CONTROL OF MULTIBODY SYSTEMS MOVING ALONG A PLANE

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Summary The dynamics of multibody systems moving along a horizontal plane is investigated in the presence of dry friction acting between the system and the plane. Control algorithms are proposed for forces and/or torques created by actuators installed at the joints. The obtained results confirmed by experiments are related to mobile robots and the biomechanics of snake-like locomotion.

INTRODUCTION

Crawling motions of snakes and other limbless animals have always been of interest for mechanics and biomechanics [1]. Recently, these motions have been implemented in biologically-inspired snake-like robots [2].
In this paper (related to [3–6]) we study the dynamics of plane multibody systems consisting of several rigid bodies (connected by prismatic and/or revolute joints) and moving along the horizontal plane. Control forces and/or torques are created by actuators installed at the joints. Dry friction forces obeying Coulomb's law act between the system and the plane, the coefficient of friction is denoted by k. It is shown that two-member and three-member systems can perform various periodic motions by alternating slow and fast phases. For multilink systems, wavelike quasi-static locomotion is possible.

RECTILINEAR MOTION

Consider first multibody systems with prismatic joints moving along a straight horizontal line (Fig. 1). Control forces F act between each pair of neighboring masses. In the case of N equal masses m (Fig. 1a), wavelike regular progressive motion is possible, if $mgk < F < (N-1)mgk$. This condition does not hold for $N = 2$. Periodic motion of a two-mass system (Fig. 1b) is proposed and analyzed. This motion consists of a slow phase in which the smaller mass m approaches the bigger mass M which stays at rest, and a fast phase where the both masses move in the opposite directions. As a result, the whole system moves forward with an average speed $v = [g\eta km(M-m)/2]^{1/2}(M+m)^{-1}$. Here, η is the range within which the distance between masses can change. The maximum speed $v_{\max} = (g\eta k)^{1/2}/4$ is attained, if $m = M/3$.

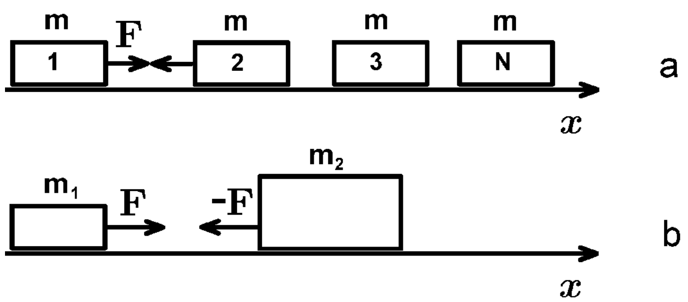

Fig. 1. Rectilinear motion

SNAKE-LIKE LOCOMOTION

Multilink systems with revolute joints can move along a horizontal plane by applying control torques at the joints connecting neighboring links (Figs. 2 and 3). Consider a two-link system with one active revolute joint where the control torque M is applied. Denote the masses and the lengths of the links by m_i, l_i, respectively, $i = 1, 2$. Here, the subscripts $i = 1, 2$ correspond to the longer and shorter links called the body and the tail, respectively. The mass of the joint is denoted by m_0.
The two-link system can perform the longitudinal motion with a period consisting of four slow and four fast phases (Fig. 2). In slow phases marked by even numbers in Fig. 2, the tail rotates by a certain angle while the body stays at rest. These phases are realizable, if $m_2l_2 < m_1l_1$ and $m_2(l_1 + l_2) < m_0l_1$. In fast phases marked by odd numbers in Fig. 2, the control torque M should be much greater than the torques created by friction forces: $M \gg m^*gkl^*$, where $m^* = \max(m_0, m_1, m_2)$ and $l^* = \max(l_1, l_2)$.
Under the conditions given above, the two-link system can not only move forward (to the right in Fig. 2), but also follow any prescribed trajectory in the plane. Similar results are obtained also for the three-link system.

The nonlinear dynamics of snake-like motions is analyzed. Displacements and the average speed of the periodic motion for the two- and three-link systems are estimated. The dependence of the average speed on the geometrical and mechanical parameters of the system is analyzed, and the values of these parameters corresponding to the maximum speed are calculated. For the two-link system, we have $v_{\max} = c(gl_1k)^{1/2}$, $c \sim 0.05$. For the lengthwise and lateral motions of the three-link system, we have $c \sim 0.1$ and $c \sim 0.5$, respectively. It is natural that the three-link mechanism equipped with two actuators can move faster than the two-link system of the same size having only one actuator.

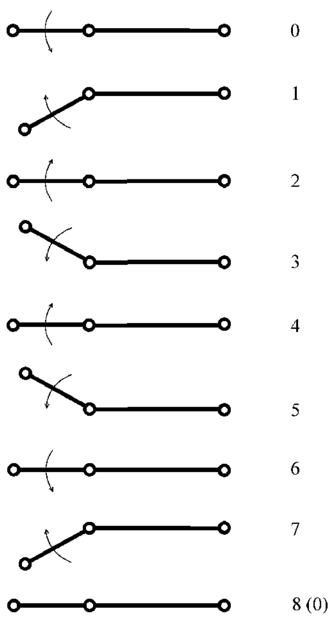

Fig.2. Motion of two-link system

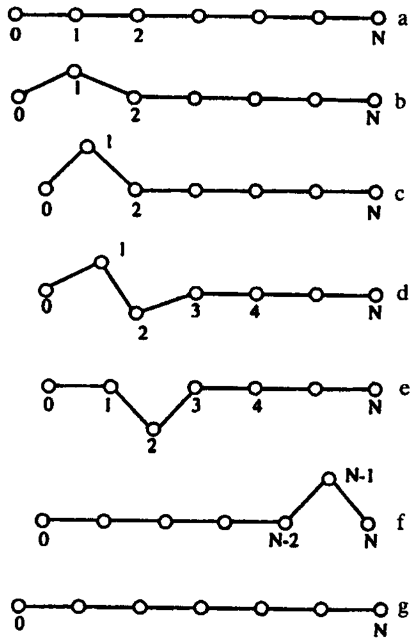

Fig. 3. Wavelike motion of multilink system

Multilink systems with more than four equal links can perform wavelike quasi-static motions (Fig.3). In these motions, only several links move at each time instant (for example, not more than three links in the motion shown in Fig. 3), while all other links stay at rest. The required control torques for the multilink mechanism are smaller than for two– and three-link systems: $M \leq 2mlk$. Here, m is the mass of the link, and l is its length.

CONCLUSION

The obtained results are confirmed by computer simulation and experimental data. The experiments were performed at the Institute for Problems in Mechanics of the Russian Academy of Sciences and at the Technical University of Munich. These results are related to the biomechanics of snake-like locomotion and may be of interest for mobile robots, especially for small ones, and for transportation systems.

References

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