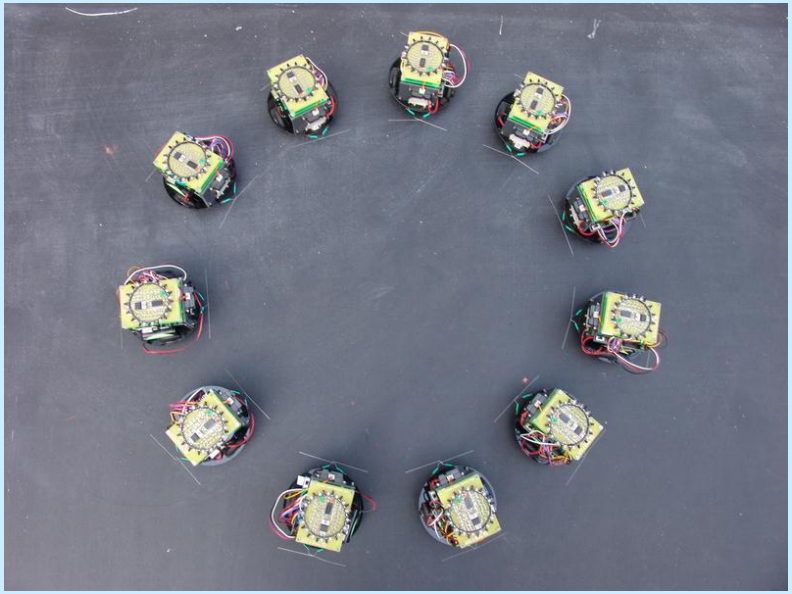
Relative Localization in Colony Robots



Christopher Atwood, Felix Duvallet, Aaron Johnson,
Richard Juchniewicz, Ryan Kellogg, Katherine Killfoile,
Alison Naaktgeboren, Suresh Nidhiry, Iain Proctor,
Justine Rembisz, Steven Shamlian, Prasanna Velagapudi

Carnegie Mellon

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Colony Robotics Background

- Uses
  - Mapping
  - Searching
  - Modeling behaviors
  - Herding

*

* http://www.pbs.org/wgbh/nova/sciencenow/3204/03-talk.html

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Colony Robotics Background

- Examples
  - MIT Swarm
  - The **G**eorgia Tech **N**etwork for **A**utonomous **T**ask**s** (GNATS)
  - Robocup Soccer (Aibo and Segway Leagues)

* http://borg.cc.gatech.edu/gnats/

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Colony Robotics Background

- Important Characteristics
  - Multiple robots
  - Distributed processing
  - Distributed sensing
- Advantages
  - Improved fault tolerance
  - Utilization of emergent behaviors

*

* http://www-2.cs.cmu.edu/~robosoccer/image-gallery/index.html

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Colony][

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Colony][

- Our Approach
  - Low cost (~$300)
  - Imprecise sensors
  - Limited computation
  - Off-the-shelf parts

- Capabilities
  - Wireless communication
  - Relative localization
  - Heat source detection and tracking

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Relative Localization

- “A method whereby each robot may determine the pose of every other robot in the team, relative to itself.”*

- Developed an algorithm to accomplish this using minimal sensor data and basic geometry.

*Howard, Andrew, et.al. “Cooperative relative localization for mobile robot teams: an egocentric approach.” [Online Document]. Available: http://robotics.usc.edu/~ahoward/pubs/howard_mrsw03a.pdf

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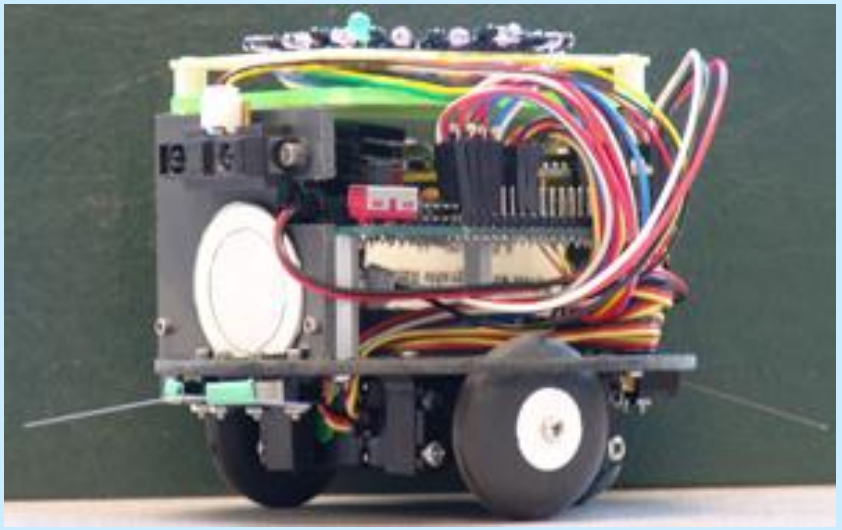
Hardware

- Pyroelectric Sensor
  - Used to detect and track heat sources
- Wireless Board
  - Used for multi-robot communication
- Bearing and Orientation Module (BOM)
  - Used to gather relative angle data between robots



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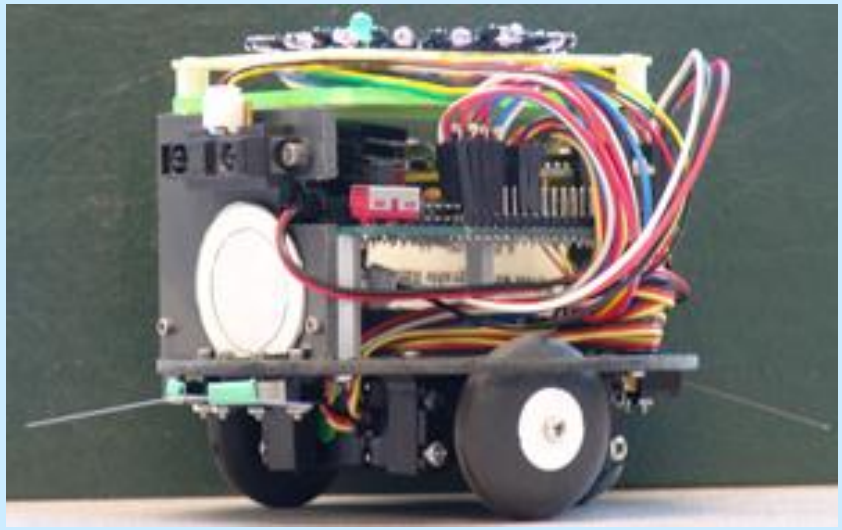

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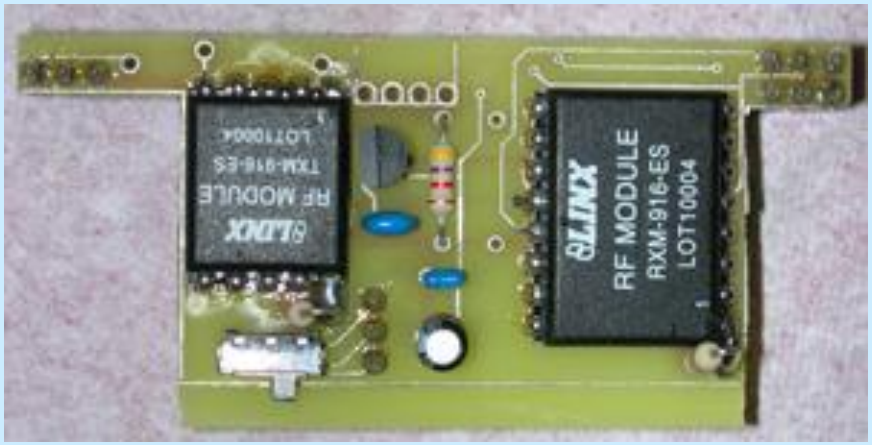
Wireless: Hardware

- 900 MHz RF transmitter/receiver pair
  - Half-duplex
  - ~30ft effective range
  - Broadcast transmission
  - Low profile daughterboard design



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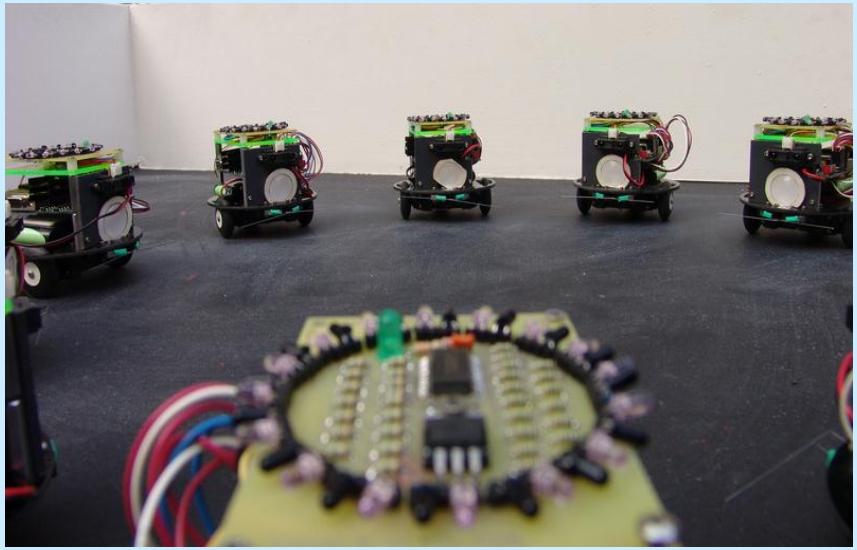
Wireless: Software

- Static token ring
  - Synchronous network protocol
  - Linked to BOM operation
    - Used as “beacon” while transmitting data
    - Used to determine sender bearing while receiving
      - Passively listens to network traffic
      - Calculates angle data to every other robot in one token ring cycle



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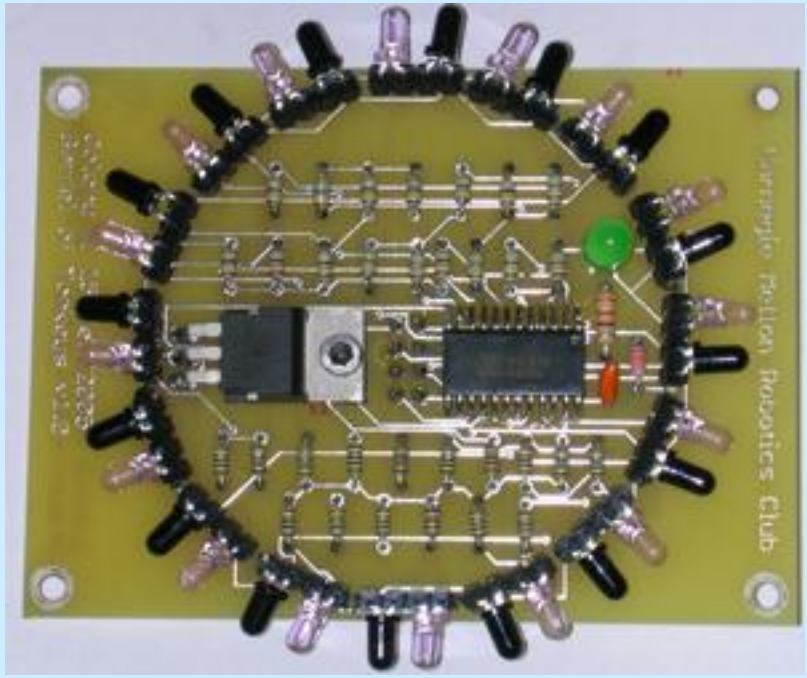
Bearing and Orientation Module

- Coplanar IR emitter and IR detector ring
- IR emitter mode
  - All emitters are powered simultaneously (beacon)
- IR detector mode
  - Detectors can be polled for analog intensity readings



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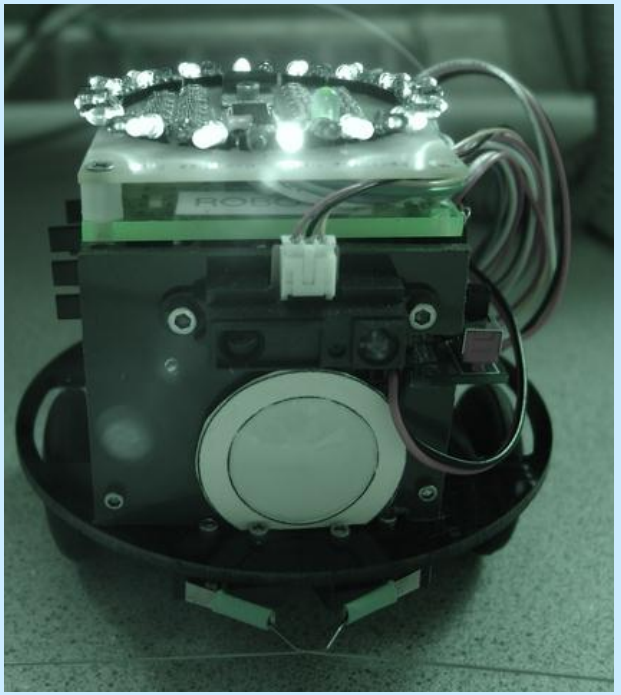
Bearing and Orientation Module

- IR emissions from one robot are highly visible to other robots
- Most excited detector is assumed to be pointing in the direction of the emitting robot.



