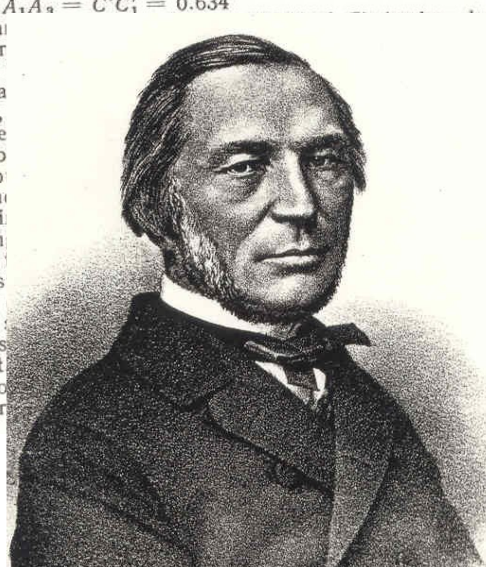
$$\overline{A_1C'} = \overline{A_2C'} = \overline{A_3C'_1} = \overline{A_4C'_1} = 0.355$$

$$\overline{CC'} = \overline{C_1C'_1} = 0.785$$

$$\overline{A_2A_4} = \overline{A_1A_3} = \overline{C'C'_1} = 0.634$$

The mecha… shaped par… $C'_1A_4B_4C_1$. parallel-cra… points M_1, … a shape re… straight po… and 8 thro… "feet" 1 an… is moved i… the drawin… remain on … and 4 are s… of motion … leave the … begin the s… will be st… direction o… repr…

…mbd …1 ar… for … then …ves of …nately …anks 7 … 10 are …ame 9 …own in …nd M_4 …feet" 1 …ection …nd M_4 …nd M_3 … and 3 …ng the …ems to



Pafnutii Livovich Chebyshev
(1821-1894)

Very early
tele-manipulator

Ivan I. Artobolevski
(9.10.1905 -21.9.1977)

Examples of machines and their inventors

Raymond Clavel

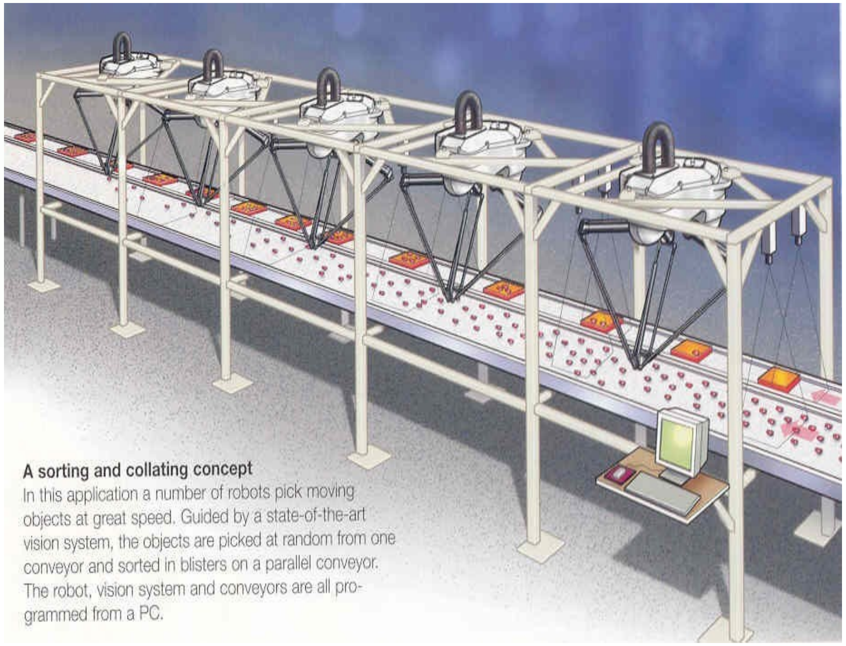
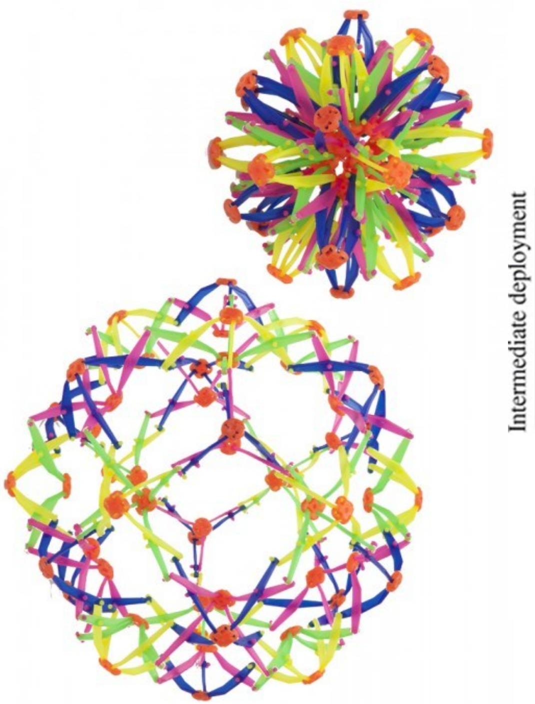


