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INNOVATION OF MMS WITH INSPIRATION FROM THE PAST

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This survey is a critical overview of main aspects and topics of today's research and innovation, with specific focus on MMS, while looking at past developments and achievements through few significant examples. Thus, we can discover that most of the today's ideas and concepts have already been explored and exploited in the past. Nevertheless, today we have the great challenge of technology that permits advanced technical results that were not possible in the past within the practical innovation that today more and more is expected from research results.

1. Introduction

'Nothing is new except what has been forgotten' wrote the Roman engineer, Julius Sextus Frontinus, in the 1-st century B.C.
Are today's research issues really new in Mechanism Design?
Is it possible to gain new ideas from past developments?
What are the new or updated challenges in Mechanism Design?

The modern obsession for innovation and novelties in any technical field pushes research activity into developing new theories and new designs. But what is really new in what is developed today in the area of MMS (Mechanism and Machine Science) and specifically in Mechanism Design?

Mechanisms have been used since the beginning of the growth of society, [1]. Over the time changes of needs and task requirements in Society and Technology have required continuous evolution of mechanisms and their uses, with or without a rational technical consciousness, [2-12]. In past evolution, technical knowledge has made it possible to propose more and more solutions enhancing mechanisms and their uses in order to satisfy demands from Technology and Society. Today it seems that we have reached a saturation and a so high level of knowledge on mechanisms that several professionals and even researchers from other fields think that there is nothing else to be discovered or conceived in MMS, [13, 14]. Historical backgrounds and developments have been outlined in a large literature even from several technical viewpoints (beside in circuits of History of Science) in several works with the aim to track historical evolution of Technology and Engineering, and to recognize the paternity of machine achievements. Recently, a specific conference forum has been established within IFToMM as HMM Symposium in which several views and studies are discussed, [15-19]. Some more specific emphasis is also addressed on historical trends on recent research activity in papers for keynote lectures and opening acts, mainly in IFToMM sponsored conferences. Even the author has attempted to outline historical developments with the aim to track the past to identify directions for future work like in the recent paper, [20].

In this survey, a vision is outlined with a historical perspective in order to show that, although many new issues in MMS and particularly Mechanism Design can be based on basic concepts that have been developed in the past, we have still several challenging issues to approach for giving proper solutions to new and updated problems in the evolving MMS Technology for the benefit of the Society. New systems and updated performance are required for mechanism/machine applications that deserve attention starting from the theoretical bases before to update or conceive algorithms for design and/or operation with optimal characteristics.

Two main considerations can be observed in order to claim that MMS is still a discipline with necessary new activity in teaching, research, and practice. Namely, they are:

- Human beings operate and interact with the environment and through systems on the basis of actions of mechanical nature; therefore mechanisms , as the core of modern systems, will be always an essential part of systems that help or substitute human beings in their operations and other manipulations.
- There is a continuous need to update problems and solutions in Technology since Society continuously evolves with new and updated needs and requirements; thus, even mechanical systems are required for new and updated problems that require a continuous evolution and update of knowledge and means for their proper applications.

2. Concepts and activity for innovation

In general, innovation can be understood as a transfer of knowledge and its applications into market sales. Figure 1a summarizes the concept of innovation as a multi-disciplinary complex of activities and actors, [21]. Innovation is achieved not only with novel ideas but mainly when the knowledge transfer reaches successfully the real world with users' acceptance. This complex of activities includes a variety of skills and when just one is weak or fails, the whole transfer process will fail. Innovation can be started when a technical idea or solution has potential contents. Thus, initiators of innovation are designers or scientists with engineering skills, but in general the main exploiters are business experts or enterprise leaders, who produce the idea at proper levels of market valorisation and users' acceptance. But, not only new solutions make innovation, but very often it is the exploitation plan that produces innovation, like for example when a product reaches the market sales with no other competitors. Therefore, the success of innovation requires a full understanding of what can be transferred with enterprise perspectives for market sales toward properly solicited/identified users. Summarizing: Science and Technology are the fundamentals, but Economics and Administration are the motors, and Education and Publicity are final tools of Innovation. University research frames can be involved both in fundamentals and final tools when referring to technical contents. Indeed, even Education and Formation are essential areas both for conceiving new ideas and preparing users to the acceptance of those new ideas.

Procedures for innovation can be proposed from different perspectives but always requiring

- Technical novelty
- Production feasibility
- Operation efficiency
- Market exploitation

Technical aspects are often emphasized as due to design creativity and ingenuity for which patent production is considered the main means both of innovation defense and dissemination.

All the above considerations for understanding innovation can be referred also to MMS when innovative ideas are related to mechanical system or machines and their operations, and users are identified not only in general users but even in stake-holders and technique developers. Thus, the general concept Fig.1a can be reshaped as in Fig.1b when it refers to the modern concept of service machines that are aimed at helping or servicing human operators in work tasks or daily life.

