Localization using Mobile Wireless Sensor Networks

Course Project - EE 617: Sensors in Instrumentation

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What are WSNs? What are we doing with WSNs?

- **Wireless Sensor Networks (WSNs)**: group of spatially distributed and dedicated autonomous sensors for monitoring (and recording) the physical conditions of the environment (and organizing the collected data at a central location).
- simple sensors: local quantities such as temperature, pH, or pressure.
- WSNs for localization, and improving conditions of living for animals and humans at IIT Bombay

Improvements in Wireless Sensor Networks

A. Benefit[1]: WSNs have developed throughout the years

- from more expensive and fewer sensors to cheaper but larger quantities of sensors,
- from discrete circuits and multi-chip solutions to system-on-chip (SoC) devices, and
- from one-way communication links to bidirectional links and mesh and star designs.

Optimizations $\rightarrow$widespread applications of WSNs

[1] A. Benefit. "The evolution of wireless sensor networks". In: *https://www.silabs.com/documents/public/white-papers/evolution-of-wireless-sensor-networks.pdf* ().

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Localization, in general and some details...

- Localization: multiple methods; GPS: very common
  Accuracy of GPS data is relatively low ($> 10m$).
- Lee et al.[2]: more accurate localization method
  $\rightarrow$Wireless Sensor Network of ZigBees: relative signal strengths for trilateration-based localization.

[2] J-H Lee et al. "An Efficient Localization Method Based on Adaptive Optimal Sensor Placement". In: *Int. Journal of Distributed Sensor Networks* (2014).

- Mobile Target Tracking (MTT) problem: find the moving path of a target in a field based on target locations that are sampled at random intervals
- Gupta, Gui, and Mohapatra[3]: algorithms to solve MTT using two aspects:
  - determining the current location of the target (localization, path tracing),
  - processing information collaboratively among multiple sensor nodes.
- MTT methods:
  - Informed selection of sensors,
  - binary sensor-based methods with centralized and distributed architectures,
  - methods based on triangulation
- Information: processed using leader-based algorithms or distributed algorithms.

[3] A Gupta, C Gui, and P Mohapatra. "Mobile Target Tracking using Sensor Networks". In: *Mobile, Wireless, and Sensor Networks: Technology, Applications, and Future Directions* (2006).

Why a new navigation system?

- Unlike open environments, locations with several obstructions or jamming hinder the proper function of the Global Position System (GPS).
- In such scenarios, it is necessary to develop a positioning system that can complement GPS.

What is the Pedestrian Navigation System?

Fang et al.[4]:

- Pedestrian Navigation System (PNS) - heterogeneous agents are used for sensing, communication and relaying information
- Sensors: part of a dead reckoning (odometry) mechanism to localize the user
  - The NavMote (sensor on the user) exchanges information with NetMotes (predetermined sensors) when they are in range,
  - otherwise it works on its own.
- Tested in both indoor and outdoor environments: distance accuracy $\pm 1\%$, heading accuracy 1°

[4] L Fang et al. "Design of a Wireless Assisted Pedestrian Dead Reckoning System—The NavMote Experience". In: *IEEE Transactions on Instrumentation and Measurement* (2016).

Beacon-based Localization

- Beacon-based localization of mobile targets:
  - some beacons are aware of their positions,
  - they provide geographic information to ordinary sensor nodes to localize,
  - the precision of localization increases with the number of beacons
- Cui et al.[5]: algorithm utilizing mobile beacons that traverse the network deployment area and broadcast beacon packets to generate a number of virtual beacons

[5] H-q Cui et al. "Three-Mobile-Beacon Assisted Weighted Centroid Localization Method in Wireless Sensor Networks". In: *Int. Conf. on Software Engineering and Service Science* (2011).

Three-Mobile-Beacon-assisted Localization

- The distance between the sensor node and the beacon can be calculated using RSSI (Received Signal Strength Indicator).
- Single-mobile-beacon system: co-linearity due to the straight line moving trajectory of the mobile beacon $\rightarrow$three-mobile-beacon-assisted mechanism: the sensor node, S_i is localized as the weighted centroid of the three beacon positions:

$$S_i(\hat{x}_{si}, \hat{y}_{si}) = \frac{\sum_{j=1}^{m} w_{ij} V_j(x_{vj}, y_{vj})}{\sum_{j=1}^{m} w_{ij}}, w_{ij} = \frac{1}{(d_{ij})^g},$$

where V_j is the jth virtual beacon, d_{ij} is the distance between S_i and V_j, and g is an adjustable degree.