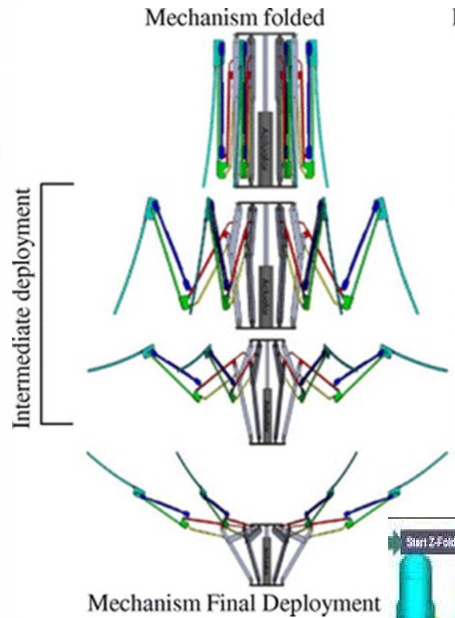
Fig. 3 **Delta parallel manipulator**

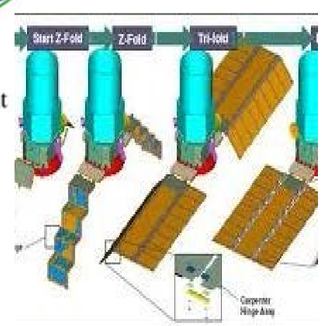
…designed in 1988:

a) **the ABB commercialized version;**
b) **b) industrial application for fast pick & place packaging**

