Collaborative SLAM for Facilitating Radiological Search and Mapping with UWB Enabled Multi-Agent Platforms

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Poster # 3

Motivation: Multi-agent Radiological Search

Remote radiological source localization and mapping needed in first response and disaster prevention scenarios in areas containing one or more radiation sources. UAVs provide ideal platforms for traversing arbitrary terrain when equipped with specialized, lightweight radiation sensors. Resolution of radiological sensing on a mobile platform is greatly improved when fused with pose estimates and 3D map information obtained through SLAM [1].

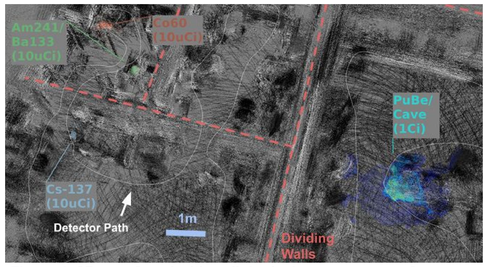


Figure 1. 3D map fused with radiological measurements for source localization [1]

Figure 2. Localization and Mapping Platform (LAMP) from LBNL [1]

Single-agent aerial radiological mapping solutions such as the LAMP (Fig. 2) exist, and there is interest in determining how these capabilities can be expanded in through a multi-agent configuration.

Although around since the 1990's, ultra-wideband (UWB) has recently matured into an inexpensive, accessible, and reliable way to collect Time of Arrival (ToA) relative range measurements. Recent robotics work has explored how to best utilize these sensors for multi-agent localization. Our current approach is to equip each agent with multiple UWB sensors, allowing for direct 3D relative pose estimation (RPE) between agents. Then this RPE can be integrated into CSLAM as an inter-agent loop closure.

Figure 3. Used UWB module, the Nooploop LinkTrack P

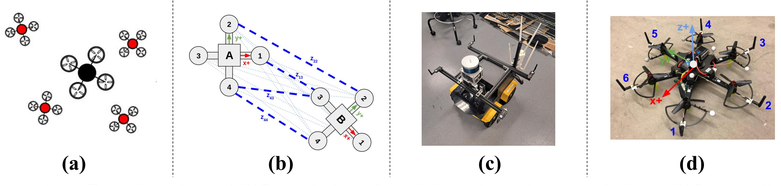


Figure 4. *(a):* Possible multi-agent UAS architectures for radiological mapping. A single, larger UAS carries the LAMP detection system, while smaller agile agents develop a SLAM map for it to search. *(b):* Two agents each equipped with four UWB modules performing relative pose estimation by using the 16 measurements between each pair of inter-agent antenna. *(c):* Our upgraded UGV hardware setup; the jackal robot is equipped with four UWB modules, a Velodyne 3D LiDAR, and an Intel RealSense 435i; this platform will allow us to integrate with Kimera-Multi [6]. *(d):* Our current UAV hardware setup; our custom-built drones are each equipped with six UWB modules, an Intel RealSense 435i, and an altitude measuring downward Terabee Evo LiDAR.

Scan QR Code for Full Paper

See our full paper, presented last Oct at IEEE's IROS'22 Conference in Kyoto Japan.

Future Demos/Collaborators?

- Our relative pose estimation system is becoming increasingly mature.
- If you have other radiological search demos you think might be useful, please reach out! (We would love to collaborate!)
- Other ideas we have discussed with folks at ETI/UPR include:
  - Football Stadium radiation monitoring
  - Compton camera multi-agent coordination

Project Description

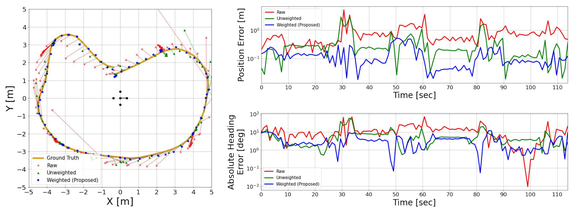
Goals: Expand remote sensing capabilities and develop algorithms for radiation source localization and mapping with a collaborative SLAM (CSLAM) framework that enables faster/more versatile search coverage while utilizing lightweight and relatively inexpensive sensing on UAVs in a bandwidth-limited network.

- Must address these challenges to determine what collaborative mapping architecture most efficiently enables multi-agent coordination in a radiological mapping setting:
  - GPS denied / No prior maps
  - Low communication bandwidth
  - Dynamic network topology

Approach: Leveraging recent work [2 - 4], ultra-wide band (UWB) is a mature, inexpensive RF technology providing comms and relative ranging data via time-of-arrival sensing suitable for robotic teams.

- Goal is to use UWB to enhance the multi-agent collaborative SLAM techniques [6] needed for effective radiological search.