Localization Schemes

- Anchor node-based schemes:
  - anchors acquire their positions in advance using GPS systems or artificial arrangement to locate unknown nodes
  - better localization accuracy
- Anchor node-free schemes:
  - unknown nodes are located using the connectivity information between unknown nodes and anchor nodes
  - smaller number of anchor nodes $\rightarrow$smaller energy consumption and hardware cost of WSNs

LMAT: An Analysis

Jiang et al.[6]:

- mobile anchor nodes - maximize the localization accuracy + decrease the energy consumption of WSNs
- Mechanism:
  - An anchor node moves based on an equilateral triangle trajectory in a WSN area and broadcasts position and time messages periodically
  - On reception, the messages are used via RSSI-based trilateration to determine the position of unknown nodes
- Pros and cons:
  - Reduces the number of beacon positions, trajectory lengths and node density
  - Remains robust at high traveling speeds of the anchor node
  - Sensitive to the standard deviation of noise

[6] J Jiang et al. "LMAT: Localization with a Mobile Anchor Node Based on Trilateration in Wireless Sensor Networks". In: *IEEE Global Telecommunications Conf.* (2011).

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What makes up a WSN?

Yu & Ephremides[7]:

- A typical WSN: a number of sensor nodes + control center.
- Sensor node:
  - collects observation data from the surrounding environment,
  - performs local processing if required,
  - routes the processed data to the control center.
- Control center: makes a final decision based on all the data it receives from the sensor nodes

[7] Lige Yu and Anthony Ephremides. "Detection, Energy, and Robustness in Wireless Sensor Networks". In: *Mobile, Wireless, and Sensor Networks: Technology, Applications, and Future Directions* (2006).

The Simplified Wireless Sensor Network Model

- No cooperation among sensor nodes:
  Each sensor node independently observes, processes, and transmits data
- No spatial or temporal correlation among measurements:
  Observations are independent across sensor nodes, and at each single node
- No routing:
  Each sensor node sends data directly to the control center
- No noise or any other interference:
  Data are transmitted over an error-free communication channel

Operating Options based on Local Processing and Data Transmission

Three options for a system of K sensor nodes and a control center:

- Centralized: Transmission of data to the control center without any loss of information [1]
- Distributed: Transmission of local decision by each sensor node as a binary quantity to the control center [2]
- Quantized: Transmission of quantized M-bit quantity after local processing by each sensor node to the control center [3]

[1] Final decision: based on the comprehensive collection of information

[2] Final decision: based on the K binary quantities

[3] Final decision: based on the K quantized quantities

A Comparison of the Operating Options

The three options are compared based on the probability of error P_e (should be small), the probability of false alert P_f (should be small), and the probability of detection P_d (should be large):

- The distributed scheme is observed to be superior in energy consumption (especially over large distances) and robustness.
- Although the centralized scheme uses fewer nodes, the distributed option needs fewer than twice that number to achieve the same detection performance.

What is the Neighbor Discovery Problem?

- The neighbor discovery problem: situations where
  - sensor nodes find their neighbors constantly in mobile sensor networks by communicating with each other while in motion, and
  - forward the collected information to a central command center.
- The active and dormant status of sensors can be controlled $\rightarrow$energy consumption is significantly reduced
- This may cause additional discovery latency: discovery is possible only when neighboring nodes have overlapping active slots.

Solving the Neighbor Discovery Problem

- Previous research: group-based method - a third state for waking up actively is used to communicate the schedule and verify the neighborhood of nodes
- Niu, Bao, and Xia[8]: algorithm that considers the embedded spatial properties and actively modifies the active time of nodes depending on the number of undiscovered neighbors
- Simulations: the discovery time is minimal wrt algorithms in existing literature.

[8] Q Niu, W Bao, and S Xia. "An Improved Group-Based Neighbor Discovery Algorithm for Mobile Sensor Networks". In: *Int. Journal of Distributed Sensor Networks* (2014).

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What is the idea?