New technical solutions in exploitations in different areas

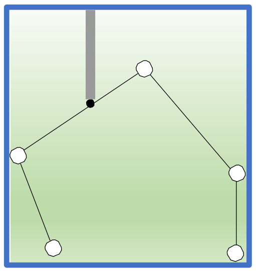


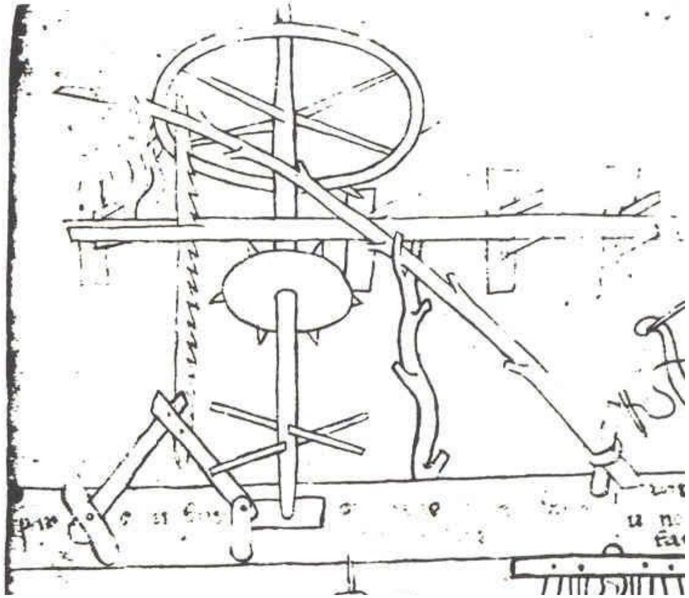


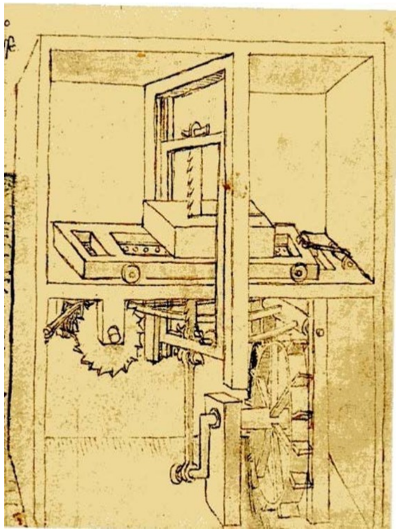


Deployable mechanisms in innovative applications:
a) in toy design; b) for space antenna structures; c) in load lifters for civil engineering

What we develop today …. Is really innovative solution?



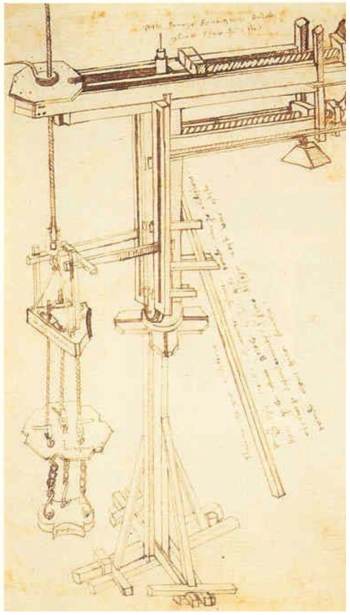


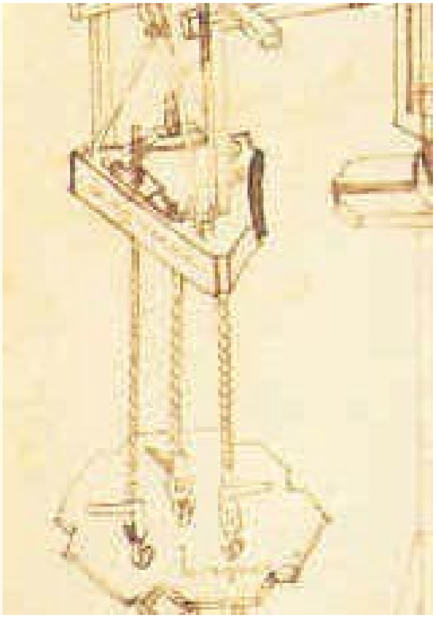


Early modern mechanisms:

*a) 2dof linkage with coupler guiding point by **Villard de Honnecourt** in13th century;*

