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Design, modelling and analysis of concepts of planar serial robots based on tensegrity structures

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The term tensegrity originated from the shortening of the phrase tensional integrity. These are stable structures composed of pressure-stressed elements that do not touch in the case of first-class tensegrities (in higher-class tensegrities, some elements are connected by joints) and a network of tensile-stressed elements. This concept was introduced by the architect Buckminster Fuller in the second half of the 20th century.

The great advantage of these structures, e.g. Fig. 1, is the fact that all elements are stressed only by tension or pressure. Since it is not necessary to dimension the individual elements for bending or torsional stresses, a rigid structure can be achieved by using elements with a lower weight than conventional structures. The load-bearing capacity of the structure is then proportional to the prestressing of the ropes.

The stability of tensegrity does not depend on gravity, which implies the possibility of arbitrary orientation in space. Unlike serial robots, the load is distributed over the entire structure, so there is no accumulation of load at critical points, [1].

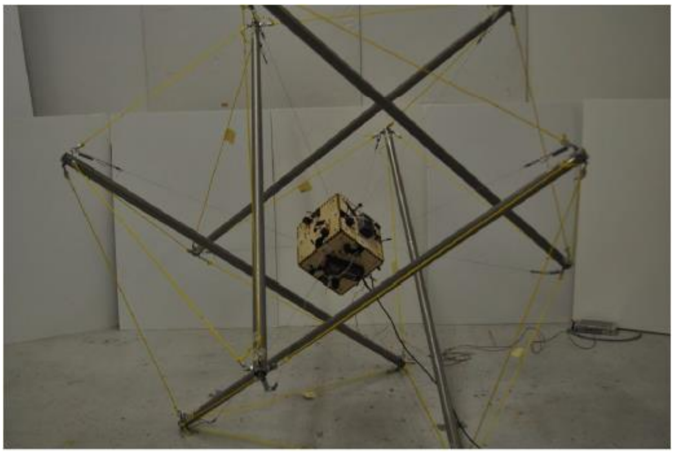

Fig. 1. Super Ball Bot (NASA Ames Research Centre) [5]

At first, tensegrities were used mainly in the art of sculpture and subsequently were introduced in architecture and civil engineering. In these areas, they have been used mainly due to their excellent load-bearing capacity / weight ratio, and the fact that these structures have a minimal area and are therefore able to withstand worse weather conditions is used to advantage in high-rise buildings. Over time they spread to robotics and space industry. By importing the drives that control the prestressing of the elements into tensegrity structures, the concept of mechatronic tensegrity was born, [2].

The deployable tensegrities are most suitable for creating manipulators. These are structures composed of individual modules (stages) that are arranged in series and together form a tensegrity beam. A great advantage of these structures is the fact that the individual modules can change their length based on the choice of the initial lengths of the ropes. On the contrary, the disadvantage is the need for high prestressing of the ropes to achieve the required bending stiffness, which is a key feature for manipulators, see Fig. 2, [4].

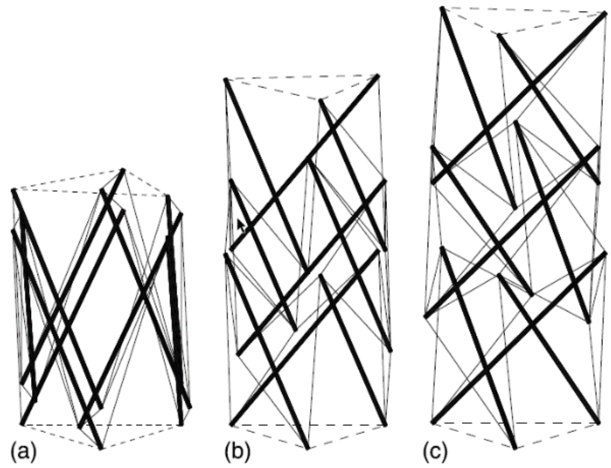

Fig. 2. Deployable tensegrity – 3 stages [3]

The design of individual concepts of planar manipulators can be described as a transition from a common serial robot to a complex tensegrity structure. The first concept (*classic*) is therefore a classic serial robot. In the second concept (*cross*), the drives in the revolute joints are replaced by a parallel connection of cables. The third concept (*tens_rev*) is class 3 tensegrity. This concept allows you to change the length of individual stages based on the choice of cable lengths. The fourth concept (*tens_fix*) reduces the number of cables needed to control the shape of stage by connecting bars into pairs. The last concept (*tens*) is then a complex tensegrity structure, see Fig. 3.

