Multi-body modelling and simulation of locomotion systems based on tensegrity structures

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I. INTRODUCTION

Tensegrities are mechanical structures based on an interaction between compressive and tensile forces. These structures are pin-jointed and their elements are, therefore, in pure axial compression or tension. By using a suitable design, free-standing structures can be built. In this contribution, we are focusing on tensegrity based locomotion systems. Two known approaches, amongst others, are the SUPERball developed by NASA, Sabelhaus and Bruce [1], and the system by Böhm and colleagues [2], based on a tensegrity structure with two curved compressed members. The systems differ in their actuation and locomotion schemes.

II. 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 review only works related to the study of motion of tensegrities. The work of Paul et. al. studies the properties of dynamic tensegrity structures with respect to hardware and simulation [3]. Further works discuss the dynamic simulation, e.g., Hirai and Shinichi generate a MATLAB model [4] and Lou et. al. use ADAMS for a simulation of the motion of tensegrities [5]. Mirletz et. al. show the differences between the motion of a real prototype and the multi-body system (MBS) simulations [6].

III. MBS-MODEL

The system in focus here is a spherical tensegrity robot for a rolling locomotion. It is based on a simple spherical morphology: the icosahedron geometric configuration. For locomotion, additional masses are moved on selected parts, in contrast to the SUPERball, which rolls by changing the shape through varying the length of the tension elements (ropes). The multi-body simulation software ALASKA is used to analyze a model of this system. The used MBS-model consists of rigid bodies, constraints and applied/reactive forces. In the following, we will refer to the compressive elements as rods and to the tensile elements as ropes. Figure 1 shows both types of elements in the ALASKA model of the tensegrity: The rods are rigid cylinders; the ropes are spring-damper-elements. The equation for the computation of the spring force is:

$$F_{Spring} = \begin{cases} -C \cdot (X - L0) & X > 0 \\ 0 & X \leq 0 \end{cases}$$

The spring force is zero, if the actual length X is shorter than the length of the relaxed spring $L0$. An important goal is the realistic modelling of the coupling points of rods and ropes. Friesen and colleagues have shown a great impact on the simulation results [7]. The additional masses are coupled on the rods with prismatic joints. The parameters of the simulation model are described in [8]. The locomotion of tensegrities depends on the interaction of system and ground. Thus, the modelling of the contact has a crucial influence on the simulation results. In this work, we use the following approach: All normal forces are calculated using a nonlinear Kelvin-Voigt-model and all tangential forces are computed by applying the Magic Formula developed by Pacejka [9].

$$f(v) = \mu_H \sin\Big(C \cdot \arctan\big(B \cdot v - E \cdot (B \cdot v - \arctan(B \cdot v))\big)\Big)$$
$$v - velocity;\ \mu - friction\ coeffizient;\ B, C, E - coeffizients$$

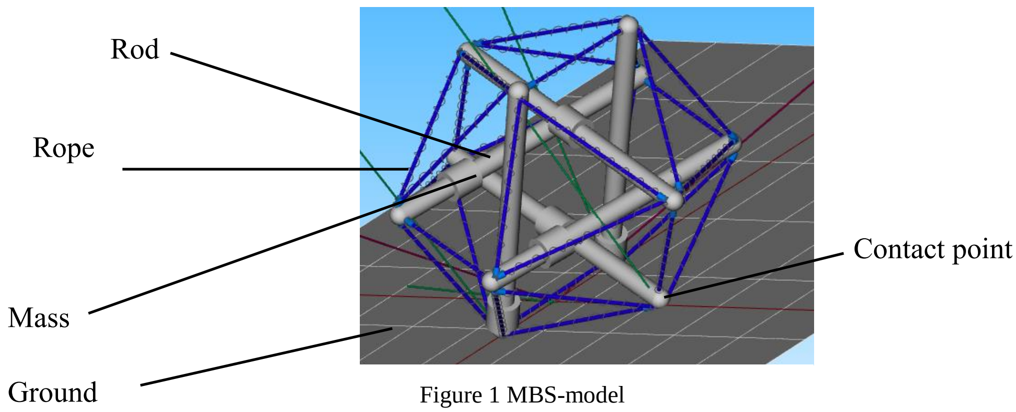

Figure 1 MBS-model

IV. RESULTS

Using the described model, numeric simulations can be performed to analyze various scenarios. At first, the model makes a one dimensional motion by moving the additional masses. The motion of the masses is obtained by a controlled change in their position, which is visualized in Figure 2. The resulting movement of the system on the ground is nearly a straight line, see Figure 3. In it, the blue line represents the path of the center of mass and the short orange segments are the stand-"phase". Additionally, the alignment of the contact triangle in the ground plane is shown.

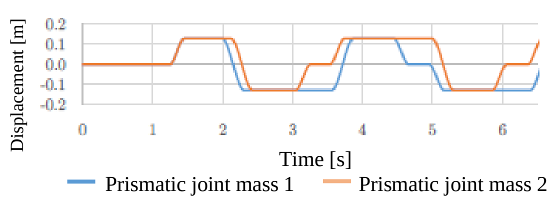

Figure 3 Function to control masses on rod one and two

Figure 2 Linear locomotion of tensegrity structure

V. CONCLUSION AND FUTURE WORK

In this work, a MBS-model of a tensegrity structure for rolling locomotion and a simulation of its movement is presented. For the contact simulation, the simulation tool ALASKA is useful, especially for simulating the system states and the dynamic behavior. The results will be used in future works to improve the control function of the moving masses and, as a next step, to realize simulations of other locomotion paths, e.g., a circular path.

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