Advances in Ultra Wideband Indoor Geolocation Systems

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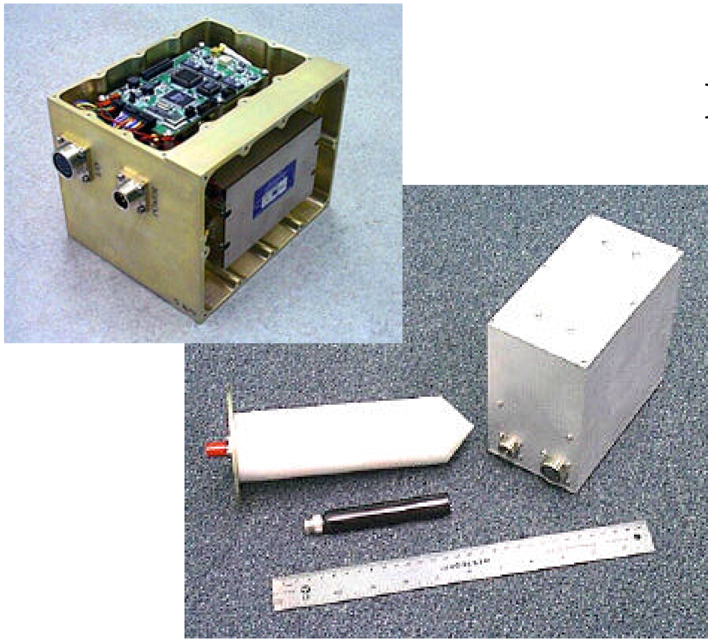
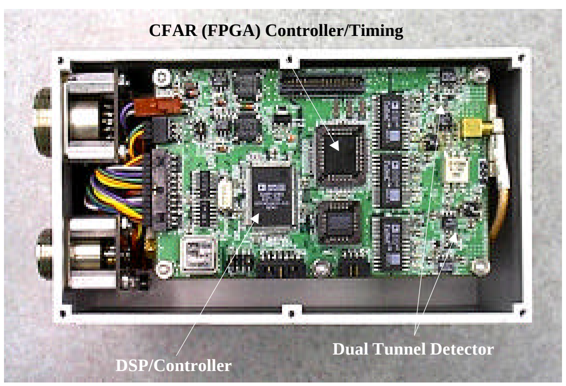
UWB Geolocation Systems

- System Architectures
  - Untethered Transponders + Tag Transceiver
  - Tethered Receivers + Tag Transmit Only
- System Issues
  - Parameters
    - Power, bandwidth, frequency
  - Propagation anomalies
  - Leading edge detection
- Deployments
  - Indoors vs. Indoors/outdoors
- Resolution/accuracy
  - Experimental data

UWB Precision Geolocation Hardware - I





UWB Single Pulse Receiver

Design Characteristics

- 3-D position from precise time-of-flight measurements
  - UWB *Rover* with multiple *untethered* UWB *Beacons*
- Implementation
  - 2.5W ERP, 400 MHz instantaneous BW
    - Spectrally shaped waveform design
    - L-band center frequency
    - 27% fractional BW
    - Packet burst, 100 updates/second
  - Leading edge detector for sub-foot resolution
  - Range
    - Up to 2 km outdoors
    - Up to 350 feet indoors (5-25 dB/wall measured attenuation)
- US Patent No. 6,054,950

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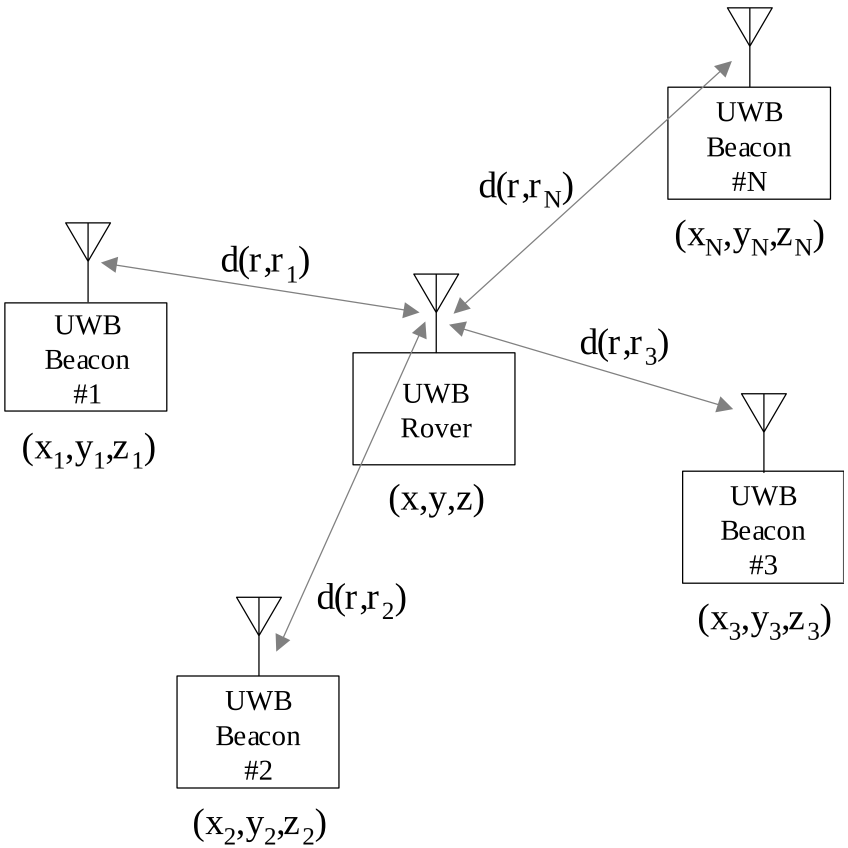
Principle of Operation - Untethered



