Localization in 3D Surface Sensor Networks: Challenges and Solutions

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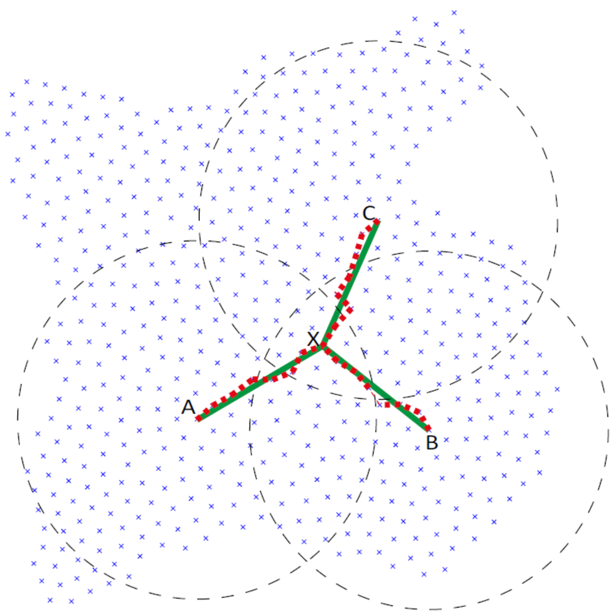
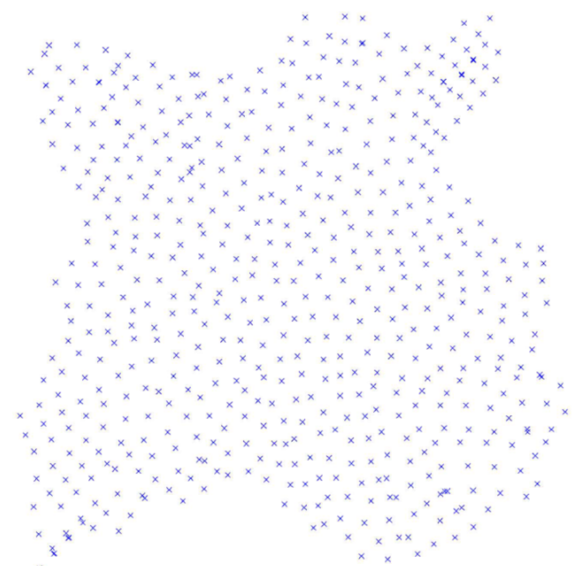
Outline

- Introduction
  - Autonomous localization algorithms
  - Unique challenges in localization on 3D surfaces
  - Contributions of our work
- Proposed localization algorithm for 3D surface sensor networks
- Simulations and experiments
- Conclusion