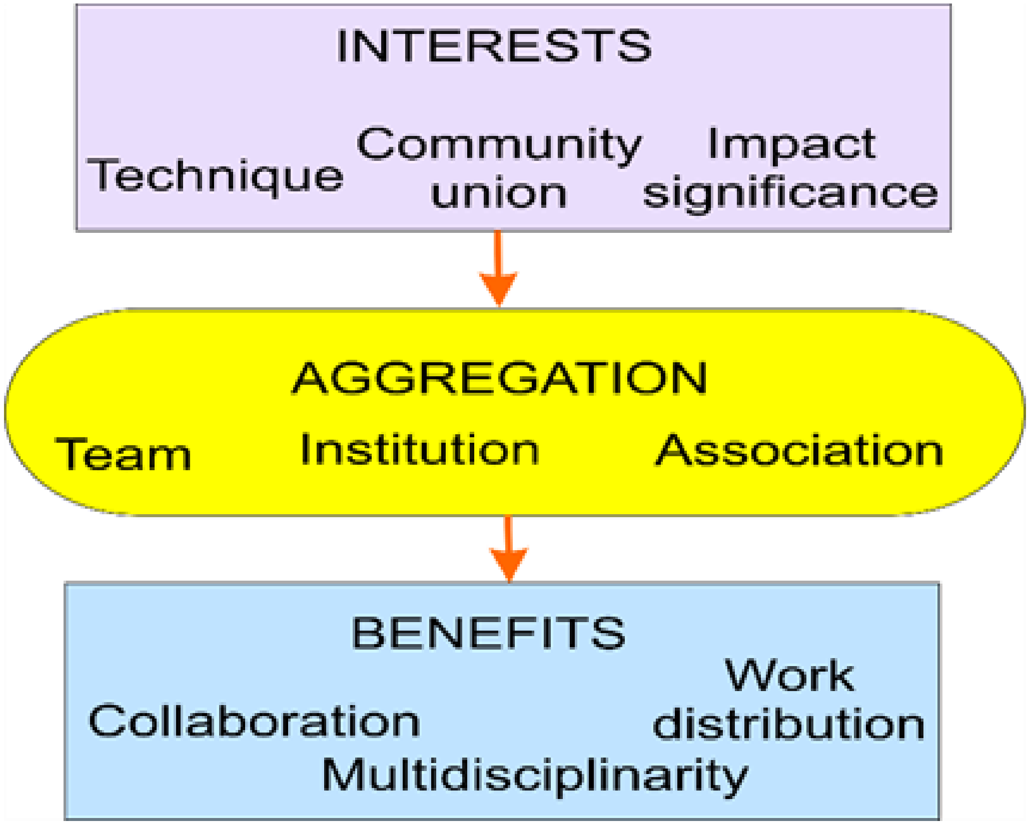
b) Machien design by Francesco di Giorgio





