COMPUTATIONAL MECHANICS 2022
37th conference with international participation
Srní
November 7 - 9, 2022

Pre-stress states and controllability of spatial cable-driven mechanisms

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The paper analyses several cable-driven mechanisms (manipulators) whose topology is based on the concept of deployable tensegrities. The term tensegrity was coined by shortening the phrase tensional integrity and the main feature of these structures is the presence of only compression (rods) and tension (cables) loaded members [3]. Deployable tensegrities are then a good choice for the creation of a manipulator, because they are divided into individual stages that form a tensegrity beam and allow a change of length in the axis of this beam [4]. Examples of the analysed structures are shown in Fig. 1.

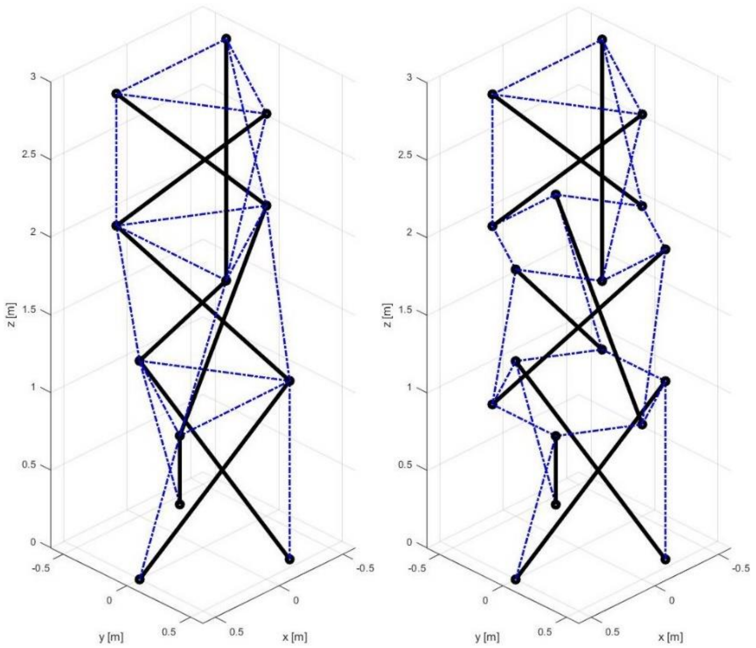

Fig. 1. Examples of analysed structure: structures with tensegrity features (left), pure tensegrity (right)

The analysis itself is then based on the definition of tensegrity described in [1], [2]. This definition classifies tensegrity structures into two groups based on the following features:

- T – the structure is truss,
- S – there is a self-stress state,
- C – tensile elements (cables) have no rigidity in compression,
- M – there is an infinitesimal mechanism stiffened by self-stress state,
- I – the set of struts is contained within the continuous net of tensile elements,
- D – compressed elements extremities do not touch each other.

The structures that have all features (T+S+C+M+I+D) are classified in the "pure tensegrity" group. "Structures with tensegrity features" fulfil three obligatory criteria (T+S+C) and have at least one of the features: M, I, or D. The main difference between pure tensegrity and structures with tensegrity properties is that only pure tensegrity has all the essential engineering properties such as the ability to tune the stiffness and natural frequency of structure based on the choice of prestress.

Thus, the key features for determining the group are M and S. Only the presence of self-stress states (S) is necessary for the possibility of controlling the tensegrity structure. The presence of self-stress states and infinitesimal mechanisms in the structure can be verified by analyzing the eigenvalues of matrices BB^T and B^TB, where B is the compatibility matrix. A least squares method was used to determine the prestressing of the entire structure, which optimizes the distribution of forces by combining the individual self-stress states so that the distribution is as close to homogeneous as possible.

Analysis of the examples shows that the structure on the left in Fig. 1 is a structure with tensegrity features and is controllable because it satisfies all features except D (there are 3 self-stress states and 3 infinitesimal mechanisms). To increase the range of motion, additional cables were added (Fig. 2), and in this configuration the structure has 9 self-stress states and no infinitesimal mechanisms. However, the use of the least squares method to choose prestress of structure determined the distribution of forces in the additional cables to be zero, thus they can be described as redundant.

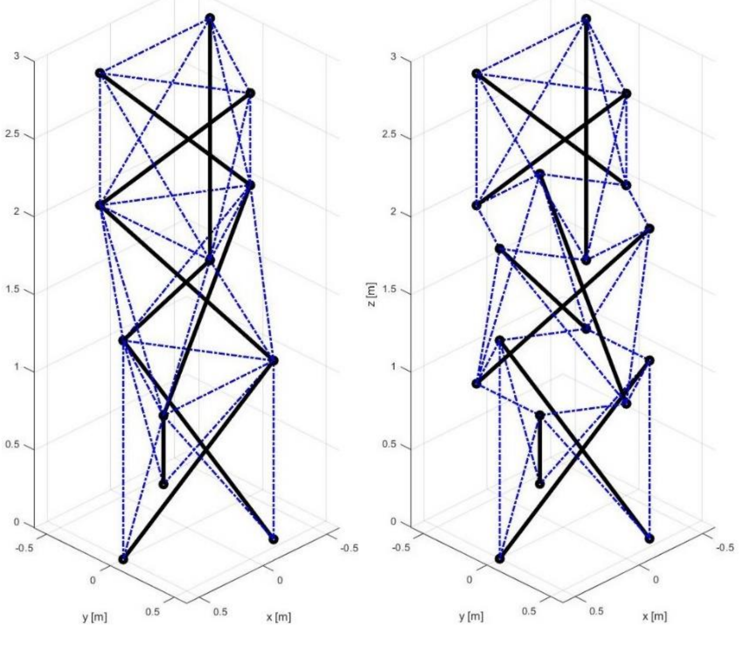

Fig. 2. Examples of analysed structure with additional cables

The structure on the right in Fig. 1, on the other hand, satisfies all features, i.e., it is a pure tensegrity and is controllable. In this configuration it has 1 self-stress state and 13 infinitesimal mechanisms. Adding cables (Fig. 2). changes the number of self-stress states to 3 and the number of mechanisms to 6. Like the structure with tensegrity properties, the added cables are zeroed using the least squares method. The controllability of this structure with the added cables is conditioned by the in-plane placement of the nodes between the stages. Thus, if the stages interpenetrate each other, the self-stress states are extinguished.

Based on the analysis, concepts were selected for which a dynamic model was built. The models were built using the SimScape environment. This tool allows the direct application of physical blocks and the definition of links between them, thus eliminating the compilation of dynamic behavior equations. The final step is then to design and build the demonstrator and control application.

Acknowledgements

The work has been supported by the Czech Science Foundation project 20-21893S "Mechatronic tensegrities for energy efficient light robots" and partly by the project SGS22/150/OHK2/3T/12 “Mechatronics and adaptronics 2022” of the Czech Technical University in Prague.

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