Introduction

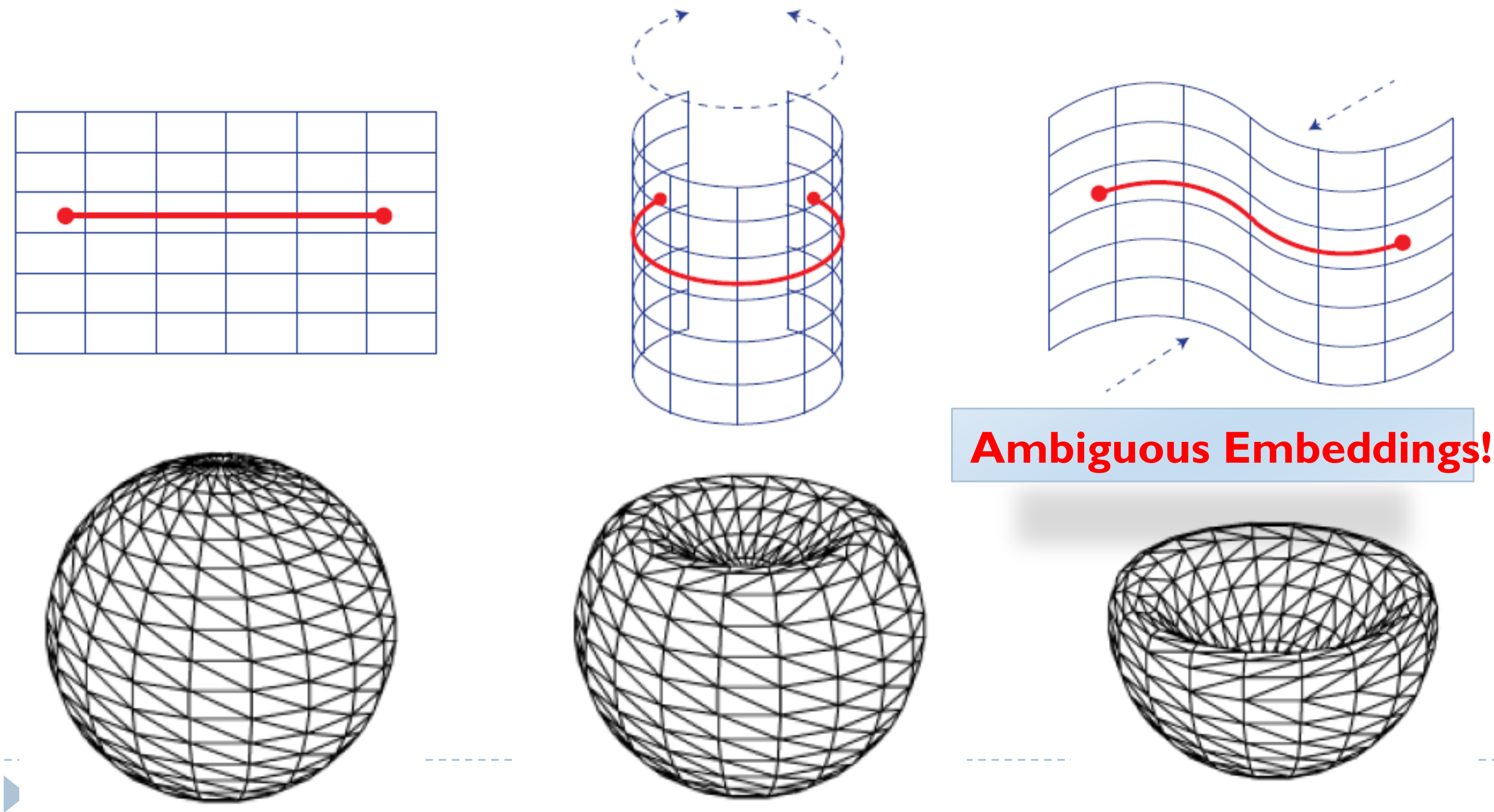
- Autonomous localization algorithms:
  - Trilateration
  - MDS and other non-linear optimization algorithms
  - Neural network based and Flat metric based





Unique challenges in localization on 3D surfaces

- **A general 3D surface is not always localizable, given surface distance constraints only.**



Introduction

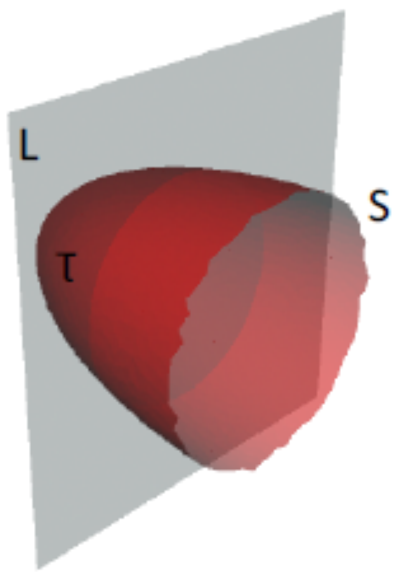
- Contributions
  - Reveals the unique hardness in localization on 3D surface and offers useful insight into the necessary conditions to achieve desired localizability.
  - Formulates the localization problem under a practical setting and introduces a layered approach to improve the localizability of such 3D surface sensor networks.