- UWB Rover sends out sequence of packet bursts
- UWB Beacons transpond after known delay D_i
- UWB Rover determines N round trip delays/distances
- Minimize error functional via Fletcher-Powell algorithm

$$c(\Delta t_i - \Delta_i) = 2\left[(x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2\right]^{0.5} \equiv 2\mathrm{d}(r, r_i) \quad \mathrm{i} = 1, \cdots, \mathrm{N}$$

$$E = \sum_{i=1}^{N}\left[d(r - r_i) - \frac{1}{2}c(\Delta t_i - \Delta_i)\right]^2$$

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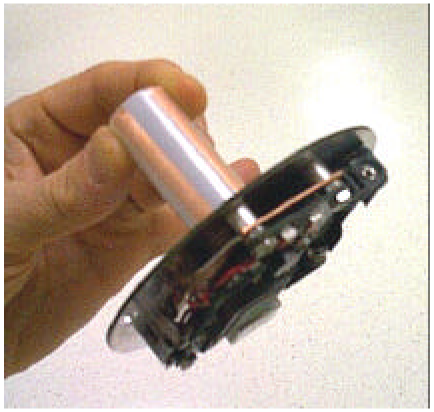
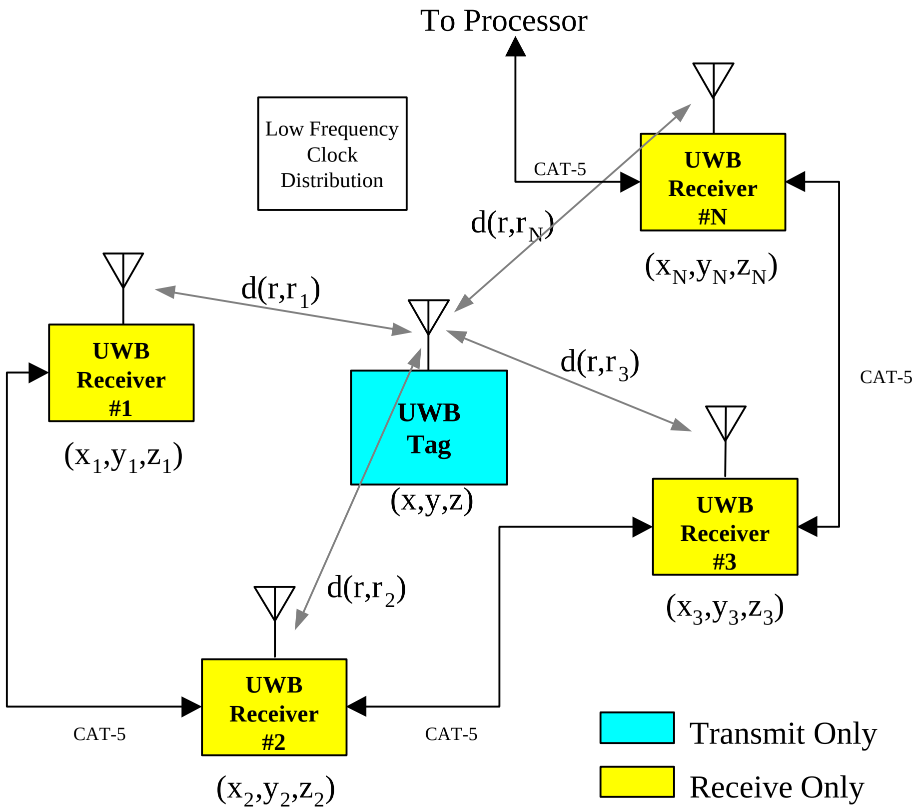
UWB Precision Geolocation Hardware - II



