Localization using Mobile Wireless Sensor Networks

Course Project - EE 617: Sensors in Instrumentation

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Table of Contents

Table of Contents

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] elucidates how 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* ().

Table of Contents

Localization, in general and some details...

- Localization can be performed using multiple methods, a very common one being GPS.
  However, the accuracy of GPS data is relatively low ($> 10m$).
- Lee et al.[2]: more accurate localization method
  $\rightarrow$a wireless sensor network of ZigBees is developed and their relative signal strengths are used 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).

- The Mobile Target Tracking (MTT) problem intends to 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), and
  - processing information collaboratively among multiple sensor nodes.
- Traditional methods involving the informed selection of sensors, binary sensor-based methods with centralized and distributed architectures can be used. Other methods based on triangulation are also suggested for tracking.
- Information can be 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).

Table of Contents

What makes up a WSN?

According to Yu & Ephremides[4]:

- A typical WSN consists of a number of sensor nodes and a control center.
- Each sensor node:
  - collects observation data from the surrounding environment,
  - performs local processing if required, and
  - routes the processed data to the control center.
- The control center is responsible for making a final decision based on all the data it receives from the sensor nodes

[4] 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).

Assumption: Simplified Wireless Sensor Network Model

- No cooperation among sensor nodes [1]
- No spatial or temporal correlation among measurements [2]
- No routing [3]
- No noise or any other interference [4]

[1] Each sensor node independently observes, processes, and transmits data

[2] Observations are independent across sensor nodes, and at each single node

[3] Each sensor node sends data directly to the control center

[4] 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 Option**: Transmission of data to the control center without any loss of information [1]
- **Distributed Option**: Transmission of a local decision by each sensor node as a binary quantity to the control center [2]
- **Quantized Option**: Transmission of a 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 deals with 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.

Here, the active and dormant status of sensors can be controlled, hence reducing the energy consumption significantly.
This may cause additional discovery latency since discovery is possible only when neighboring nodes have overlapping active slots.

What is the solution?

Previous research had introduced the group-based method where a third state for waking up actively is used to communicate the schedule and verify the neighborhood of nodes.

Niu, Bao, and Xia[5] propose an algorithm that considers the embedded spatial properties and actively modifies the active time of nodes depending on the number of undiscovered neighbors. This has been tested using simulations and the discovery time has been found to be minimal when compared to algorithms presented in existing literature.

[5] 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).

Table of Contents

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[6], 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

[6] 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[7] 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.

[7] J Jiang, G Han, and Xu 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[8]
  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

[8] SS et al. Majumder. "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.

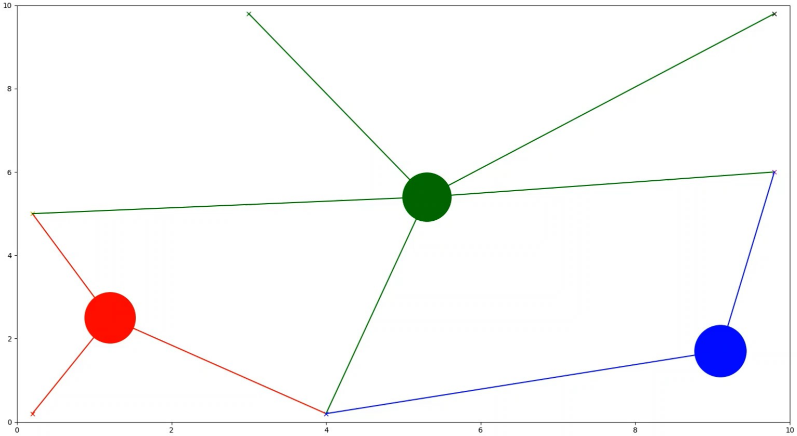

Figure: Initial Configuration - Without Tag Links

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.

