Mechanisms and Machine Science

Med Amine Laribi
Carl A. Nelson
Marco Ceccarelli
Saïd Zeghloul *Editors*

New Advances in Mechanisms, Transmissions and Applications

Proceedings of the Sixth MeTrApp Conference 2023

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Mechanisms and Machine Science 124

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The series is promoted under the auspices of International Federation for the Promotion of Mechanism and Machine Science (IFToMM).

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Marco Ceccarelli · Saïd Zeghloul
Editors

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ISSN 2211-0984 ISSN 2211-0992 (electronic)
Mechanisms and Machine Science
ISBN 978-3-031-29814-1 ISBN 978-3-031-29815-8 (eBook)
https://doi.org/10.1007/978-3-031-29815-8

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

The Sixth Conference on Mechanisms, Transmissions and Applications, MeTrApp 2023, was organized by the Cobotics, Bio-Engineering & Robotics for Assistance (CoBRA) Team of the Pprime Institute of the University of Poitiers and was held at the Futuroscope Technopole, the CNAM-IFMI building, in the city of Poitiers, France, during the period 24–26 May 2023.

This conference constitutes the continuation of the MeTrApp conference tradition, which was held for the first time in Timisoara, Romania, in 2011; the second time in Bilbao, Spain, in 2013; the third time in Aachen, Germany, in 2015; the fourth time in Trabzon, Turkey, in 2017; and the fifth time in Dalian, China, in 2019.

The International Federation for the Promotion of Mechanism and Machine Science, IFToMM, has several technical committees, two of them being the technical committee on linkages and mechanical controls and the technical committee on micromachines. One of the main efforts of these two committees is directed to promoting the interaction among university professors and researchers, engineers that work in industry and postgraduate students, with the purpose of testing hypotheses and sharing knowledge in the field of machine theory. In this sense, this conference provides a highly suitable atmosphere to achieve this target.

The contents of this conference are brought together in this book formed by a collection of 38 peer-reviewed papers, dealing with important and up-to-date topics in the field of mechanisms and robotics. The main areas covered in this conference are computational and experimental methods, cobots and human–robot interaction, mechatronics, parallel manipulators, medical applications of mechanisms and robots, mechanism and machine design, dynamics of mechanisms and mechanical transmissions.

A significant number of authors have contributed to the success of this conference. The research papers included in this book are a compilation of relevant results developed by active research groups from many universities and institutions all over the world such as: Canada, China, Germany, Japan, India, Italy, Ireland, Kazakhstan, Mexico, Netherlands, France, Poland, Romania, Russia, Taiwan, Tunisia, Turkey, Spain, UK, USA and Vietnam.

We are grateful to the authors for their contributions and to all reviewers for their critical and valuable recommendations.

We also acknowledge the support of the International Federation for the Promotion of Mechanism and Machine Science (IFToMM, http://iftomm.net/). We thank the TC on Linkages and Mechanical Controls and the TC on Micromachines of IFToMM, as well as IFToMM France, the French Section of IFToMM, for their sponsorship.

We thank the University of Poitiers, in particular the Fundamental and Applied Science Faculty, for its availability to host the MeTrApp2023 event.

The conference received generous support from local sponsors, namely the University of Poitiers, the Grand Poitiers, and the Nouvelle-Aquitaine region, which were crucial to make this conference possible.

A special recognition is also due to all members of the local organizing committee for their continuous work during the preparation of the meeting.

Finally, we thank the publisher Springer and its editorial staff for accepting and helping in the publication of this Proceedings volume within the book series on Mechanism and Machine Science (MMS).

May 2023

Med Amine Laribi
Carl Nelson
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Contents

Keynote

Mechanism Design for Robot in Italy: Historical Backgrounds, Achievements, and Challenges

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Abstract. In the lecture past and modern achievements and results in Robot Design are presented through significant examples in order to stress the variety of solutions and creativity that the Italian community has provided and still provides in terms of theory and practice of technological developments as well as in terms of knowledge acquisition and formation of next generations.