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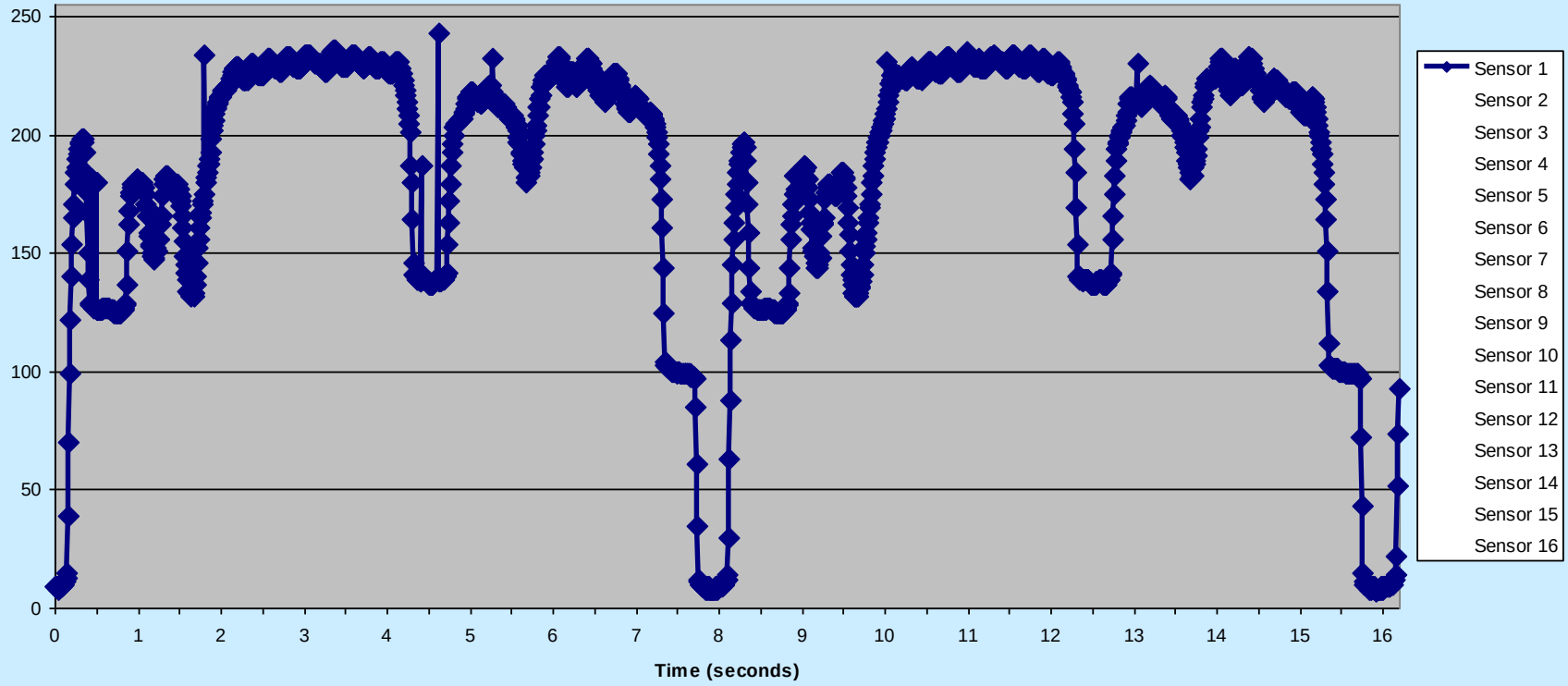
Robot 1 BOM Detection Test
Raw Data Over Two Full Rotations



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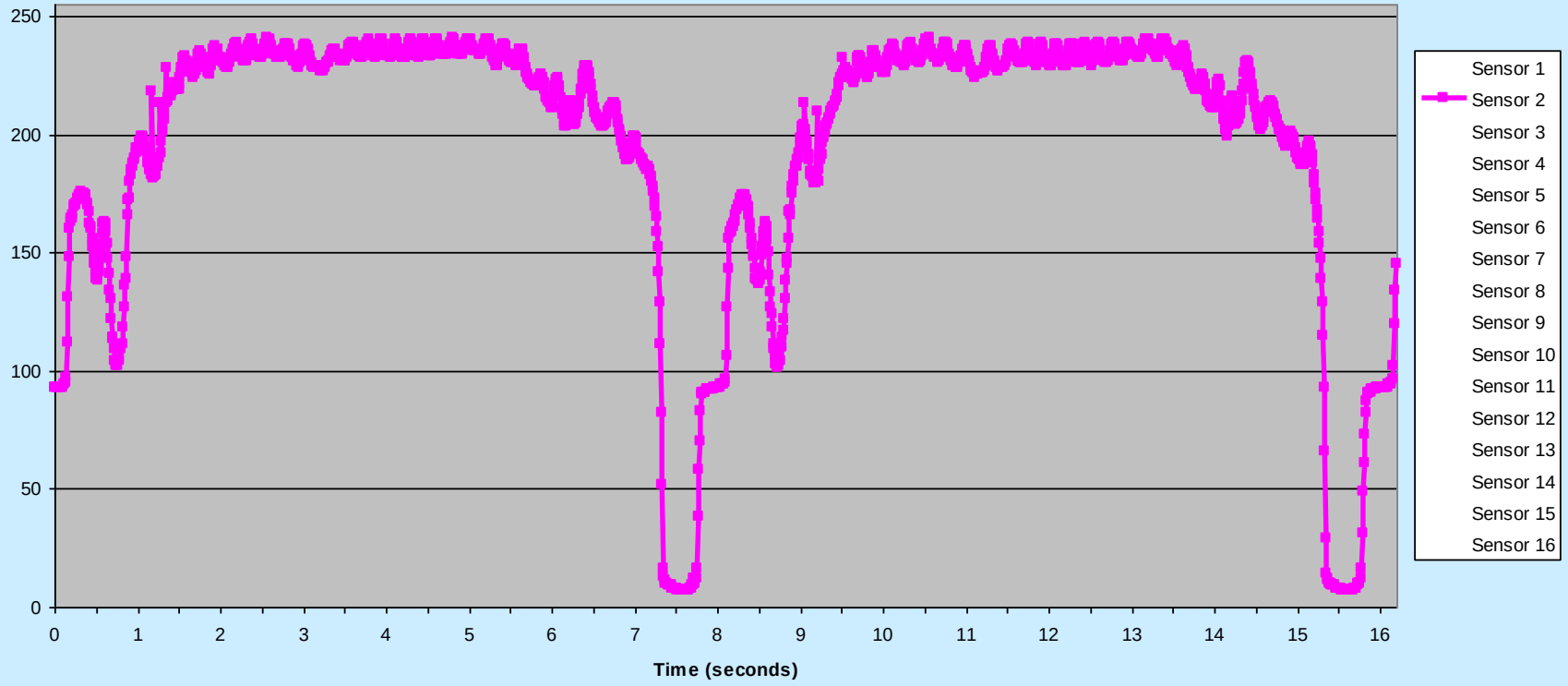

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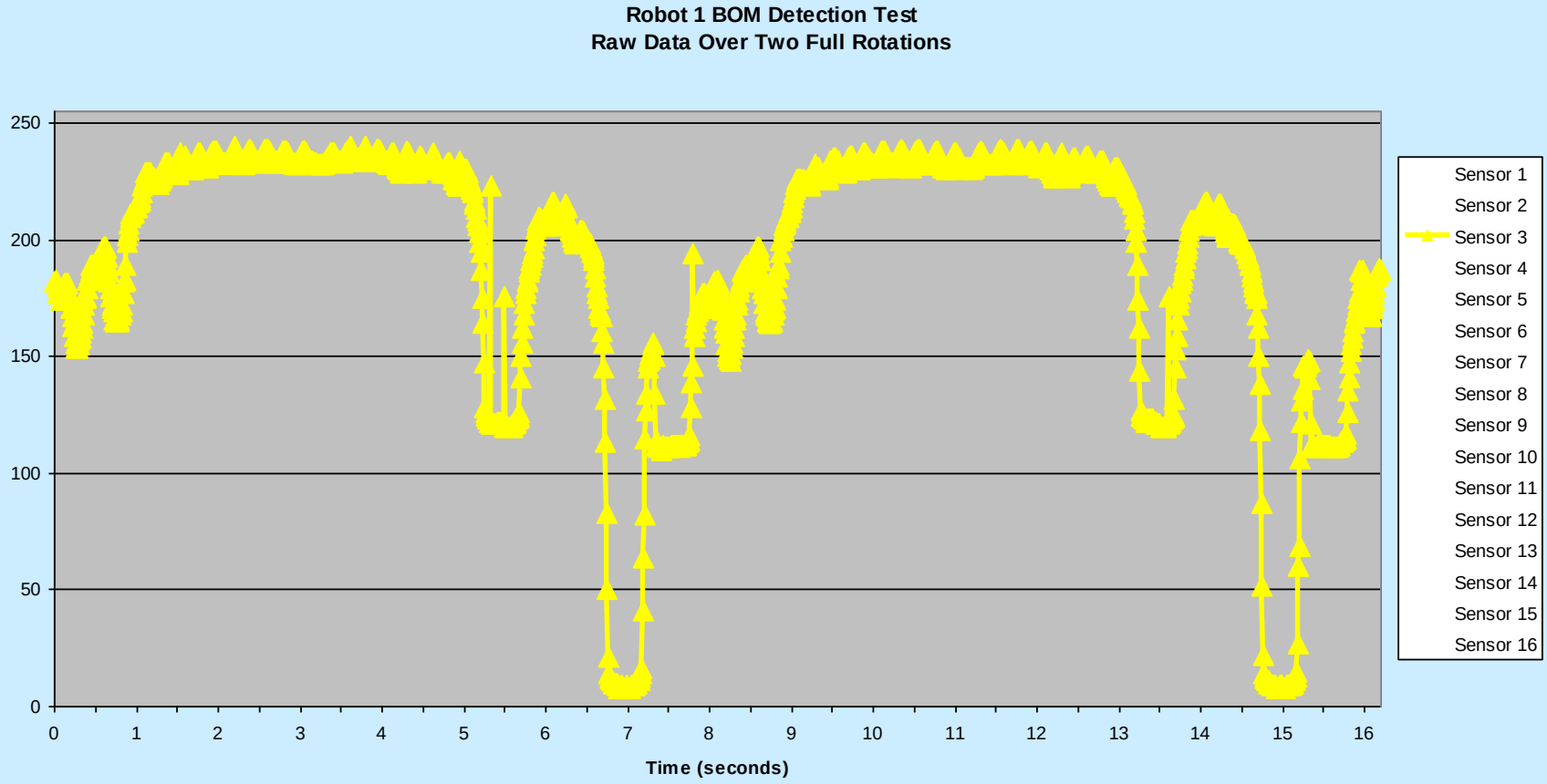

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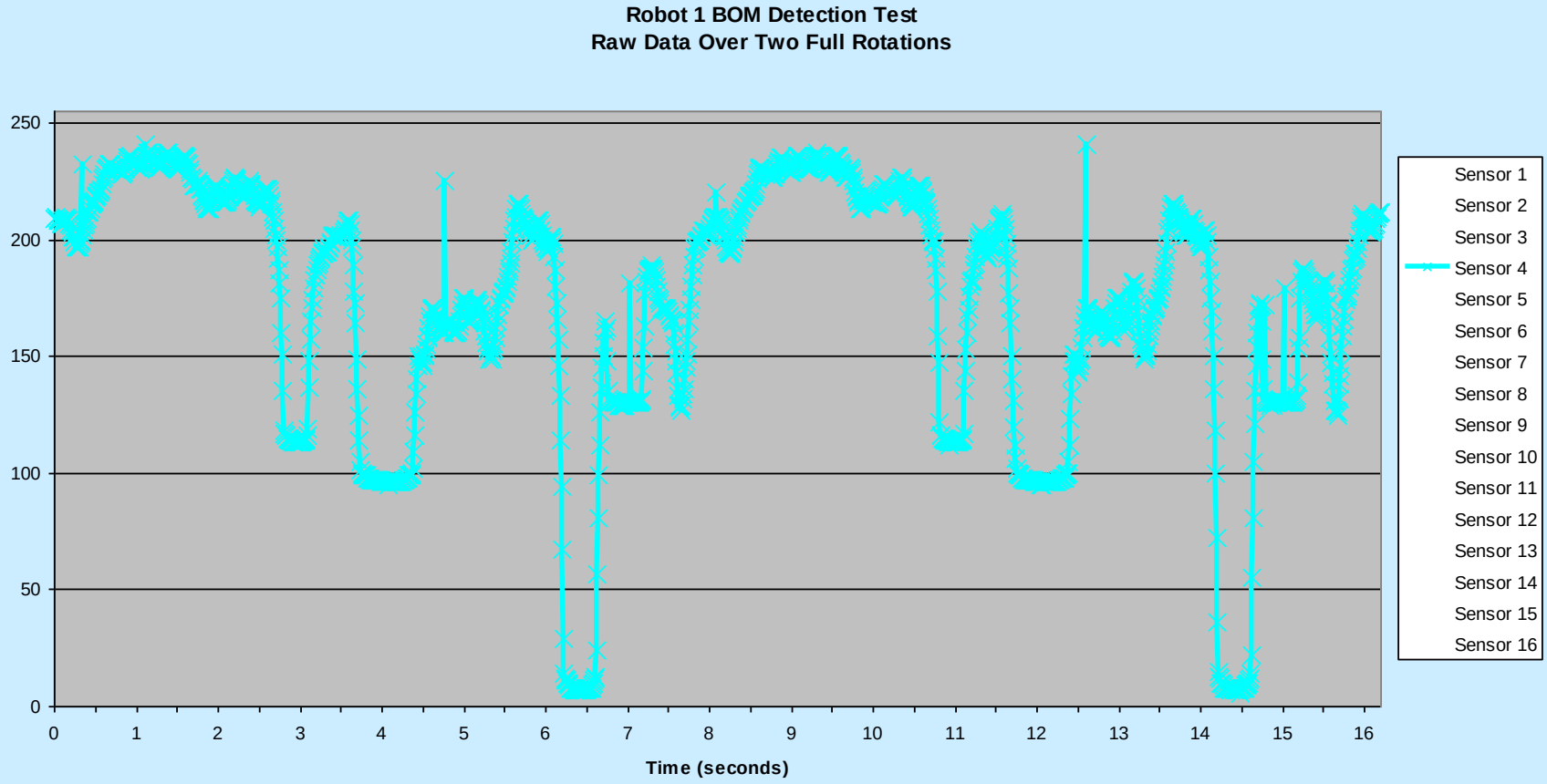

