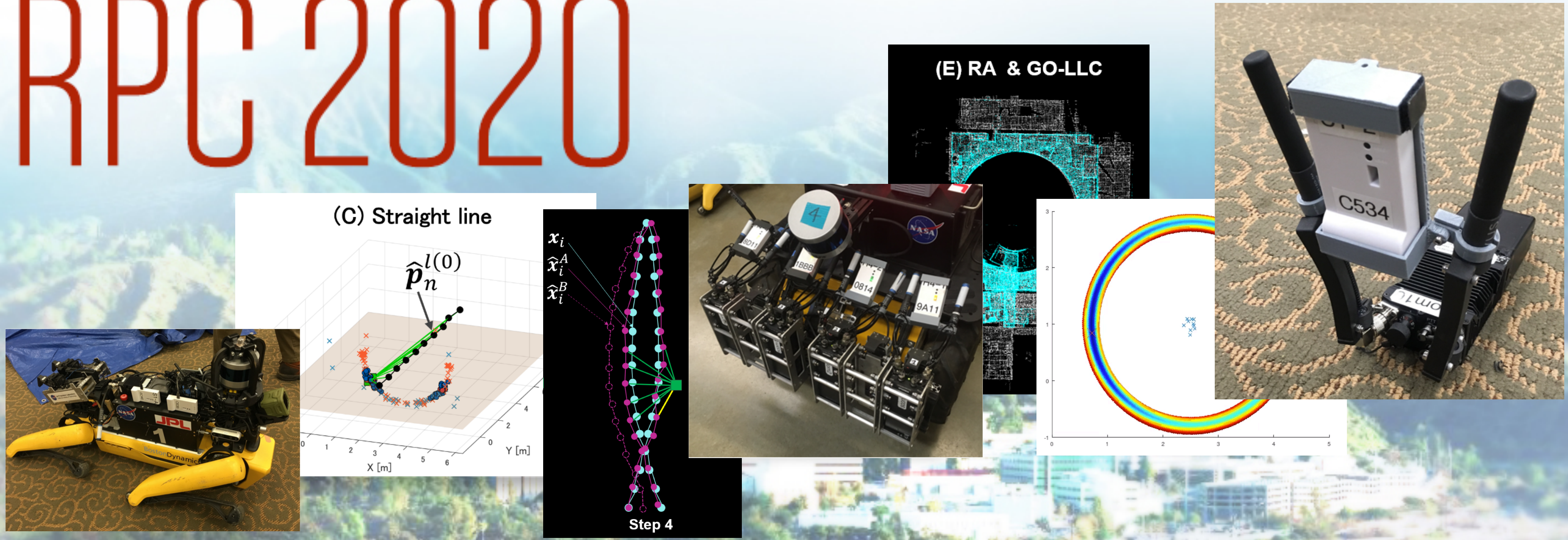
RPC 2020



Virtual Research Presentation Conference

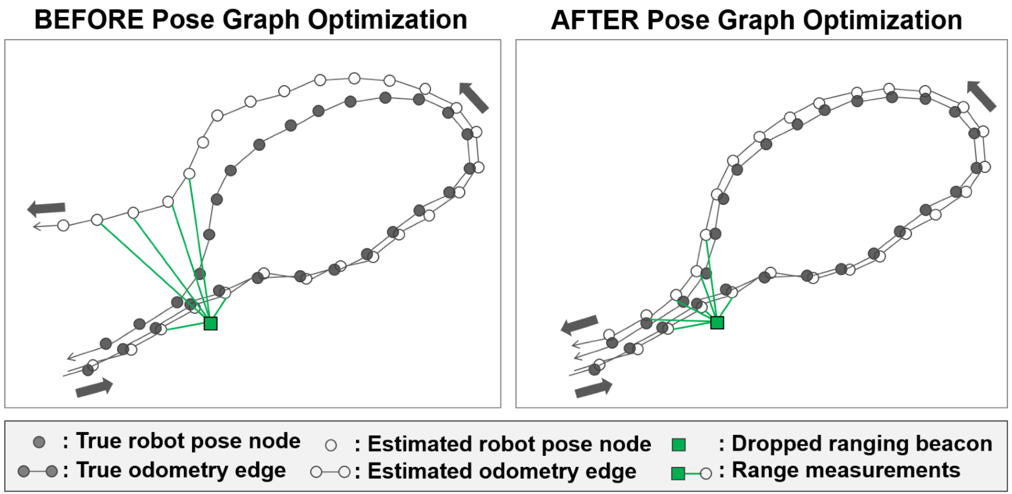
Global Localization with Dropped Ranging Beacons for Underground Exploration

