Deployment Dynamics of Mesh Antennas with a Modeling Method of Tackling the Inherent Multiscale Problem

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Deployable mesh antennas have been of increasing interest to the aerospace industry in recent decades [1] because of their high packaging efficiency and low areal densities [2]. In structure, an antenna, for example Astromesh shown in Fig. 1, mainly contains a network of cables and a metallic mesh to reflect electromagnetic signals, and a foldable structure that enables unfolding of the antenna from the stowed state for launch to the deployed state in orbit. If the deployable structure fails to unfold the antenna, it will immediately result in a fatal failure of the satellite. Therefore, understanding the deployment dynamics of mesh antenna is of great concern for designing purpose.

Taking the Astromesh as an example, its ring truss is composed of periodic parallelogram bays whose diagonal distances are adjustable, so that the truss can be deployed by reeling in a driving cable, which runs over pulleys and along the diagonals and is powered by two motors. As shown in Fig. 1, each synchronous connection contains a pair of interlocking gears to force its two connecting longerons to rotate in unison. Thus, if all the truss members are stiff enough to be theoretically considered as rigid bodies [3], the whole truss has only one degree of freedom (DOF). As a result, all the bays deploy with the same speed in a synchronous manner [3]. However, the flexibility of the members is becoming increasingly vital with the increasing size of the antenna, ranging from 6 to 25 m currently [4]. With flexible deformation, the truss is no longer a single-DOF system. Moreover, friction between the driving cable and the pulleys causes the cable tension to decrease exponentially with the number of the pulleys passed over. As a result, the bays practically unfold with different speeds (i.e., those near the motors unfold faster than those far from the motors) in an asynchronous way. In this case, both longerons and battens suffer from notable bending moments, especially around the synchronous connections, because the interlocking gears force the adjacent bays to deploy synchronously. Therefore, it is necessary to understand that how the flexibility and the friction affect the dynamics of the deployment, the bending moments of truss members, and the motor driving forces, which are of great concern in the design.

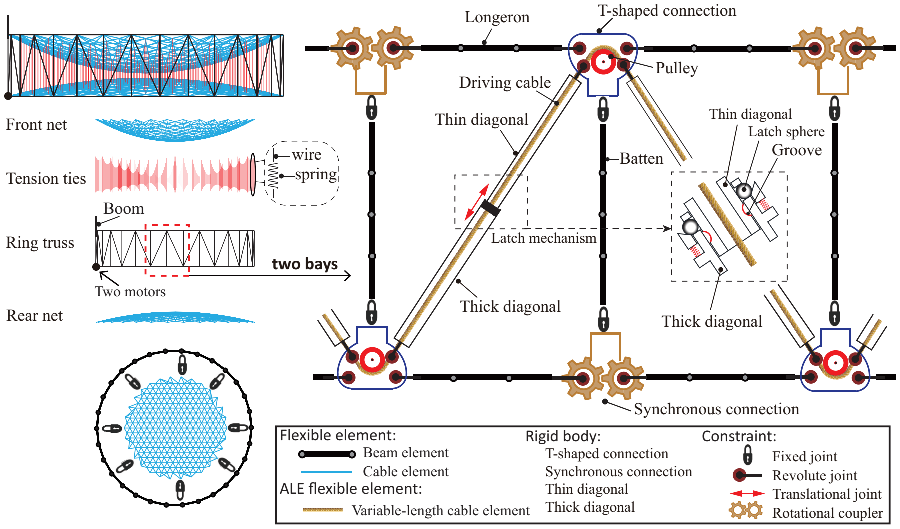

Fig. 1: Schematic of the flexible multibody model of the Astromesh

A flexible multibody simulation is supposed to be one of the methods for studying the dynamics of the deployment because a system- level test of a large antenna is impractical [5]. However, building a full-scale multibody simulation model for a large antenna, such as Astromesh, is an extremely challenging task. This is mainly caused by the inherent multiscale nature of deployment dynamics both in length scale and time scale. On the one hand, the length scale spans four orders of magnitude since the pulleys are 10mm, trusses are 1m and the driving cable is 100m. On the other hand, the time scale spans five orders of magnitude since the contact event is 1ms, while the entire unfolding process last for 100s. These problems conventionally requires fine finite element mesh and small numerical integration time step, resulting in extremely low calculation efficiency. Fortunately, the key multiscale problem in the deployment of mesh antenna is caused by the contact between pulley and driving cable since both the small length and the small time duration comes from it. If there is a proper method to model the pulley-cable system, then the multiscale might be removed and then feasible a full-scale simulation of the deployment.

To achieve this goal, we proposed novel method to model the pulley-cable system. The basic idea is using a variable-length cable element to model the driving cable, and an equivalent force to account the effect of friction between the driving cable and the pulley. This modeling method significantly reduced the level of multiscale, meanwhile reduced the number of generalized coordinates and made the simulation of a full-scale antenna feasible so that we can complete the deployment simulation of a 12.25 m Astromesh within 5 h with a four-core personal computer (Intel Core i7-4770 3.4 GHz). Next, based on the multibody model, the kinetics of the deployment, the bending moments of the truss members, and the motor driving forces were systematically investigated. Furthermore, the energetics of the deployment was addressed to understand more deeply the underlying dynamics of deployment.

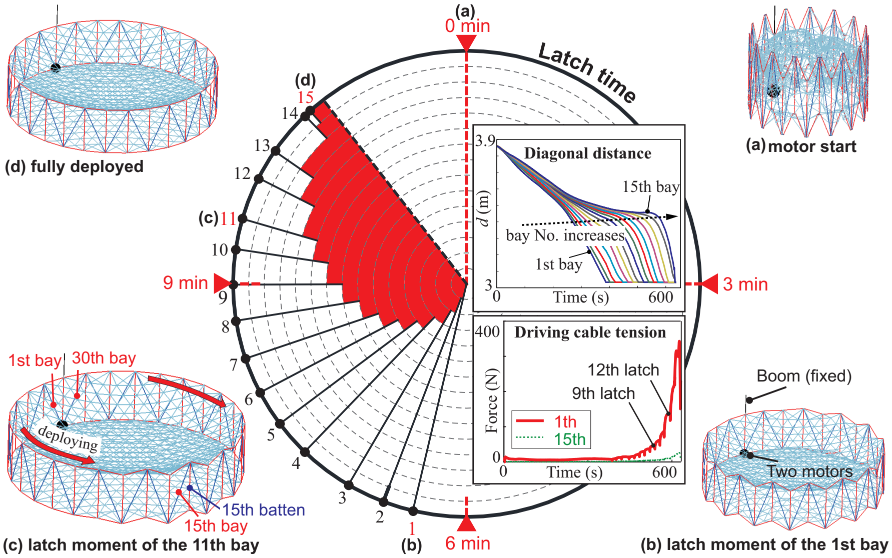

Fig. 2: The simulated asynchronous deployment of the Astromesh

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