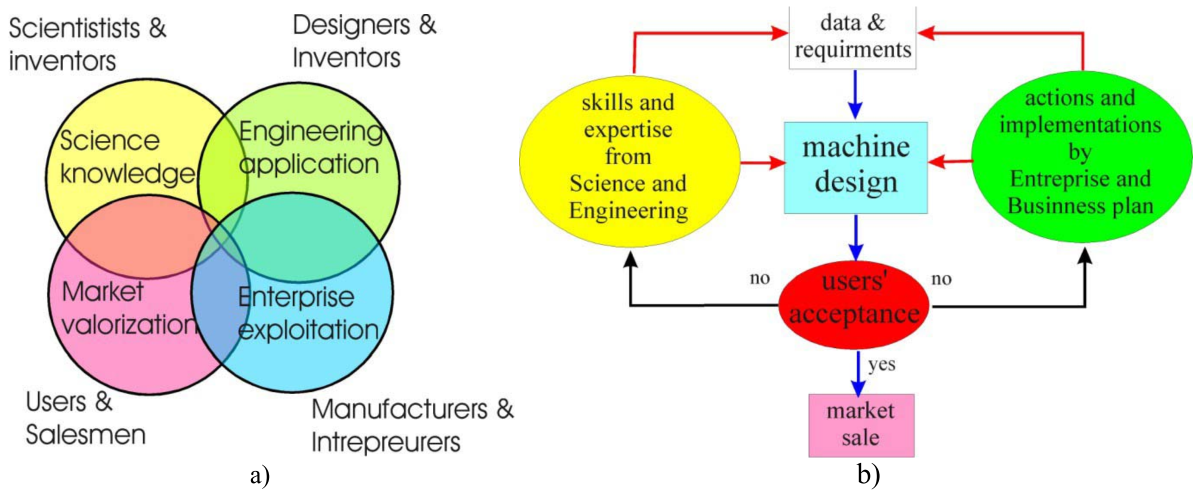


Fig.1. Conceptual schemes for innovation: a) for a general understanding; b) in MMS areas.

In Fig.1b the traditional engineering process is synthetically indicated in the central block of the diagram as the core of developments of mechanical systems, [22]. But the multidisciplinary aspects can be considered very influential in the design development of machines as coming from the two lateral blocks that summarize all those other aspects that are necessary to have a machine design and an innovation proposal. The peculiarity of MMS areas can be summarized in the above-mentioned concept of service machines by which goals of MMS developments are finalized to improve and/or to solve new or evolved needs in users' activities both in daily life and technological labor.

3. MMS and IFToMM: a community and its identity

The identity of a person or even a Community can be indicated by a name giving a synthetic description of personality and main capability or characteristics. The names of IFToMM, TMM (Theory of Machines and Mechanisms), and MMS (Machine and Mechanism Science) identify the IFToMM Community who refers to MMS at large, [23-25]. The names of IFToMM, TMM, and MMS are related to fields of Mechanical Engineering concerning with Mechanisms in broad sense.

IFToMM terminology, [27, 27] gives:

- Machine: mechanical system that performs a specific task, such as the forming of material, and the transference and transformation of motion and force.
- 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.

  The term MMS has been adopted within the IFToMM Community since 2000, [12], after a long discussion (see [25] in the IFToMM Bulletin), with the aim to give a better identification of the enlarged technical content and broader view of knowledge and practice with mechanisms.

  Indeed, the use of the term MMS has also stimulated an in-depth revision in the IFToMM terminology since the definition of MMS has been given as, [27]:
- Mechanism and Machine Science: Branch of science, which deals with the theory and practice of the geometry, motion, dynamics, and control of machines, mechanisms, and elements and systems thereof, together with their application in industry and other contexts, e.g. in Biomechanics and the environment. Related processes, such as the conversion and transfer of energy and information, also pertain to this field.

In conclusion, since the modern assessment TMM has been considered as a discipline, which treats analysis, design and practice of mechanisms and machines. This will also hold in the future for the area named MMS today, since we shall always have mechanical devices related with life and working of human beings.

Technically, MMS can be seen as an evolution of TMM, having a broad content and view of Science, including new disciplines. Historically, TMM has included as main disciplines: History of TMM; Mechanism Analysis and Synthesis; Theoretical Kinematics; Mechanics of Rigid Bodies; Mechanics of Machinery; Machine Design; Experimental Mechanics; Teaching of TMM; Mechanical Systems for Automation; Control and Regulation of Mechanical Systems; RotorDynamics; Human-Machine Interfaces; BioMechanics. The modernity of MMS has augmented TMM with new vision and means but also with many new disciplines, whose the most significant can be recognized in: Robotics; Mechatronics; Computational Kinematics; Computer Graphics; Computer Simulation; CAD/CAM for TMM; Multibody Dynamics.

The evolution of the name from TMM to MMS, that has brought also a change in the denomination of the IFToMM Federation from the "IFToMM International Federation of TMM" to "IFToMM, the International Federation for the Promotion of MMS", can be considered due both to in enlargement of technical fields to an Engineering Science but even to a great success in research and practice of TMM with an increase of engineer community worldwide.

IFToMM was founded in 1969, [20, 28] as a Federation based on the activity of individuals within a structure shown in Fig.2 with the aim to facilitate co-operation and exchange of opinions and research results in all the fields of TMM. Many individuals have contributed and still contribute to the success of IFToMM and related activity, (see IFToMM webpage: www.iftomm.net) under a vision coordination of IFToMM Presidents over time. The modernity and relevance of IFToMM activity can be recognized in the common frame of views and results on MMS, in many different technical fields.