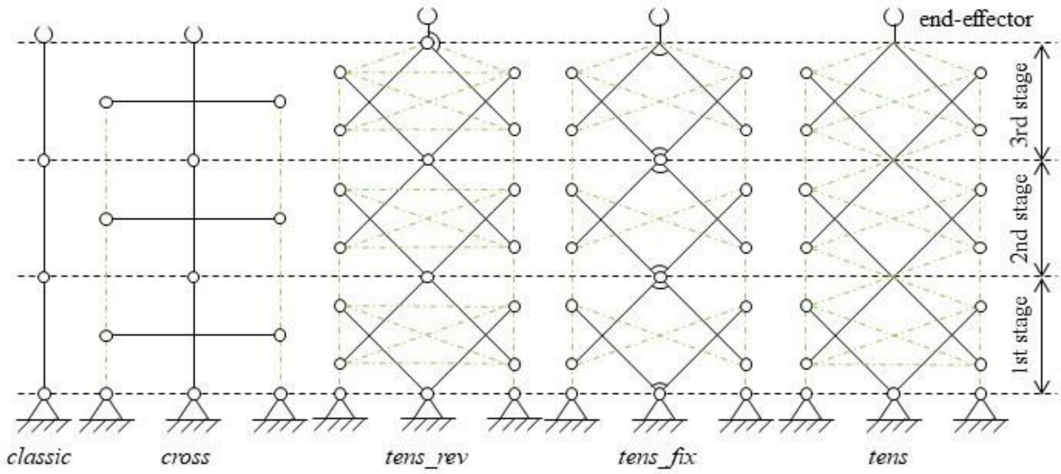

Fig. 3. Sequence of design of planar manipulators

Dynamic models of individual concepts were compiled with the Simscape environment of the program Matlab. This environment allows the direct application of models of physical blocks, which greatly simplifies the compilation of equations and the determination of dynamic properties.

The concept *tens_fix* was chosen for control design, because in contrast to complex tensegrity, the revolute joints between stages allows a greater range of motion and, compared to the concept of *tens_rev*, is less demanding on control. The actual length control was chosen for the system. The free length of cable is controlled by a PID controller based on the difference between the required and the measured length of cable.