Keywords: Robot Design · Mechanism Design · History of robotics · History of MMS · Italian distinguished figures

1 Summary

Robots are designed and applied in more and more application field in helping or substituting humans in their labour tasks and diary life. Achievements in Mechanism Design for Robots are developed in theoretical, numerical, and design works that once implemented in engineering practice or in science applications they contribute to innovation or even they are innovation themselves both in technical-scientific and social frames. Italian community has contributed and still give challenging solutions, [1].

The concept and role of mechanism design in the structures and functionality of robots is clarified in the scheme in Fig. 1 considering that a robot interacts with the environment and with the object of the manipulative task in terms of movement and force which require mechanical systems capable of transmitting motion and force, [2, 3]. The concept of innovation is summarized again in Fig. 1 in the complex multi-disciplinary synergy of various actors among which the inventor and precisely the mechanical designer is fundamental to start the development of innovative solutions. The integration of these aspects is shown in the example of the flowchart which takes into account some of the most influential topics in the design of a service robot, [4].

Figures 2, 3 and 4 show examples of personalities and emblematic inventions in the development of robotics both in the past and in the present day. In particular, Fig. 2 refers to the Italian ingenuity during the Renaissance by engineers such as Mariano di Jacopo, Francesco di Giorgio and Leonardo da Vinci with solutions of mechanisms that can still today be considered of great interest in service robotics, [5–8].

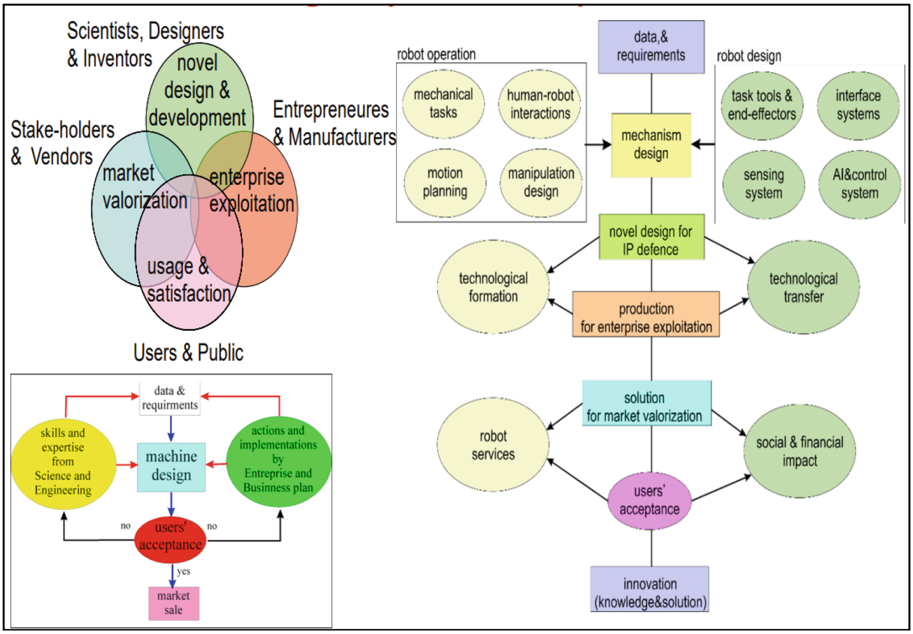

Fig. 1. Schemes summarizing central role of mechanisms in robot design, [2, 3].