Principal Investigator: Benjamin Morrell (347)
Co-Is: Jeremy Nash (347), Nobuhiro Funabiki (UTokyo), Alessandro Buscicchio (347), Arash Kalantari (347), Ali Agha (347), Thomas Touma (Caltech)
Program: Spontaneous Concept

Assigned Presentation #: RPC-255

Jet Propulsion Laboratory
California Institute of Technology

Tutorial Introduction



- Simultaneous Localization and Mapping (SLAM) is a critical part of robotic **exploration in unknown environments**, e.g. underground.
- Accurate SLAM is **difficult over large scales**, as drift accumulates.
- **Loop closures** (recognizing when a location is revisited) can help correct those errors.
- However, loop closure at **large scales** is limited by high computational cost and susceptibility to false detections.
- One solution is to **deploy ranging beacons** from a robot and to utilize them for **unambiguous place recognition.**
- We combine ranging beacons with geometric sensors (**cameras or lidars**) to do loop closure and improve localization
- Our results, in robot field tests, show that our approach can achieve **equivalent accuracy** of geometric-only lidar-based loop closure with significantly **lower computational cost** (95% reduction) and eight-times **fewer false detections**.
- This approach also works for **multiple robots**, to do loop closures between different robots

Problem Description

Context:

a) Global location -> important for *robotic navigation* and *science context*

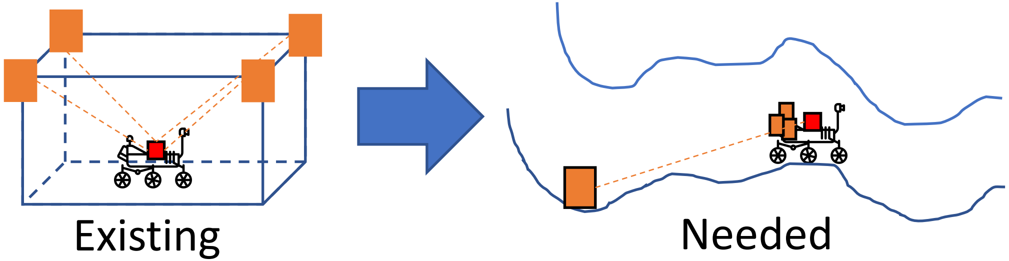
State of the Art:

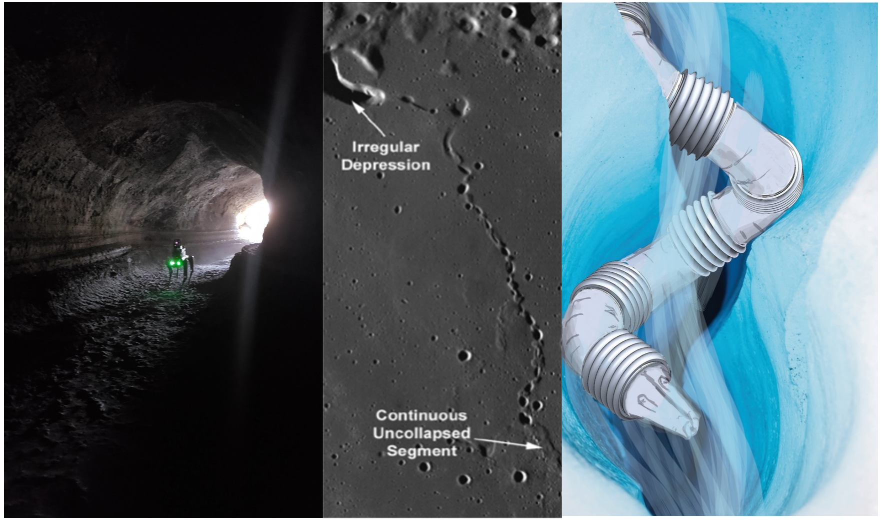
a) Vision-only systems drift too much

b) Mars Rover global localization uses HIRISE imagery
Not possible underground!