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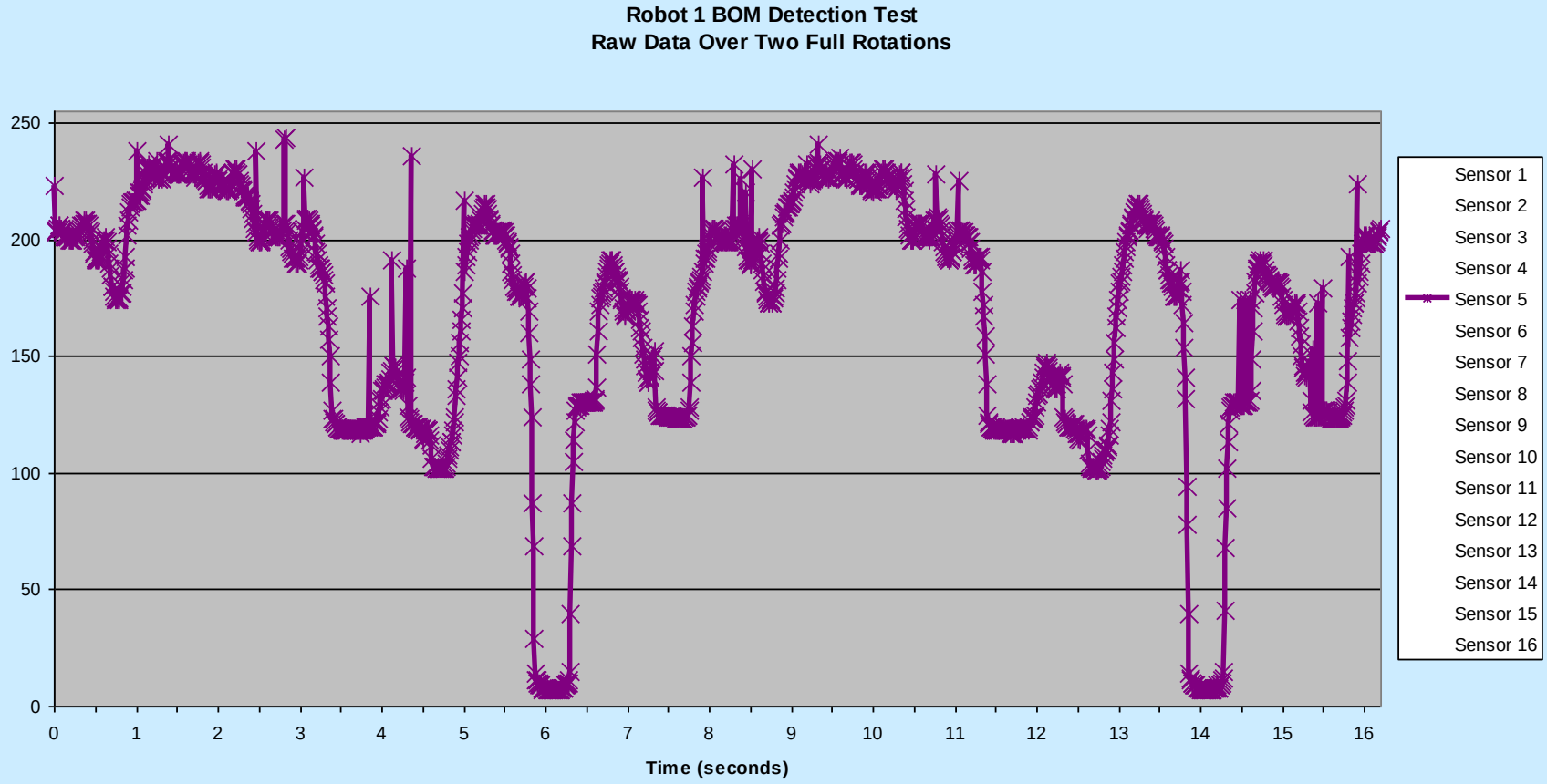

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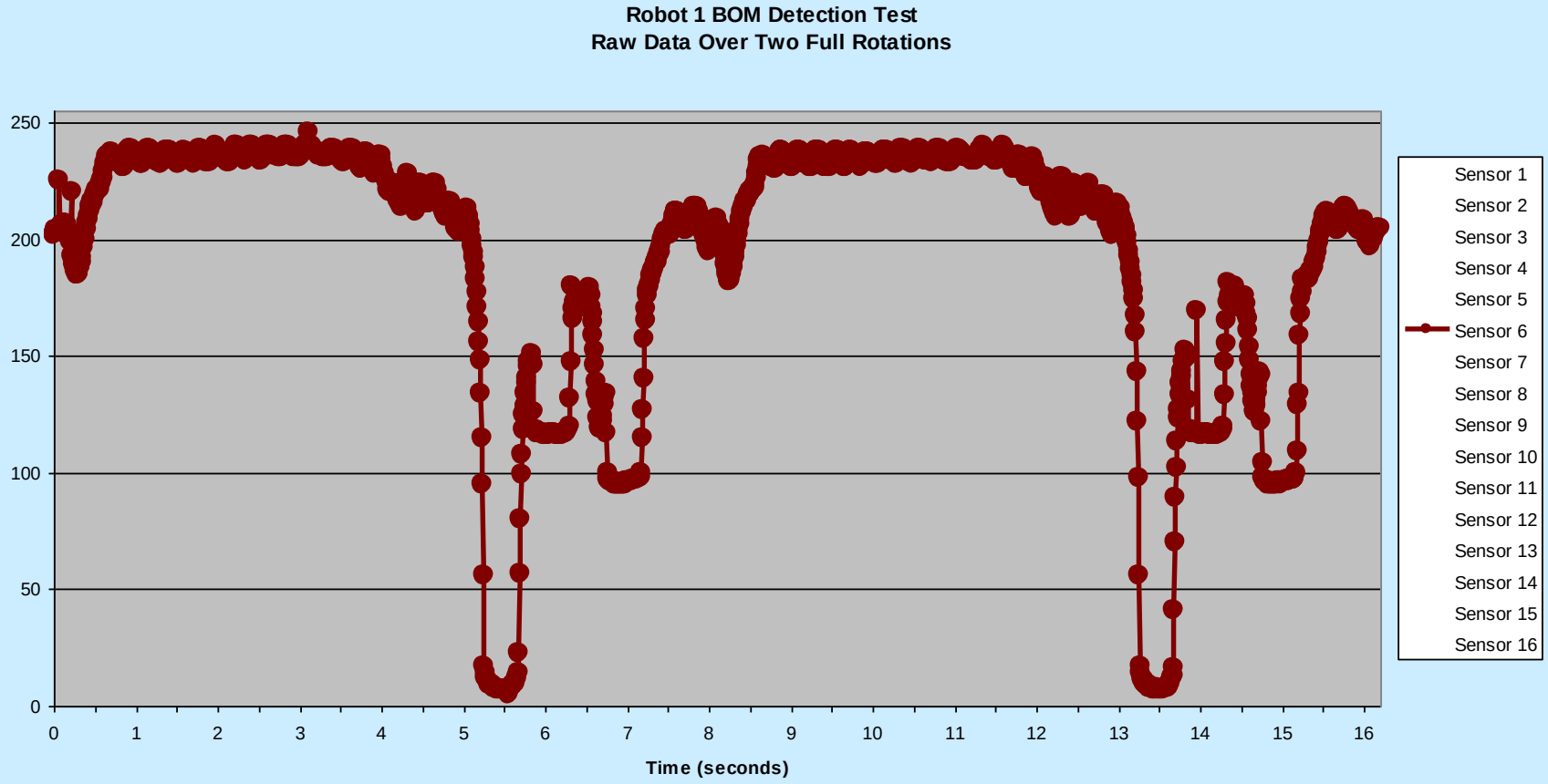

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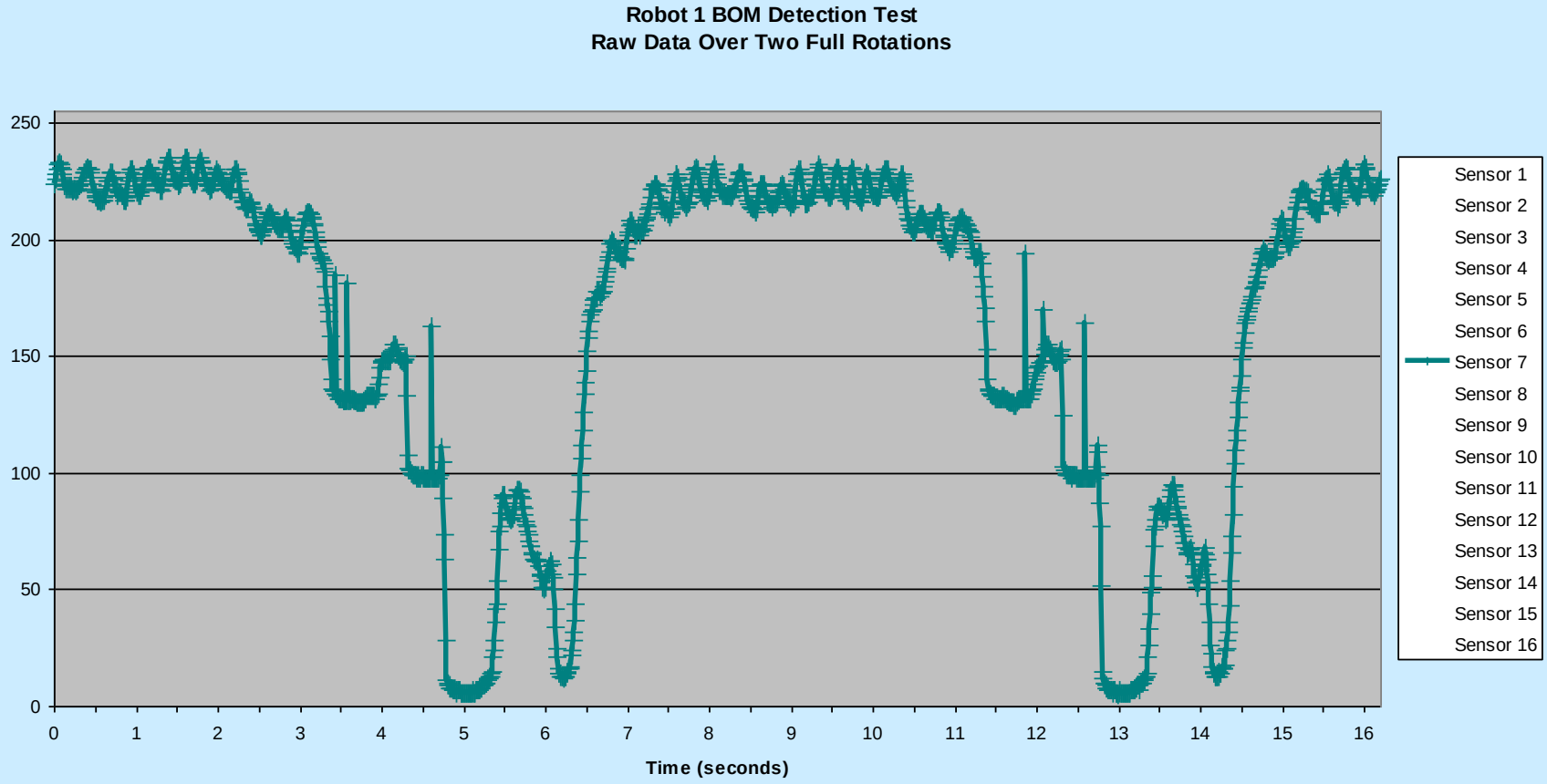