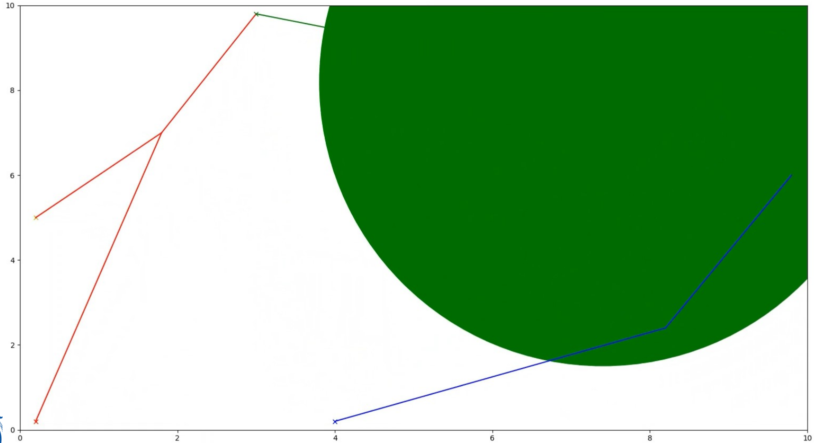

Figure: Final Configuration - Without Tag Links

What do we observe... with tag links?

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

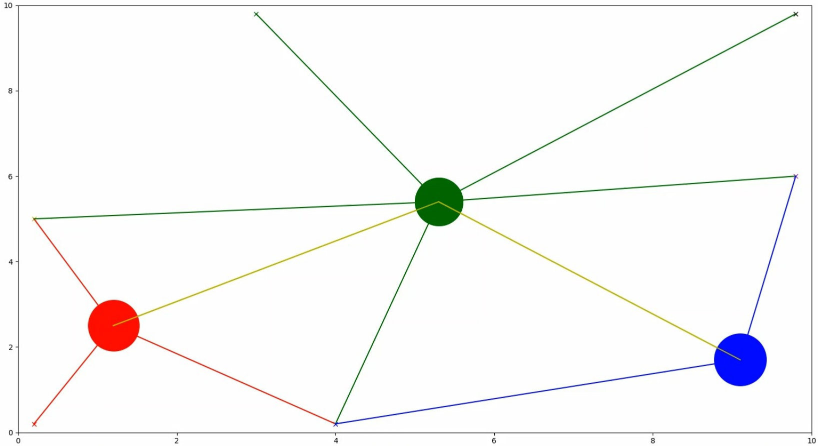

Figure: Initial Configuration - With Tag Links

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?

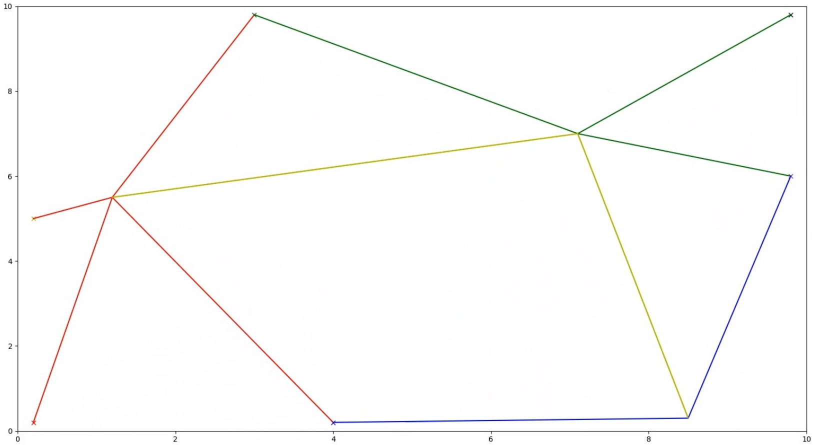

Figure: Final Configuration - With Tag Links

Table of Contents

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[9], Rezaee and Kobravi[10], Cao and Doan[11]).

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

[10] 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).

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