c) Ranging beacons have been very effective for localization, but only in locations with **many beacons** with **known locations**

d) For exploration of unknown environments underground, we need to use **sparsely deployed beacons**





NASA Relevance

a) Future missions of leading scientific interest require exploration into unknown locations, underground
   a) Enceladus surface missions
   b) Martian and Lunar Lava Tubes

b) Long-range rover traverse require limited drift

Methodology

Formulation, Theory and Experimental Design

a) Build on top of a pose-graph SLAM framework, LAMP [1]

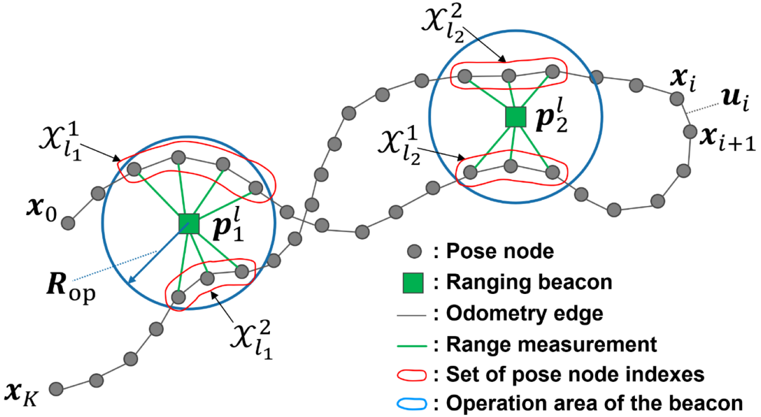
b) Group pose-nodes that share observations of a common ranging beacon

c) Process measurements to select pose-nodes as loop candidates -> perform **geometric loop closure on these candidates** (vision and lidar)

d) Implemented on hardware and tested with robot teams using Ultra-Wide-Band (UWB) beacons

Innovation, advancement

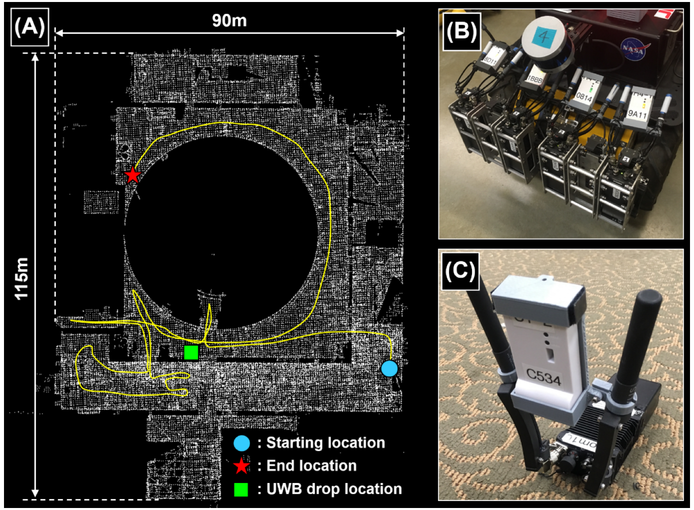
a) Combine artificial beacons an geometric loop closures to get the pros and remove the cons
   - a) Lower computation
   - b) Lower false detections
   - c) High accuracy
   - d) Minimal infrastructure (vs UWB state of the art applications)
     - a) <u>**Can use sparsely deployed beacons**</u>