*a) cable-based parallel manipulator by **Filippo Brunelleschi** (1377-1446).*

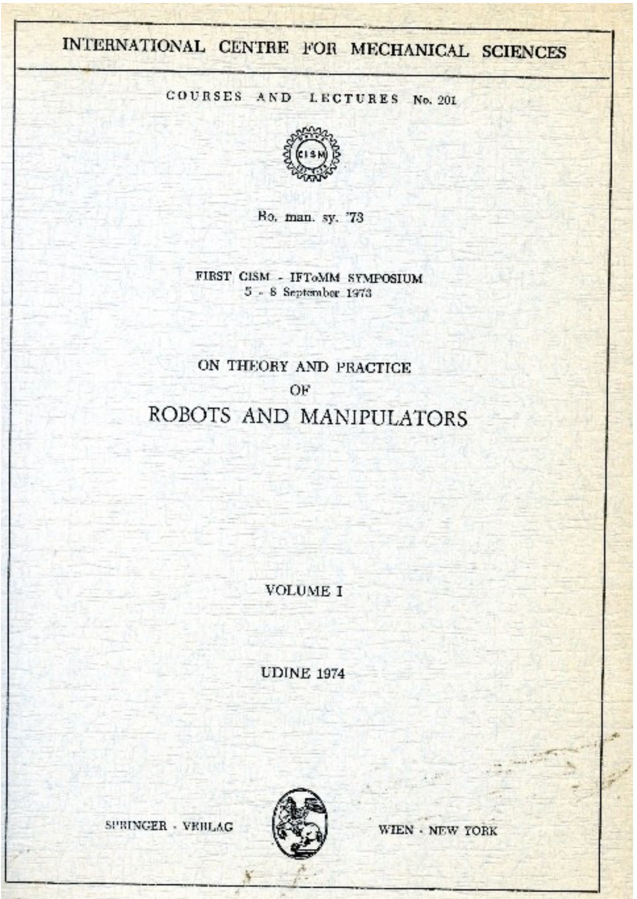
community definition



- Innovations is produced by inventors coming **from a community** and producing **new figures in the community.**
- Significance of innovation is produced and supported by the **corresponding community**
- particularly significant **the history and role of MD** in Robotics and MMS at large

Fig. 3 Main aspects of aggregation for a community definition

example of innovation from community viewpoints



INTERNATIONAL CENTRE FOR MECHANICAL SCIENCES

COURSES AND LECTURES No. 201

Ro. man. sy. '73

FIRST CISM - IFToMM SYMPOSIUM
5 - 8 September 1973

ON THEORY AND PRACTICE
OF
ROBOTS AND MANIPULATORS

VOLUME I

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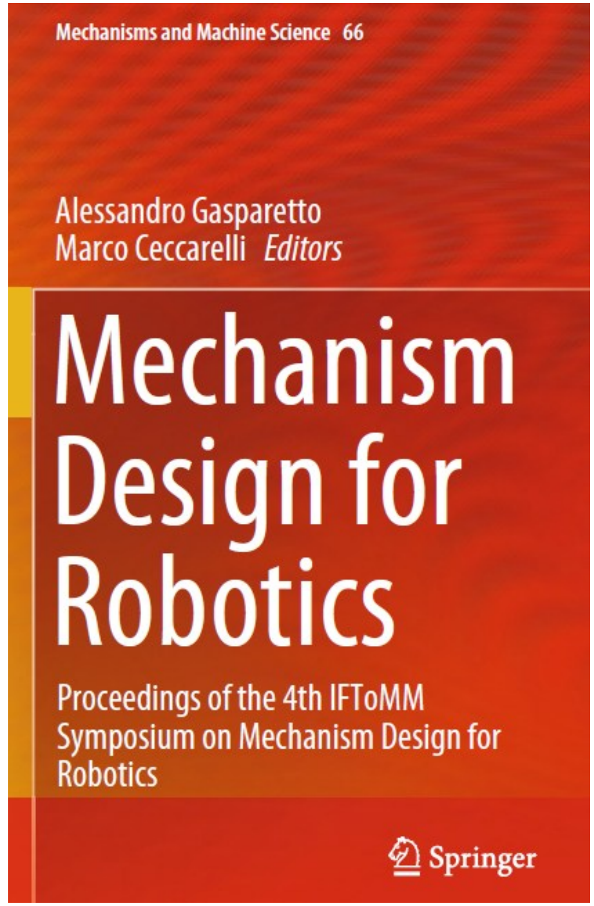

Title page of proceedings of:
a) Romansy in 1973, [4];

b) MEDER in 2018,

Community activities:

Conference initiatives & publication frames:

- To disseminate
- To discuss
- To generate innovation

with Science & Technological transfer

MEDER

IFToMM sponsored conference
Mechanism Design for Robotics

MEDER is aimed to collect designs and developments of the mechanical design and operation of robots by looking at the advances in solutions and procedures that can provide enhancements in robot structures and their functionalities even in new areas of application.

Papers on robot design and functioning from theory up to practical applications.