Problem Formulation

- A **3D surface sensor network** consists of sensor nodes deployed on a 3D surface where wireless signals between nearby nodes propagate along the surface only.
- Graph G = {V;E}, where V is the set of sensor nodes and E is a set of edges between any two neighboring nodes within their radio communication range, the localization problem studied in this research is formulated as follows:
  - Input: $\{z_i | i \in V\}$, $\{l_{ij} | ij \in E\}$,
  - Output: $\{(x_i, y_i, z_i) | i \in V\}$,
- The height (or altitude) of a sensor on a 3D surface is its z- coordinate. (usually can be obtained by measuring atmospheric pressure)
- If the above problem is solved (or can be solved), the network is called **localized** (or **localizable**).

Enough Information?

- **A general 3D surface is not always localizable based on surface distance and nodal height information only.**



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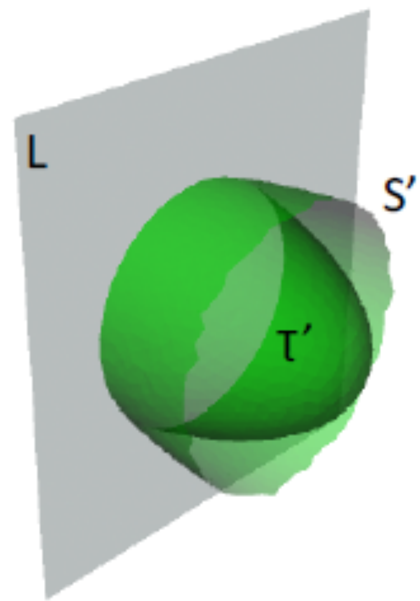


(a) Original surface S.

(b) Surface S' after mirroring.

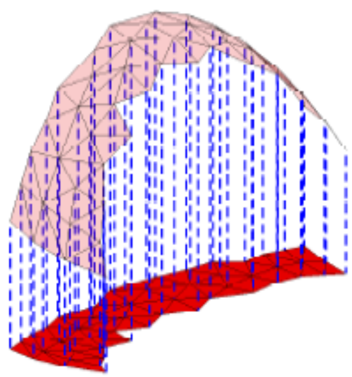
Localizable 3D Surfaces

- A **single-value (SV)** 3D surface is a surface on which any two points have different projections on the x-y plane.

- A SV surface is common in many practical applications: sensors are airborne to a mountainous region or dropped to underwater seabed

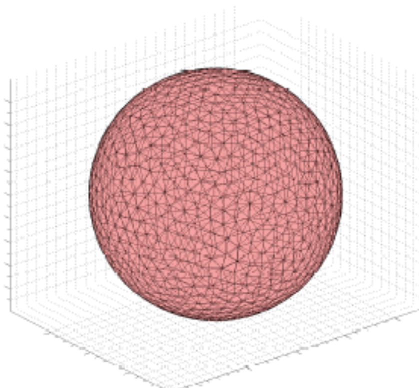
Localization of SV 3D Surfaces

- **A triangulated SV 3D surface sensor network is localizable**
  - **Step 1:** a distributed algorithm is applied to establish a triangular mesh structure
  - **Step 2:** the triangular mesh is projected to the *x-y* plane
  - **Step 3:** a distributed 2D localization algorithm is applied

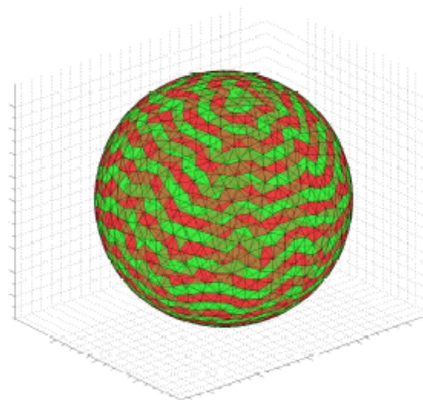


General 3D Surface - Layered Approach

- **Intuitive: convert a general 3D surface sensor network (especially a network deployed on NSV surface) to SV 3D surface sensor networks.**
- Layer Slicing: A general 3D surface is divided into layers.
- Layer Localization



(a) A NSV 3D surface network.