(A) Map of test environment

(B) Robot with deployment mechanism

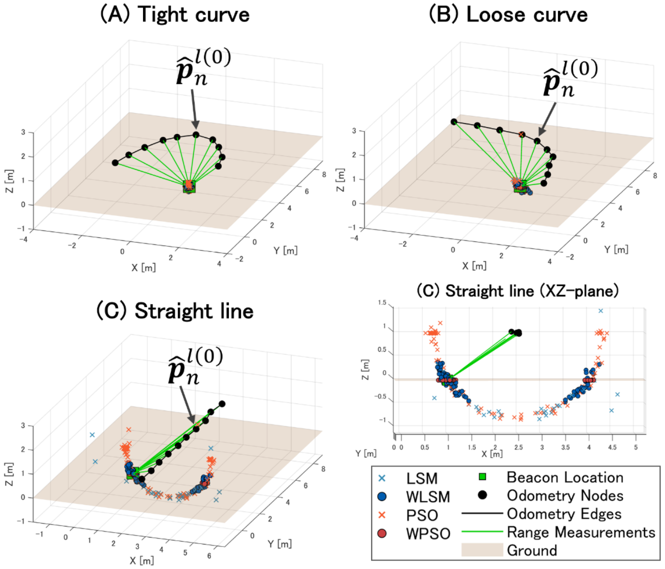
(c) UWB ranging beacon



Results

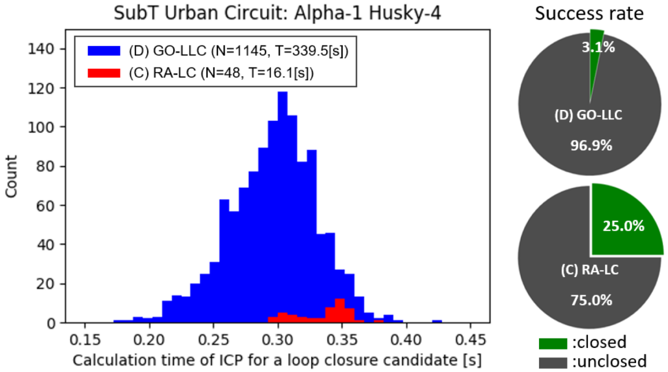
Goal	Accomplishment
1. Develop algorithms to use UWB for global localization	a) Shown limitations of applying existing approaches b) Developed Range-Aided Loop Closure (RA-LC) UWB + lidar or vision c) Vs lidar-only loop closures: same accuracy, 95% lower computation, 8x less outliers d) Publication [A]

a) Ambiguity of data



Three different types of trajectories for the simulation of Conventional Method 2 (Multilateration-Based Translation Constraints). Circle of local minima can be seen for case (C).

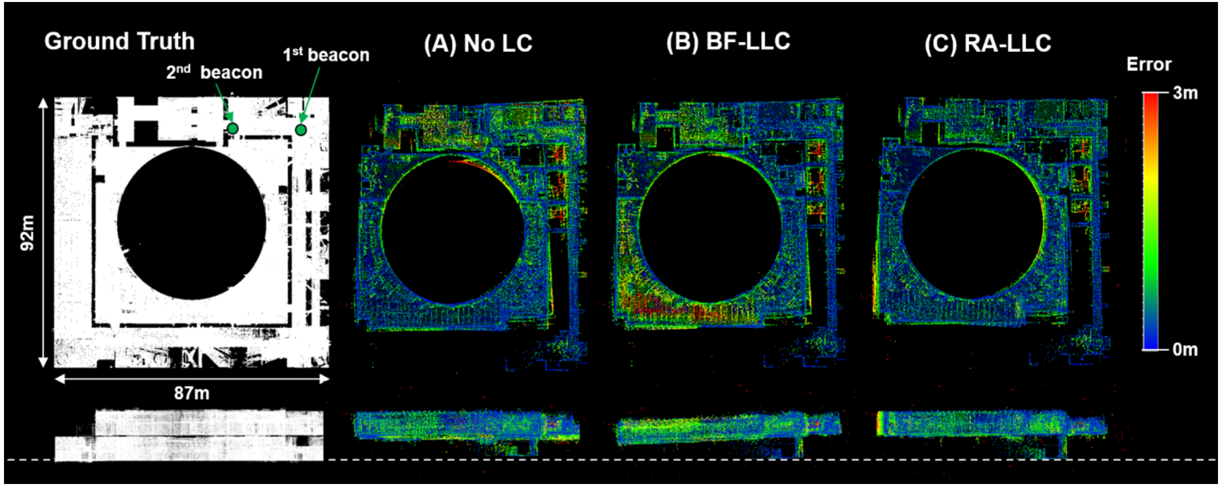
b) Performance



Comparison of calculation time and success rate of loop closing: (D) GO-LLC (Geometric-only Lidar Loop Closure) vs. (C) Range-aided LC (Loop Closure), N: Total number of loop closure candidates, T: Total calculation time

