COMPUTATIONAL MECHANICS 2021
36th conference with international participation
Srní
November 8 - 10, 2021

# Research on the utilization of mechatronic tensegrities in robotics

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The basic research in the field of robotics is currently very intensive in many directions involving different new possibilities of artificial intelligence, as well as the improvement of mechanical and especially dynamic properties, both with new concepts of mechanical structures and the new concepts of their control. The most common robots today have the well-known serial structure. They have good ratio between the built-up space and the effective workspace. Their main disadvantages are typically the low effective stiffness, low damping and in particular, the unfavourable ratio between stiffness and mass. The parallel kinematic mechanisms (PKM) can be used as an alternative to serial ones with better stiffness, but worse built-up/usable space ratio, usually more complicated control and higher number of possible collisions within the workspace. In case of the redundantly actuated PKMs even the singular positions can be eliminated and other parameters of the mechanism can be improved as well. The cable driven variants of the PKMs combine principles of parallel kinematics with the usage of cables/fibres as links, which brings further advantages – namely the lightweightness, large range of motion, possibility of anti-backlash property, easy reconfiguration and even cheaper construction compared to traditional mechanisms.

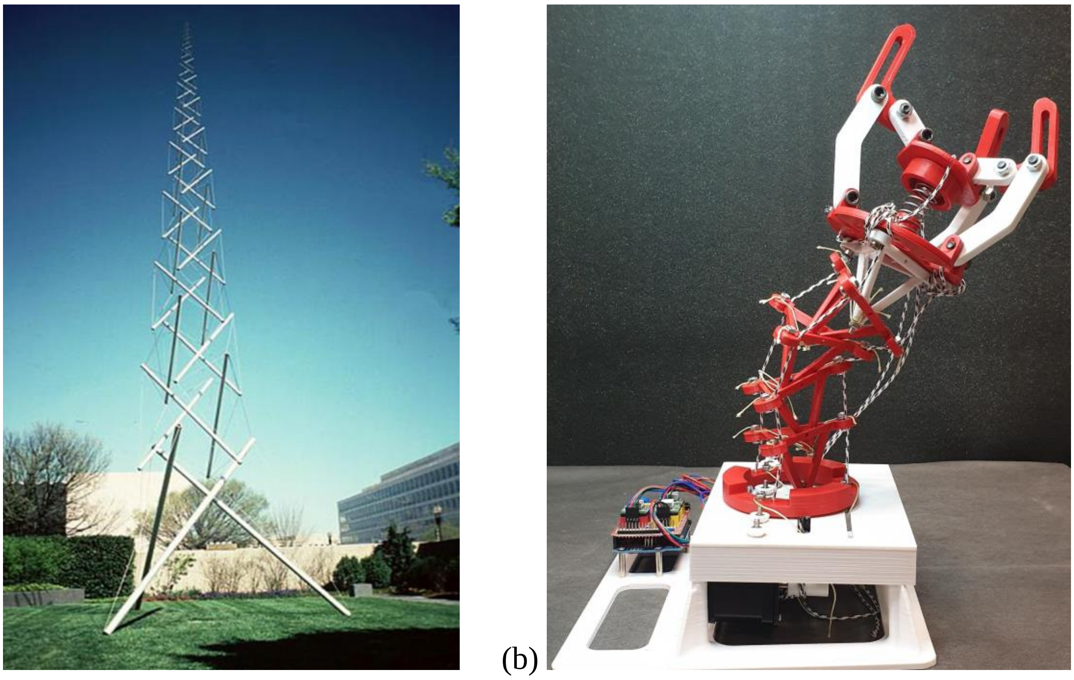
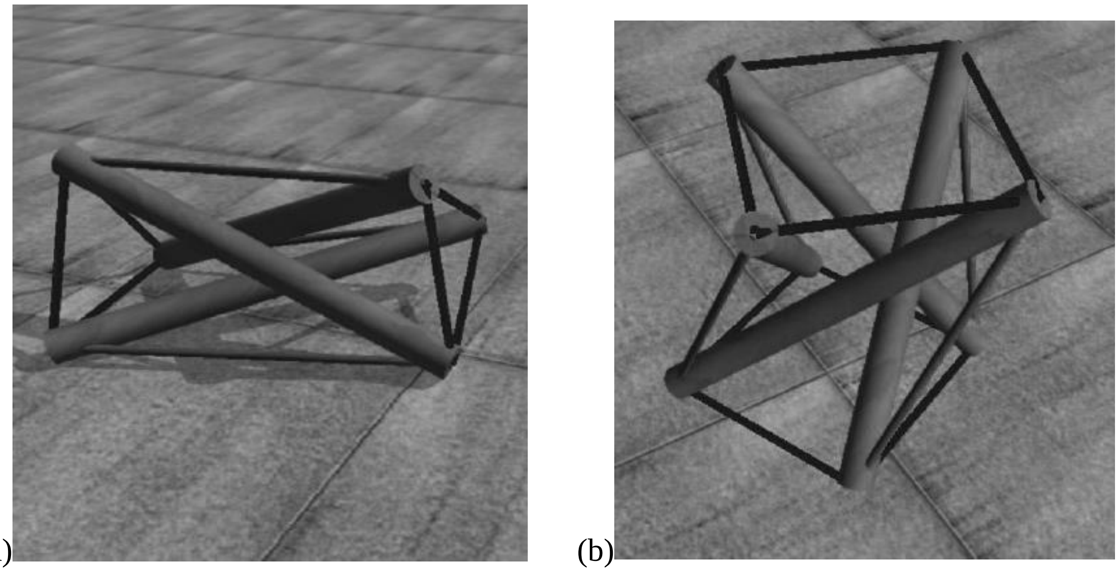