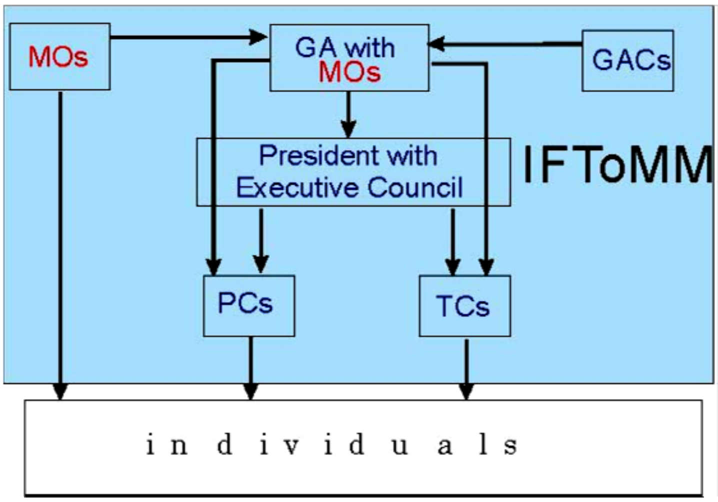


Fig.2. The structure of IFToMM.

The IFToMM community evolved in character from that of a family of a few enthusiastic pioneers/visionaries and founders into a scientific worldwide community through the following generations:

1950s-1975 – First generation: founding fathers and their colleagues up to the 4th IFToMM World Congress in New Castle upon Tyne in 1975 with Prof. Leonard Maunder as Congress Chair.

1976-1995 – Second Generation: pupils and people, who were educated in TMM by founding fathers and their colleagues; up to the 9th World Congress in Milan in 1995 with Prof. Alberto Rovetta as Congress Chair.

1996-2011 – Third Generation: educated people with MMS activity in the frames of IFToMM and within IFToMM activity with 48 national organizations as IFToMM members, up to the 13th World Congress in 2011 in Guanajuato, Mexico with Prof. Carlos Lopez-Cajùn as Congress Chair.

2011 – Today – Fourth Generation: educated people working in frames that are linked to IFToMM and within IFToMM activity with 47 organizations as IFToMM members.

4. Old and new in MMS

Mechanisms and Machines have addressed attention since the beginning of Engineering Technology and they have been studied and designed successfully bringing specific results, [1-12]. But TMM have reached a maturity as an independent discipline only in 19-th century.

The main current interests for new research in MMS can be summarized in the following topics:

- 3D Kinematics and its application in practical new systems and methodologies
- Modeling and its mathematization
- Multi-d.o.f. multibody systems
- Spatial mechanisms and manipulators
- Mechatronic designs
- Scaled mechanisms
- new materials and technologies for mechanical systems
- Reconsideration and reformulation of theories and mechanism solutions.

Those topics are motivated by needs for teaching and activity by professionals too.

Teaching in MMS requires attention focused on modern methodologies that can use efficiently computer and software means, which are still evolving rapidly. Thus, there is a need to update also the teaching means that makes use of simulations and computer oriented formulation. In addition, mechatronic lay out of modern machinery suggests to teach mechanisms as integrated with other components like electric/electronic components, actuators and sensors since the beginning of the formation curricula.

Activity of professionals involves novel applications and high performance designs of machines as they are continuously needed in evolving/updating systems and engineering tasks. In addition, there is a need to make new methodologies understandable to professionals for practical implementation both of their use and results. New solutions and innovation is continuously requested not only for satisfying technical needs but even for political/strategic goals of company success.

IFToMM community works for innovation in MMS but through developments and applications of mechanical systems by means of an action of leadership and coordination of activities and trends in worldwide international frames. Significant examples of contributions of IFToMM to innovation contents can be summarized both in community aggregation and identification as well as in specific activities such as:

- New TCs for new research subjects of large interest
- New forums and publication frames
- New demands for formation in research and profession.

Innovation can be focused on new research subjects that in IFToMM can be motivation for establishing new TCs in order to focus and coordinate trends and developments. New subjects are arising that could permit/require the creation or enlargement of TCs with suitable groups of interested persons and institutions from IFToMM Member Organizations. In addition, in each of the existing TCs activities are continuously worked out to stimulate new trends and challenges together with the usual activities of meetings, conferences, and information flows.

Similarly, innovation in IFToMM is stimulated and also disseminated through publications in international frames that can be considered themselves innovation. Thus, recently IFToMM has more affiliated international journals with the aim to facilitate aggregation of publications of works from the IFToMM community as well as Springer book series have been started with specific focus and link to MMS.

Formation with advanced issues is of great interest since the early days of IFToMM. New results can be considered the planning of several specific tutorials, mainly as Summer schools by TCs and even a Student Olympiad that this year has been planned in its third event.

Beside the above, innovation of MMS is obtained in IFToMM through specific results in new theories, designs, and applications that are achieved for new solutions.

Are the above-mentioned topics really new arguments in the History of MMS and source for technological innovation? It is quite clear that modern developments in Technology and Science have stimulated and required developments and novelties in machines and mechanisms too, because of the growth of new and updated needs, but also because of current practical possibilities for mechanism solutions that were utopist in the past.

Past solutions and efforts can be helpful to understand situations and developments that are needed to reach successful achievements fulfilling today is requirements.