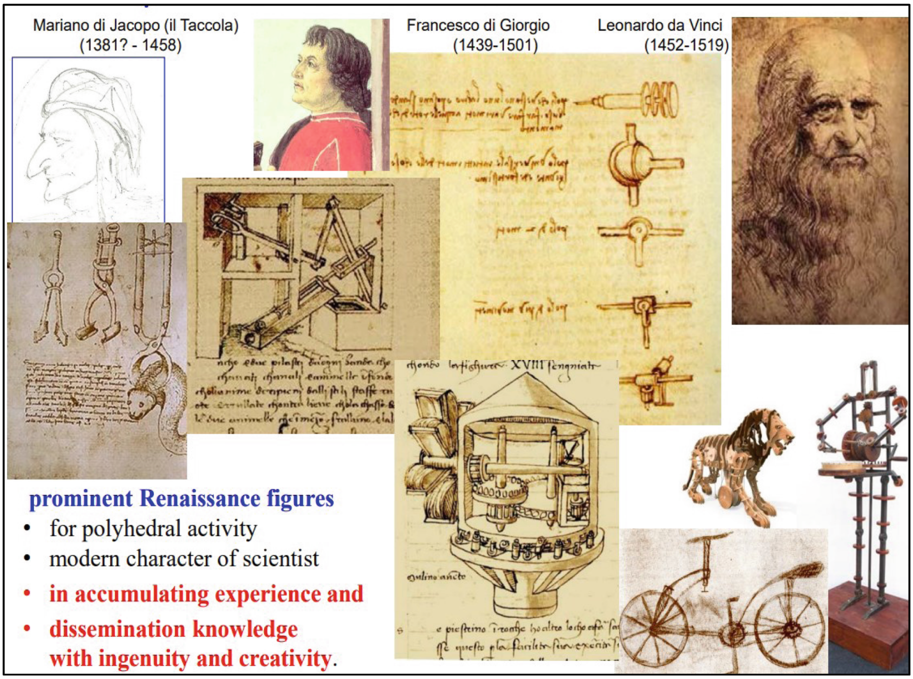

Fig. 2. Italian inventors and inventions in Mechanism Design at Renaissance, [5–8].

Figure 3 summarizes the pioneering contribution of Professor Alberto Rovetta in the early years of robotics in the aspects that made him famous for his ingenuity and creativity in the development of robots with mechatronics integrated mechanical designs, [9]. Finally, Fig. 4 shows examples from the direct experience of the author and his collaborators in developing a motion assistance system for the functionality and rehabilitation of the elbow using cable-driven manipulator systems with innovative solutions relating to aspects of creativity supported by the experience and expertise in the kinematics of parallel manipulators, [10, 11].

The above can be summarized in the fact that ingenuity and creativity in the design of robots as based on solutions for mechanical systems and in particular the mechanisms, is undoubtedly dictated by a prior knowledge of the issues concerning the problem under invention but also from a personal attitude for conceiving and investigating innovative solutions both in terms of new solutions and adaptations and improvements of existing solutions. In these aspects, Italians both in the past and in the present day demonstrate that they have these capacities for creativity and ingenuity in the design of mechanisms for robots as a combination of experience and knowledge with an attitude for conceiving solutions dictated by their own personal creativity.

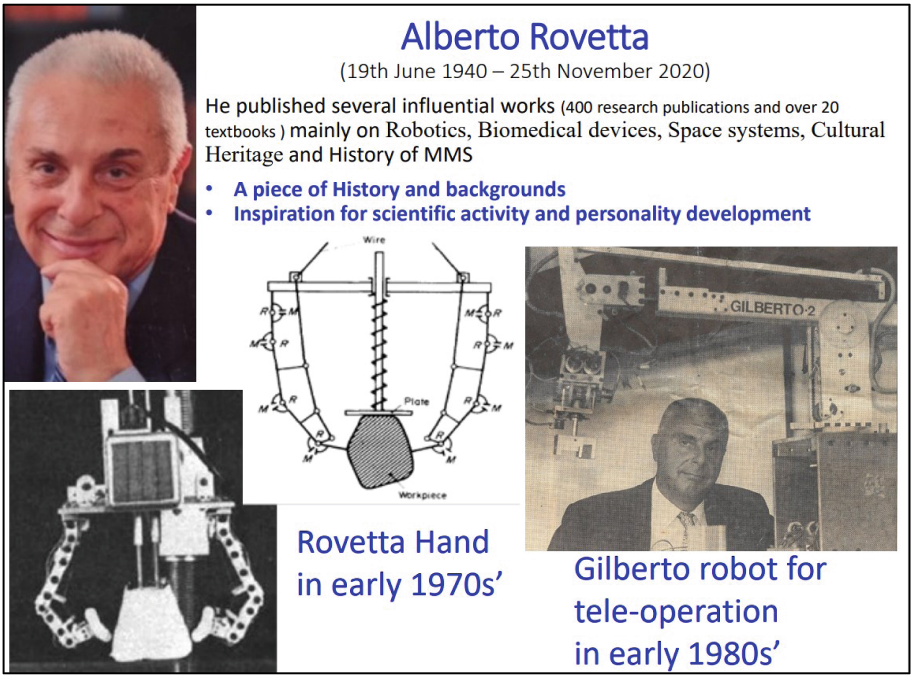

Fig. 3. Alberto Rovetta: portrait and pioneering achievements in Robotics, [9]

