Change of the body orientation by means of internal masses

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Abstract. Three-dimensional reorientation of a rigid body by means of several auxiliary moving masses is considered. According to the presented control algorithm, the masses perform simple circular motions relative to the body. It is shown that the case of several masses, if their number exceeds three, has certain advantages compared to the case of one mass. The results can be of interest for the control of capsule robots, spacecraft, and other moving objects.

Introduction

One-dimensional translational motions of capsule robots and similar systems were studied in many papers, see, for example [1-3]. Two- and three-dimensional motions of such systems important for turns of mobile robots were considered in [4-7]. In this paper, we consider the dynamics of a rigid body carrying several internal moving point masses. The control algorithm for moving masses is proposed that guarantees the required reorientation of the body under the assumption that the external forces are negligible. This assumption holds, if these forces are small compared to the internal ones and/or the turn is fast.

Main results

Let a system consist of a rigid body *P* of mass *M* and *n* particles Q_i of masses $m_i,\ i = 1, ..., n$, equipped with actuators. Masses Q_i interact with the body, can move relative to it, and do not interact with the outward environment. The system is at rest at the initial time moment, and there are no external forces acting upon it. Hence, the momentum and angular momentum of the system remain constant and equal to zero. We look for time-histories of vectors $\mathbf{r}_i(t)$ describing the positions of masses Q_i relative to body *P* that ensure the prescribed reorientation of the body. We represent the motions of points Q_i as $\mathbf{r}_i = \mathbf{r}_i^0 + \boldsymbol{\rho}$ where vectors $\mathbf{r}_i^0$ fixed relative to body *P* and $\boldsymbol{\rho}$ satisfy equations

$$\mathbf{J}^* \cdot \boldsymbol{\omega} + \mu M \boldsymbol{\rho} \times (\boldsymbol{\omega} \times \boldsymbol{\rho} + \dot{\boldsymbol{\rho}}) = 0, \quad \mathbf{J}^* = \mathbf{J} + \mathbf{J}^0,$$
$$\mu = m/(M+m), \quad m = \sum_{i=1}^{n} m_i, \quad \sum_{i=1}^{n} m_i \mathbf{r}_i^0 = 0.$$

Here, $\boldsymbol{\omega}$ is the angular velocity of body *P*, $\mathbf{J}$ is its tensor of inertia relative to its center of mass, $\mathbf{J}^0$ is the tensor of inertia of a rigid body consisting of masses m_i fixed at points with $\mathbf{r}_i^0 = 0$. The prescribed reorientation of body *P* can be implemented by means of three consecutive plane rotations about principal axes of tensor $\mathbf{J}^*$. Each of these rotations is realized, when masses Q_i perform circular motions in planes perpendicular to these axes. These motions correspond to the planar rotation of vector $\boldsymbol{\rho}$. The centers, radii and angles of rotations of points Q_i can be chosen from a wide range. Together with the choice of vectors $\mathbf{r}_i^0$, one can choose the location and size of the domains where the auxiliary internal masses move. It is shown that the use of several $(n \geq 4)$ moving masses gives certain advantages and can facilitate the system design.

References

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