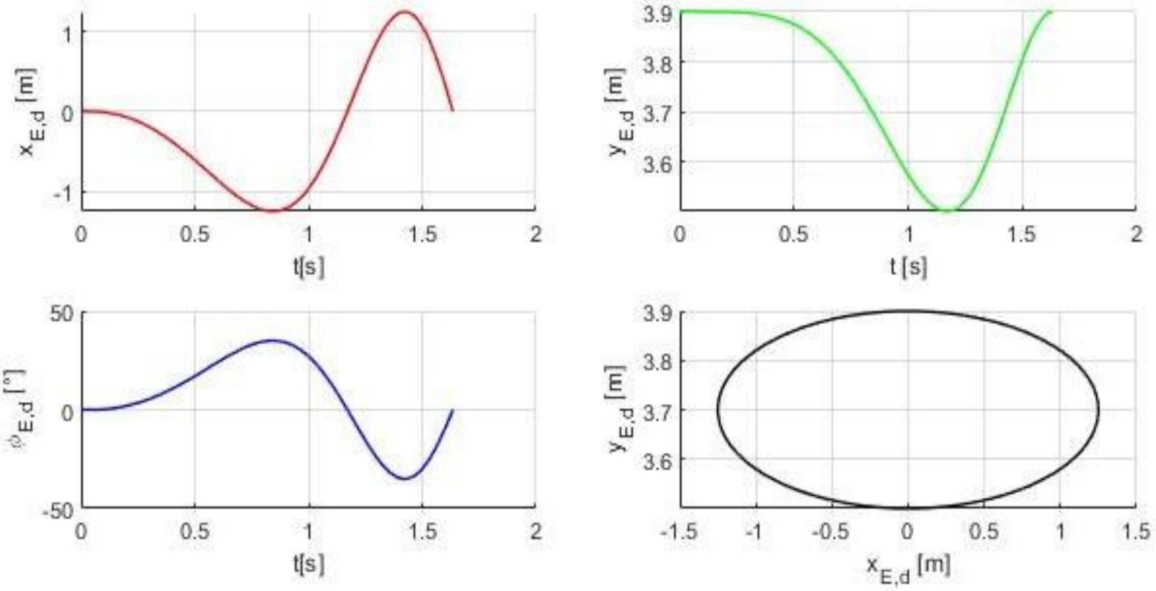

Fig. 4. Trajectory of end-effector E

To demonstrate and optimize the control, the trajectory of the end-effector E of a four-stages robot of the *tens_fix* type shown in Fig. 4 was used. The optimization parameters are then the proportional, integration and derivative gain (k_p, k_i, k_d) of the PID regulators. Due to the large range of parameters, a sensitivity analysis of individual parameters was first performed to determine the starting point of optimization. The target function is defined as the sum of the weight multiples of the position and angle deviations (e_E^x, e_E^y, e_E^ϕ). The *fmincon* function was used for the optimization itself. Fig. 5 shows the end-effector deviations of the optimized system.

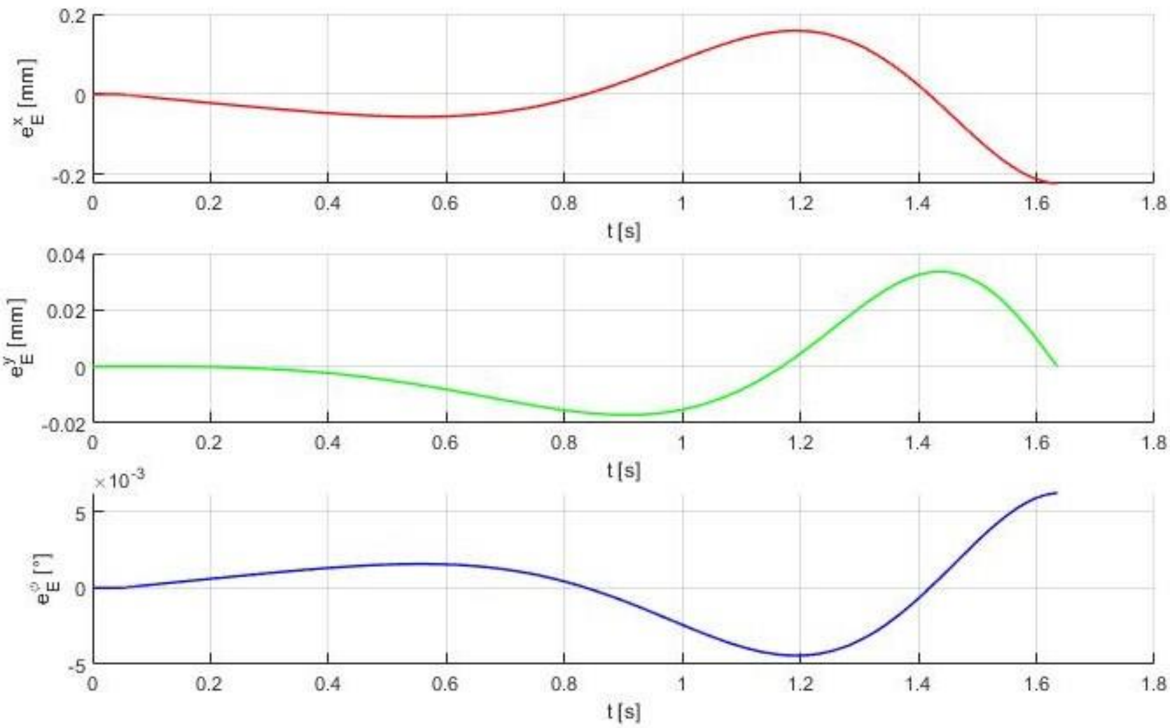

Fig. 5. End-effector deviations of optimized system

Acknowledgements

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