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Optimization and control of mechatronic tensegrity for robotics

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1. Introduction

Tensegrities are stable structures consisting of discontinuous compressive members and continuous tensile members. In engineering applications compressive members are often rods that do not touch each other, while tensile members are often pretensioned cables. The word *tensegrity* comes from conjugation of words *tension* and *integrity* [4]. Active tensegrities are gaining popularity in applications regarding mobile robots and deployable structures (Fig. 1). Our goal is to explore possibilities of active tensegrity application in robotic manipulators.

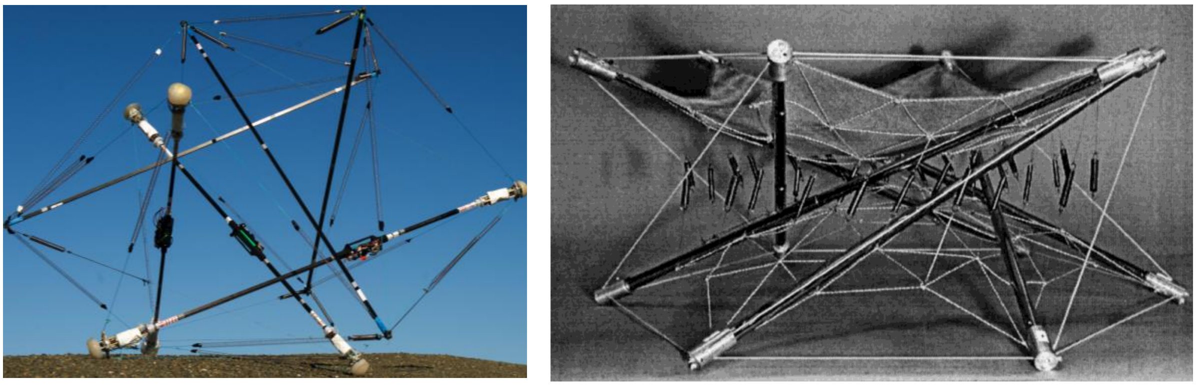

Fig. 1. (Left) mobile tensegrity robot "Super Ball Bot", (right) deployable antenna using tensegrity structure

2. Dynamic model of planar tensegrity

Dynamic model is derived using Lagrange Equations of Second Kind with following assumptions. Individual rods are considered as perfectly rigid bodies, friction in joints is ignored, mass of cables is ignored, and cables are modelled as parallel combination of tension spring and linear viscous damper. However dynamic model alone does not provide stability of tensegrity.

3. Form-finding optimization

Form-finding is a process of searching for such pretension in cables that stabilizes the tensegrity structure. Static form-finding method, called *Force Density Method*, is used to stabilize the dynamic model. Advantage of this method is that only topology describing the connection of cables and rods needs to be known. Force density method analyses so called *Stress Matrix* which describes force densities between individual nodes of a tensegrity [1]. Genetic algorithm is used to solve the form-finding problem as presented in [2]. This approach also allows to use the symmetric nature of tensegrity structures to reduce the number of optimization parameters significantly.

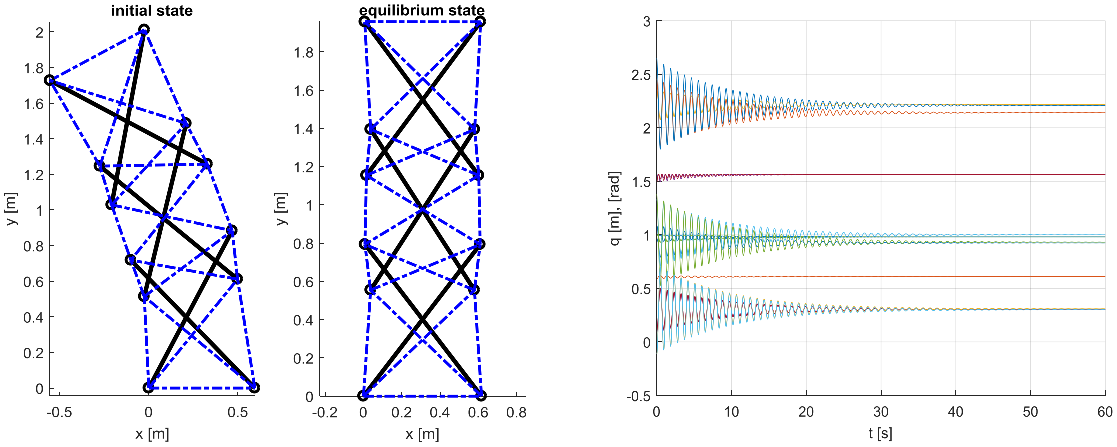

Fig. 2. (Left) initial state of 15 DOF tensegrity and its equilibrium state. (Right) plot showing the evolution of individual coordinates of the dynamic model from the initial state to the equilibrium state

