EELS-DARTS: a Planetary Snake Robot Simulator for Closed-Loop Autonomy Development

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Abstract

Exobiology Extant Life Surveyor (EELS) is a large degree of freedom (DOF) snake-like robot in development at the Jet Propulsion Laboratory (JPL) for the exploration of icy ocean worlds such as Enceladus [3]. Such environments offer limited communication infrastructure and highly unstructured terrains with uncertain properties. Because of this, EELS is designed to be largely autonomous without the need for extensive human operator feedback. EELS features a versatile autonomy stack, NEO, that allows the robot to sense its environment, perform high-level risk assessment and planning, and employ varied locomotion gaits [6]. EELS employs *bend* and *twist* actuators to alter the shape of the robot, enabling so-called *shape-based locomotion* gaits. The robot also features active skin actuation in the form of rotating screws that allows mobility through tight channels where shape-based gaits are not available and over unconsolidated materials such as sand or snow.

In this paper we present **EELS-DARTS**, a versatile dynamics simulator based on the JPL Dynamics Algorithms for Real-Time Simulation (DARTS) software framework [4]. The EELS-DARTS simulator is used by engineers across the EELS project as a closed-loop controls, autonomy, and perception algorithms development test bed. We discuss the design and features of the simulator that allow end-users to rapidly prototype throughout the life-cycle of the project. *Versatile framework for integrating robot designs:* A core feature of the EELS-DARTS simulator is the ability to support the project in rapidly prototyping new robot designs and multibody topologies. It offers the ability ingest a standard robot description in the Unified Robot Description Format (URDF) and optimizes the multibody structure as needed. *ROS interface*: The simulator is designed as a drop-in replacement for actual EELS hardware. A ROS interface publishes and receives messages in the form of sensor data, actuation commands, and simulation actions to close the loop with the EELS onboard software. This simulation analogue empowers engineers to rapidly prototype autonomy stack features and shake out issues before any code is deployed on hardware. *Environments & placement:* A wide variety of environments can be simulated in EELS-DARTS. Synthetic terrains can be used for both surface and subsurface robot traversal scenarios. Meshes from field-test scans of glaciers can be imported. Placement tools such as robot rigging/tethering and inverse-kinematic-based placement algorithms are available to assist in initializing the large number of degrees of freedom to suit arbitrary terrain shapes. The aforementioned features allow EELS-DARTS to be a single versatile analysis tool across many different robot designs and mission scenarios, as shown in Fig. 1.

We also discuss the framework and design of the EELS-DARTS simulator. *Fast dynamics algorithms*: DARTS is a general, multi-mission, flexible multibody simulation software. It uses a minimal coordinates multibody representation and the Spatial Operator Algebra (SOA) methodology for low-cost recursive algorithms to solve the multibody dynamics [5]. *Contact:* EELS-DARTS offers a choice among distinct back-ends to handle collision detection. Both back-ends make use of the open-source Bullet library [2]. One back-end uses convex-hulls representations of the meshes. The other uses a signed distance field (SDF) representation of the terrain and a hand selected set of possible contact points on the screws to enable faster collision detection between the screws and the terrain. This second method ignores body-to-body collisions and instead leverages fast SDF queries for body-to-terrain collisions. Querying collisions in this manner results in significant run-time performance improvements at the cost of some reduction in simulation fidelity. Screw-terrain contact forces are computed using an anisotropic friction model to apply skewed traction forces produced by the threads of screws. *Perception:* EELS-DARTS provides

real-time ray tracing based simulation models for cameras and LiDARs to enable closed-loop testing of perception algorithms using IRIS-DARTS [1].

EELS-DARTS has been successfully used in field test planning to assist in controller design, tuning, and traverse testing. We discuss findings and lessons-learned from a recent trip to the Athabasca glacier in Alberta, Canada. We also perform a quantitative analysis comparing simulation predictions with experimental results for a surface traversal experiment on hard, synthetic ice in the lab.

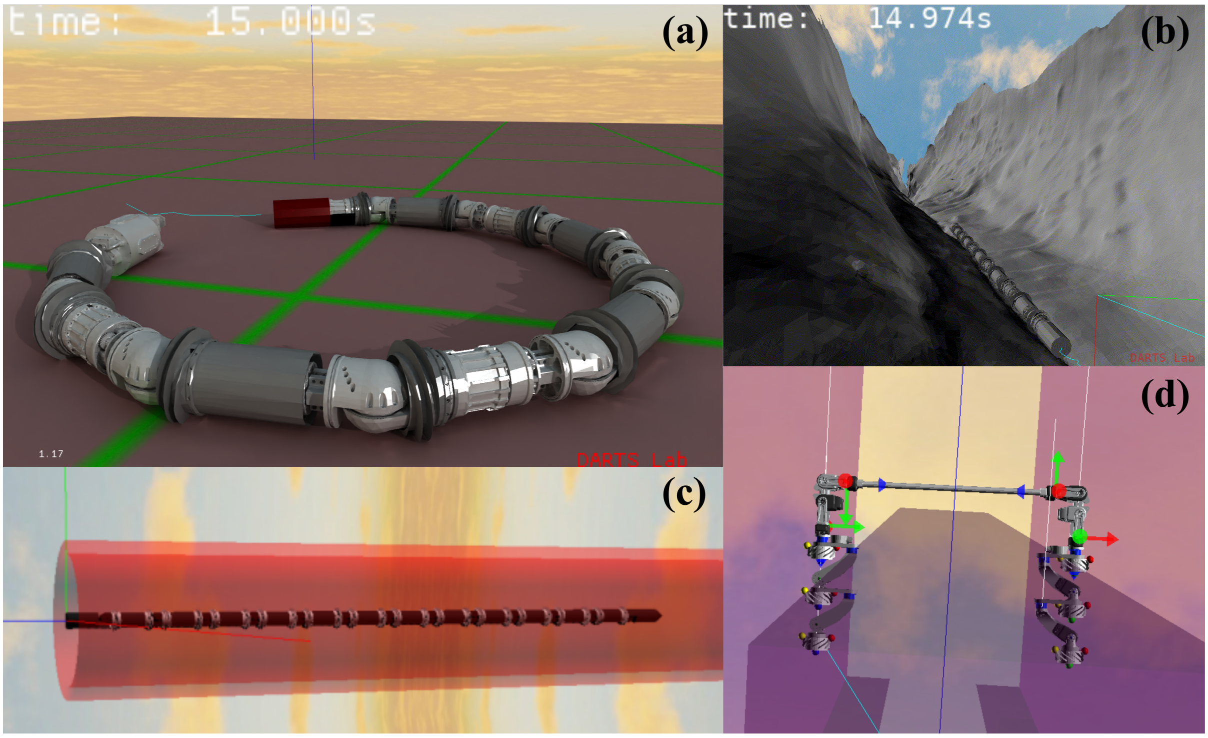

Figure 1: (a) EELS version 1.0 initialized into a crescent shape during a surface traversal scenario on flat synthetic terrain. (b) EELS 1.0 traversing inside a field-test scan of a glacier channel taken from Athabasca, Canada. (c) An example of a synthetic cylinder-tube subsurface environment. (d) EELS version 1.5 rigged into a synthetic U-channel subsurface environment. The white lines indicate tethers used to support the robot before the robot has fully supported itself by pushing against the walls.

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