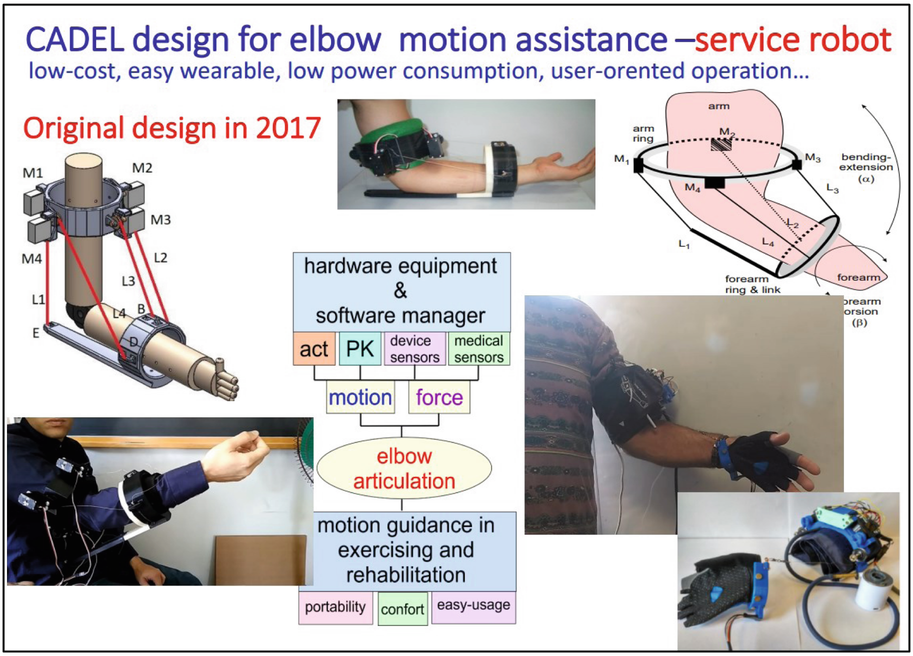

Fig. 4. Examples of creative design solution in motion assistance at LARM2, [10, 11]

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Mechanism Design for Robot in Italy: Historical Backgrounds, Achievements, and Challenges

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M. A. Laribi et al. (Eds.): MeTrApp 2023, MMS 124, pp. 7–11, 2023.
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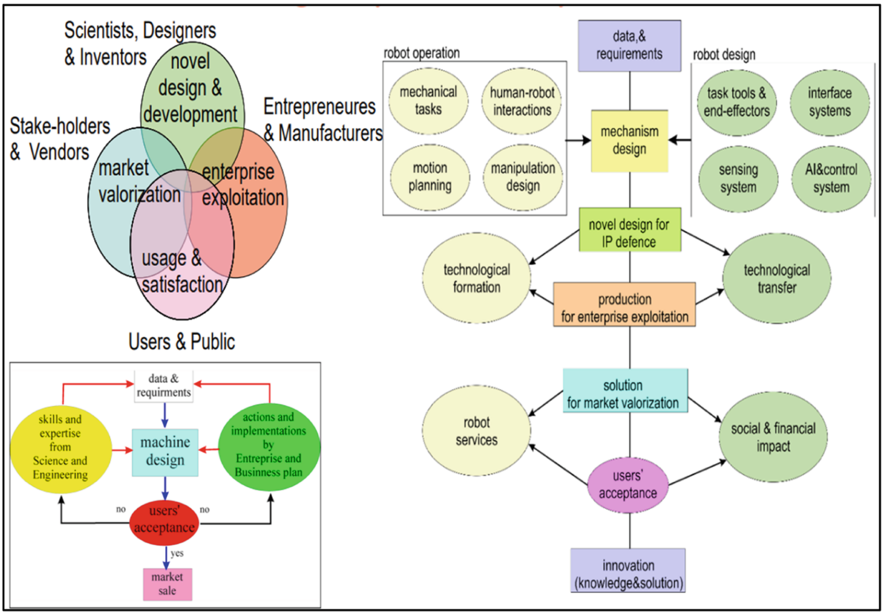