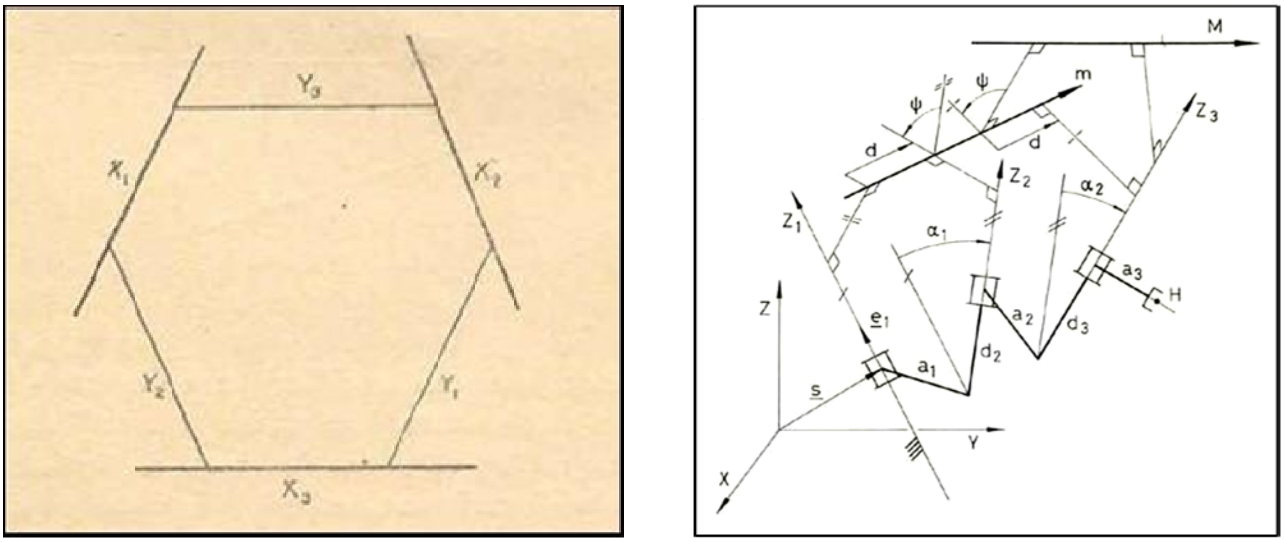
In the following, few examples are shown to illustrate what was developed in the past that can be considered new today and therefore of inspiration for today's research in MMS.

Lots of today's activity is addressed to new models and new mathematizations for mechanisms. The attention is not new, but procedures and means can be considered new since they are related to goals of using modern means of calculus. Today a high level of abstraction is used in treating kinematic chains and motion characteristics of mechanisms. However, even in the past abstraction was used to study properly a general but specific motion of a rigid body.

But still today dualistic viewpoints are proposed as based on graphical and mathematical approaches. Thus, for example graphs and algebraic groups are used to describe kinematic chains of mechanisms and their functionalities.

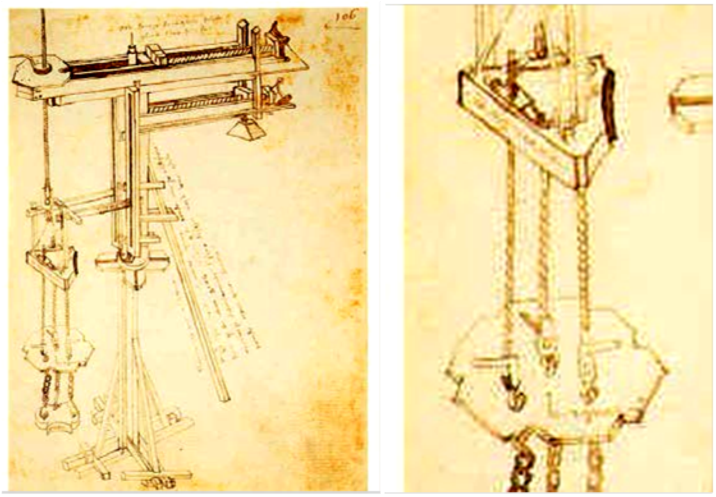
Similarly, Graph Theory with matrix algebra and Group Theory are introduced to formulate the operation of mechanisms and then new design algorithms. A great of work is addressed to suitable mathematization of mechanism aspects that can be efficiently treated through computer means. This issue, indeed, is an old need, i.e., designers and researchers work on engineering views as based on computational issues with means of the time and therefore, theories and algorithms are needed to be formulated or re-formulated according to the capacity of these available means. Computer means can make mathematical means available for practical engineering purposes with great computational accuracy, when they are properly adjusted to each other. An example from the past is the Algebra of matrices that today is commonly used in Robotics. It was not used until computer calculation made it feasible and more efficient than traditional graphical procedures. New attention is paid today to other algebras and even using quaternions and biquaternions in considerably growing literature. Today computational issues seem to motivate also basic research and re-formulation of problems that were considered as definitively solved even in a recent past. This is because the new mathematization and related computational algorithms can give further insight both into solutions and desgin algorithms. Emblematic is the attention to the kinematics of four-bar linkages whose fecundity (as Hartenberg pointed out in the 1950s') still gives new insights and procedures for designing also more complex systems or new solutions for practical applications (see for example actuation mechanisms for backdoors of cars). The issues of mathematization are still of current interest not only for computational purposes, for example also for 3D kinematics. The great attention on 3D kinematics has been motivated from engineering viewpoint since when there has been the possibility to operate and regulate spatial mechanisms in practical applications. This happened when it was possible to control and to sensor spatial motion by using electronic components. Indeed, even the increase of spatial tasks for manipulations and industrial processes have made of practical interest mechanisms that have been studied since the second half of 19-th century, but mainly for pure academic interests. Screw systems are today extensively modeled and formulated to design and operate manipulators and spatial mechanisms in practical applications in several fields other than industry, like for example in medical engineering. Schemes from Screw Theory are used and although they are presented in new algorithms, the basic concepts were conceived in the past. An example is shown in Fig.3 in which the so- called Screw Triangle is outlined by Bricard in 1926 for a design algorithm that still addresses great attention mainly for suitable computer-oriented formulation in a very rich growing literature. Thus, the concepts of the Screw Theory have been outlined since the 18-th century (through the works of Euler, D'Alembert, Bernoulli, Frisi, and Mozzi (see [29]) and then it has been clearly formulated in the 19-th century mainly through the works of Ball. But a useful mathematization and consequent practical implementation have been developed in modern terms and are still under development as a function of mathematical and informatics means through several approaches.

