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DESIGN AND PERFORMANCE ANALYSIS OF A SPHERICAL UGV POWERED BY PENDULUM AND CONTROL MOMENT GYROSCOPES FOR PLANETARY EXPLORATION

Abstract

Spherical robots are an emerging class of UGV (Unmanned Ground Vehicle) that is becoming attractive for space exploration for the possibility to deal with extreme planetary surface conditions. In fact, because of the shape, internal components and sensors can be protected from the outside, and the system is prevented from overturning. The work presents the advances in the design of a spherical UGV for planetary surface explorations. The robot is made of a spherical shell that encloses a locomotive system, related electronics and dedicated sensors to navigate and collect data, such as images, pressure, humidity, temperature, radioactivity and gas composition. The locomotion system that is responsible for rolling is based on a single-pendulum differential-driven mechanism, enhanced by Control Moment Gyroscopes (CMG). This solution allows for a greater torque compared to robots powered by single pendulum only, and improves capabilities against obstacles, in particular steps. In fact, for pendulum mechanisms, the driving torque depends on the barycentre offset on the radial direction, which is theoretically confined to the sphere radius. The concept described in this work adds the gyroscopic torque produced by a pair of flywheels. Coupling CMG and single pendulum mechanisms has some technical challenges. The current version of the spherical robot has a diameter of 0.5 m and a mass of 22 kg, so that it can be stored into existing landers, even in multiple units. Fitting the hybrid mechanism within such a compact size, together with power and control electronics, required an iterative design, that considered the actual space available inside the shell and the desired performance of the robot. The paper summarizes design methods, parts dimensioning, mechatronic integration, control and energy balance of the pendulum-CMG system. The design is supported by numerical models of the subsystems, like gyroscopes, pendulum and transmission. Multibody simulations of the complete system analyse the motion of the robot rolling on straight trajectories, curved paths, inclines and steps. Performance analysis of the proposed locomotion system shows significant improvements compared to classical single pendulum version. The result is a spherical robot that can run up to 2.5 m/s, climb slope of 15 and overcome steps that are 10 times higher with respect to single pendulum robots of the same size. An energetic analysis is carried out to evaluate autonomy in relevant mission profiles.