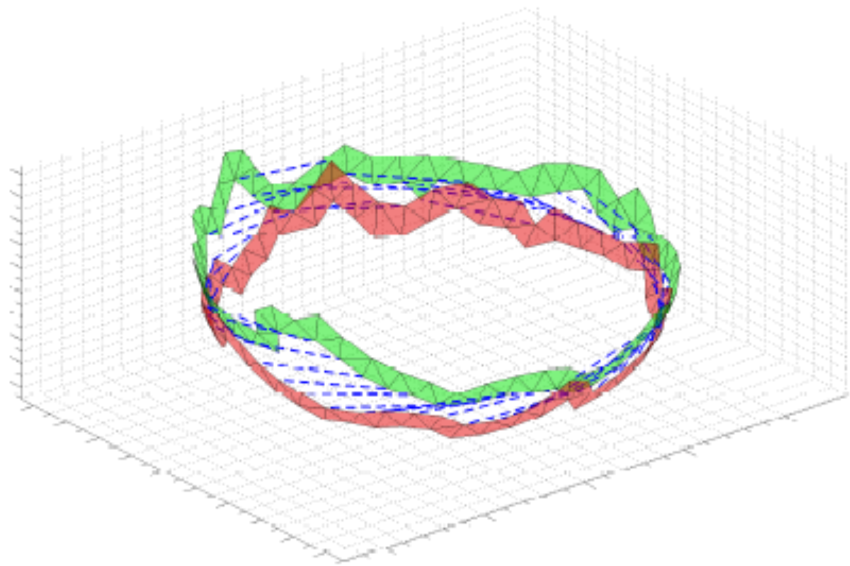


(b) Layer slicing.

- Note: the slicing process does not guarantee every layer of a NSV surface to be SV.

General 3D Surface - Layered Approach

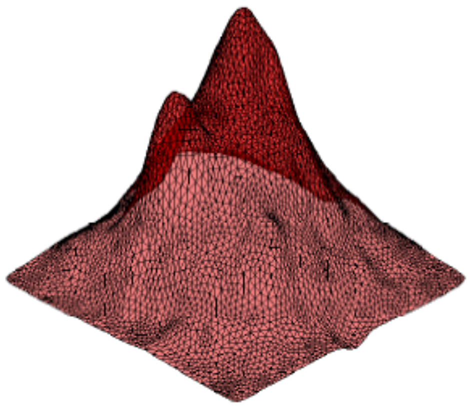
- Layer suturing: The suturing process tunes the upper layers based on lower layers to keep nodal coordinates network-wide consistent.
- If there are NSV layers between two SV layers, non-linear optimization is needed(to align non-adjacent layers).



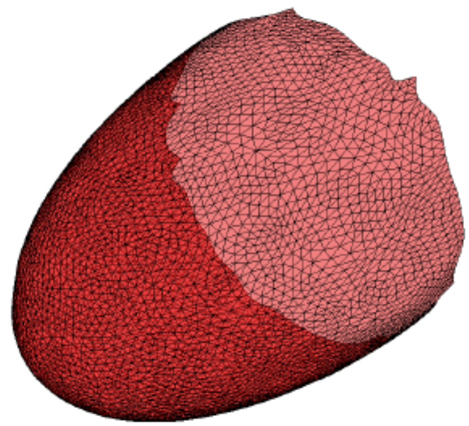
(c) Layer suturing.