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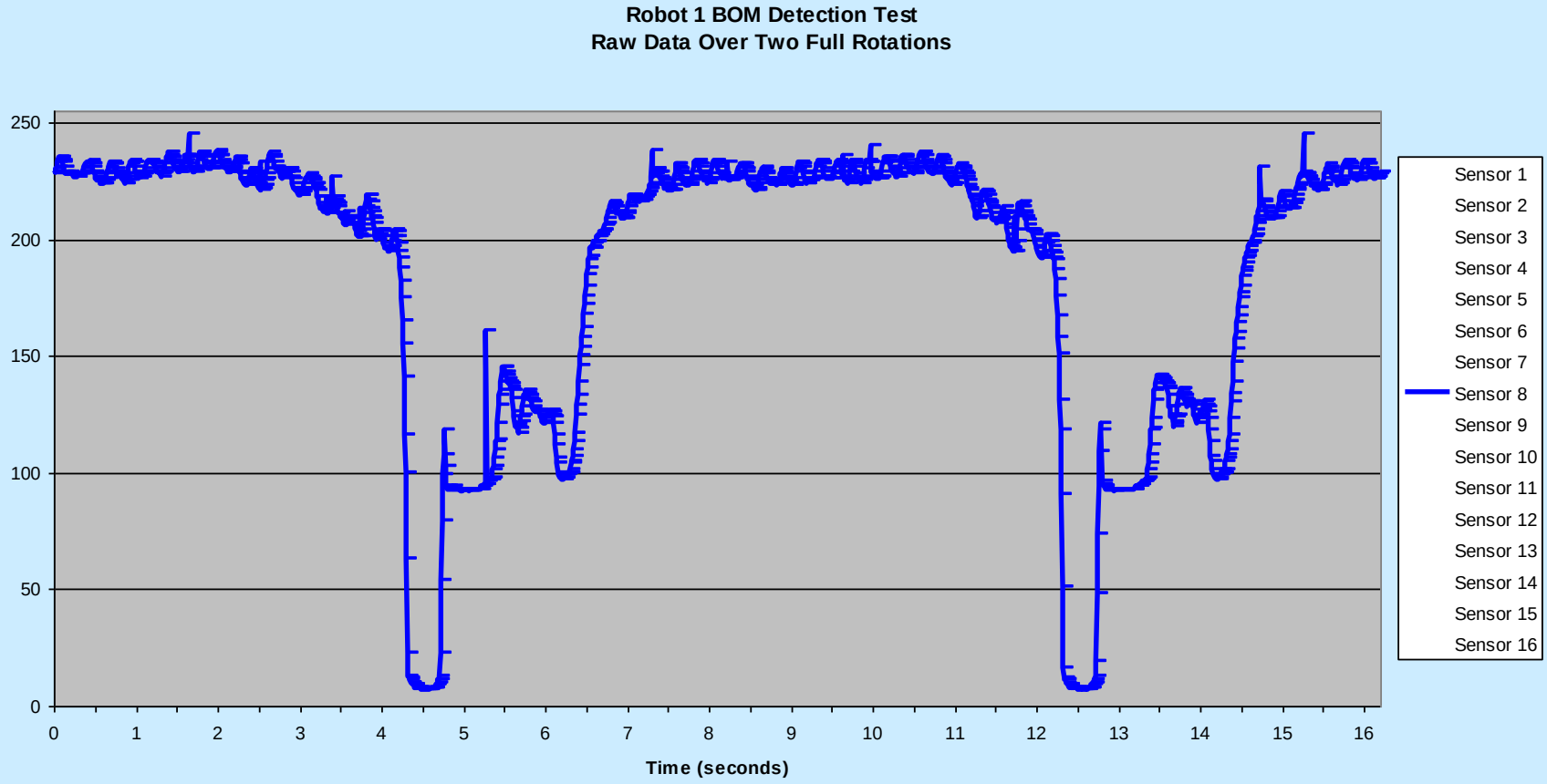

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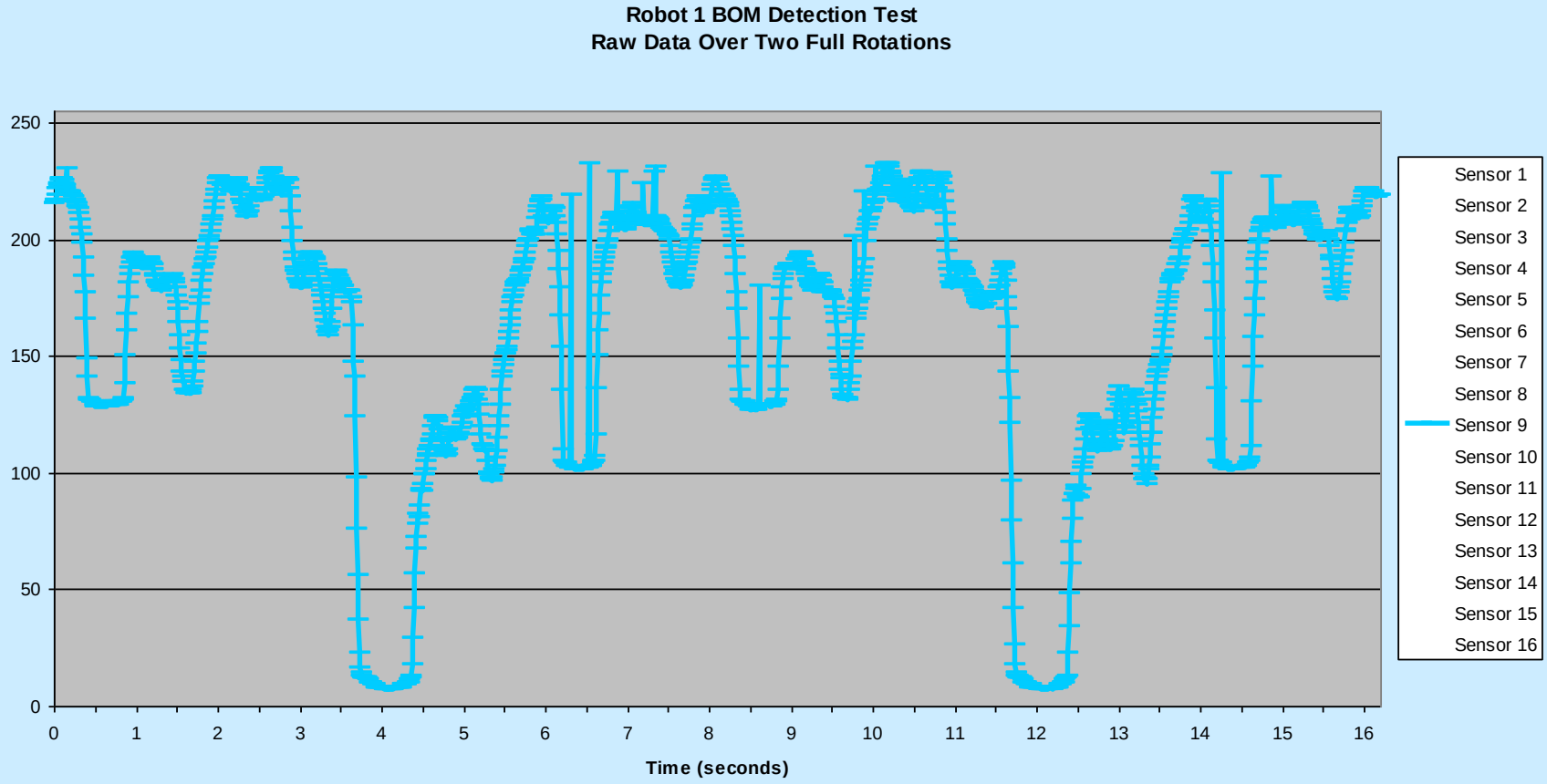

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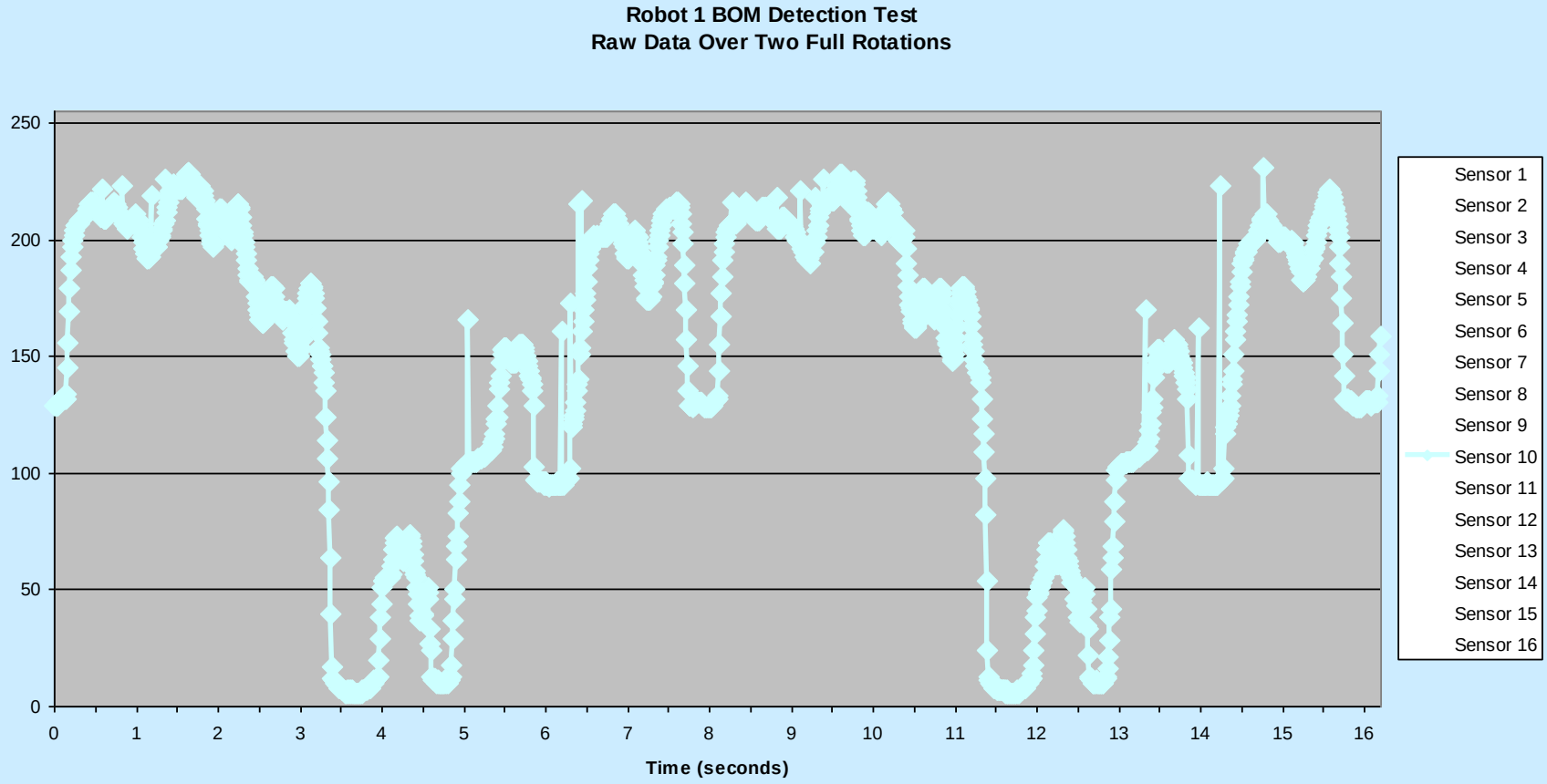

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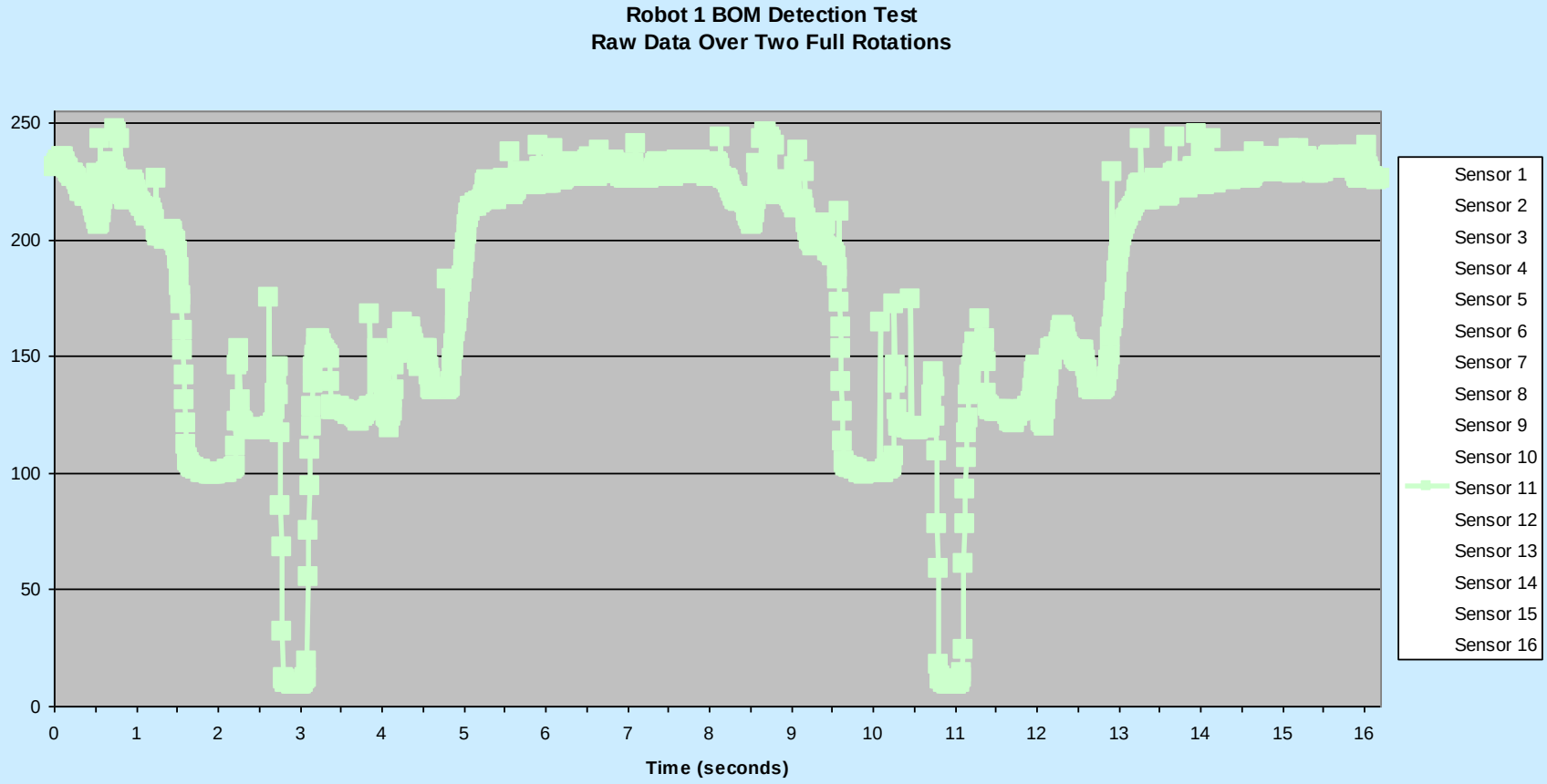