Results

Goal	Accomplishment
2. Extend 1 to multi-robot localization	a) RA-LC fused in multi-robot, centralized SLAM. Demonstrated with 2-4 robots. b) Vs lidar-only loop closures: same accuracy, 97% lower computation, 3x less outliers c) Publication [B]
3. Demonstrate 1 and 2 on a team of ground robots	a) Hardware system developed – nodes and deployment mechanisms b) Tested with four ground robots in urban underground environment

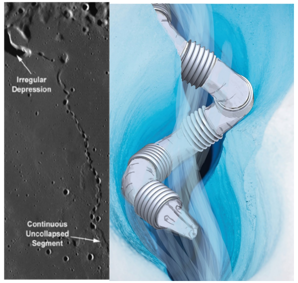


Two robot SLAM with RA-LC.

TOP: the two robots used to test, with range beacon deployers.

LEFT: Ground truth map (white) and the estimated maps (colored) by the algorithms: (A) no loop closure, (B) geometric loop closures only and (C) our algorithm, RA-LC

Results



Significance

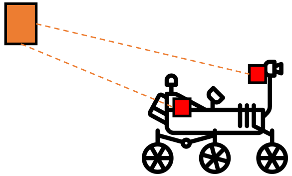
a) Demonstration of the benefits ranging beacons can bring for localization in an exploration context
    a) To inform future mission designs for underground exploration (Enceladus, Mars, Moon)
    b) The possibility to provide a new sensor modality choice

b) A test-platform that could be used for quick evaluations for the use of ranging beacons in future projects

Next steps

a) Deep analysis highlighted the main challenges for using deployed ranging beacons – measurement ambiguity

b) Primary focus for next steps is to resolve the ambiguity to provide a larger benefit to localization (consistently improve accuracy)
    a) To use multiple beacons distributed on the robot
    b) To add small visual or audio markers on beacons to give bearing



c) Automated selection of when and where to drop beacons

d) Funding: Small research funds and infusion in larger development projects.

Publications and References

Publications

[A] Nobuhiro Funabiki, Benjamin Morrell, Jeremy Nash, Ali-akbar Agha-mohammadi, "Range-Constrained Pose-Graph-Based SLAM: Applications of Deployable Ranging Beacons for Unknown Environment Exploration," accepted September 4th, 2020, *IEEE Robotics and Automation Letters*

[B] Nobuhiro Funabiki, Benjamin Morrell, Alessandro Buscicchio, Thomas Touma, Fernando E Chavez, Arash Kalantari, Torkom A Pailevanian, Angel Santamaria-Navarro, Jeffrey A Edlund, Tiago Stegun Vaquero, Kyohei Otsu, Jeremy Nash and Ali-akbar Agha-mohammadi, "MaD-RSN: Hybrid Mobile-and-Deployable Robotic Sensor Network, A System-level Architecture for GPS-denied Multi-robot Navigation," submitted June 30 2020, *17th. International Symposium on Experimental Robotics*

References

[1] Kamak Ebadi, Yun Chang, Matteo Palieri, Alex Stephens, Alex Hatteland, Eric Heiden, Abhishek Thakur, Nobuhiro Funabiki, Benjamin Morrell, Sally Wood, Luca Carlone, and Ali-akbar Agha-mohammadi, "LAMP: Large-Scale Autonomous Mapping and Positioning for Exploration of Perceptually-Degraded Subterranean Environments," *International Conference on Robotics and Automation*, IEEE, 2020

Acknowledgements

We would like to thank Thomas Touma, Fernando E Chavez, Torkom A Pailevanian, Angel Santamaria-Navarro, Jeffrey A Edlund, and Kyohei Otsu for their assistance in making the hardware, integration and field tests possible.