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Ice Transit and Performance Analysis for Cryorobotic Subglacial Access Missions on Earth and Europa

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It is widely recognised that the icy moons of our solar system are interesting candidates for the search for habitable environments beyond Earth. While upcoming space missions such as the Europa Clipper and JUICE missions will give us further insight into the local cryo-environment of Jupiter's moon Europa, any conclusive survey to detect life will require the ability to penetrate and traverse the ice shell and access the subglacial ocean directly. Developing a robust, autonomous cryobot for such a mission is an extremely demanding challenge and requires a concentrated interdisciplinary effort by engineers, geoscientists and astrobiologists.

We report on recent progress in developing ice transit and performance models as a first step towards a modular virtual testbed. The modularity of the virtual testbed allows easy exchange of the trajectory model used, the environmental conditions, such as ice parameters, and the description of the cryobot. We introduce a trajectory model that allows the evaluation of mission-critical parameters such as transit time and energy demand for different cryobot designs and deployment scenarios both on Earth and on icy moons.

Specific analyses presented in this study highlight the trade-off between minimum transit time and maximum efficiency of a cryobot, and allow quantification of different sources of uncertainty for cryobot trajectory models. Based on the terrestrial scenarios, our results show that the fastest transit time for the TRIPLE IceCraft cryobot is consistently achieved at all deployment sites, while its average energy consumption is rather high. The most energy efficient cryobot considered in our work is the EnEx-RANGE APU, that is, however, not designed for carrying large payloads.

While we have focused on idealized models that, for example, assume a planar melting head and a laterally isolated probe, future extensions of the virtual testbed will include more detailed models and take into account non-uniform distributions of salt concentration observed in terrestrial ice drilling. Our models are a first major step forward in estimating the efficiency of melting probes and can help develop and improve robust, autonomous cryorobotic technologies for extraterrestrial missions that can ultimately shed light on the potential for life to exist in the alien oceans of Europa and other icy moons.