Simulations and Experiments

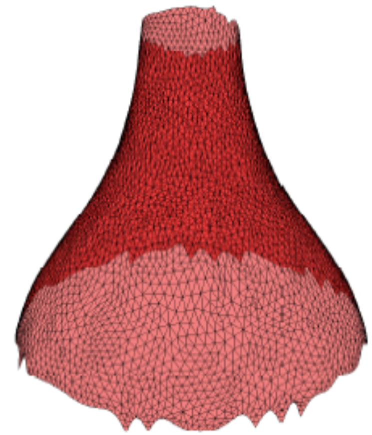
- Simulation Setup
  - Three models inspired by the exploration and monitoring of mountain terrain, sea cave and seismic activities in volcano.
  - About one to four thousands of sensor nodes are randomly deployed in each model
  - Assume every node is aware of its height
  - Distance and height are subject to measurement errors.
  - Based on the connectivity graph, a distributed algorithm [28] is applied to establish a triangular mesh structure.



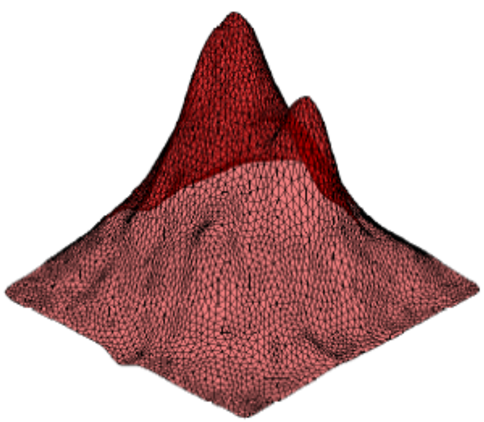
(a) Model 1: mountain model.



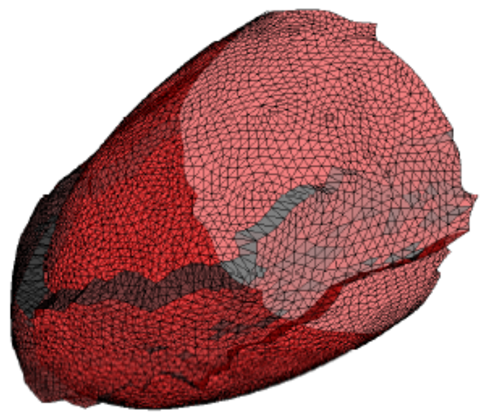
(b) Model 2: sea cave model.



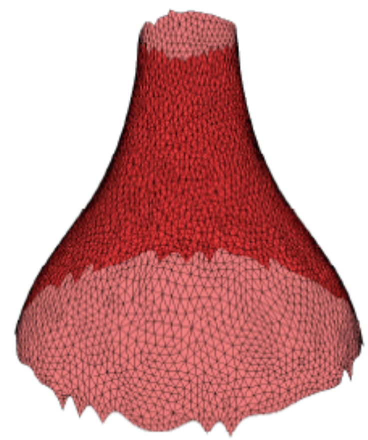
(c) Model 3: volcano neck model.



(d) Localization result of Model 1.



(e) Localization result of Model 2.



(f) Localization result of Model 3.

Simulations and Experiments

- Localizable Rate - percentage of nodes that can be localized.

TABLE I
LOCALIZABLE RATE.

