Sextant: A Unified Node and Event Localization Framework Using Non-Convex Constraints

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Challenges in Localization

**Hardware**
- Expensive
- Power Consuming

**Infrastructure**
- Initial setup required
- Not always available

**Modeling**
- Irregular wireless coverage area
- Introduces error
Sextant Approach

- Extract geometric constraints
- Disseminate them transitively
- Solve in a distributed manner
Contributions

- Unified Node and Event localization
  - Accurate
    - Negative as well as positive information
    - Explicit representation
  - Practical
    - Constraint extraction
    - Deployed on MICA-2 motes, laptops and PDAs
Sextant Approach

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- Unified Node and Event localization
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Negative constraint

Positive constraint
Sextant Approach

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- Need not be convex
- May have holes
- May have disconnected components
Sextant Approach

Contributions

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Node Localization

Positive Information

Nodes A and B with positive information at point M.

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Intersection of Positive Information
Node Localization

Negative Information
Node Localization

Subtraction of Negative Information

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Transitive Dissemination of Positive Information
Transitive Dissemination of Positive Information
Node Localization

Transitive Dissemination of Positive Information
Node Localization

Transitive Dissemination of Positive Information
Combining Positive and Negative Information
Combining Positive and Negative Information
Transitive Dissemination of Negative Information
Node Localization

Transitive Dissemination of Negative Information
Refining Location Estimates
Refining Location Estimates
Sextant Approach

Each Node $x$

- Location Estimate: $\mathcal{E}_x$
- Positive Constraint: $\mathcal{P}_x$
- Negative Constraint: $\mathcal{N}_x$
- Set of positive constraints: $\Gamma_x$
- Set of negative constraints: $\Theta_x$

Invariant

$$\mathcal{E}_x = \bigcap_{p \in \Gamma_x} p \setminus \bigcup_{n \in \Theta_x} n$$

Polygons with Bézier boundaries
Sextant Approach

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Sextant Approach

Union of circles in $\mathcal{E}_x$

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### Sextant Approach

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Intersection of circles in $\mathcal{E}_x$
Sextant Approach

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Event Localization

Similarity to Node Localization

- Constraints from sensing hardware vs. wireless radio
- Boolean sensed/not-sensed signal vs. boolean connectivity

Differences from Node Localization

- Annotate resultant areas with probabilities
Event Localization

Positive Contribution
Sensor somewhere in $E$ detects event; probability event in grid $G_i$.

Negative Contribution
Sensor somewhere in $E$ does not detect event; probability event in grid $G_i$.

Solution
Product of positive and negative contributions from sensors sensing and not-sensing the event.

Bayesian Probability
Feedback
Events as a Source of Constraints
Events as a Source of Constraints
Optimizations

Wireless Hardware
- Range Measurements
- Angle of Arrival

Sensor Hardware
- Event Distance
- Directional Sensors

Annulus for range $x$
Optimizations

Sector for angle $\alpha$

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Wireless coverage area is non-convex and has holes

**Wireless Radio**

Boolean packet-received / packet-not-received.

- All reachable nodes ≤ \( R \) away
- All unreachable nodes ≥ \( r \) away
Wireless Radio

Boolean packet-received / packet-not-received.

- All reachable nodes $\leq R$ away
- All unreachable nodes $\geq r$ away
### Neighborhood Discovery

- Nodes transmit periodic beacons
- Threshold beacon reception required for boolean connectivity

### Gossip

Disseminate constraints as long as they are useful
- Positive information – used only at first hop
- Negative information – used within the first few hops
## Implementation

- Implemented on MICA-2 motes, laptops and PDA
- About 2kB of storage per node
- About 80kB data transmitted per node until convergence

## Setup

- 50 MICA2 motes placed in a grid pattern
- Landmarks chosen at random
- 80% packet reception threshold chosen for connectivity
Comparing Node Localization

- **Triangulation** – Centroid of neighbor nodes
  - GPSLess
- **Single-hop** – No transitive dissemination
  - Active Badge, Cricket, GPSLess, Localization Using Moving Target
- **Positive-constraints** – No negative information
  - APS, Convex position estimation, N-hop Multilateration, Robust Positioning
- **Sextant**
Validation of Node Localization

Sextant locates more nodes accurately

Node Localization

- Accurate
- Efficient
- Scalable
Validation of Node Localization

Sextant requires few landmarks

Node Localization
- Accurate
- Efficient
- Scalable
Validation of Node Localization

Sextant requires fixed landmark density

Node Localization

- Accurate
- Efficient
- Scalable
Validation of Event Localization

Setup

- 50 MICA2 motes placed in a grid pattern
- Event is a flash of light
- Appreciable change in analog value triggers sensor

Comparing Event Localization

- **Triangulation** – Centroid of sensors reporting the event
  - Acoustic Ranging
- **Sextant**
Validation of Event Localization

- Accurate
- Efficient
- Robust

Sextant locates more events accurately
Validation of Event Localization

Sextant: Node and Event Localization

Event Localization

- Accurate
- Efficient
- Robust

Accuracy improves with nodes
Validation of Event Localization

Event Localization
- Accurate
- Efficient
- Robust

Sextant independent of sensing range

Sextant: Node and Event Localization
Sextant unifies node and event localization in the same framework.

Sextant achieves high accuracy and scalability:
- Explicit representation of regions using Bézier curves
- Conservative and comprehensive extraction of negative as well as positive constraints
- Transitive dissemination of constraints
- Use of events to refine node location

Sextant is practical:
- Deals well with violations of simplistic assumptions
- Implemented on MICA-2 motes, PDAs and laptops

http://www.cs.cornell.edu/People/egs/sextant/
Positive Information

- **GPS-Free '01**: Capkun, Hamdi and Hubaux
- **APS '01**: Niculescu and Nath
- **Convex Position Estimation '01**: Doherty, Pister and Ghaoui
- **Robust Positioning '02**: Savarese, Rabay and Langendoen
- **N-hop Multilateration '02**: Savvides, Park and Srivastava
- **APS-AoA '03**: Niculescu and Nath
- **Mere Connectivity Localization '03**: Shang, Ruml, Zhang and Fromherz
- **Connectivity-Based Positioning '04**: Bischoff and Wattenhofer
- **Unit Disk Approximation '04**: Kuhn, Moscibroda and Wattenhofer
- **Virtual Coordinates '04**: Moscibroda, O’Dell and Wattenhofer
## Single-Hop

- **Active Badge** ’92: Want, Hopper, Falcão and Gibbons
- **GPS-Less** ’00: Bulusu, Heidemann and Estrin
- **RADAR** ’00: Bahl and Padmanabhan
- **Cricket** ’00: Priyantha, Chakraborty and Balakrishnan
- **RF-Based Location Tracking** ’04: Lorincz and Welsh
- **VORBA** ’04: Niculescu and Nath
- **Localization Using a Moving Target** ’04: Galstyan, Krishnamachari, Lerman and Pattem
Related Work

Event Localization

- **Fine-grained Localization** '01: Savvides, Han and Srivastava
- **Collaborative Processing** '03: Zhao, Liu, Guibas and Reich
- **Acoustic Ranging** '04: Sallai, Balogh, Maroti and Ledeczi
- **Countersniper** '04: Simon, Maroti, Ledeczi et al.
- **Entity Tracking** '02: Brooks, Griffin and Friedlander
- **Energy-Efficient Surveillance** '04: He, Krishnamurthy, Stankovic et al.