An analysis method for a system with mass and extremely flexible component and its application to analysis of deployable satellite

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Abstract

In recent years, systems with extremely flexible components and masses (hereinafter called "SEFM") are often employed for satellites in order to realize various vast structures in orbit. For example, S310-36[1] project demonstrated a deployment of a large antenna. As Figure 1 shows, the antenna had a triangle shape and had consisted of a mesh made by thin and light-weight strings, a mother satellite which was located on center of the triangle and three daughter satellites which were connected to each vertex of the triangle. In such a system, the effect by the mesh on the whole dynamics of the system can be ignored if there is no tensile force in the strings. On the other hand, such an effect can be significant if at least one string has tensile forces. As seen above, SEFM has states with and without tensile forces, and there are two kind of state transition as Figure 2 shows. One is the transition from a state with tensile force to that without tensile force (F1), and the other is the transition from a state without tensile force to with tensile force (F2). Therefore, it is important to detect such state transitions for analysis of SEFM. In general, careful treatments are required for the analysis of such a system, because number of the combination of state increases dramatically depending on the number of mass and flexible component, which results in the difficulty in the computation. However, there is no strong method for analysis of such a system.

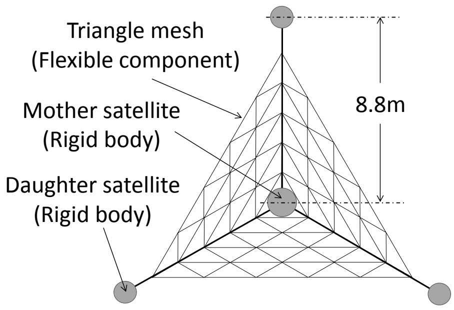

Figure 1: Example of SEFM (S310-36 project)

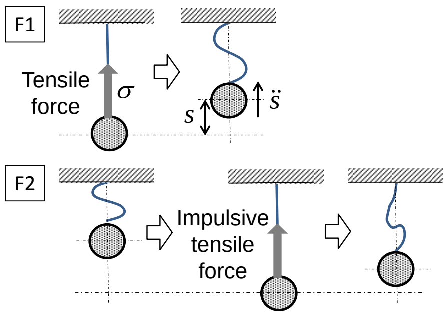

Figure 2: Two state transitions in SEFM

Authors have found analogy between the state transitions of the SEFM and rigid bodies contact problem. Rigid bodies contact problem is solved efficiently by use of Linear Complementary Problem (hereinafter called "LCP"), which is proposed by Pfeiffer, et al. Therefore, it is also possible to solve the state transition problem of SEFM. For example, state transition F1 is formulated as

$$\ddot{s} = A\sigma + B \tag{1}$$

$$\sigma \geq 0, \quad \ddot{s} \geq 0, \quad \sigma \cdot \ddot{s} = 0 \tag{2}$$

where $\ddot{s}$ and σ are acceleration of relative slack displacement s and tensile force, respectively as shown in Figure 2, A and B are the parameters which are determined from the system parameters. Either of $\ddot{s}$ and σ becomes zero and both of value satisfy Eq. (1) and state transion F1 is detected by monitoring the values of $\ddot{s}$ and σ. Eq.(1) and (2) constitute a LCP and the values of $\ddot{s}$ and σ is derived effectiely by numerical algorithm. State transition of F2 is also derived by use of LCP as well as F1.

In order to evaluate the proposed method, some numerical examples are demonstrated. For example, the system in Figure 3 is one of the analysis object and it consists of one mass and one string which connect the mass and ceiling. In the numerical example, string has slack in the initial state and motion of the mass is analyzed by use of proposed method and result is compared with result obtained by conventional method (Nonlinear FEM). As the figure shows, both results show good correspondence and comparison of calculation time shows that the proposed method saves 99% of the calculation time.