Design Characteristics

- 3-D position from precise *differential* time-of-flight measurements
  - UWB *Rover* with multiple *tethered* UWB Receivers
  - Daisy-chained CAT-5 cables relay *processed* time-of-arrival data
- Implementation
  - 0.25W peak, 400 MHz instantaneous BW
    - Spectrally shaped waveform design
    - L-band center frequency
    - 27% fractional BW
    - Packet burst, 12 updates/minute
  - Leading edge detector for sub-foot resolution
  - Range
    - 100+ feet indoors (low power units)
- US patent applied for

Principle of Operation - Tethered



- UWB Tag sends out sequence of packet bursts
- Frequency-locked UWB Receivers measure times-of-arrival
- Processor determines set of differential times-of-arrival
- Minimize error functional (utilizing time differences of arrival) via Fletcher-Powell algorithm

UWB Receiver Characteristics

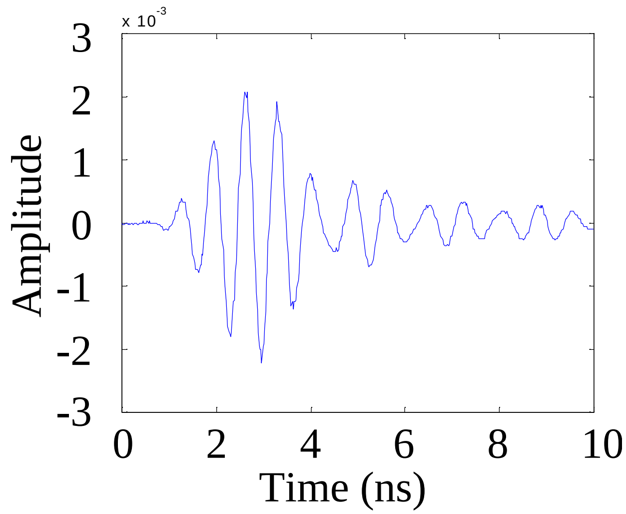
- Receiver utilizes integrating (charge sensitive) tunnel diode detector
  - Leading edge detection

$$Q = \int_0^t i(u)du \geq q_{threshold}$$

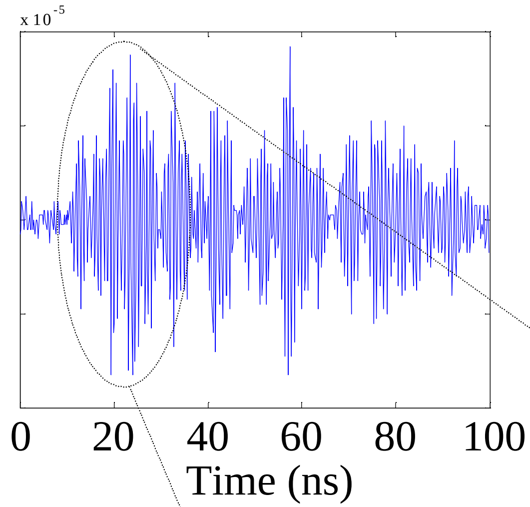
  - Constant false alarm rate (CFAR) bias loop for device stability
  - Detection statistics related to level-crossing problem for Brownian motion process (e.g., Gikhman-Skorokhod 1969)
- Single pulse detection capability
  - Analogous to optical "photon" detection
  - Charge sensitive detection of single UWB pulse