2010: Mexico city …. as workshop for Students

Starting promoters:

M. Ceccarelli
M. Acevedo
J. Rooney
T. Koetsier
I. Jokowski
J.A. Carretero
G. Gogu

2010: Mexico city, Mexico
2012: Beijing, Cina
2015: Alborg, Danmark
2018: Udine, Italy
2021: Poitiers, France
2024: Timisoara, Romania

ISC2025

Marco Ceccarelli (Univ. Rome Tor Vergata, Italy) (Chair)
Ding Xilun (Beihang Univ., China)
Mario Acevedo (Univ. Panamericana, Mexico)
Shaoping Bai (Aalborg Univ., Denmark)
Yukio Takeda (Tokyo Inst Tech., Japan)
Alba Perez (Tech.Univ.Barcelona, Spain)
Yan Jin (Belfast Univ., UK)
Erwin Lovasz (Tech. Univ. Timisoara, Romania)
Said Zeghloul (Poitiers Univ., France)
Chedli Bouzgarrou (SIGMA Clermont, France)
Victor Petuya (Univ. of Basque Country, Spain)
Alexey Fomin (IMASH, Russia)
Kenji Hashimoto (Waseda University, Japan)
Gao Huang (Beijing Tech University, China)
Matteo Russo (Univ. of Rome Tor Vergata, Italy)
Rogério Sales Gonçalves (Uberlandia Uni, Brazil)

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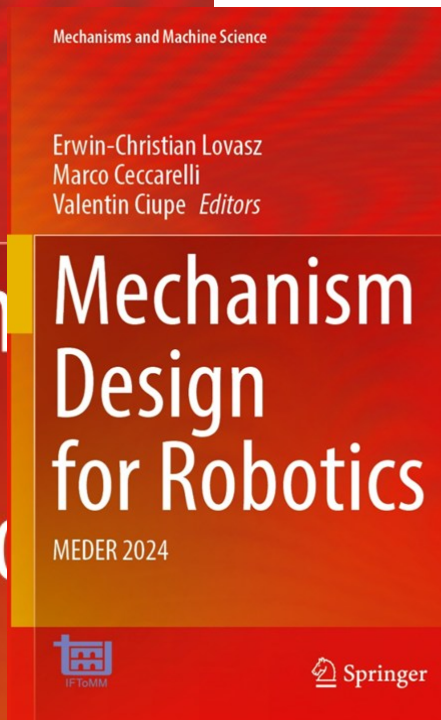



2018 Best Paper Award

Best Paper Awards
in Research, Applications, & Student
Started in 2015
- by an Award Committee (AC)
- by considering the reviews
- 3 levels Gold, Silver, Bronze.

2024: papers from 18 countries

2021: Poitiers …..2024 Timisoara

2026 Uberlandia, Brazil


2018 cultural visit at Aquileia

UFU

FEMEC

7th IFToMM Symposium on Mechanism Design for Robotics

MEDER 2026

Uberlandia, Brazil, June 17-20, 2026

MEDER

Second Call for Papers

The aim of the Symposium on Mechanism Design for Robotics (MEDER 2026) is to bring together researchers, industry professionals and students from a broad range of disciplines related to mechanisms and robotics to share the latest developments and discuss the directions for the future of mechanism and robotics research. MEDER 2026 continues a successful series of Symposiums that has been started in Mexico 2010, continued in China 2012, in Denmark 2015, in Italy 2018, France 2021 and in Romania 2024.

The MEDER 2026 Symposium will be held in Uberlandia at Federal University of Uberlandia, Brazil.

Secretariat Website:
https://www.even3.com.br/meder-2026/

Correspondence Address:
Prof.Dr.-Ing. Rogério Sales Gonçalves
Universidade Federal de Uberlândia