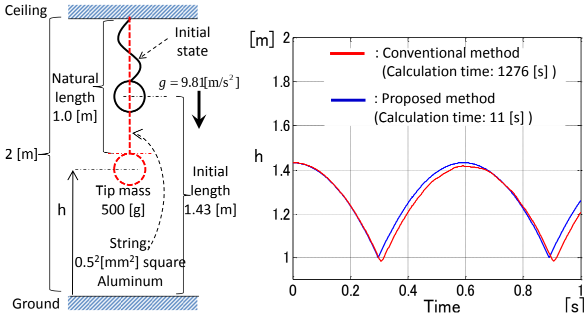

Figure 3: Comparison between the proposed and conventional method

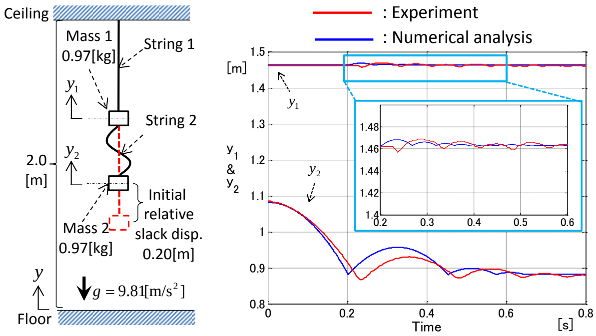

Figure 4: Comparison between the proposed method and experimental data

Furthermore, results of numerical analyses are compared with experimental data for validation of the proposed method. Figure 4 shows one of the comparisons. As Figure 4 shows, qualitative correspondence between both data is confirmed, however quantitative difference is observed. The difference comes from the fact that friction force is not considered in the proposed method and the difference does not have significant influence on the experimental validation.

In order to demonstrate the analysis of the deployable satellite's motion by the proposed method, a simple model of deployable satellite is introduced as Figure 5, which shows the satellite's state without any slack of strings. Mass 1 is set to 6 [kg], however Mass 2 and 3 is 5[kg], to observe the influence of the asymmetric distribution of masses on the deploy motion of the system. In the initial state, strings between Mass1 and 4, Mass2 and 4, and Mass3 and 4 is set to 7.0[m], and shape of the satellite is symmetric, i.e. vertex Mass 1, 2 and 3 is located on the vertexes of triangle and Mass 4 is located on the triangle's centroid (not center of mass in the case). Furthermore, Mass 1, 2 and 3 have velocity of 6.6 [m/s] in the CCW directions vertical to the lines from each mass to Mass 4. Figure 6 is the result of numerical analysis and it shows the trajectories of each masses for 5[s] from initial state. As Figure 6 shows, Mass 4 moves to left and trajectory does not converge to steady state, while it is confirmed in preliminary analysis that trajectory converges to steady state within 5[s] in the case that Mass 1 has also 5[kg], i.e. symmetric mass distribution.

In our study, in addition to above-mentioned results, several numerical analyses are performed and discussed in order to validate the proposed method.

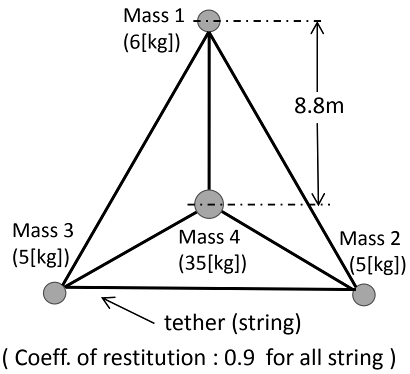

Figure 5: Simple model of deployable satellite

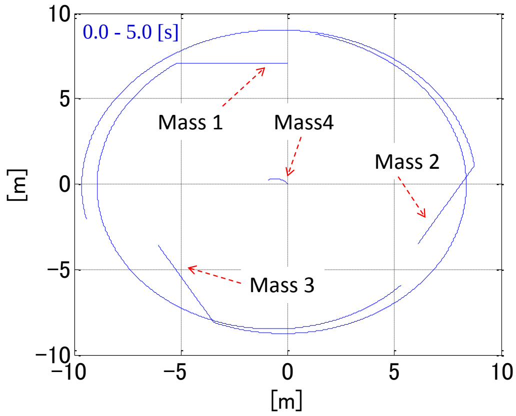

Figure 6: Example of numerical analysis

References

[1] Nakasuka, S., et al., "Sounding Rocket Experimental Results of Large Net Extension in Space to be Applied to Future Large Phased Array Antenna.", Space Technology - Space Engineering, Telecommunication, System Engineering and Control, Vol. 26, No.3-4, pp.165-170, 2006.

[2] Pfeiffer, F. and Glocker, C., "Multibody Dynamics with Unilateral Contacts", Wiley-VCH, 1996.