Why Leading Edge Detection is Essential

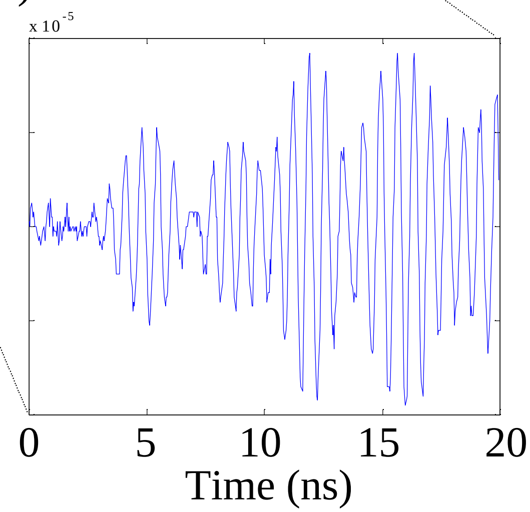
Typical Pulse Responses



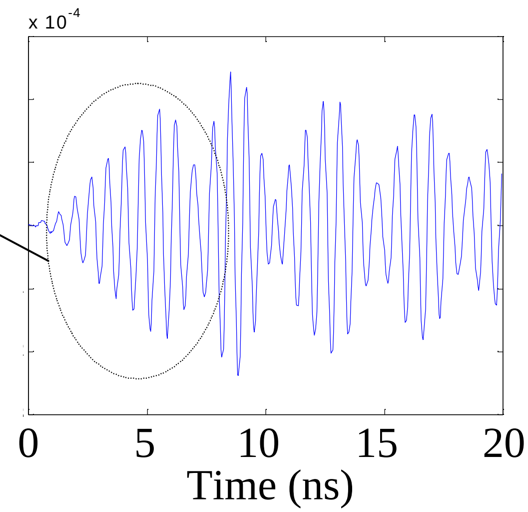
Free space measurement of UWB transmit pulse



12.8 meter "Hallway" pulse reverberation



Another "Hallway" response exhibiting close-in multipath



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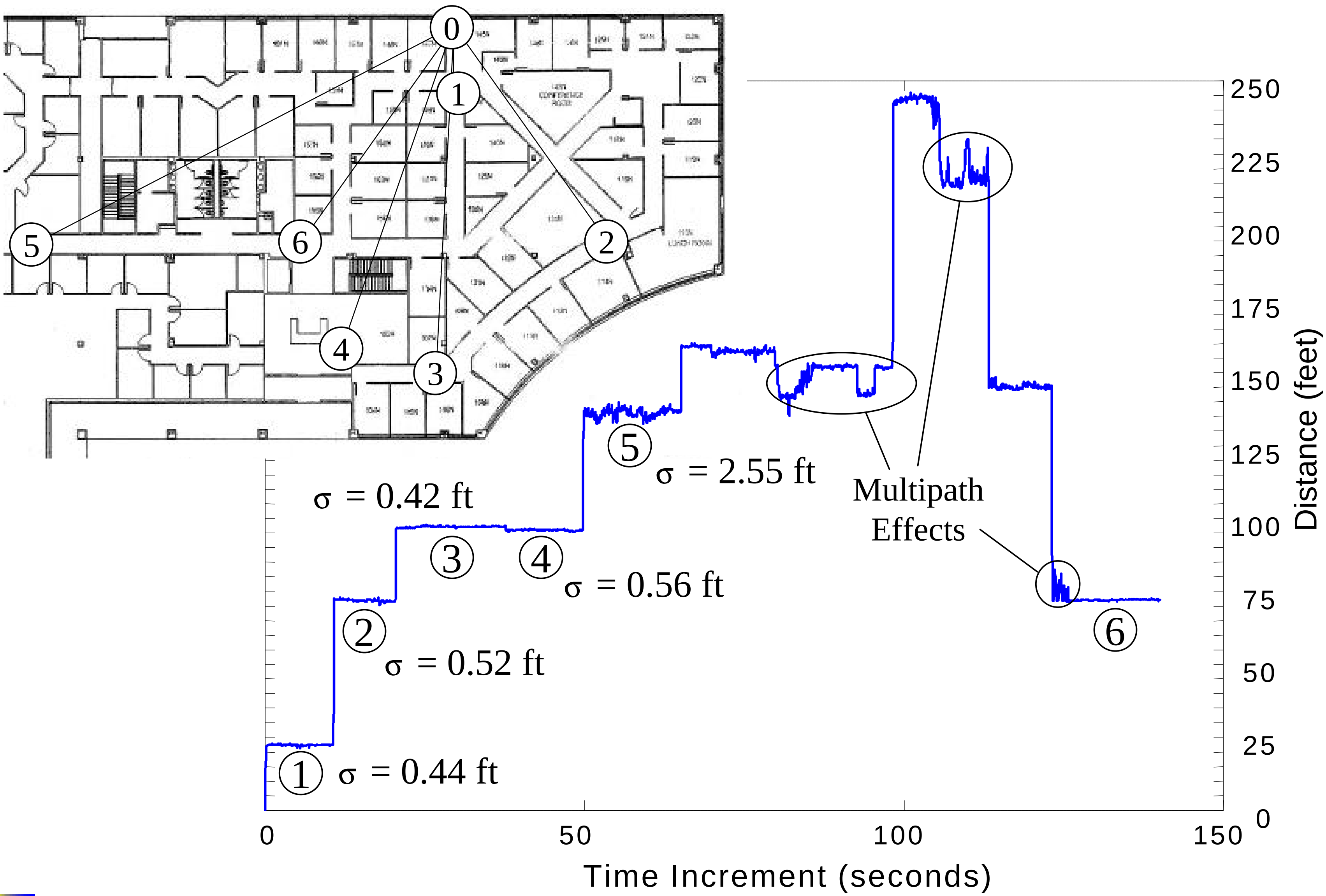
Distance Measurement (Single Beacon)