(a) (b)

Fig. 1. (a) Example of tensegrity (Needle Tower located in Washington D.C., USA) – taken from [1]; (b) example of sophisticated parallel bio-inspired tensegrity robot HEDRA – taken from [6]

The important task of basic mechanical engineering research in robotics is to propose, investigate and optimize unconventional combinations of different structures and possibilities of their advanced control. Tensegrity (abbreviation of “tensional integrity”) mechanisms, combining some serial and parallel aspects, can be taken as next qualitative level arising from cable mechanisms. The idea of tensegrity is one of the very interesting concepts of spatial structures, which is currently being investigated both in the sphere of civil engineering constructions and in the design of innovative reconfigurable mechanisms of the future. The tensegrity structures in a narrow sense are the structures composed from isolated (do not touch each other) members (usually rods or struts) in compression inside a net of prestressed tensioned members (usually cables, fibres or tendons) – see for example Fig. 1. A tensegrity configuration that has no contacts between its rigid bodies is a class 1 tensegrity system (see Fig. 2 and Fig. 3c), and a tensegrity system with as many as $k$ rigid bodies in contact is a class $k$ tensegrity system (see Fig. 3d). The basic step in the design phase of a functional tensegrity structure is to determine its equilibrium configuration, a process called as “form-finding” [1]. “Form-finding” is the search for new topologies and morphologies of tensegrity structures.

Although the original idea is not new [4], the current possibilities of mechatronics open a new intensive research field of their actively controlled and reconfigurable variants. The actuators deforming some members (rods or cables) on a tensegrity structure can be used to control its shape [7]. The robots TR-3 and TR-4 (see Fig. 2), based on the three-prism tensegrity structure, are analyzed in [2].



(a) (b)

Fig. 2. (a) Robot TR-3, based on the three-prism tensegrity structure; (b) robot TR-4, based on the four- prism tensegrity structure – both taken from [2]

Tensegrity modelling and control tools have been developed, among others, by NASA Ames Research Center as an open source Tensegrity Robotics Toolkit (NTRT) [5]. Many control strategies (e.g. $H_2$ and $H_\infty$ synthesis, genetic algorithms, the output-feedback linear parameter-varying) have been developed to treat locomotion of tensegrities (e.g. [2]). There are currently several demonstrators of the tensegrities either with active rods or active cables. Another realization of active cables uses e.g. piezoactuators or shape-memory alloys.

The replacement of classical serial robot by light active tensegrity mechanism can significantly improve its stiffness/mass ratio and bring completely new possibilities of controllability and observability by internal actuators and sensors. The great benefit of active tensegrities is that we can reach a high level of force control within the structure. The low authority control (vibration suppression) can be combined with the high authority motion control and force control. The possibility of temporary relaxation of potentially colliding tendons can enlarge the reachable workspace. The nature of tensegrity mechanisms containing many springs or other pre-stressed components seems to be suitable for an interesting concept called as “eigenmotion” [3]. This control approach is based on a constant sum of kinetic and potential energy, e.g. pendulum like motion. With absence of external load and neglected energy dissipation this results in motion with zero energy consumption. These aspects associated with tensegrity robots are very promising, but have not yet been sufficiently investigated. Research on these topics is a key objective of or activities.

the goal of our activities is a complex basic research of a new type of hybrid serial-parallel mechanisms for robotics. These mechanisms will be composed of both rigid bodies and cable/fibre/tendon components. Such type of mechanisms can be characterized as mechatronic tensegrity. The challenge is to maximize overall mechanical and dynamic properties, especially collision free workspace, dexterity, calibrability, stiffness, damping and modal properties. Improving these features will be accomplished together by the optimization of mechanical structure of tensegrity mechanism itself and its advanced control. The ultimate goal is to increase operational accuracy and speed of the robots in large workspace and reduce their energy consumption.