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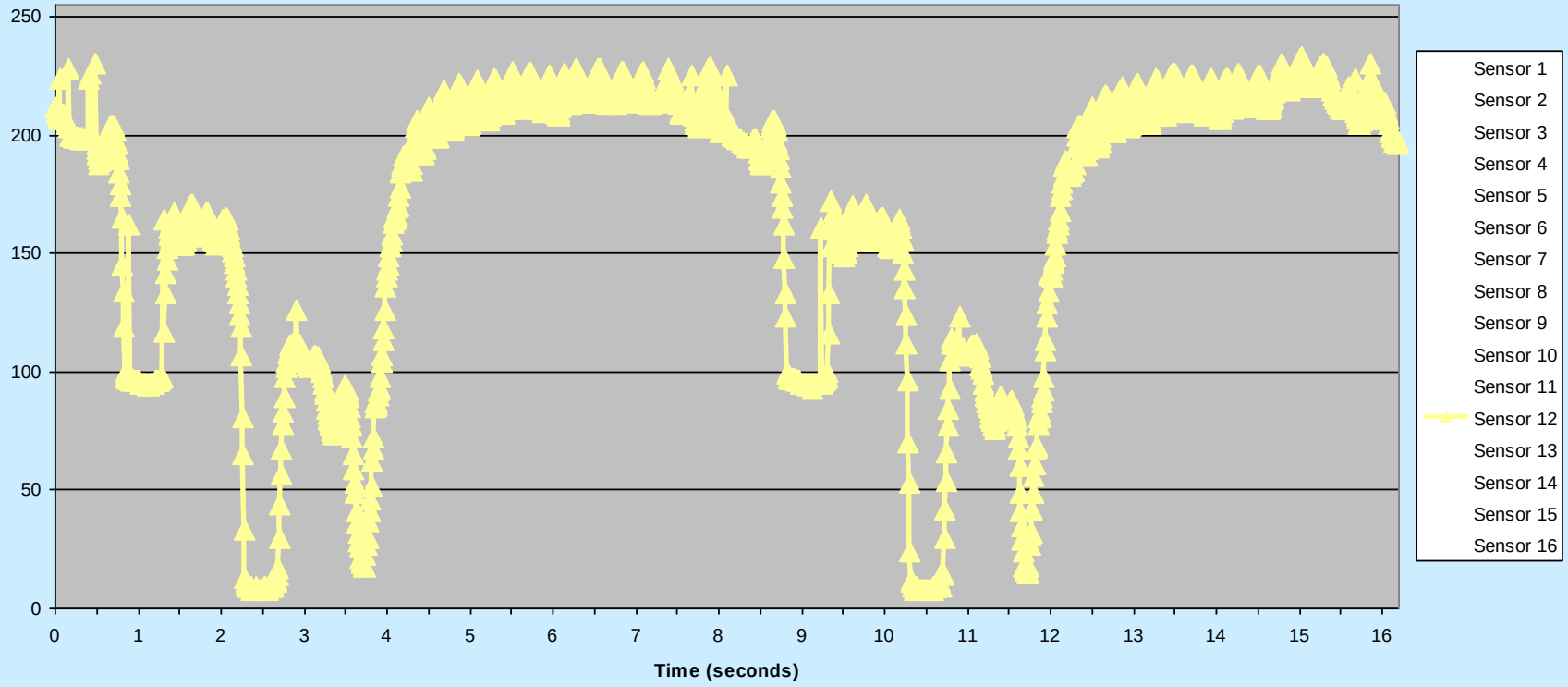
Raw Data Over Two Full Rotations



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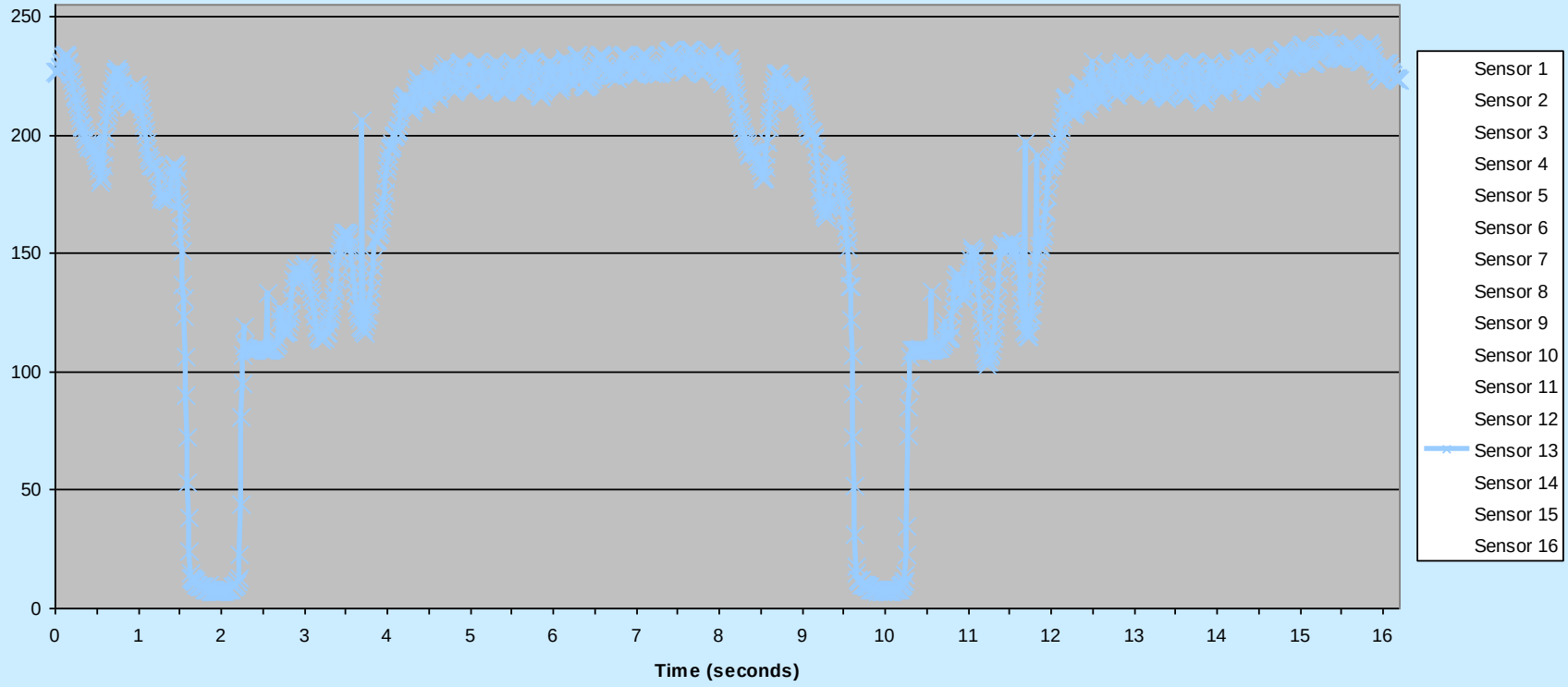

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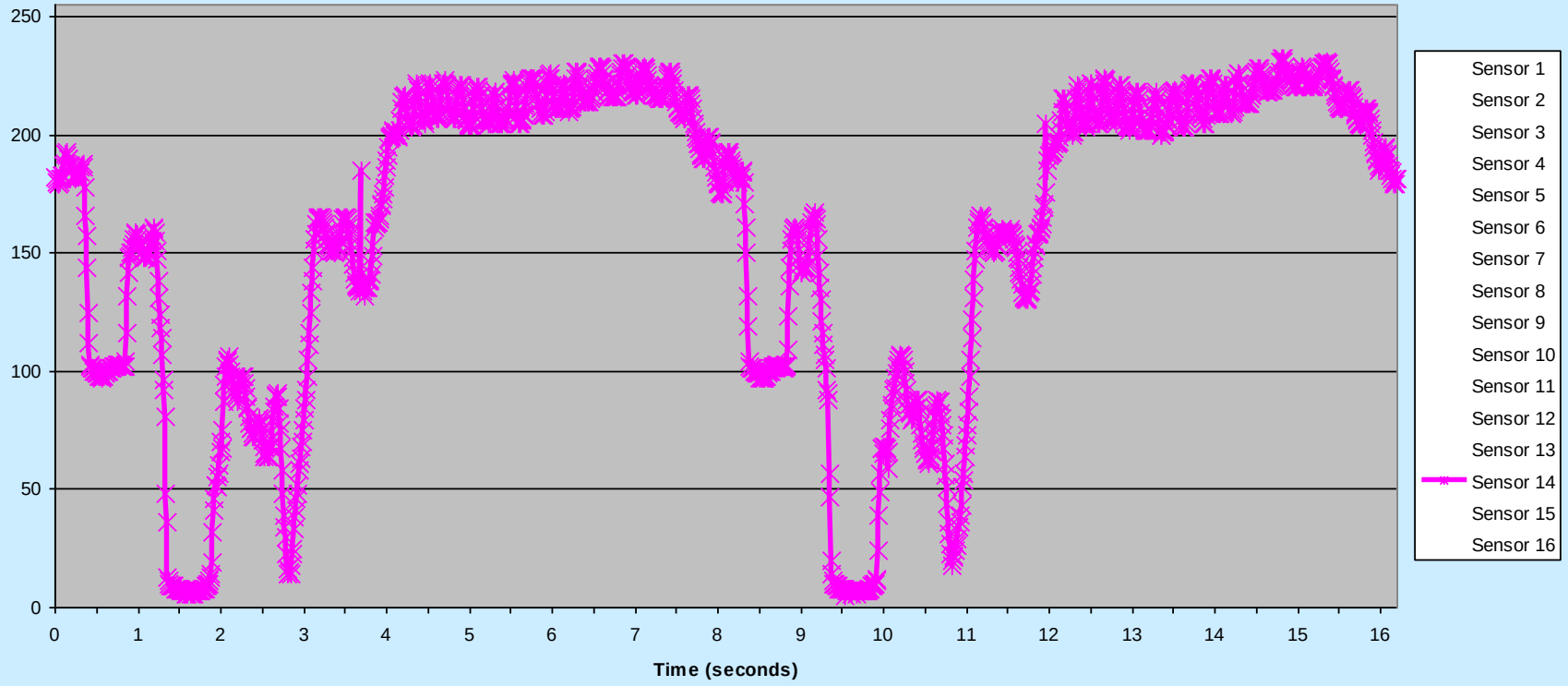

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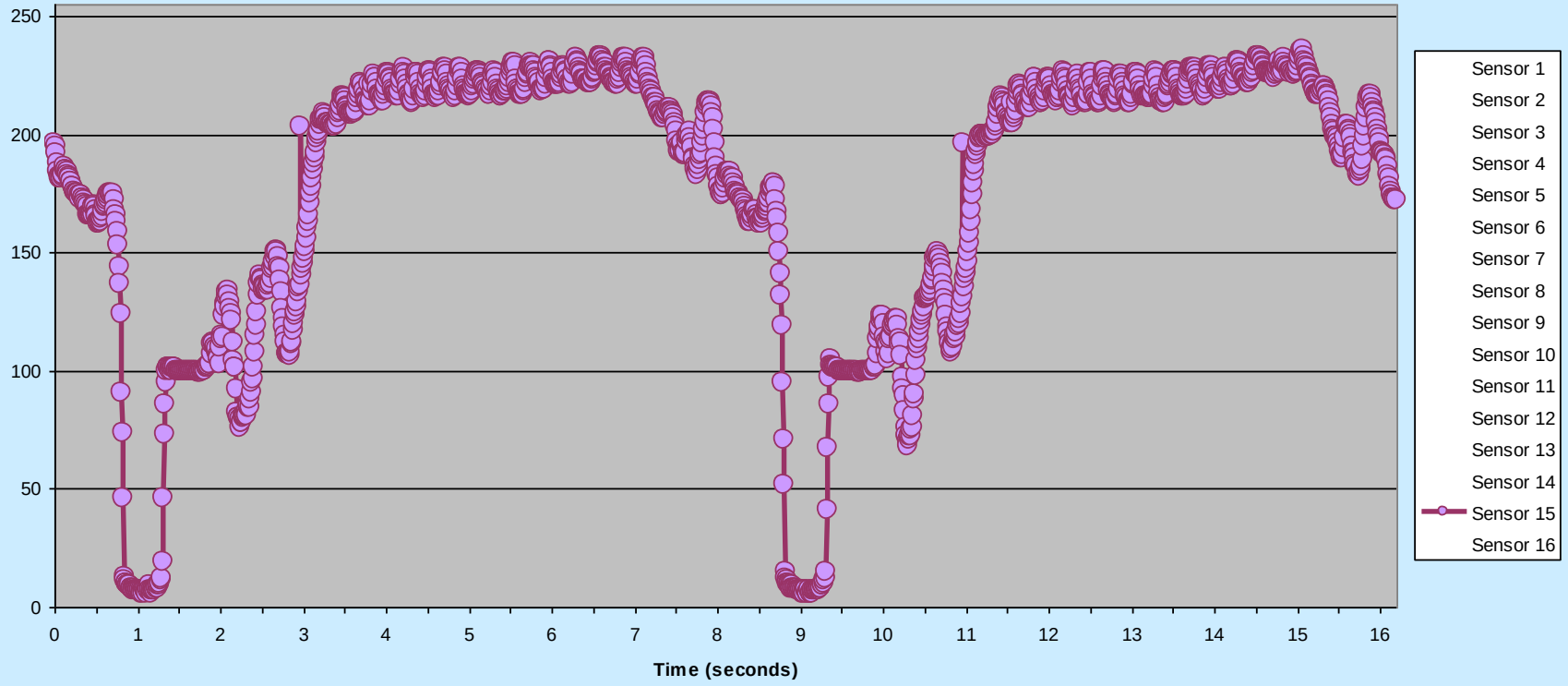