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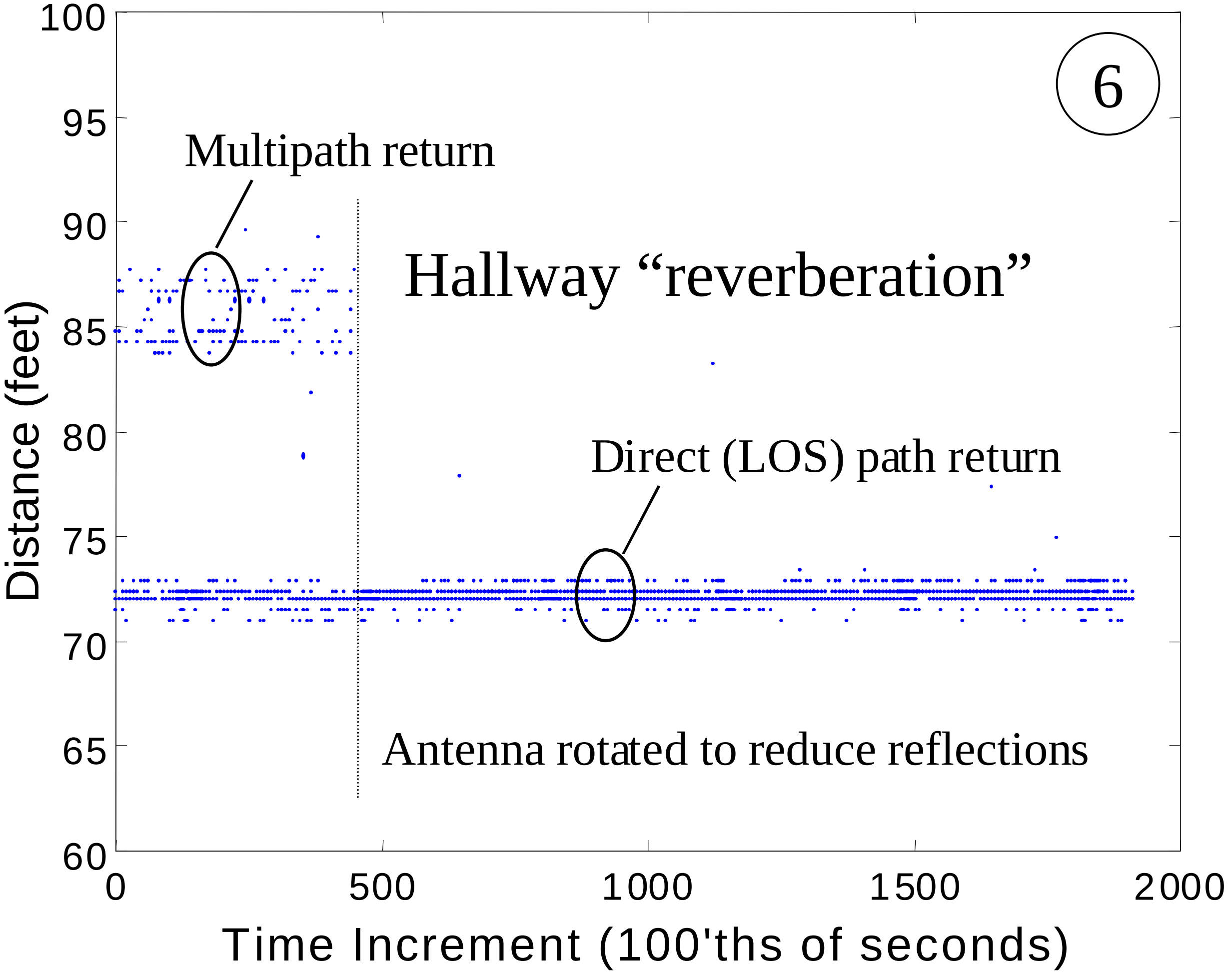