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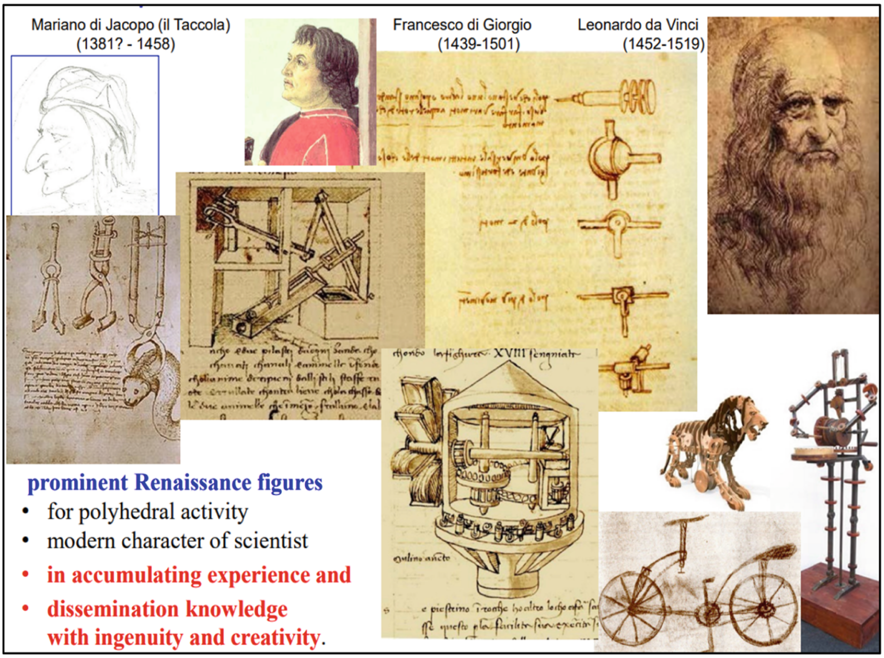

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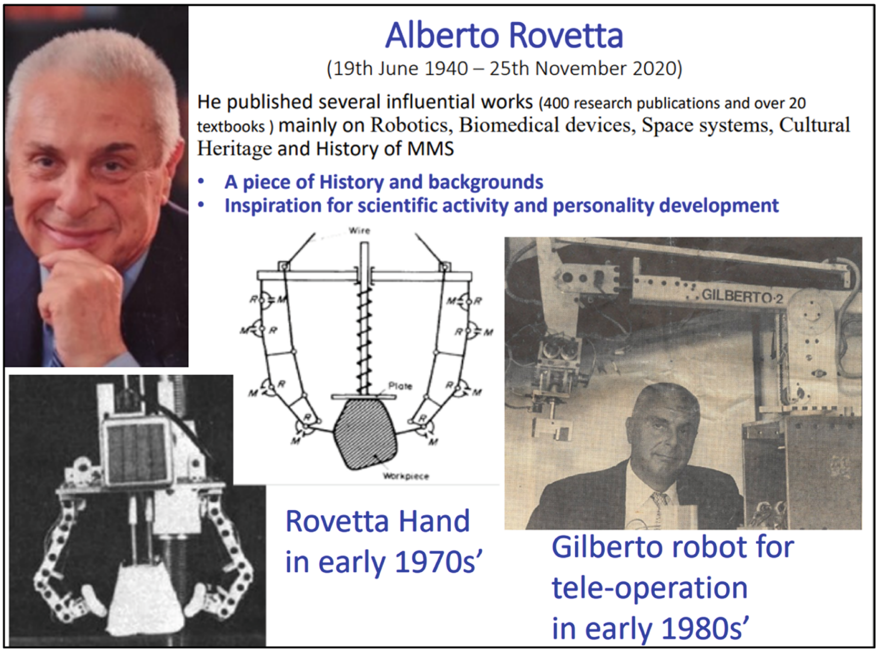