Challenges for today and tomorrow

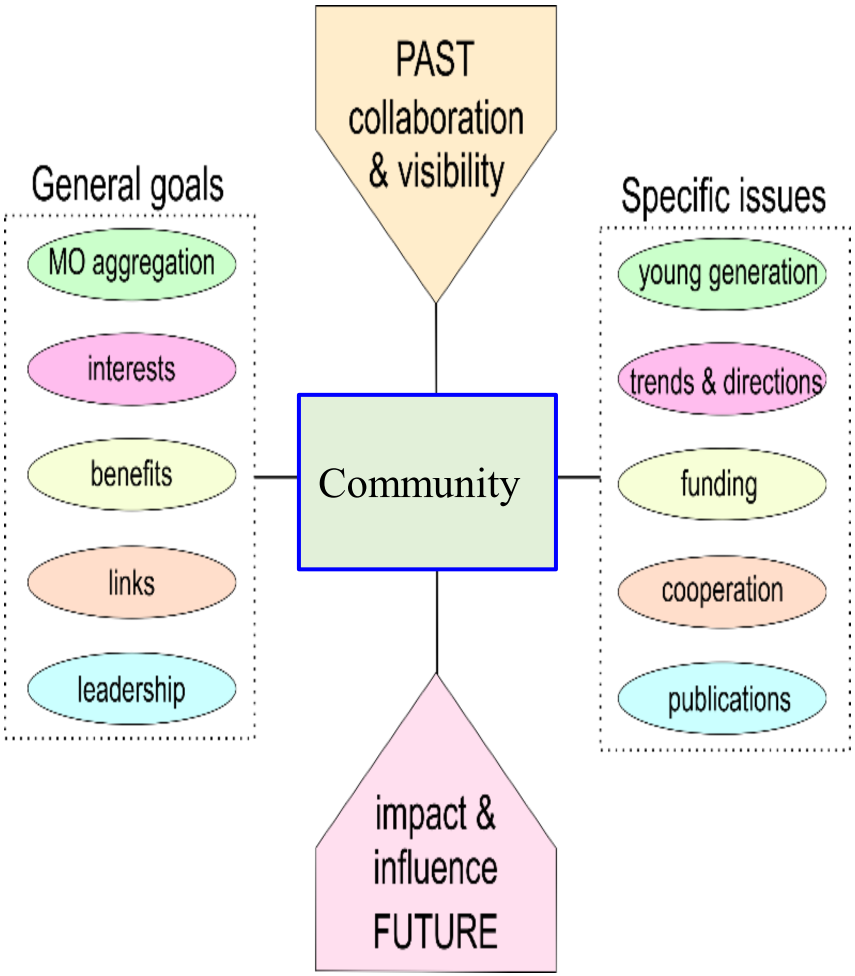


Fig. 7. Issues from past achievements to future challenges

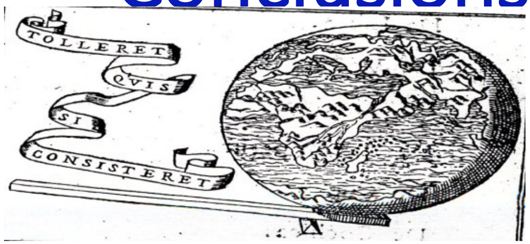
- **Attraction** to societies and its activity
- **Aggregation**
- Enlargements of **the domains of interests**,
- More **interdisciplinary** activity,
- Collaboration with **other communities**, not only in engineering
- Improvement and increase of the **benefits**

- To increase **visibility** and **influence of our community**
- To increase **leadership in**
- To improve **participation in collaborations**
- **Funding** in/for our communities and interests

- . . . .

- **MMS in Internet Globalization**
- **New publication frames**
- **New promotion means**
- …………

Conclusions




2025: LARM2 team members

Innovation is a result of knowledge and creativity (**which comes first?**)
With success of products and people
today **commercial exploitation** reduces the merit of technical valorization.

important bases for innovation not only in Robotics

- **achievements and solutions in Mechanism Design KEY ROLE**
- the **corresponding community … aggregating in MEDER initiative**

without which no innovation is possible in MMS areas
and even in more other fields.

But **a full modern innovation**
requires a community with **multi-disciplinary skills**

MEDER community can work such a role
as established with vision of international frames a for collaboration purposes
with impact and application in technological developments
for the benefits of the society.