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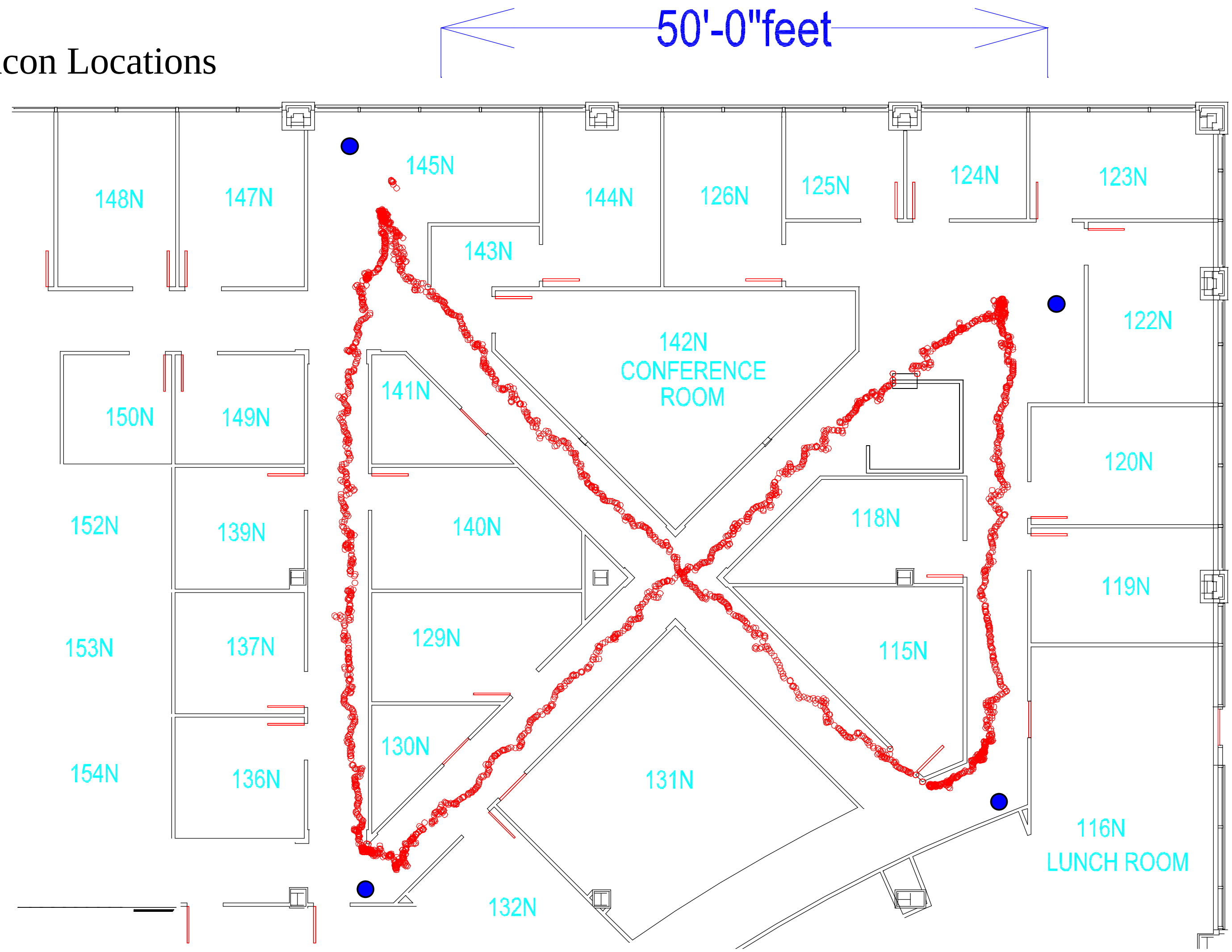