- Indian Institute of Technology Bombay - over 500 acres - home not only to humans but also a wide array of plants and animals from leopards and crocodiles to cows, dogs and cats
- Issues for humans from stray dogs + Issues for dogs from human activities
- What can we do? - track and guide dogs without causing harm to both the human and dog populations

Ideas from Mobile Target Tracking

- Based on mobile target tracking[9], a network of distributed sensors may be placed at suitable locations in the institute.
- Large size of the campus →not a scalable solution (number of sensors and energy consumption will be huge)
- The distribution of dogs across the institute need not be uniform →Placing sensors at certain locations will not be efficient although there is a possibility for a small number of dogs to visit these areas

[9] A Gupta, C Gui, and P Mohapatra. "Mobile Target Tracking using Sensor Networks". In: *Mobile, Wireless, and Sensor Networks: Technology, Applications, and Future Directions* (2006).

Ideas from LMAT

- The movable sensors on the dogs can behave as anchors[10] using which other movable sensors can localize themselves via trilateration.
  $\rightarrow$The number of fixed sensors can hence be reduced if the number of dogs is large
- Simulation:
  - number of fixed sensors $= 6$,
  - total area $= 10m \times 10m$,
  - each sensor can sense sensors within a radius of $7m$,
  - three movable sensors are placed such that the size of their point represents the uncertainty of finding their location.

[10] J Jiang et al. "LMAT: Localization with a Mobile Anchor Node Based on Trilateration in Wireless Sensor Networks". In: *IEEE Global Telecommunications Conf.* (2011).

Into more details

- Neighbors of a sensor - sensors capable of connecting to and providing information about position and time to the sensor for trilateration at that instant
- Geometric uncertainty principle - the uncertainty of the location of the sensor increases given the number of neighbors is less than 4 and decreases otherwise
- Free-ranging dogs generally exhibit territoriality[11]
  Dogs in the institute - territorial in considerably small pieces of land (individual hostels, small strips of roads)
  $\rightarrow$Similarly, the three sensors in the simulation are constrained within particular regions

[11] SS Majumder et al. "A dog's day with humans – time activity budget of free-ranging dogs in India". In: *Current Sciences 10(6)* (2014).

What do we observe... without tag links?

The mechanism is simulated in two-dimensional space within the given dimensions. We initialize the sensors with some positional uncertainty.

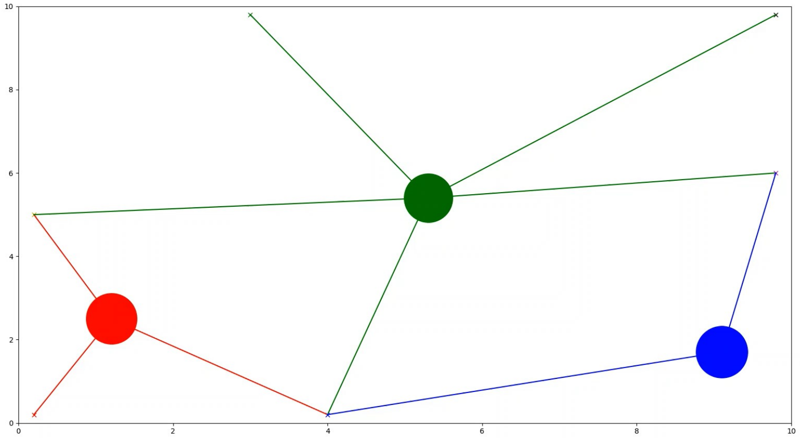

Figure: Initial Configuration - Without Tag Links

What do we observe... without tag links?

On deactivating links between tags (i.e., they do not behave as mutual anchors), there are larger periods when the number of links is 2 due to which the uncertainty of some sensors is observed to diverge with time.

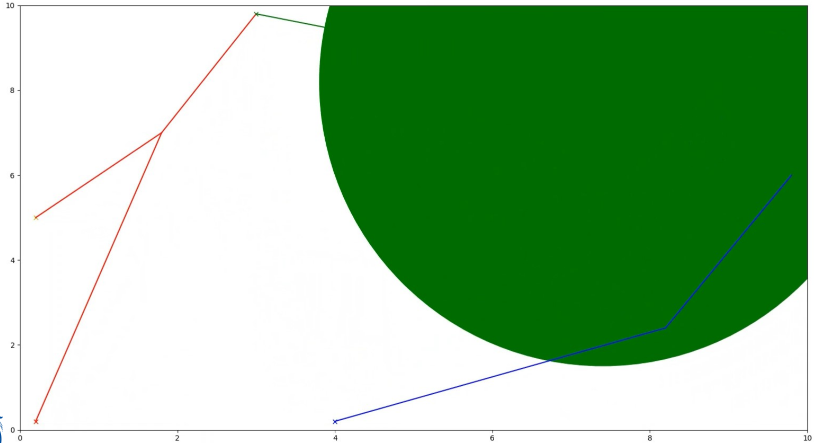

Figure: Final Configuration - Without Tag Links

What do we observe... with tag links?