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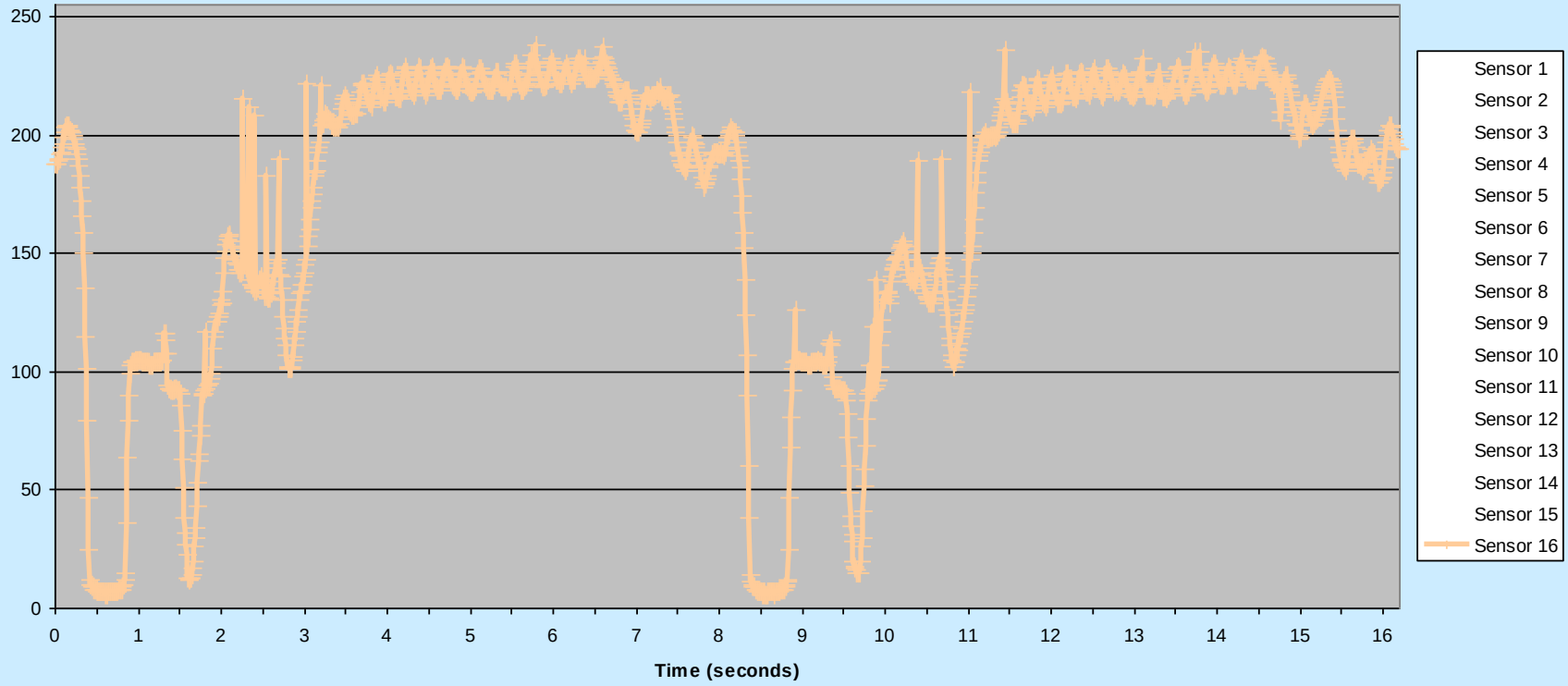

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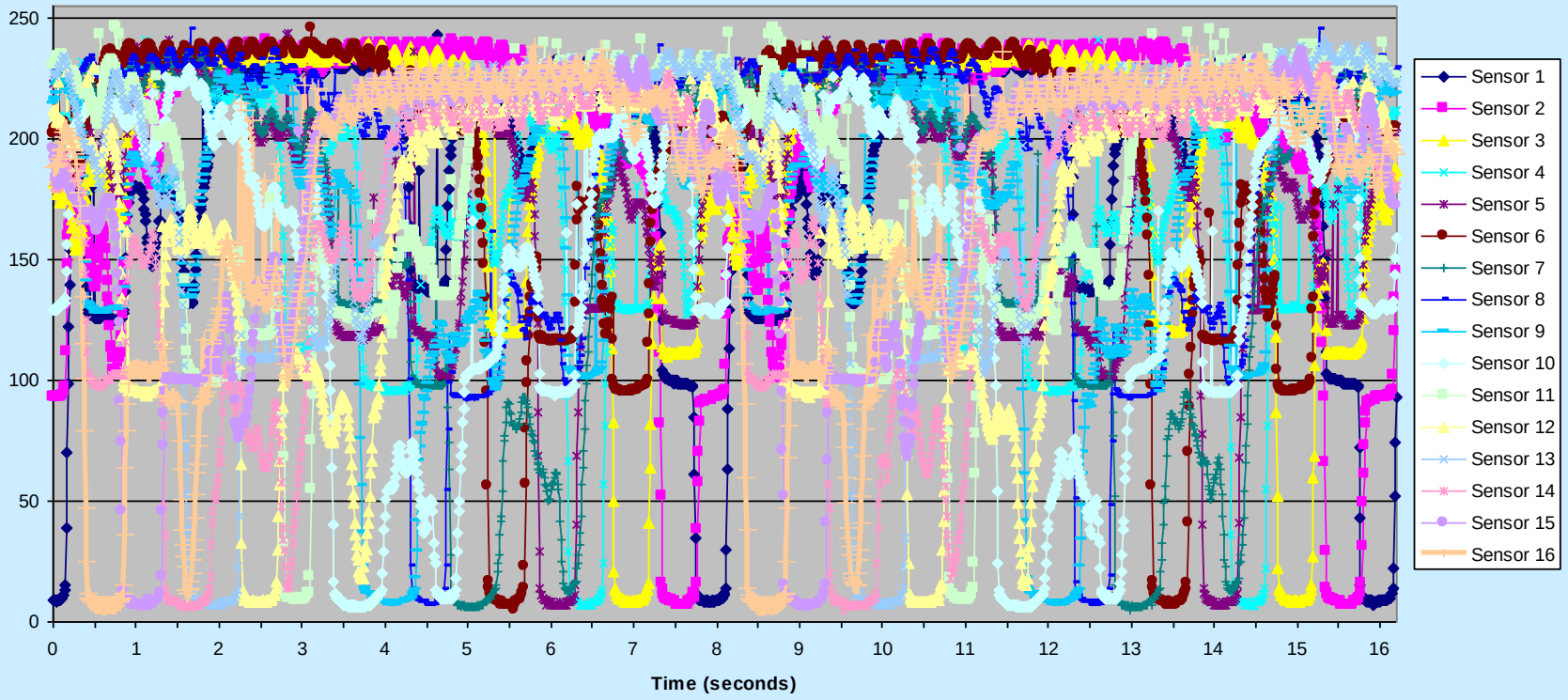
Robot 1 BOM Detection Test
Raw Data Over Two Full Rotations



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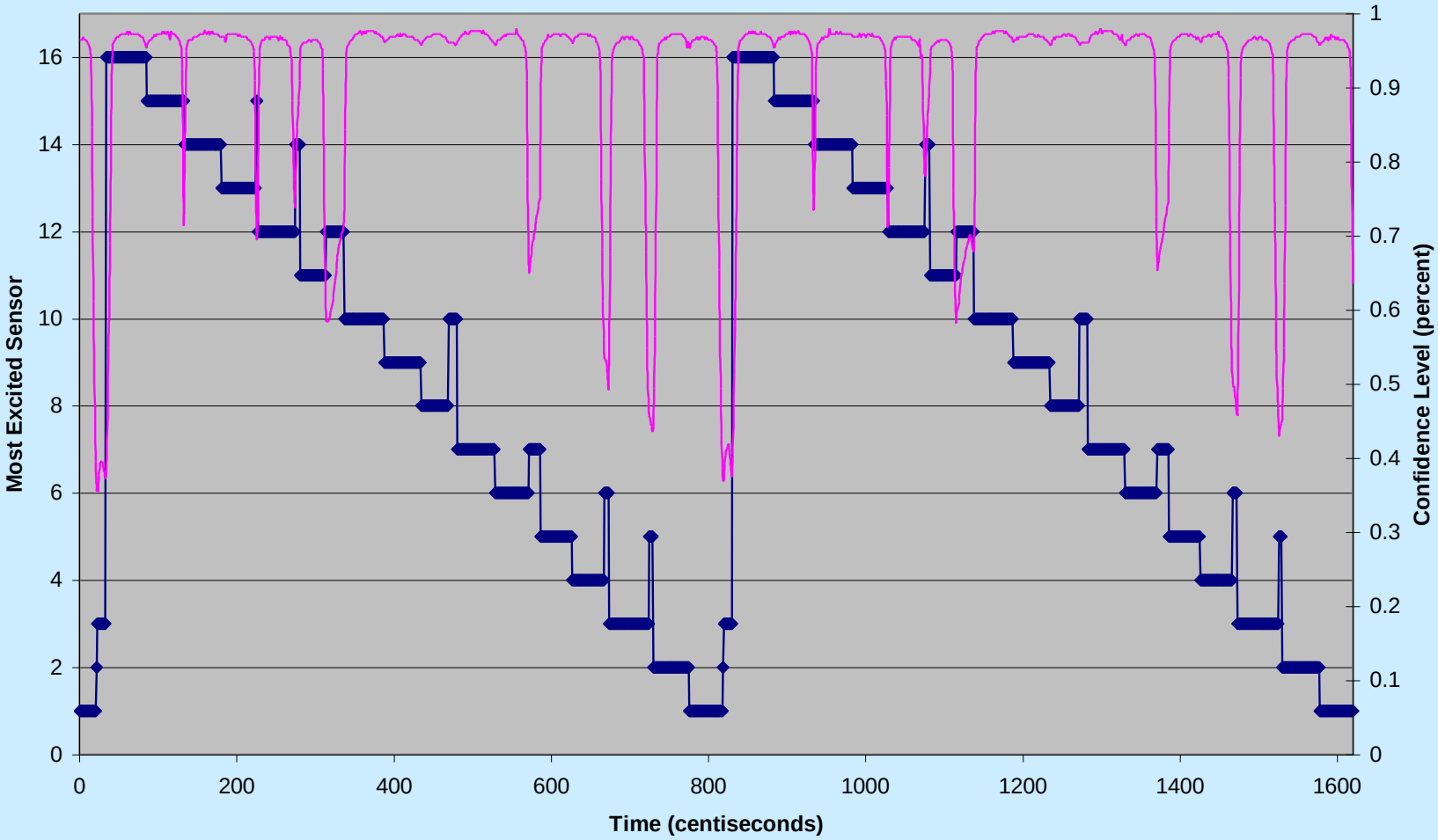
Robot 1 BoM Detection Test
Filtered Data Over Two Full Rotations



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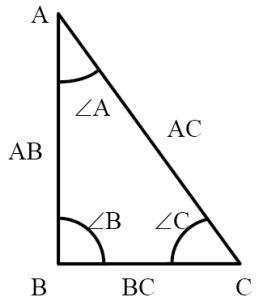
Software

- Relative triangulation
  - Each robot stores the relative angle from itself to every other robot
  - If the position of two robots is known, the position of a third can be calculated



$$|BC| = \frac{|AB|\sin(\angle A)}{\sin(\angle C)}$$

$$|CA| = \frac{|AB|\sin(\angle B)}{\sin(\angle C)}$$

$$\frac{\sin(\angle A)}{|BC|} = \frac{\sin(\angle B)}{|CA|} = \frac{\sin(\angle C)}{|AB|}$$

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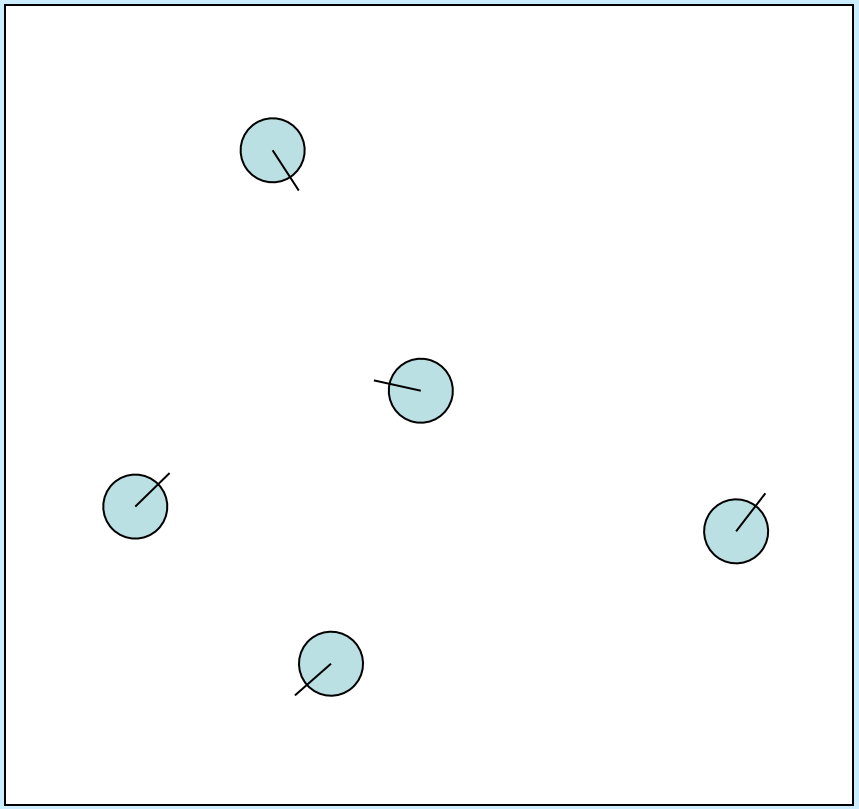
Software