4. Motion control

Motion control of stable planar tensegrity is achieved by varying free lengths of pretensioned cables. For this purpose, *Computed Torque Control* method is applied to the dynamic model of planar tensegrity with 15 DOF (Fig. 2). Since this method involves solving inverse dynamics problem and it is assumed that each of total 22 cables are active, an undetermined system of equations needs to be solved. This allows to optimize the result in such way that all cables are pretensioned and no force exceeds specified limit given by the cable properties.

5. Eigenmotion

To plan the motion of the 15 DOF tensegrity a concept called Eigenmotion is used. Characteristic of Eigenmotion is that total mechanical energy is constant during motion [3]. This concept allows to control the motion of the tensegrity so that control inputs only compensate the energy dissipation in the system. Furthermore, Eigenmotion of tensegrity can be varied by adjusting mass of individual rods or stiffness of cables to match the Eigenmotion with desired motion. Adjusting of these parameters is solved as an optimization problem. This optimization is solved in a model without energy dissipation. Applying optimization results to a model with active control and energy dissipation leads to an energy efficient control.

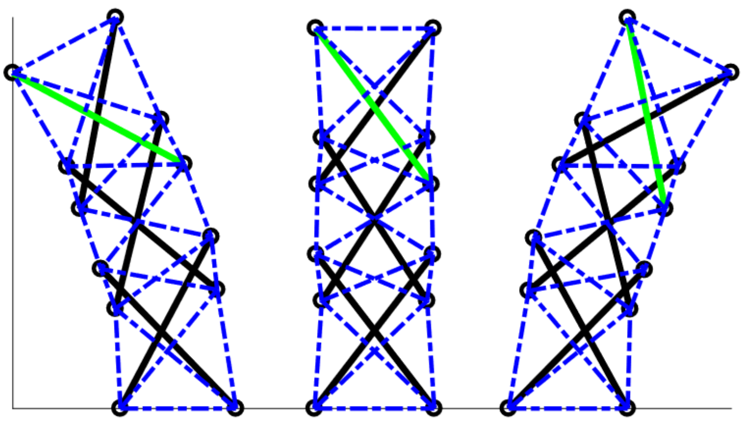

Fig. 3. Desired positions of rod 6 at time t = 0 s, t = 0.4 s, and t = 0.8 s for Eigenmotion optimization

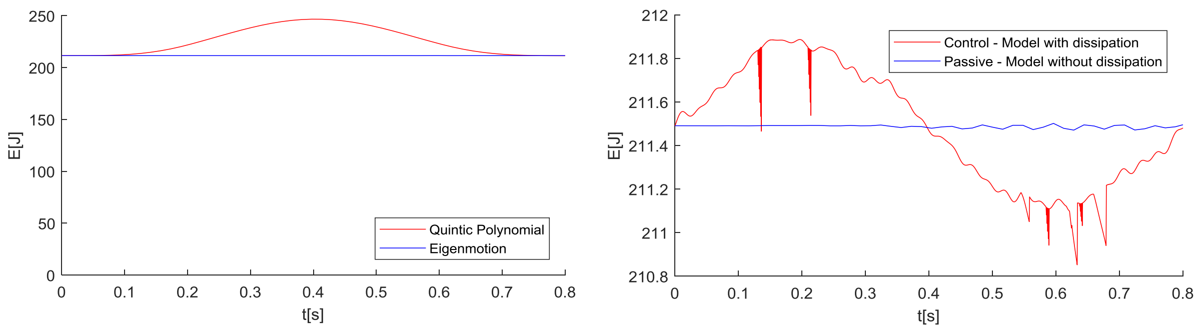

Fig. 4. (Left) comparison of total mechanical energy between trajectory generated with quintic polynomials (red) and trajectory obtained from Eigenmotion optimization (blue). (Right) comparison between total mechanical energy of passive tensegrity in a model without dissipation (blue) and total mechanical energy of controlled tensegrity in a model with dissipation (red)

6. Conclusion

To explore the possibilities of use of active tensegrities in robotic manipulators a dynamic model of planar tensegrity was derived. This model was then stabilized using genetic algorithm to solve the form-finding problem. Computed torque control was then applied to the model to control motion of tensegrity. Lastly, Eigenmotion concept was applied to control the tensegrity in energy efficient manner.

Acknowledgements

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