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AUTONOMOUS IN-ICE EXPLORATION OF THE SATURNIAN MOON ENCELADUS

Abstract

The data collected by the Cassini spacecraft provide strong evidence for the existence of liquid water under the ice-covered surface of Saturn's moon Enceladus. For that reason, it is currently one of the most promising candidates to find extraterrestrial life in our solar system. The Enceladus Explorer (EnEx) initiative of the German Aerospace Center proposes a concept for a lander mission to probe that moon for life, which uses one maneuverable melting probe to retrieve a sample from the sub-glacial water reservoir as well as multiple smaller melting probes as navigation aids. In addition to technical challenges, a major prerequisite for the success of that mission is the ability to autonomously navigate through the ice of Enceladus. We present an integrated system for multi-sensor fusion, high-level planning and autonomous decision making, as well as trajectory optimization and optimal control, which aims to solve that challenging task. The sensor fusion module is responsible for localizing the probes as well as creating a map of the environment. It uses an approach based on graph optimization techniques, which simultaneously estimates the position and attitude of all probes in 3-dimensional space. For mapping, an extended formalism for representing uncertainty is utilized, which allows one to distinguish between different causes of uncertainty. Based on that information, the autonomy module decides on the further course of action. It creates a high-level plan in order to reach the mission goal or sub-goals, e.g., improving the localization by taking further measurements. In addition, autonomous fault detection is performed, and if required, the system's behavior is adapted in order to compensate for degraded components or unexpected situations. For realizing the high-level plan, the guidance module computes a trajectory in consideration of different optimality criteria. Finally, a model predictive control algorithm generates and applies the corresponding control commands and ensures a reliable tracking of that trajectory. Both trajectory planning and control take information provided by the sensor fusion into account. Furthermore, in order to cope with the high degree of uncertainty regarding environmental conditions, the model of the system dynamics is improved by means of automated parameter identification and adaption. In addition to a description of our system, we present preliminary results from a field test campaign on an European glacier with the entire EnEx system.