Locomotion of a non-conventional tensegrity structure - simulated as multi-body system

Erik Gerlach[1], Klaus Zimmermann[1]

[1] Faculty of Mechanical Engineering
Technische Universität Ilmenau
PF 100565, 98694 Ilmenau, Germany
erik.gerlach@tu-ilmenau.de

EXTENDED ABSTRACT

1 Introduction

Tensegrities are mechanical structures based on an interaction between compressive and tensile forces. This contribution deals with modeling and dynamic simulation of a mobile robot based on a tensegrity structure. Normally these structures are pin-jointed and their elements are, in pure axial compression or tensions. A well-known application is the SUPERball developed by NASA, Sabelhaus and Bruce [4]. This paper investigates a spherical mobile robot based on a tensegrity structure with curved compressed members. The modeling as a multi-body system, including contact mechanics and control, are considered.

2 Background and prior work

The most essential property of tensegrities - local impact on the structure yields a global change of its shape - is the base for locomotion systems with large shape variability and a simple system design. In the present work, the focus is on the dynamics, therefore, we works with multi-body system model to study the motion of tensegrities. The ability of tensegrity structures to change their shape makes them ideal for use as mobile robots. We achieve this by preloading the tension elements. The movement is created by shifting and tilting the structure. The preload variation is associated with considerable design efforts in real applications. One solution is to add weights which are moved on selected, defined paths. The mobile robot, designed by Kaufhold [2], moves based on a combination of rolling and tilting motions. The system is described as a non-conventional structure, because there are not only pure tensile or compressive loads in the elements[1]. It is important to consider the points of contacts of elements, floor, and movable parts when simulating the multi-body systems[3].

3 Multi-body model

The system is studied with the simulation tool *alaska*. The prototype [6] consist of (see Fig. 1, left):

- two curved compressed elements (arch element)
- 12 clamping elements (wire ropes)
- two drive units with additional weights

To simulate the dynamics of the robot, we use a multi-body model, see Fig. 1 right. The two curved elements are the main elements of the structure and touch the floor. In this work, we use the following friction approach: Tangential forces at the contact point are computed by applying the Magic Formula developed by Pacejka [5]. Normal forces are calculated using a nonlinear spring-damper-model based on contact theory according to Hertz.

$$F_N = ca^b + k\dot{a} \quad b > 1 \tag{1}$$

c – spring constant, k – damper constant, a – penetration depth

Fig.1: Tensegity Prototype (left) and MBS-model (right)

The wire ropes are modeled with springs attached to the ends of rigid tubes. The forces acting on the wire ropes are caused by tensile stress alone.

$$F_s = \begin{cases} \frac{E_s A_s}{\lambda_{S0}}(\lambda_S - \lambda_{S0}) + k_S \dot{\lambda}_S & \lambda_S > \lambda_{S0} \\ 0 & \lambda_S \leq \lambda_{S0} \end{cases} \tag{2}$$

The drive is carried out by the torque generated by the stepper motor. A gearbox, consisting of bevel gear and rack, transfers this to the carriage of the drive unit, so that it moves along the guides in the arch element. In the model, the forces required to shift the drive units to the target position is calculated using a control algorithm.

4 Simulation and Results

The two kinds of locomotion show the dynamic simulations. The model is able to carry out rolling and tilting sequences. Figure 2 shows the selected drive unit control sequences for rolling. As a result, the location on the ground of the center was determined, see Figure 3. Furthermore, we investigated the influence of the friction coefficient and the tilting of the structure.

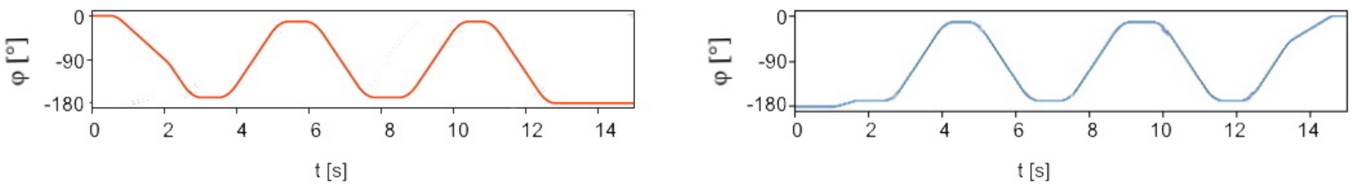

Fig.2: Selected control sequences for rolling (drive unit one (left) and two (right))

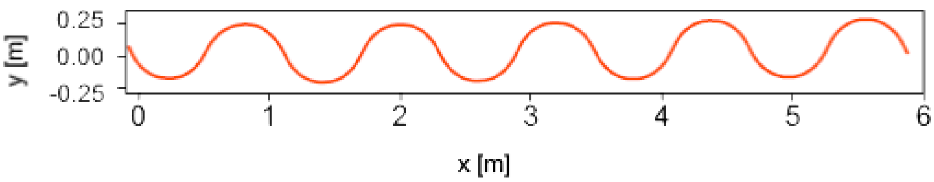

Fig.3: Location of center in the x-y-plane (rolling)

5 Conclusion and future work

In this work, a MBS-model of a non-conventional tensegrity structure for locomotion is presented. Dynamic simulations show that the structure is capable of performing uni-axial rolling as well as tilting sequences on a plane floor. The results will be used in future work to improve the control function of the drive units and to test position controls for the whole system.

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References

[1] V. Böhm u. a. “Spherical mobile robot based on a tensegrity structure with curved compressed members”. In: 2016 IEEE International Conference on Advanced Intelligent Mechatronics (AIM). IEEE. 2016.

[2] T. Kaufhold. “Modellbildung, Simulation und Prototypenentwurf von mechanisch nachgiebigen, mobilen Robotern”. PhD Thesis. Technische Universität Ilmenau, 2017.

[3] G. Hippmann. “Modellierung von Kontakten komplex geformter Körper in der Mehrkörperdynamik”. PhD Thesis. Technische Universität Wien, 2004.

[4] A. Sabelhaus, J. Bruce, K. Caluwaerts, “System Design and Locomotion of SUPERball, an Untethered Tensegrity Robot.”, Proceedings of the Robotics and Automation (ICRA) Conference, 2015.

[5] H. Pacejka, Tire and Vehicle Dynamics. 2nd edition, Oxford, Elsevier, 2006

[6] L.M. Kutschat, "Modellierung und Simulation des dynamischen Verhaltens einer Tensegrity-Struktur als Mehrkörpersystem". Bachelor Thesis, TU Ilmenau, 2020