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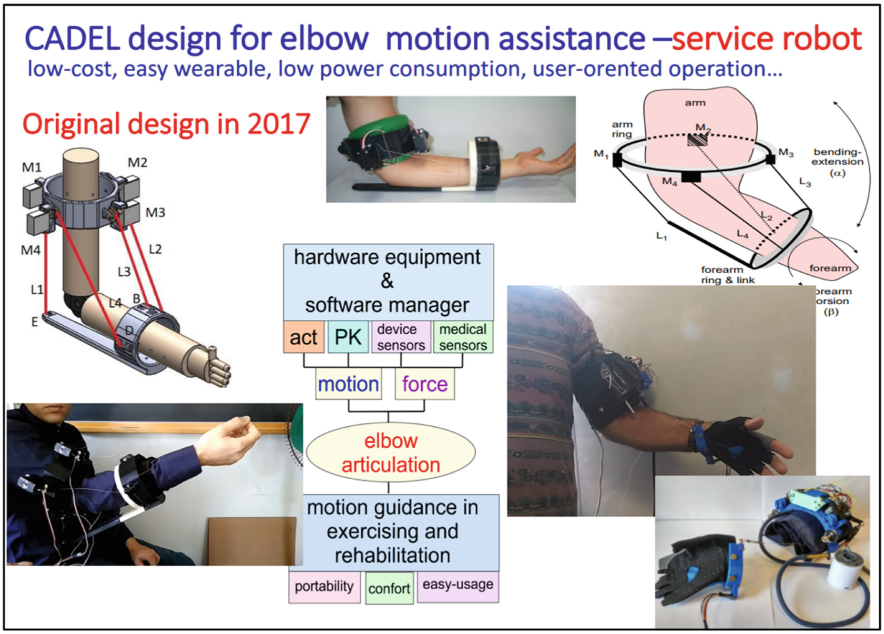

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Computational and Experimental Methods

Design and Performance Characterization of a Gripper End-Effector for a Space Berthing Manipulator

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Abstract. In this paper the task of berthing is presented with a suitable end-effector design. A geometry-based gripper is designed to capture microsatellites CubeSat on their ribs. To minimize the volume, one d.o.f.-mechanism is designed with a foldable structure. The workability of the design is tested by dynamic simulation to find and check the limitations of the construction.

Keywords: Space Robotics · On-Orbit Service Robotics · Space Berthing · CubeSats · Grippers

1 Introduction

The increasing amount of the satellites on orbit creates problems for the space discovering [1]. Malfunctioning due to absence of energy or components disability turns the satellite into space debris. Uncontrollable flight can cause collisions with other satellites. In the worst case, an uncontrollable chain reaction of collisions, which is called Kessler syndrome [2], can happen. To solve this problem, projects are undergoing for investigating design solutions of proper space robotic systems. The Engineering Test Satellite VII (ETS-VII) [3] demonstrated autonomous rendezvous and capturing technologies for cooperative space target. Target satellite was equipped by the markers, transponders, and reflectors to help the chaser satellite approach and capture it by the end-effectors. A malfunctioning satellite is a non-cooperative target, and usually it is not considered to be captured. German Space Agency presented the concept of the satellite [4] for transferring the non-cooperative space target from geostationary to graveyard orbit.

As in the general description from [5], a berthing task contains several stages considering attaching the interfaces installed on the manipulator and in the aimed satellite called chaser. This scheme is widely used for most operations in the International Space Station (ISS). Examples of on-orbit service robots, such as Canadarm [6], Canadarm2 [7] with Dextre [8], European Robotic Arm [9], and Japan Experimental Module Remote Manipulator System [10] use latch interfaces for connection to objects, move and replace them. Therefore, one of the requirements for any space objects to be manipulated is the availability of a compatible attachment port. Not all the satellites are designed with this

M. A. Laribi et al. (Eds.): MeTrApp 2023, MMS 124, pp. 15–22, 2023.
https://doi.org/10.1007/978-3-031-29815-8_2

port available. In this case, geometry-based grasping can be convenient. The class of the microsatellites CubeSat [11] has a standardized parallelepiped geometry with durable ribs, which are suitable for grasping by a robot end-effector. One of the formulations of the grasping problem for the tumbling target is outlined in [12].