Spatial mechanisms are thought to be conceived in the last five decades. But the possibility to use them is not new. One of the last systems are considered cable parallel manipulators that have addressed attention the researchers and designers only recently. But in Fig.4 Filippo Brunelleschi seems to have used such a system in a crane to increase payload and mechanical versatility, already in 1420, [11].



a) b)

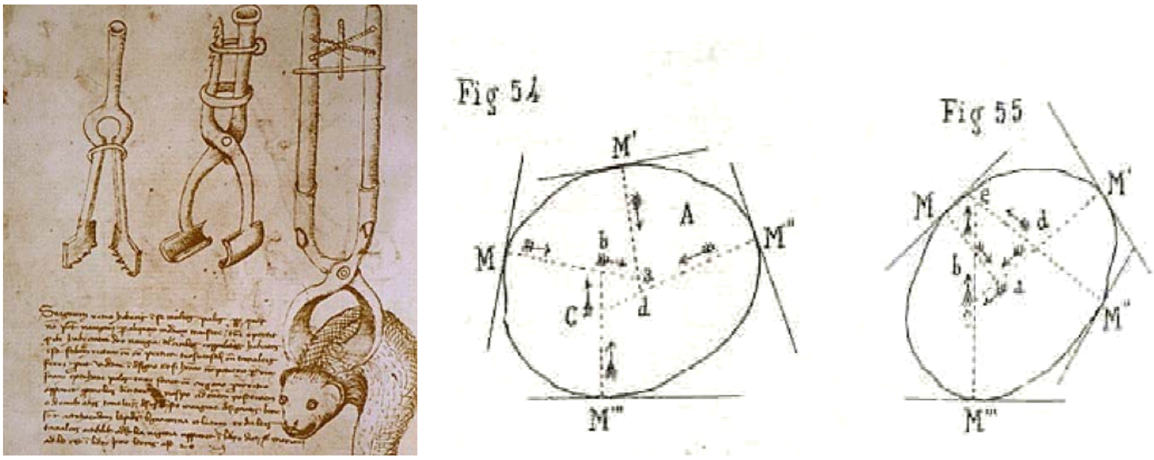
Fig.3. A scheme for Screw Triangle of a 3R manipulator: a) by Bricard in 1926,) b) as drawn today.



a) b)

Fig.4. An early cable parallel manipulator in crane by Filippo Brunelleschi in 1420: a) the crane system; b) zoomed view of an early cable-driven parallel manipulator.

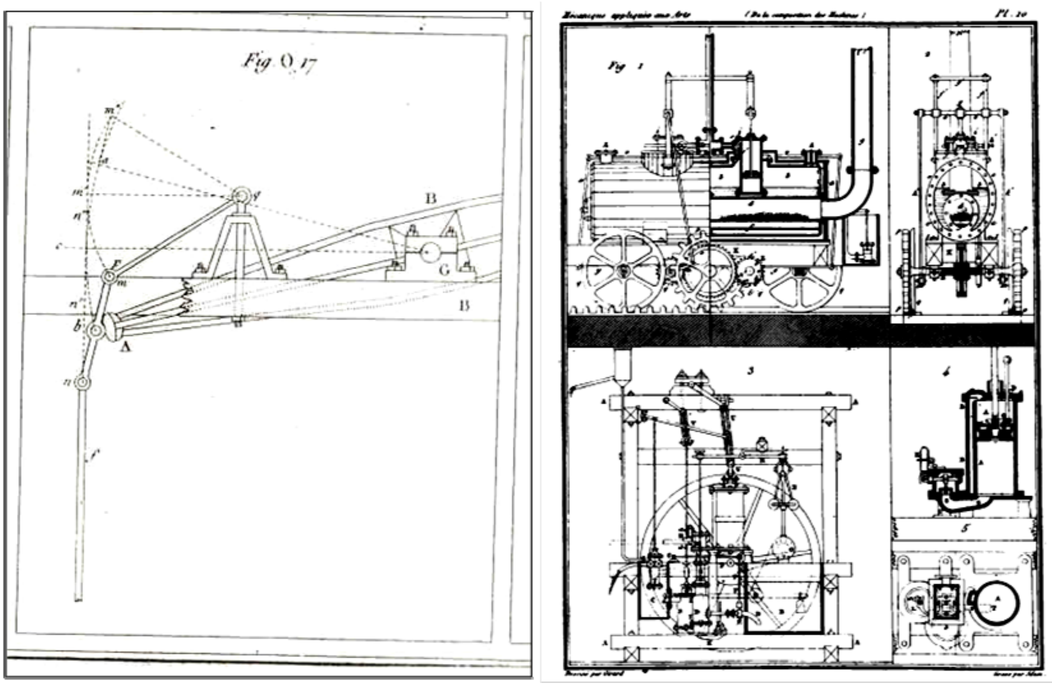
Problems that are related to manipulation mechanisms, such as for grasping, are today of fundamental relevance, and considerable attention is paid to the variety of grasps and to the general model and formulation of the mechanics of grasp. Those needs have been determined by a variety of tasks and objects that can be grasped. In Fig.5a a study by Mariano Di Jacopo (il Taccola) in the 14-th century is reported in which different grippers are examined in terms of fingers and locking systems, likewise in today investigations. In Fig.5b schemes are shown as used by Francesco Masi in 1897 to study the stability of a grasp with multiple contacts, likewise today's approaches for multi-fingered robotic hands. Indeed, the sketches recall very much the today's schemes for investigating the stability of multi-contact grasps.