Number of sensors	Maximum measurement error (%)	Mountain (%)	Sea cave (%)	Volcano neck (%)
1×10^3	0	100	91.2	100
	5	99.8	90.9	99.9
	10	99.2	90.3	99.4
	20	98.9	89.4	99.1
2×10^3	0	100	90.4	100
	5	99.9	90.0	99.9
	10	99.7	89.5	99.5
	20	99.1	88.6	98.8
4×10^3	0	100	90.9	100
	5	99.7	90.1	99.9
	10	99.5	89.2	99.7
	20	98.3	88.7	98.6

Simulations and Experiments

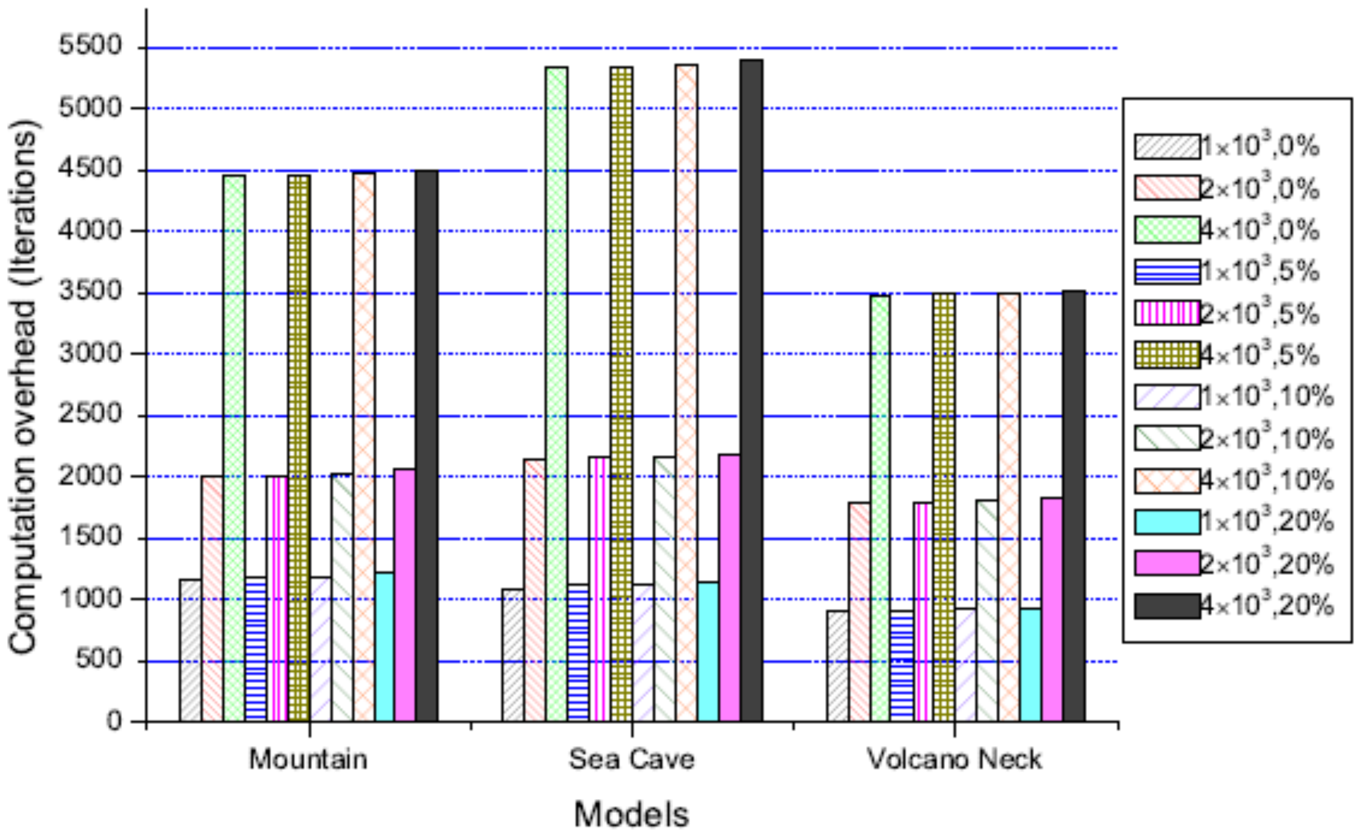
- Average Location Error - $|l - l'|/r$

TABLE II
AVERAGE LOCATION ERROR.