The second simulation involves links between neighboring tags. This starts from the beginning of the simulation.

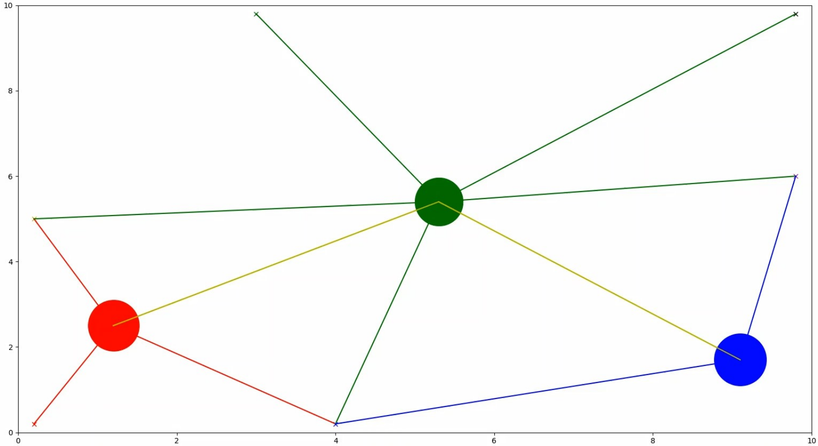

Figure: Initial Configuration - With Tag Links

What do we observe... with tag links?

For simplicity, we assume that the range of the tag sensors is equal to that of the anchors although, in a practical scenario, this might not be the case since the former will consist of simpler circuits and transceivers, hence resulting in smaller ranges.
The uncertainty of the previously mentioned sensors does not diverge since the sensors are in contact with each other for several periods which previously had led to the divergence of uncertainty.

What do we observe... with tag links?

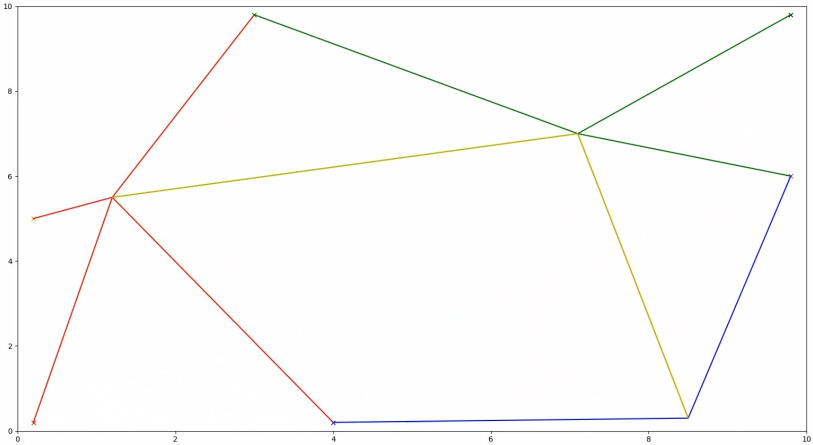

Figure: Final Configuration - With Tag Links

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What can be done?

- Wearing traditional sensors for a long duration may be detrimental to the health of the dog, and the sensing quality may degrade from the environmental and hygienic conditions.
- Biosensors and flexible electronics may be more appropriate long-term options.
- The long-term effects of biologic cybernetics and electronic stimulation on dogs is open to research although there has been progress in short-duration studies on several animals (Johnson and Fuglevan[12], Rezaee and Kobravi[13], Cao and Doan[14]).

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[12] LA Johnson and AJ Fuglevand. "Mimicking muscle activity with electrical stimulation". In: *Journal of Neural Engineering vol. 8(1)* (2011).

[13] Z Rezaee and HR Kobravi. "Human Gait Control Using Functional Electrical Stimulation Based on Controlling the Shank Dynamics". In: *Basic and Clinical Neuroscience vol. 11(1)* (2020).

[14] F Cao et al. "A Biological Micro Actuator: Graded and Closed-loop Control of Insect Leg Motion by Electrical Stimulation of Muscles". In: *PLOS ONE 9(8)* (2014).