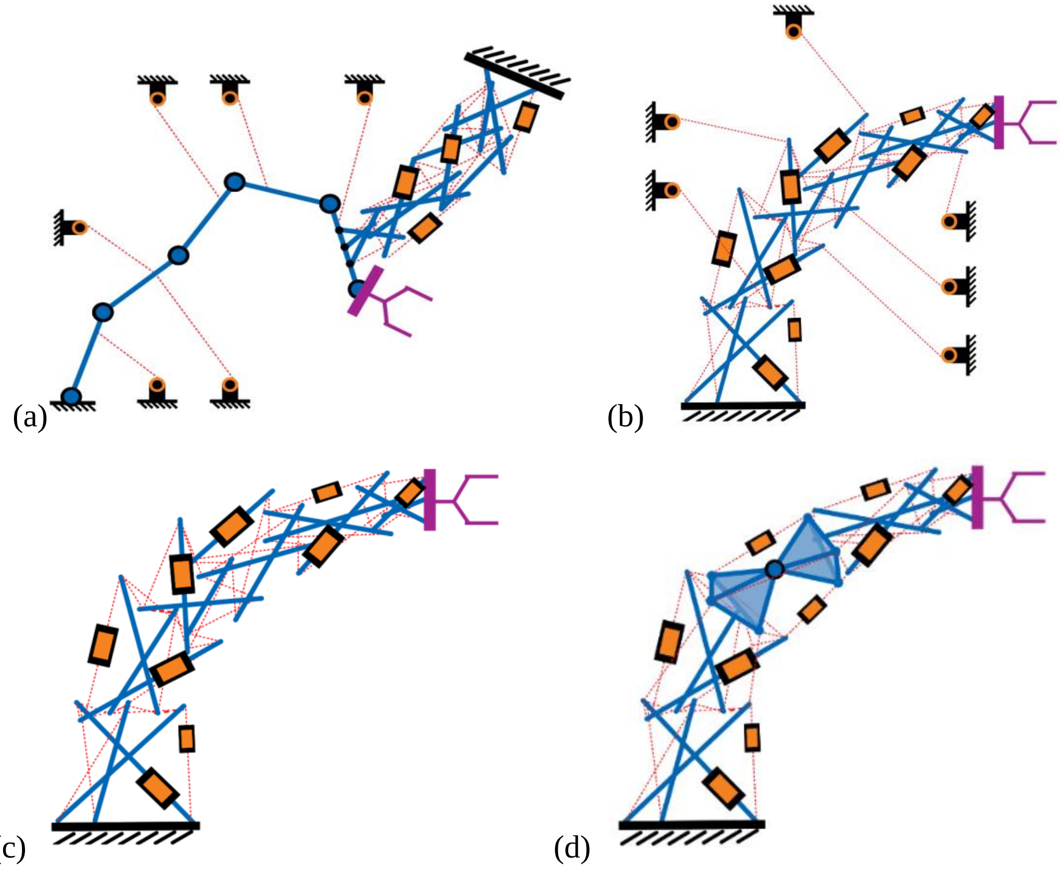



Fig. 3. Some concepts of robots with controlled tensegrity mechanisms: (a) Robot with additional cable drives and tensegrity, (b) tensegrity robot with additional cable drives, (c) robot created by tensegrity class 1 and (d) robot using tensegrity of higher class

The idea of active tensegrity usage for robots can be concretized in many ways. Some of possible concepts are in Fig. 3. First variant of more or less classical serial robot with additional cable drives and tensegrity is in Fig. 3a, tensegrity robot with additional cable drives is in Fig. 3b, robot created by tensegrity of class 1 in Fig. 3c and robot built using tensegrity of higher class in Fig. 3d. The tensegrity types of mechanisms have the potential to comprise strong points of both main robot types (serial, parallel) together, primarily the large workspace together with the favourable ratio between stiffness and mass. Important challenge is to use natural property of tensegrity mechanisms with spring tendons to absorb potential energy. This property can be used for minimizing the energy consumption of tensegrity robot during its motion control. The optimized variants of tensegrity robots and their best control strategies will be tested on complex virtual models and partly also experimentally using a simplified demonstrator.

One of examples of a new robotic mechanism based on tensegrity robots and reconfigurable modular robots is the bio-inspired modular tensegrity robot with polyhedral parallel modules (HEDRA) [6]. An adaptive cable driven robotic gripper is designed and attached to the tensegrity manipulator for grasping objects in different shapes, weights, and sizes (see Fig. 1b). Consequently the particular objectives of our activities can be summarized as follows:

1. To investigate and optimize different variants of tensegrity mechanisms suitable for future light robots. The target is to use specific properties of tensegrity structures to maximize non-collision workspace, dynamic stiffness, controllability and observability at minimum mass.
2. To develop advanced motion and force planning strategies of the whole tensegrity structure fulfilling requested non-collision operations of end-effector together with minimization of energy consumption and other requests.
3. To investigate and develop optimum mechatronic solution of tensegrity robot with optimization of control algorithms, actuators and sensors in order to maximize robot performance. The low authority control (vibration suppression), high authority motion control and force control will be combined using special possibilities of tensegrities.
4. To build complex simulation models of most promising variants of investigated tensegrity robots, to evaluate mechanical and operational properties and test the control strategies.
5. To realize experiments with a proposed simplified demonstrators for verification of selected properties of a smart tensegrity mechanisms.

## Acknowledgements

The paper has originated in the framework of solving No. 20-21893S project of the Czech Science Foundation entitled “Mechatronic tensegrities for energy efficient light robots”.

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