a) b)

Fig.5. Grasping and design solutions: a) a variety of two-finger grippers with different locking systems by Mariano Di Jacopo in 14-th century; b) Sketches for the analysis of planar multi-contact grasp by Francesco Masi in 1897.

Figure 6 refers to the design of the very famous today Watt mechanism that was used to increase the efficiency of steam motors thanks to the better accuracy in piston guidance. The success led to the wide application of steam motors also in the new machines for transportation and other industrial applications. Technical novelty s related to MMS of the time can be recognized in using coupler curve for motion guiding purposes. This is an emblematic example from the past in which knowledge, expertise, and ingenuity have produced and in innovation in machinery with strong impacts not only in technological developments but in social and economic evolutions.



a) b)

Fig.6. 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.

3D kinematics has been deepened and abstraction has reached good results so that is it used also in many other fields. Today one of the most successful field of novel applications is considered Computer Vision and Graphics, after that vision systems are available with suitable advanced capabilities. But already in the last decade of the 19-th century there was a successful activity in applying kinematics to Graphics with perspective to Vision. Emblematic is the example dated 1880 in Fig.7 in which computations results from kinematics are used for shadowing complex objects. The topic was specifically addressed to enhance technical drawing towards its standardization. This is again the case today as related to user-oriented CAD techniques that can give results useful also for vision applications.

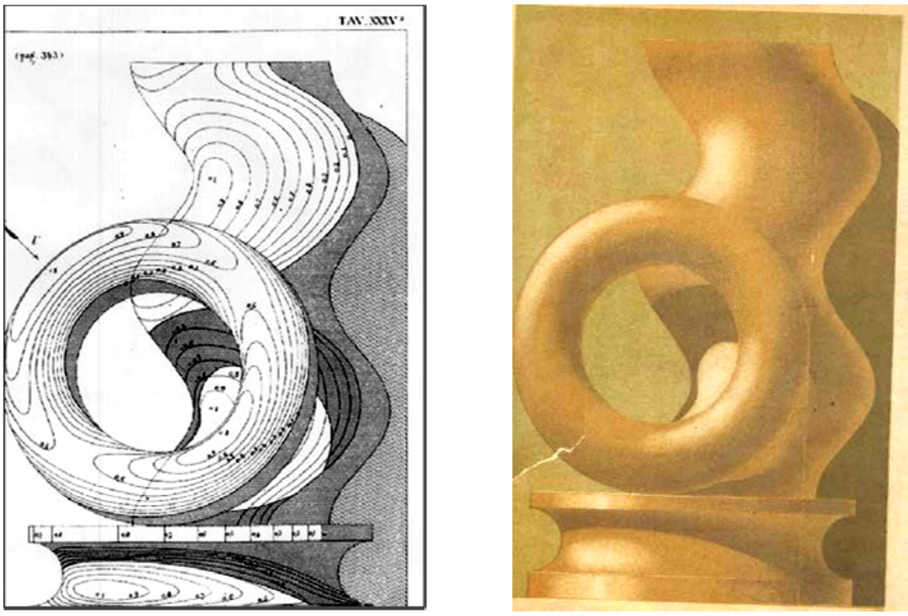


Fig.7. An example of early results for Computer Vision and Graphics by using Kinematics by Domenico Tessari in 1880.

Nowadays automatic machinery requires multi-d.o.f. mechanisms that have been possible only with the advent of modern control engineering. But solutions were designed and used also in the past by using mechanical devices and/or ingenious designs. Figure 8 shows the design of an automatic wood sawing machine by Villard de Honnecourt in 13-th century. In the machine one can identify the axle of the water turbine transmitting motion both to the saw linkage mechanism and wood feeding slide. In addition the saw linkage mechanism can be interpreted as two surprising operations, namely the saw is guided by using a coupler point (usually James Watt is said to have been the first using coupler curves for body guiding, but in 1742) and/or the mechanism can be understood even as a five-bar linkage by looking at the drawn bars as movable links when the second input can be used to adjust the saw operation yet.

Mechatronics is usually considered a last achievement of modern engineering by which modern systems are designed and operated because of integration of several components of different natures with a multi-disciplinary engineering approach. Although engineer formation was and is still achieved by teaching separately courses on specific disciplinary subjects, nevertheless machines have been always treated by looking at the integration of different aspects. Of course, nowadays the multitude and sophistication of those multi-disciplinary aspects require to emphasize on the multi- disciplinary frames asking expertise in specific fields but in a wider and wider context. Technical integration of different engineering aspects was considered also in the past, as one can see for example in the design shown in Fig.9 as an early mechatronic design of a machine by Heron of Alexandria (who lived in 2-nd century B.C.) in a drawing during Renaissance to show a so-called hydraulic organ with a combination/integration of mechanisms, hydraulic actuators, and regulation devices.

