IAF SPACE EXPLORATION SYMPOSIUM (A3)
Solar System Exploration including Ocean Worlds (5)

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A NOVEL CONCEPT FOR TITAN ROBOTIC EXPLORATION BASED ON SOFT MORPHING AERIAL ROBOTS

Abstract

This work proposes a novel concept for space exploration based on soft morphing aerial robots leveraging the use of flexible adaptive materials. The controlled deformation of the multirotor arms, actuated primarily by a pneumatic system together with a tendon mechanism, provide the explorer robot the ability to perform full-body perching and land on irregular surfaces, as well as efficient sampling (by using its own soft arms as continuum manipulators and the pneumatic system to suck the samples). The folding capability of the robot also relaxes hypersonic aeroshell design constraints. The rotors are embedded in the deformable material to guarantee a smooth interaction with the environment, which is leveraged to access caverns or confined spaces.

Specifically, a detailed conceptual aerial robot design for the exploration of the Sotra-Patera cryovolcano is presented, whose exploration can help to understand Titan's methane cycle and its resemblance to Earth. Titan has a great exploration potential given its dense atmosphere and low gravity (NASA's Dragonfly mission is planned for 2027). The proposed material for the deformable arms is 3D-printed PTFE at low infill rates (30%), thermally stable in a wide range of temperatures. Unlike the arms, the aerial robot body has thick insulation (as the Huygens probe) which includes the electronics and main systems (mass spectrometer, composition sensors, cameras, and others), and is maintained at mild temperatures using the waste heat from the MMRTG. The aerodynamic design of the rotors in Ducted Fan configuration is more efficient than on Earth due to the high Reynolds numbers (corresponding to high densities and low viscosities of Titan). The increase in the number of blades also reduces rotational speed and therefore Mach number at the tip (this is important for efficiency since in Titan the speed of sound is lower, around 194 m/s).

The methodology followed is based on a performance comparison with the Dragonfly's aerial robot design, focused on Gazebo simulations in Titan's atmosphere, CFD simulations for the rotor aerodynamics, and an experimental characterization of PTFE behavior at temperatures around -180 °C, using liquid nitrogen. The goal is to demonstrate weight savings (expected to be around 20%) for the same payload requirements and elaborate a detailed power budget for the aerial robot. Preliminary studies suggest that energy consumption in flight could be reduced to 3 W/kg. Moreover, the robot's ability to smoothly adapt to the environment and access complex locations will be tested in simulation.