In this work, the requirements for the end-effector are formulated in terms of grasping parallelepiped shaped targets, such as CubeSat microsatellites. According to the requirements, a novel design is proposed in the paper and its basic performance is evaluated via simulation for an operation characterization.

2 Task and Requirements

To define the task clearly, the scheme of all possible ways of mating is presented in Fig. 1. Key points can help to clarify and choose the right way of mating. Typical discovered object, or target, is the CubeSat satellite. According to the type, it has a form of a cube or a parallelepiped from 100 × 100 × 100 mm to 226.3 × 226.3 × 366 mm. With such a small size, it is assumed not to have any docking or berthing ports, as for the docking [13] or berthing task [14]. On the other hand, CubeSat's geometry allows to attach and fix it on the surface of a larger satellite, which can be named as "base". It is possible to fix multiple targets on the base.

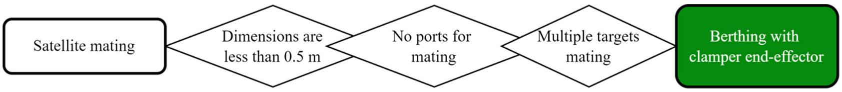

Fig. 1. A flowchart for mating strategy with the target satellite

CubeSats are designed with durable ribs, which can be used for grasping. Grasping by the ribs has another advantage, such as alignment, which is useful to define the position of an object regarding the coordinate system of the end-effector and to place CubeSat in the geometry-based berthing port on the base.

CubeSat can be assumed as a passive object. The capturing task can be described as for cooperative or non-cooperative target, as in [3] and [4]. These projects did not consider the multiple targets fixture. If to adopt an end-effector for a specific target, it is possible to improve it in terms of grasping, mass, and volume.

General requirements for design of the end-effector for berthing task can be represented in the following parameters:

- Geometry-based grasping of targets with dimensions from 100 × 100 mm (CubeSat 1U) to 226.3 × 226.3 mm (CubeSat 12U)
- Alignment of targets
- Minimization of impact when grasping
- Force feedback to ensure a continuous contact during grasping
- Minimization of the mass and inertial characteristics
- Minimization of the volume of the end-effector when folding

3 A Proposed Solution

It is necessary to look at the geometry aspect of the grasping process, or how the fingers contact the ribs of the target. The planar task for a target profile 6U is presented in Fig. 2. Grasping area is defined by the corner profile of fingers $A_{g1}A_{g0}A_{g2}B_{g2}B_{g0}B_{g1}$, or $< A_gB_g >$. The main grasping axis is $A_{g0}B_{g0}$ with the maximal length L_{open}. The angle $A_{g1}A_{g0}A_{g2}$ is equal 90 deg, length $A_{g1}A_{g0}$ is equal to $A_{g2}A_{g0}$, so the width of the grasping area $H_c = \sqrt{2 \cdot (A_{g1}A_{g0})^2}$. The target can be grasped only if one of its diagonals is fully placed inside the grasping area. This condition can be written as