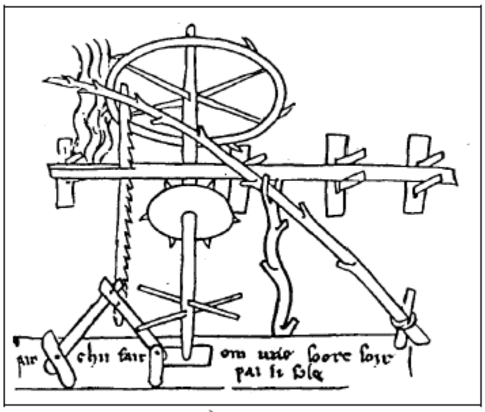


Fig.8. An automatic wood sawing machine by Villard de Honnecourt in the 13-th century.

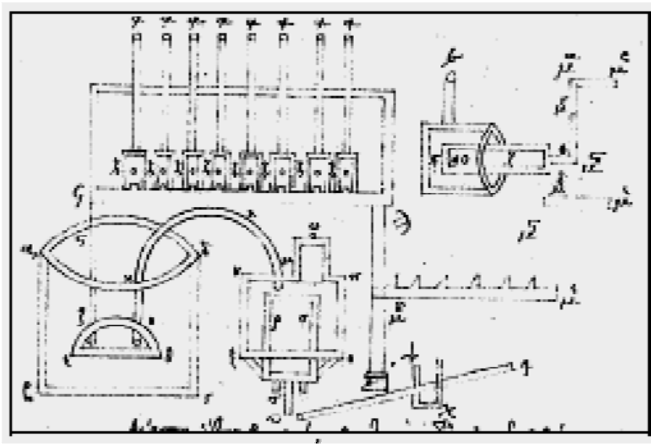


Fig.9. A hydraulic organ designed in the 2-nd century B.C. by Heron of Alexandria as redrawn in 15th century.

Another modern issue is related with machinery materials and related tribological problems. Today, but even in the past, main limits of life duration of machines (or at least of their efficiency) are considered as related to tribological issues due to friction and wear. This critical issue was understood since the beginning of using moving connected bodies and several solutions were studied and attempted both in terms of materials and manufacturing/operation techniques in order to have a control and/or an estimation of the effects. In Fig.10 an example of such an attention and adopted consequent action is reported form the time of antique Egyptians. A man at the foot of the statue is specifically devoted to spray a liquid (water?) as lubricant on the sliding surface to reduce the friction for moving then heavy load of the statue. There, we have the principle of attaching a tribological problem by using intermediate lubricant material, suitable surface design, and even controlled operation, likewise today, although today we have a greater variety of materials and technologies.

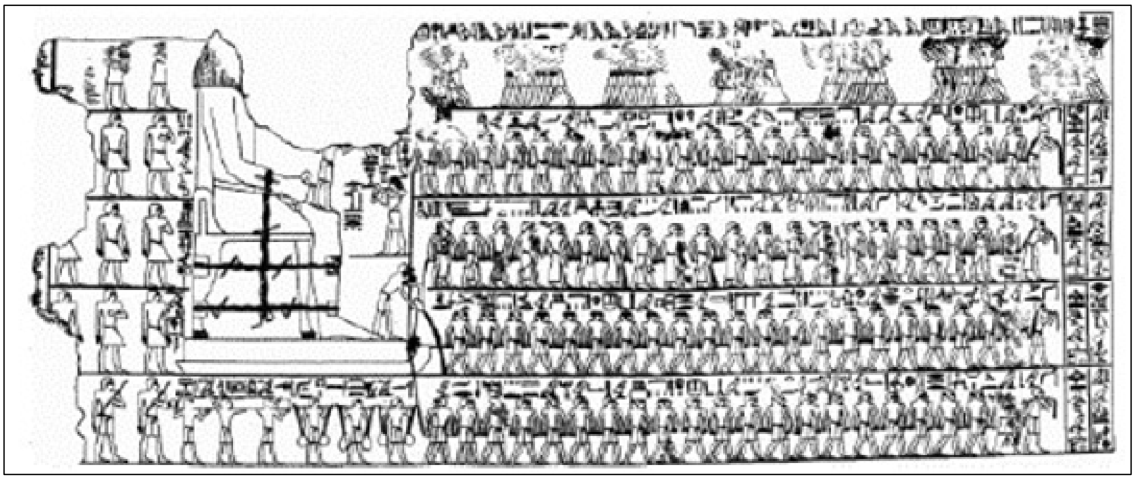


Fig.10. A tribological solution with lubricant application for transportation of a statue at the time of Antique Egypt.

Another challenging trend in MMS can be identified in scaled mechanisms/machines and their applications both to very small and very large sizes. Miniaturization has been experienced in the last decades and today micro-mechanisms are almost usual machines so that research is now directed to molecular scales. On the other hand the increase of power needs has required larger and larger size of mechanical devices. Even spatial exploration and exploitation have stimulated a great consideration of very large mechanism with deployable mechanism structures. While miniaturization at today levels is indeed a novelty in the history of engineering, the scaling need is not new and engineering approaches were developed to adapt the mechanism size to the application requirements even by considering peculiarities of the scaling in terms of actions and relative significance. In particular, the history of Mechanism Design is mainly related to an increase of tasks by enlarging mechanisms in terms of power, motion, and productivity. Thus once more, the new scaling of design and operation has required and still require to re-consider the basic principles of mechanisms.

