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# Improving dexterity of tensegrity structures using a set of local linear models

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The paper deals with the research of future robotic-type mechatronic structures based on tensegrities [4]. The aim is to replace serial robots with tensegrity mechanisms and to maintain a large collision-free workspace while significantly improving the ratio between stiffness and weight and the overall variability of the robot.

Tensegrity structure has typically more degrees of freedom than its end-effector. The set of local linear models is used to find the optimal configuration of these redundant degrees of freedom. The goal is to maximize dexterity throughout the workspace.

The dexterity optimization was performed on a simulation model of planar 3-stage tensegrity tower [2] shown in three different positions in the left part of Fig. 1. The structure consists of 6 bars and 22 tendons of variable length. The centre of mass of the upper left bar was selected as the working point (end effector). The workspace was defined using 100 predefined positions of this working point.

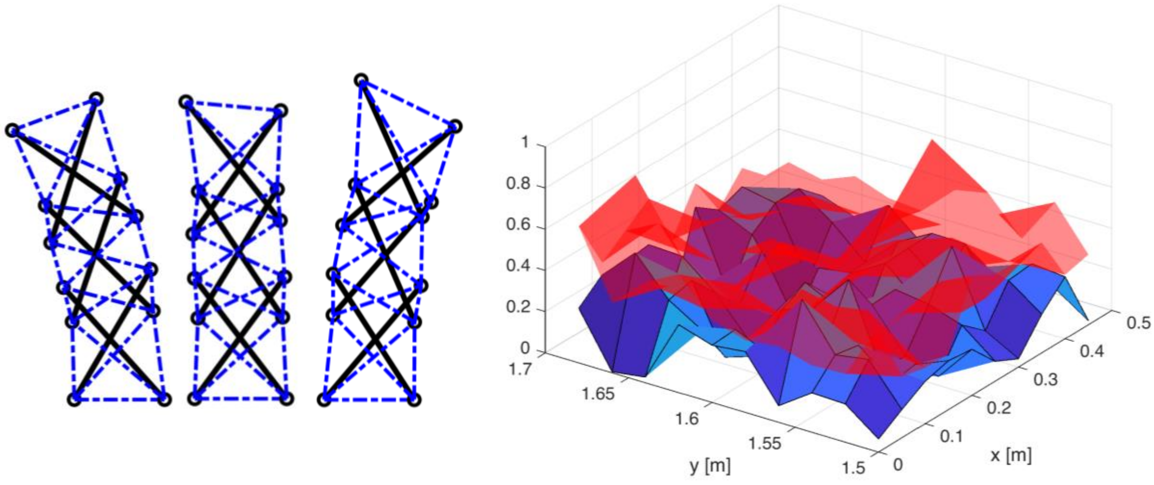

Fig. 1. Different positions of controlled tensegrity structure (left), comparison of optimized and nominal dexterity throughout predefined workspace (right)

Dexterity quantifies the ability to control the end-effector using available actuators. We describe it mathematically as

$$D = \frac{1}{cond(\boldsymbol{J})}\,, \tag{1}$$

where $\boldsymbol{J}$ is a Jacobi matrix describing the transfer between velocities of actuators/tendons $\dot{\boldsymbol{l}}$ and velocity of the end effector $[\dot{x}_S, \dot{y}_S]^T$

$$\boldsymbol{J} \cdot \dot{\boldsymbol{l}} = \begin{bmatrix} \dot{x}_S \\ \dot{y}_S \end{bmatrix}. \tag{2}$$

The structure in Fig. 1 is described using 15 independent coordinates. The positions of the end effector $x_S$ and $y_S$ were prescribed and the remaining 13 coordinates represents optimization parameters that were optimized to maximize dexterity in defined workspace points [1]. The subsequently calculated tendon lengths were used as input to the local linear model tree algorithm (LOLIMOT) [3]. The whole workspace was divided by this algorithm into 46 sub-areas, in which a linear model was created for each tendon, Fig. 2. These models are represented in the approximated model by the validity function and the membership function. The product of all validity and membership functions is then equal to one in the whole domain of the model. The resulting model is then given by the sum of the individual local linear models with the corresponding validity and membership function.

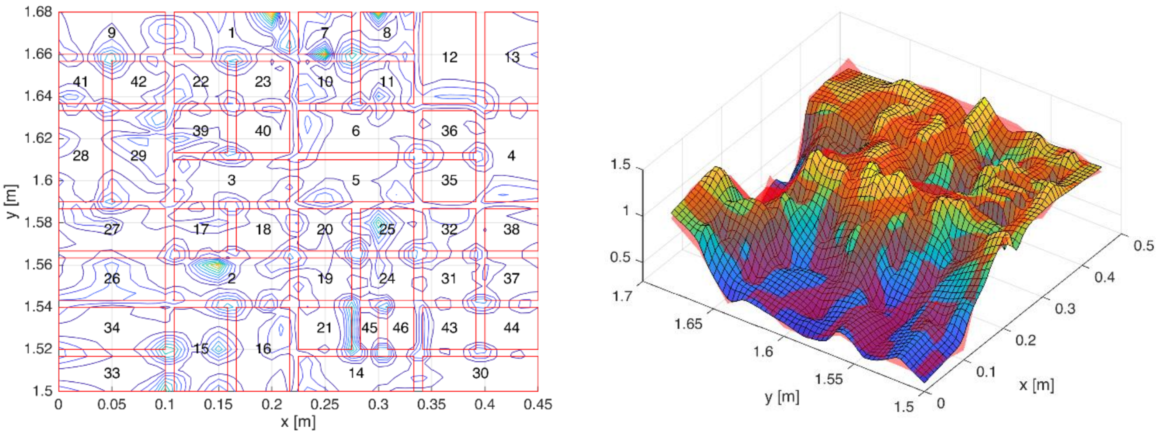

Fig. 2. Workspace division using LOLIMOT and model error (left), comparison of LOLIMOT approximation with exact values (right)

In the right part of Fig. 1 is the resulting comparison of dexterity when the redundant degrees of freedom are controlled using the set of local linear models (red surface) and the nominal configuration of tensegrity taken from a form-finding approach. There is an obvious improvement throughout the entire workspace. The simulation experiments confirmed that the set of local linear models is a suitable approximator for finding rules for controlling the length of tendons even in positions between optimized points.

## Acknowledgements

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## References

[1] Balon, A., Optimalizace a řízení mechatronické tensegrity pro robotiku, Master thesis. ČVUT, Praha, 2019. (in Czech)
[2] Jílek, M., Zlepšení manipulovatelnosti tensegritických struktur využitím sítě lokálních lineárních modelů, Master thesis. ČVUT, Praha, 2021. (in Czech)
[3] Nelles, O., Local linear neuro-fuzzy models: fundamentals. In: Nonlinear System Identification. Springer, Berlin, Heidelberg, 2001.
[4] Skelton, R.E., de Oliveira, M., Tensegrity systems, Springer-Verlag US, 2009.