Number of sensors	Maximum measurement error (%)	Mountain (%)	Sea cave (%)	Volcano neck (%)
1×10^3	0	0.00	0.00	0.00
	5	2.53	2.57	2.54
	10	5.70	5.74	5.46
	20	15.9	16.6	13.5
2×10^3	0	0.00	0.00	0.00
	5	2.55	2.58	2.53
	10	5.45	5.69	5.58
	20	16.4	17.8	14.3
4×10^3	0	0.00	0.00	0.00
	5	2.55	2.55	2.53
	10	5.54	5.62	5.43
	20	18.1	15.7	14.0

Simulations and Experiments

- Computational Overhead

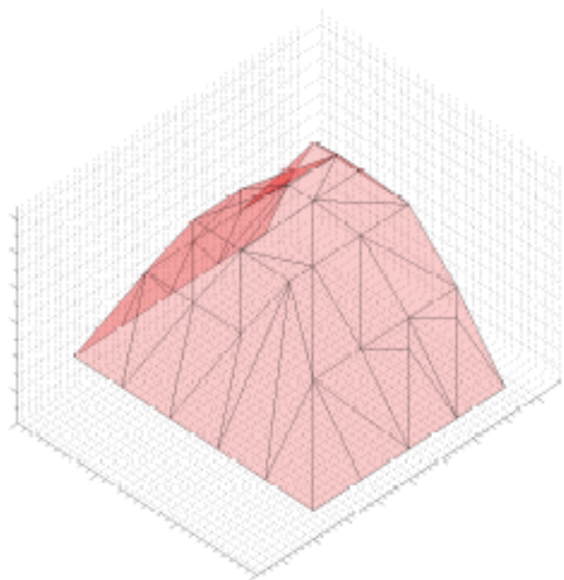


Simulations and Experiments

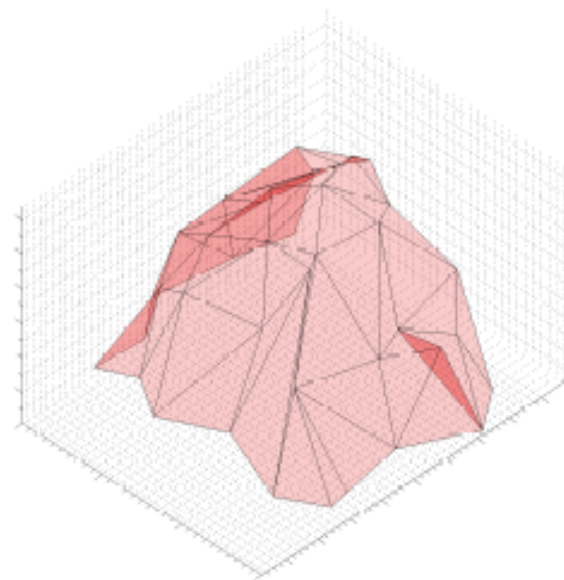
❑ Experiment setup

- 39 Crossbow Micaz randomly deployed on the surface of a 3D structure, to mimic an airborne network
- The radio transmission distance ranges from 15cm to about 50cm
- Range estimation has an error rate as high as 20%

Simulations and Experiments



(b) Ground truth.



(c) Localization result.

Localizable rate: 100%
Average location error: 13.5%

Conclusion

- Our investigation has revealed the unique hardness in localization on 3D surface in comparison with the well-studied localization problems in 2D and 3D space and offered useful insight into the necessary conditions to achieve desired localizability.
- We have formulated the localization problem under a practical setting with estimated link distances (between nearby nodes) and nodal height measurements. We have introduced a layered approach to improve the localizability of such 3D surface sensor networks.
- Our simulation results have shown that it can effectively improve localizable rate and achieve low location errors and computational overhead, with the desired tolerability to measurement errors and high scalability to large-size wireless sensor networks.

Questions?


THANK
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