One of the greatest attention for novelties in Mechanism Design can be considered the conception of new mechanisms and systems that can fulfill (optimally) identified new problems. Today is very difficult to conceive new mechanisms from theoretical viewpoint, after that in the past, efforts have obtained mechanism classifications with exhaustive listing of kinematic chains, [30]. It is not only because of the milestone work by Franz Reuleaux that for example Francesco Masi and many others have completed by listing many type of mechanisms (up to millions of different architectures) but even in a very past, the variety of mechanisms was considered in unifying approaches that helped in conceiving new mechanisms. Figure 11 is a brilliant example of such an early activity for mechanism classification that Francesco di Giorgio Martini discussed for pumping systems to derive an early concept of kinematic inversion of mechanism as in the example of the second drawing of the second column.

Summarizing this brief account through few significant illustration examples, in MMS there is much of new in what is old but still novelties can be conceived not only by looking at the past.

A fundamental aspect, which is in common to the new from the past and real today novelties, can be identified in issues that are related to mathematization and computation of theories and mechanism solutions. Challenging problems, like in the past, are related to derive methodologies (i.e. knowledge) that can be used in practical engineering at current modern levels and means of efficiency, which are still feasible for updating tasks and requirements.

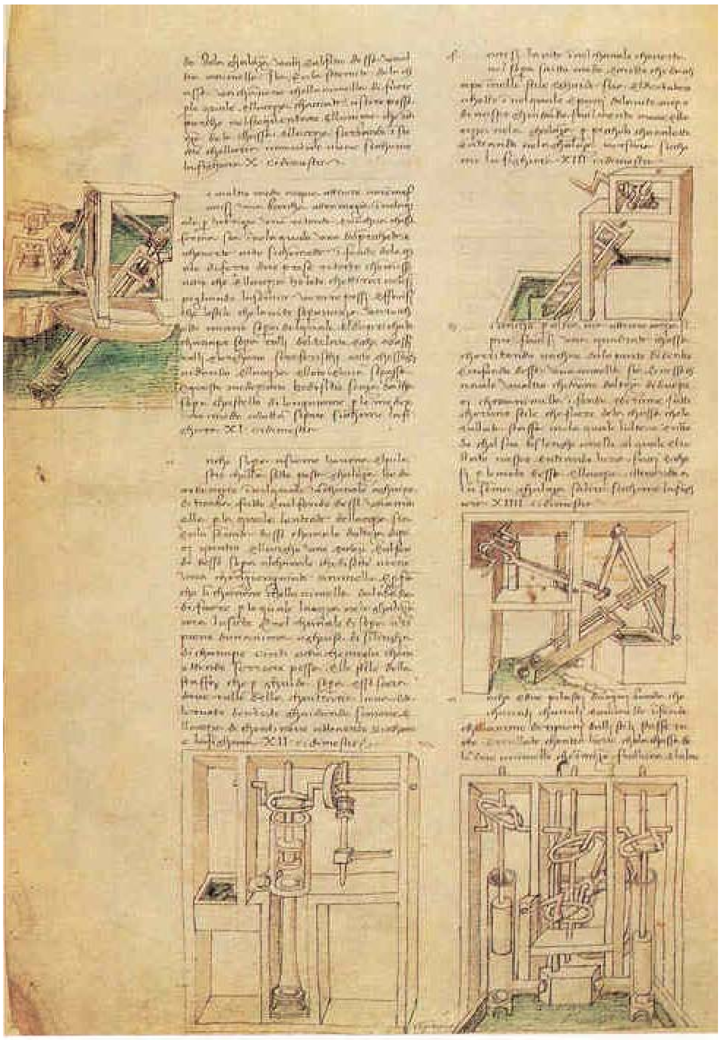


Fig.12. An early classification of mechanism for pumping systems by Francesco Di Giorgio Martini in 15-the century.

Conclusions

Not everything is new or recently developed in MMS and specifically in Mechanism Design. But this does not mean that there is no interest and need to work on developing and enhancing knowledge and application of MMS Design. An aware of historical backgrounds can give not only consciousness of past efforts and solutions, even for paternity identification, but it can also help to find ideas for new and updated problems to solve. Many of today new issues in MMS have been conceived in the past in terms of basic principles that are often forgotten. But the rapidly evolving needs of Technology and Society will require a continuous re-thinking and re-conceiving of methodologies and solutions in suitable updated applications. Thus, main challenges for future success in MMS can be recognized in the capability of being able to keep updated the field and therefore in being ready to solve new and updated problems like it has been done successfully in the past. Achievements and solutions in MMS as well as the corresponding community, can be considered important bases for innovation with technical content and background, without which no innovation is possible in machine area and even in more fields. But a full modern innovation exploitation up to users' satisfaction requires a community with more multi-disciplinary skills, even from Business and Administration areas and IFToMM community can work such an influential role in stimulating/guiding innovation activity since it was established with vision of international frames for collaboration purposes in the growth of MMS with impacts and application of technological developments for the benefits of the society.

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