- **solve_self(C) {**
  for each pair of robots (A, B) {
  solve_triangle(A, B, C)
  }
  if (C == 0)
  recenter_robots()
  }
- Iterate through robots until stable state is reached (~10 cycles)
  - Closely approximates actual positions
  - Self-corrects as new data is introduced (with further iteration)



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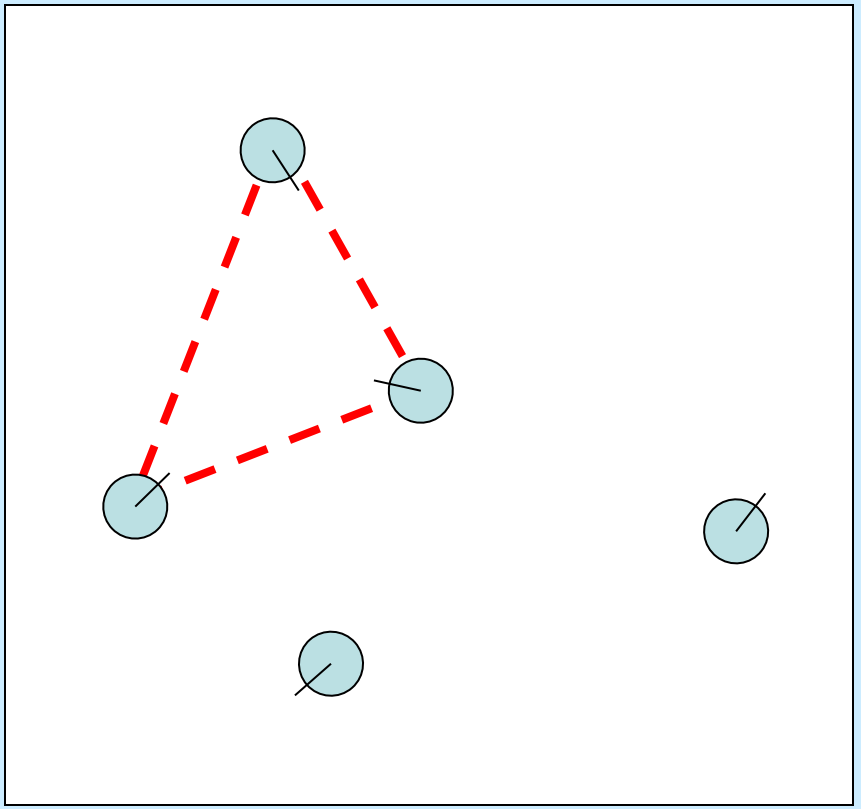

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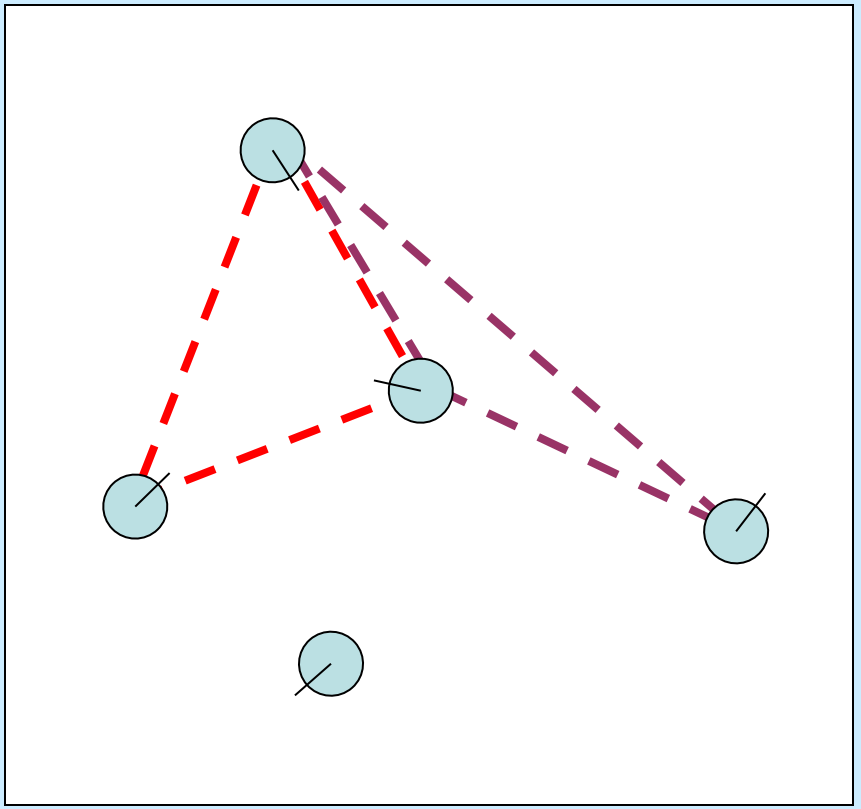

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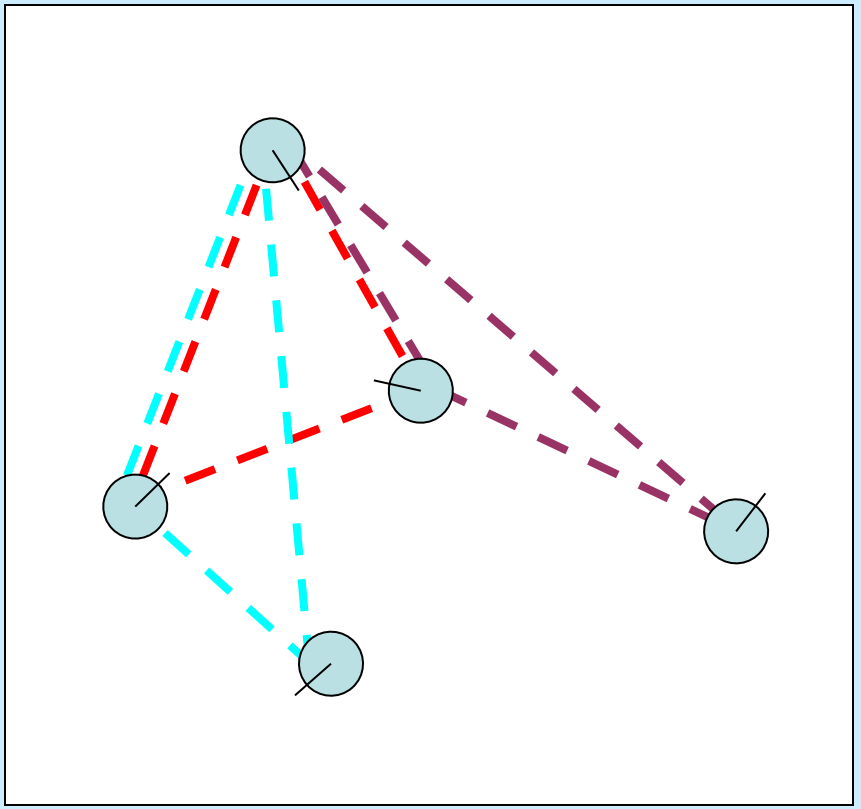

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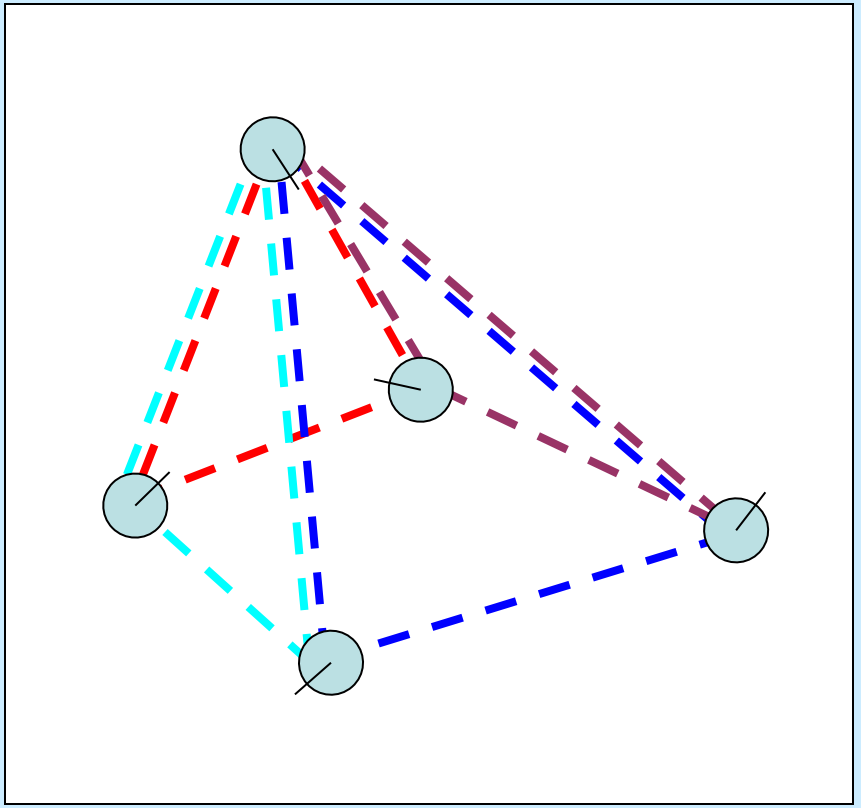

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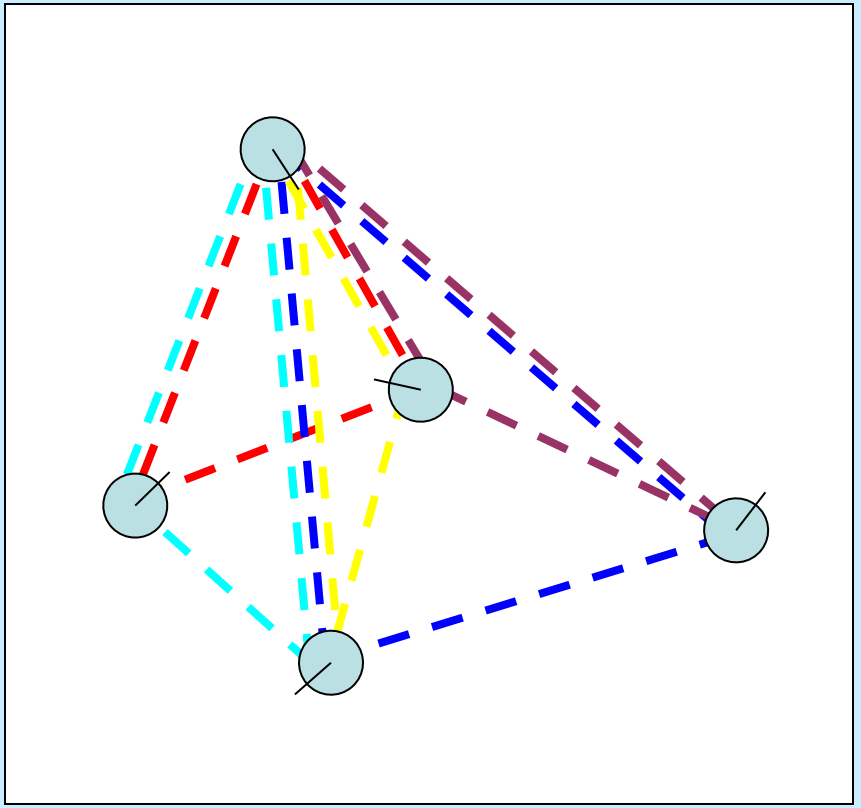

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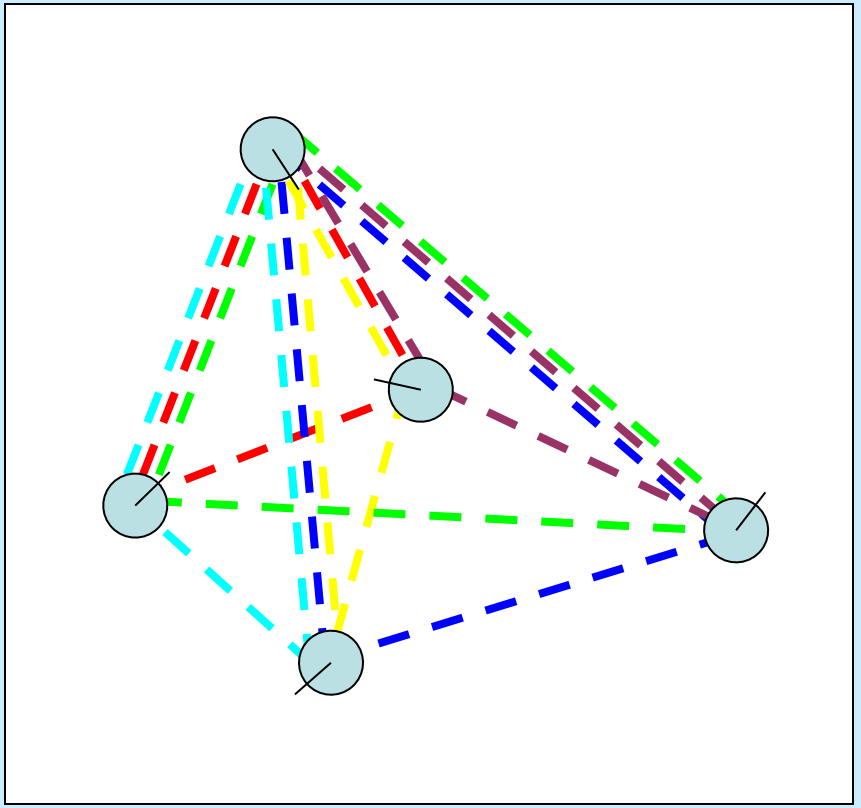