Experimental Results: UWB 2D Relative Pose Estimation (RPE)



Position Error [m]	kidney-bean		
Method	Mean	Max	Std
Raw	0.76	5.20	0.68
Shift only	0.47	4.77	0.73
MovingAvg only	0.68	3.40	0.47
Unweighted (Eq. 3)	0.36	2.91	0.44
Weighted (Eq. 8) **[Proposed]**	**0.13**	**0.52**	**0.11**

Abs Heading Error [deg]	kidney-bean		
Method	Mean	Max	Std
Raw	12.06	70.33	12.17
Shift only	8.10	80.20	12.72
MovingAvg only	10.32	57.96	8.73
Unweighted (Eq. 3)	6.15	58.70	8.38
Weighted (Eq. 8) **[Proposed]**	**3.95**	**11.97**	**2.98**

Figure 5. Results from recent hardware trials showing the accuracy of our UWB 2D RPE process. Experiments are conducted in a mocap space (for ground truth comparison) using turtlebot robots (our upgraded UGV hardware is shown in Figure 4C). Here RobotA is kept stationary and performs RPE on RobotB using our nonlinear least squares optimization formulation (see Fig. 7A). Plots and tables compare using only the raw UWB measurements, only our calibrated UWB measurements, and both our calibrated UWB measurements and our weighting function (proposed) – this comparison highlights the benefits of our calibration and weighting function. Note the plots of two Error vs Time plots report error with a logarithmic scale. When comparing our results to those of [2], we find our approach gets better mean positional error while remaining competitive in other metrics, while only using UWB measurements – [2] relies on continuously transmitting odometry between agents to achieve their results.

Experimental Results: UWB 3D Relative Pose Estimation (RPE)

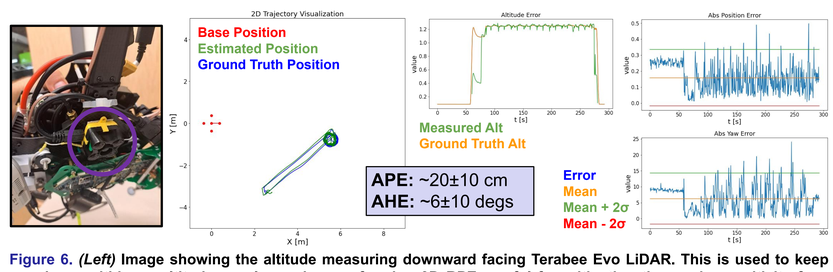


Figure 6. *(Left)* Image showing the altitude measuring downward facing Terabee Evo LiDAR. This is used to keep our drone within an altitude envelope when performing 3D RPE, useful for mitigating the z-axis sensitivity from having all antennas in a single z-plane. *(Right)* Results from recent hardware trials showing the accuracy of our UWB 3D RPE process. Experimental setup is similar to Figure 5, except RobotB is a drone with 6 UWB modules. Results yield an Absolute Position Error (APE) and Absolute Heading Error (AHE) ~20±10 cm and ~6±10 degrees, respectively. These results have only a slight (expected) performance degradation verses 2D.

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Ongoing Working

Our UWB 3D RPE approach is formulated as a nonlinear least squares optimization using only locally collected UWB relative range measurements as input (i.e., no additional measurements, such as odometry, is needed between agents). We are currently integrating these instantaneous relative pose estimates into our SLAM pipeline.

(a)

$$\underset{\mathbf{x}}{\operatorname{argmin}} \overbrace{\sum_{i\in\{1,\ldots,N\}} \sum_{j\in\{1,\ldots,N\}}}^{\text{Sum over all pairs of inter-agent antennas}} \underbrace{w_{ij}(\mathbf{x})}_{\text{Weighting Function}} \underbrace{\left(d_{ij}(\mathbf{x}) - \overbrace{\hat{z}_{ij}^{(t)}}^{\text{Calibrated UWB relative range measurement}}\right)^2}_{\text{UWB Range Terms}}$$

Weighting Function: Devalues terms where an antenna is obstructed or has bad relative 3D positioning.

UWB Range Terms: Minimize error between each pair of inter-agent antennas at known relative locations on each agent's body frame and the received range measurement

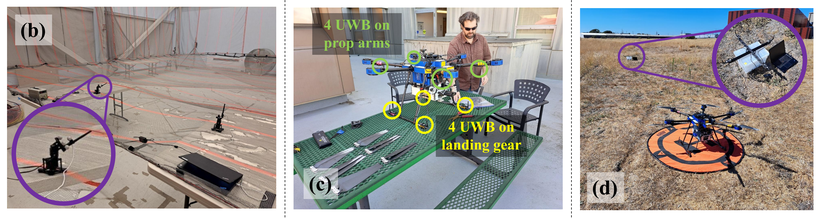

Figure 7. (*Top)* Our optimization problem annotated for reader comprehension. Solves for position and heading using only UWB measurements. Weighting function differs between 2D and 3D to account for different antenna properties. (*Left)* Experiment showing two UWB modules in our mocap space on rotating platforms. These platform automatically rotate the UWB modules into different relative orientation and records the measurement error. This experiment helps us build a better measurement model (i.e. weighting function) for our 3D RPE. (*Center)* LBNL collaborator Brian Quiter, working with us to install eight UWB modules on the LAMP platform for testing. Larger aerial platform allows for UWB sensors to be in multiple z-planes without destabilizing flight. By having four modules on the landing gear and prop arms respectively, z-axis sensitivity is reduced. (*Right)* Flight test at LBNL. Our surrogate UGV sits on the ground as the LAMP platform flies overhead with eight UWB modules. Test demonstrates initial UWB RPE algorithm integrated with a radiological search platform. Future experiments will have addition experiments, tests, and demonstrations with LBNL's LAMP platform.

Next Steps

- Complete 3D relative pose extension paper
- Complete integration into Kimera-Multi [6] SLAM pipeline
- Additional LAMP/radiological search demos/test at LBNL

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