Range-based Wireless Sensor Network Localization for Planetary Rovers

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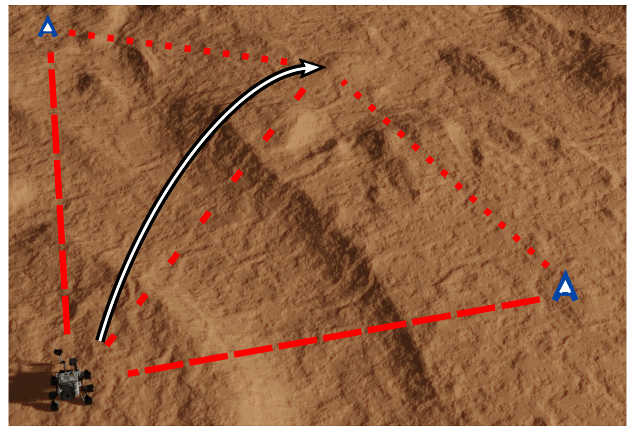
Rovers continue to play a major role in planetary exploration. They enable a range of science experiments not feasible with orbital sensing, such as sample extraction or analysis and in situ atmospheric measurements. However, due to the high mission costs, they are operated in a very risk-averse manner. Frequently, science targets are located among obstacles such as steep slopes and rock formations and are therefore avoided. Many locations, such as lunar or Martian lava tubes are not only difficult for rovers to maneuver, but severely limit return communication links.

To counter this problem, a prototype system, PHALANX (Projectile Hordes for Advanced Long-term and Networked eXploration), is under development at NASA Ames. It employs ranged deployments of wireless sensor nodes: small sensor-equipped units meant to collect scientific data and wirelessly transmit this back to the rover. The nodes can be equipped with instruments that measure gas composition, temperature, microscopic imagery, and even in-flight overhead imaging[1]. Placed nodes can collect data over long time-periods to measure ephemeral and dynamic effects, otherwise not tractable considering valuable rover mission time. Together nodes form a network, enabling communication by relay over longer distances, around obstacles, and along cave tunnels.

Node locations are needed to map and visualize science data. By using integrated radio ranging transceivers, distances can be estimated from node to node and node to rover. The formed network can therefore be used for range-based localization in estimating node positions. Because the rover is part of this network, an opportunity also arises to aid rover localization, otherwise commonly performed by a combination of dead-reckoning and visual odometry. The latter is an accurate and precise, although expensive computation, typically performed rather infrequently, except in specific high-precision slow-driving modes [3] and is still subject to slow drift.

The required output performance of rover and node localization vary by mission and situation, whether by scientific demand or to ensure mission safety. Performance of range-based localization in wireless networks is dependent on various qualities, such as node connectivity, measurement noise, and network geometry. With the ability to deploy nodes rather flexibly and shape the network geometry, this becomes a uniquely interesting topic for mission planners and operators.

Range-based localization and mapping in sensor networks has been studied extensively [2], [4]. We introduce the reader to distinguishing planetary application specific peculiarities and relevant operational concepts that may arise, such as:



- *incrementally placed nodes* due to sequential deployment by the rover, thus providing
- *a-priori estimates* to the localization algorithm as an initial guess determined by ballistic estimates of the sensor deployment that are valuable in disambiguating network geometry, along with
- *anchorization*, in which external sensing, such as rover cameras, allow the position of a node to be determined more exactly (turning it into an "anchor") and thereby constraining the whole solution set.

We then describe a model and implementation of a simulation environment that we use to investigate the effects of varying the network properties such as node placement, rover trajectory, and disturbances such as increased measurement noise, loss of communication, and loss of nodes.

Results are presented as overall error in estimates (RMSE) and estimator covariances, across repeated simulation experiments under varying settings and parameter choices. These experiments demonstrate operation in typical expected mission application scenarios and are used to identify principles that make for increased localization performance, such as appropriate network sizes and node placement heuristics.

References

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