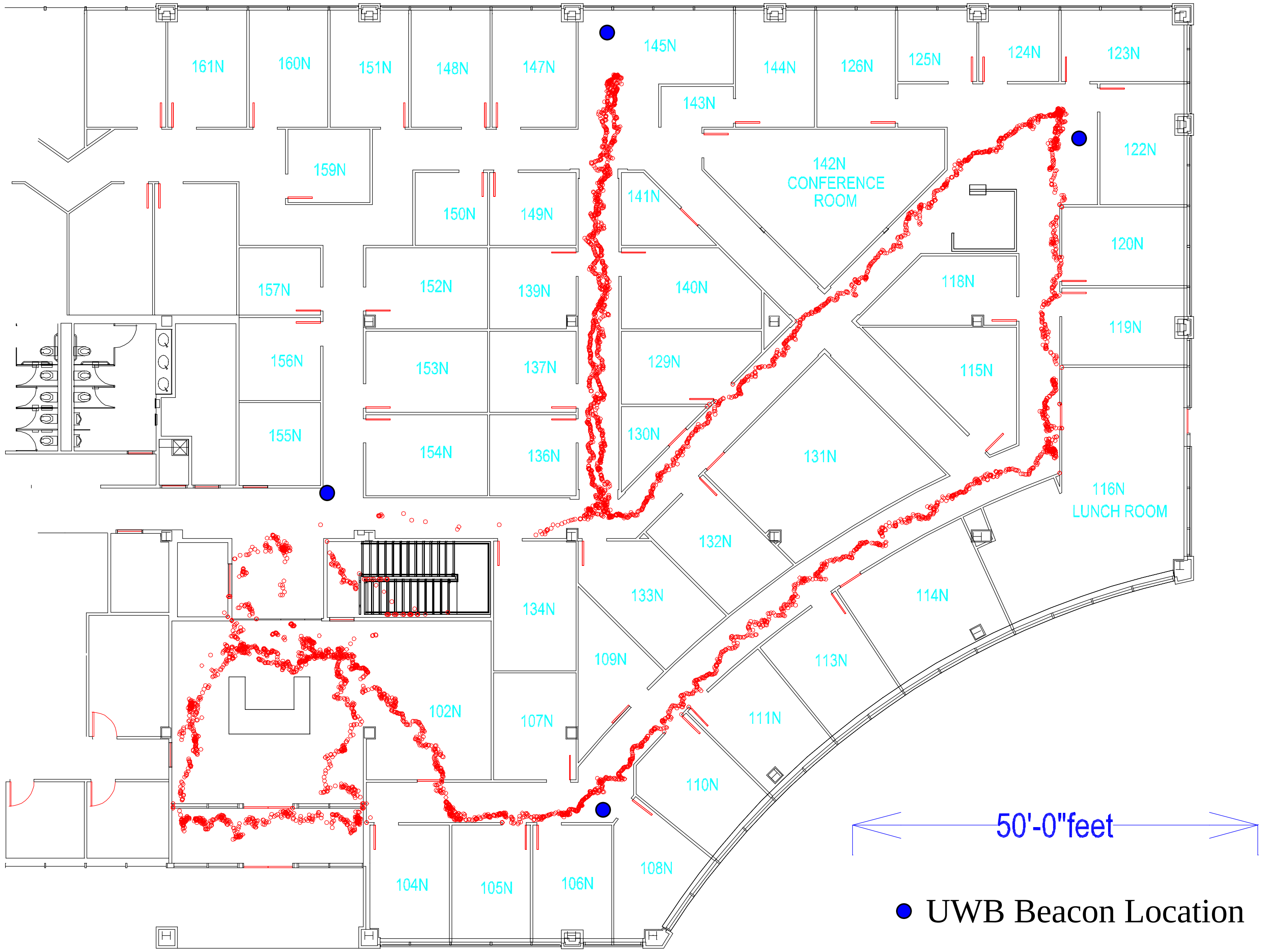
Indoor UWB Geolocation Experiment