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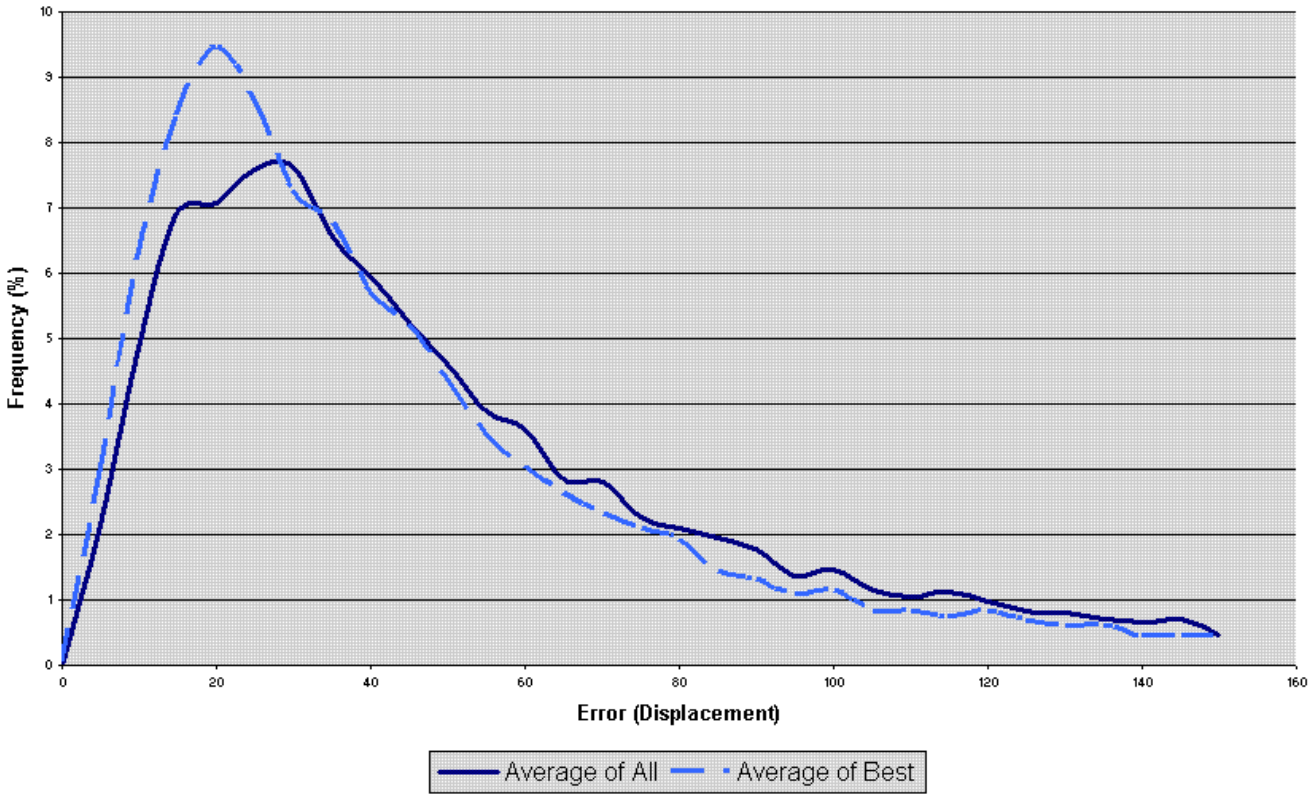
Data Collection

- Simulator
  - Reads robot positions from file
  - Introduces slight Gaussian Error
  - Runs localization algorithm for 1000 trials
    - Each trial consists of 10 iterations
- Error measurement
  - Robots centered, rotated, and scaled to minimize error distances
  - Distance between transformed position matrices is totaled for standard error
  - Outliers are removed from data set, and error recalculated for “best” error

Error Distribution



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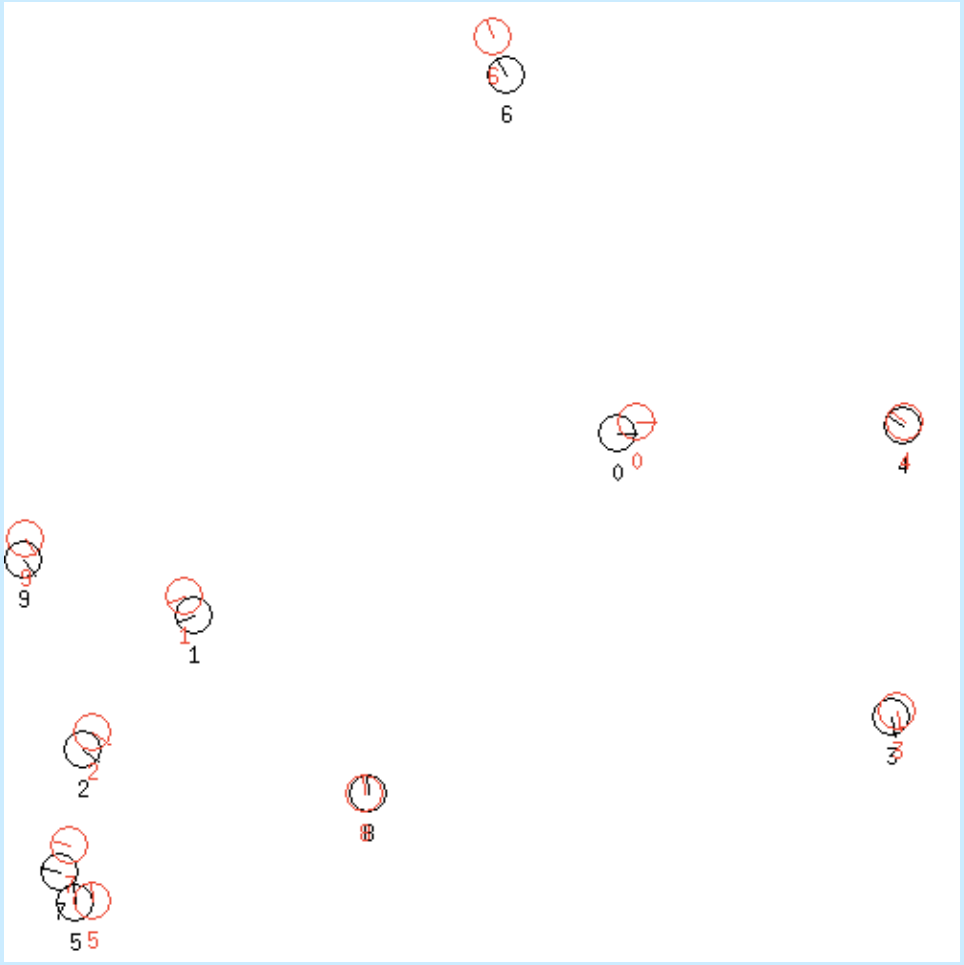
Typical Error of ~12

Red – predicted positions
Black – actual positions



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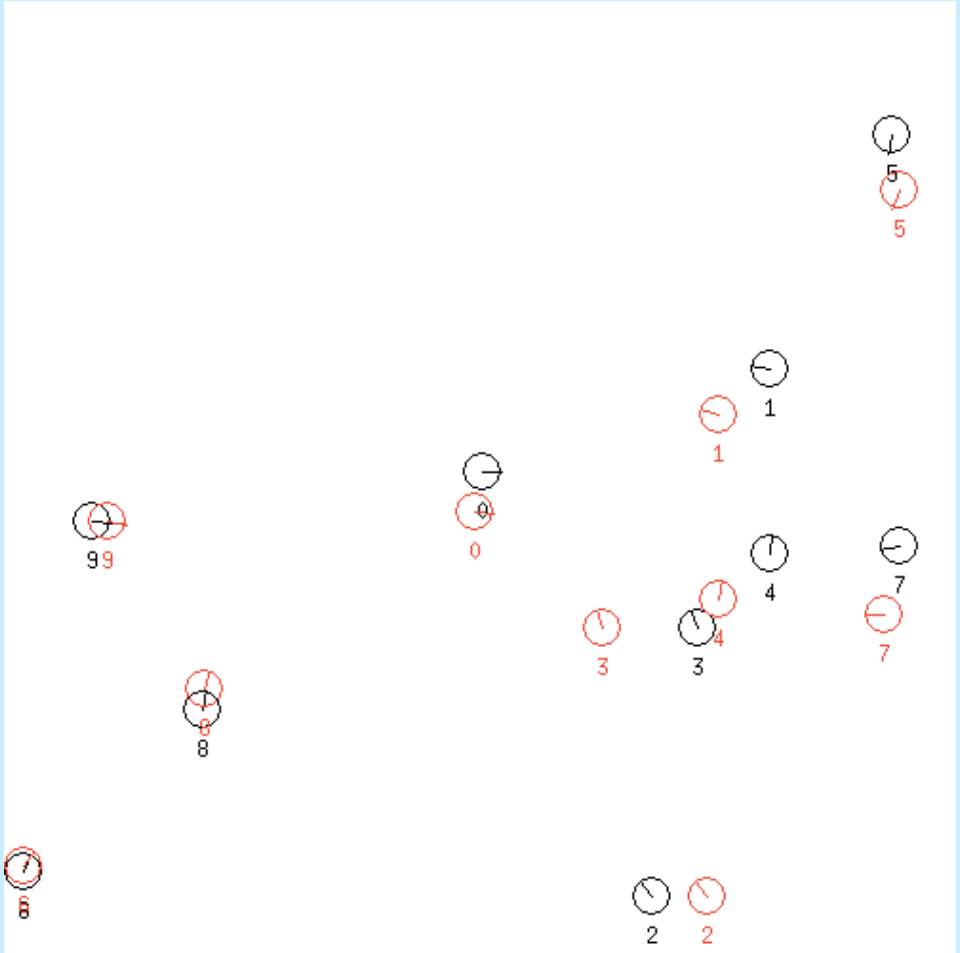
Typical Error of ~72

Red – predicted positions
Black – actual positions



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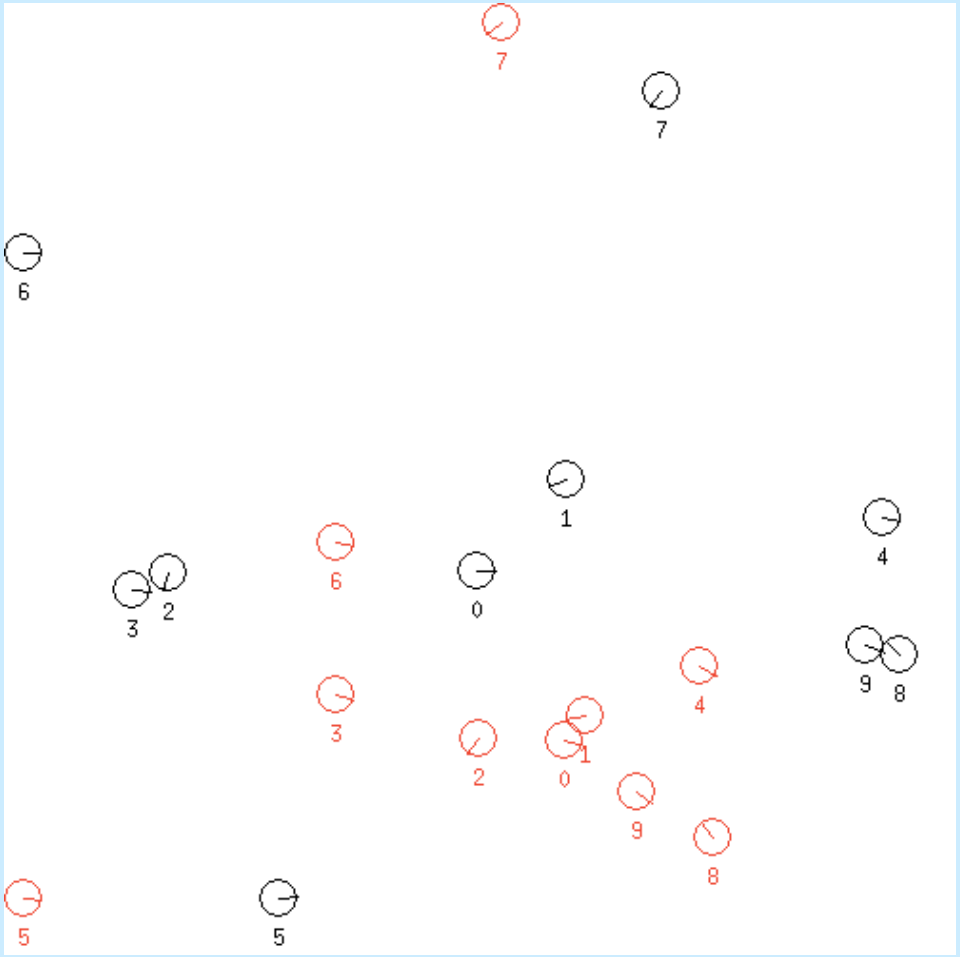
Typical Error of ~280

Red – predicted positions
Black – actual positions



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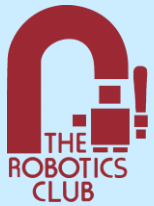
Analysis

- Practical and robust algorithm
  - Provides reasonable accuracy
  - Modest fault tolerance
  - Ideal for low-accuracy, behavior-based systems
- Lightweight processing
  - Requires only small (O(n)) length transmissions to be exchanged between robots
  - Optimized solving kernel is only ~2000 RISC assembly instructions (per robot per cycle)

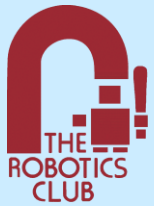
Summary

- Created a low-cost toolkit for colony development
  - All hardware and software is open source
  - http://www.roboticsclub.org/colony/
  - Lowers barrier to entry on colony research



Future Research

- Integrating sub-parts into a functional colony for further emergent behavior research
- Further characterization of sensor error
- Improve error rejection in relative localization algorithm
- Dynamic mesh networking
- Autonomous robot recharging



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