$$A_{t0} \in \langle A_gB_g \rangle \bigcap B_{t0} \in \langle A_gB_g \rangle$$

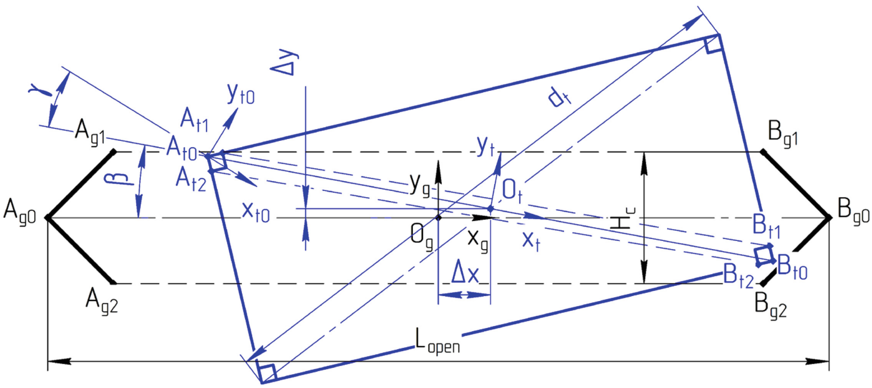

Fig. 2. A design scheme for grasping a rectangle-profile target type 6U

Δx and Δy are the linear misalignments of the target are measured as the distance between centres. β is the angular misalignment between a diagonal of the target and the main grasping axis. The diagonal of a target is defined as d_t. The grasping condition can also be written as

$$\Delta y + \frac{d_t}{2}\sin\beta < \frac{H_c}{2}$$

For a rectangle-profile target, γ is an inclination angle, which shows a difference between square and rectangle diagonals. To align 6U target profile in fingertips of an end-effector, fingertips should be able to rotate to angle $\pm\,\gamma$ around A_{g0} and B_{g0}, respectively. For 6U target, measured $\gamma = 21.8°$.

To grasp all mentioned types of targets, distance between fingertips of end-effector was defined in the following way. According to Fig. 3, grasping is provided by the fingertips, only two dimensions are needed. The dimensions of the smallest target are 100 × 100 mm, the biggest one is 226.3 × 226.3 mm. Diagonals for the square or rectangle bodies are calculated with the Pythagorean theorem. The smallest diagonal is 141.4 mm, the biggest one is 320.0 mm. The distance between fingertips should be more than the biggest diagonal. It is assumed as 5% more than biggest diagonal or 336 mm. For this case, $L_{max} = l_0 + h$, where $l_0 = l_1 + l_2$. Length h = 25 mm is a gap between rotational joint, which is connected to the finger, to its fingertip. D/2 is the half of the diagonal of the target. To grasp the smallest object, distance L_{min} is assumed 1% less than diagonal of the smallest target or 140 mm. In this position, $\alpha = 90°$. To calculate the lengths l_1 and l_2, the equation system is presented as

$$\begin{cases} l_1 + l_2 = L_{max} - h \\ l_1^2 + (L_{min} - h)^2 = l_2^2 \end{cases}$$

According to this equation system, length $l_1 = 64.4$ mm and $l_2 = 78.6$ mm.

To grasp targets with all listed dimensions, the rotation angle α is calculated by using cosine rule.

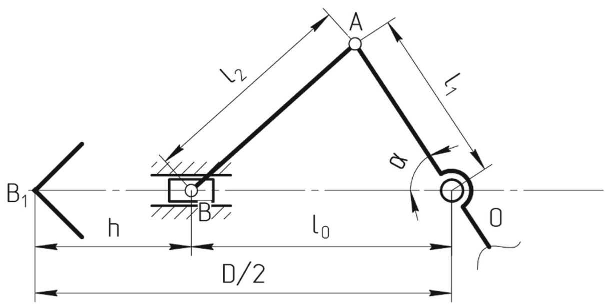

Fig. 3. Kinematic scheme of the end-effector

Knowing l_1, l_2, l_0, angle α is calculated by following equation:

$$\alpha = \cos^{-1}\frac{l_0^2 + l_1^2 - l_2^2}{2 \cdot l_0 \cdot l_1}$$

For CubeSat 12U, 6U, and 1U, α is equal to 23.4°, 53.5°, and 90°, respectively.

4 A CAD Design

Following the requirements, the novel mechanism of the end-effector has been designed. The main movement is grasping the parallelepiped body. It is assumed the grasping should be carried out by the ribs of the target. Three dimensions of the target profiles are proposed: two square forms 100 mm and 226.3 mm, and a rectangular form 100 × 226.3 mm. To grasp these forms, the end-effector is implemented as a double slider-crank mechanism with L-shaped fingertips, as in Figs. 2 and 3. The translational synchronized movement of fingers executes the grasping. The movements of the end-effector fingers are coplanar with the diagonals of these profiles. The mechanism design with the target type of 12U is presented in Fig. 4. To show the components, target is presented half transparent.