● UWB Beacon Locations



Indoor UWB Geolocation Experiment



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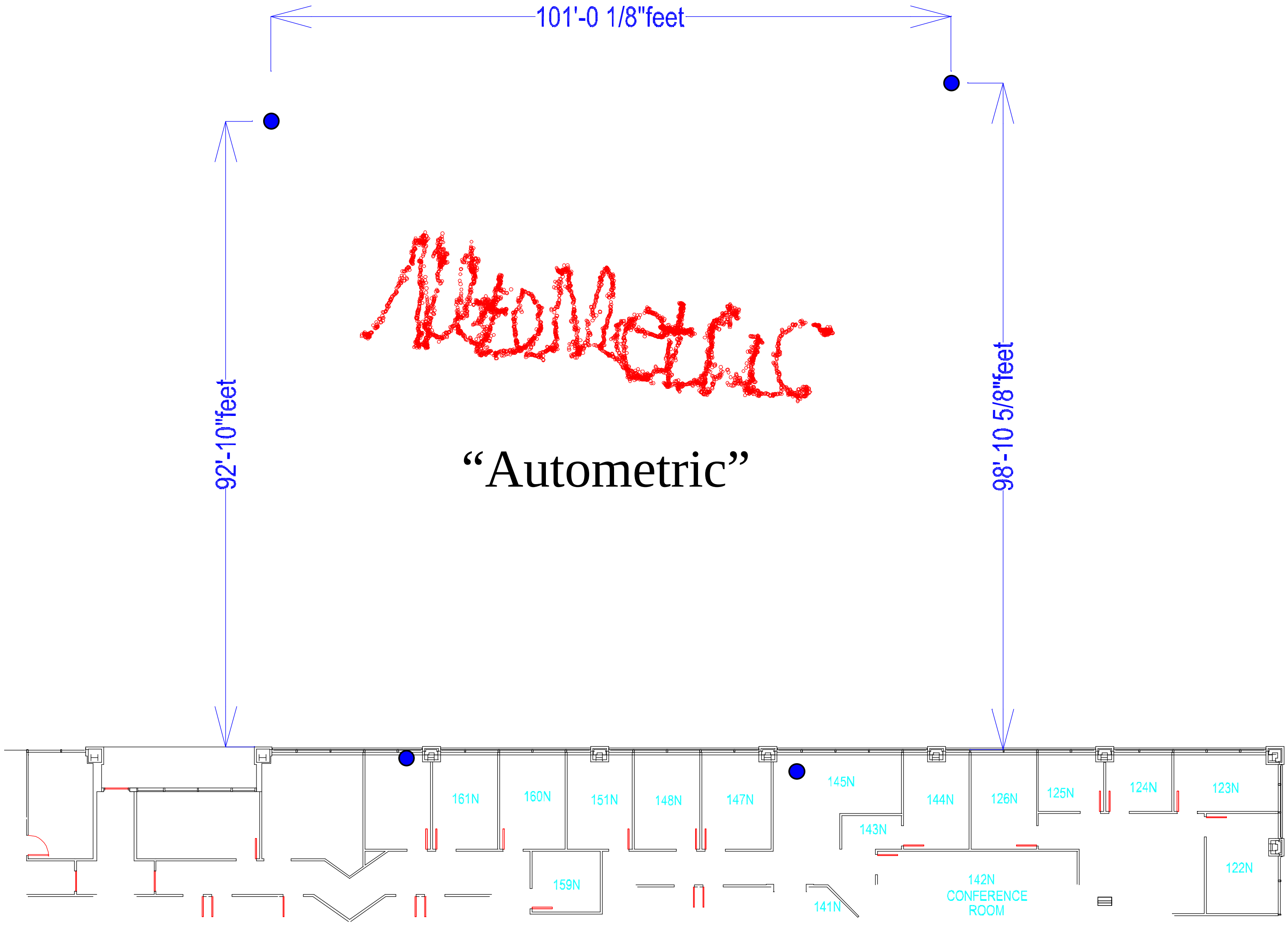
Indoor/Outdoor UWB Geolocation Experiment



● UWB Beacon Location

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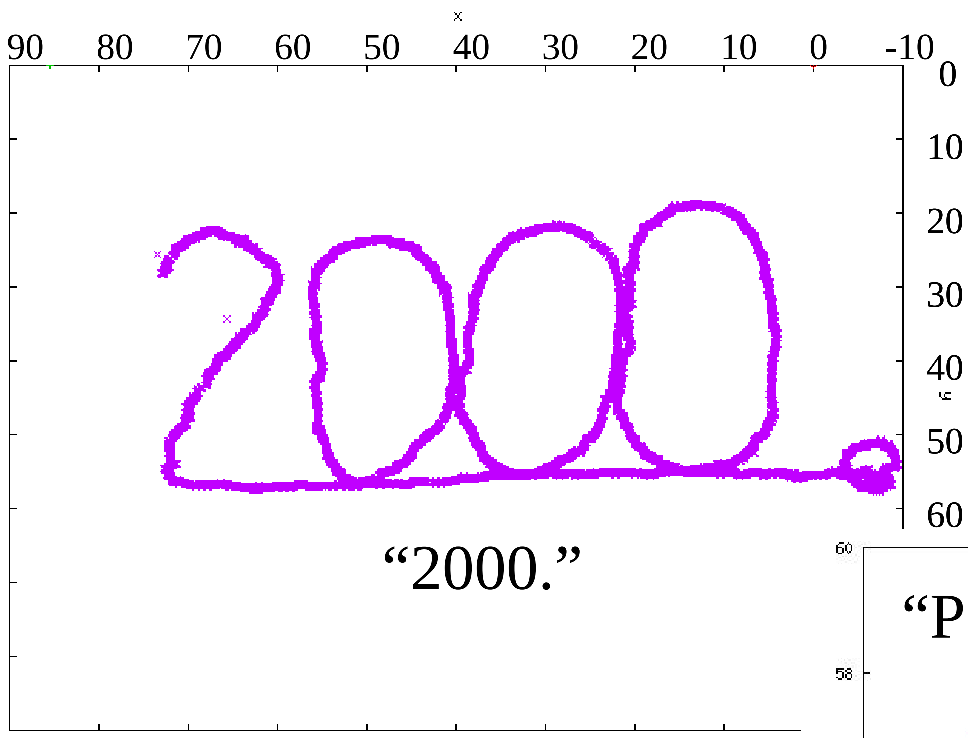
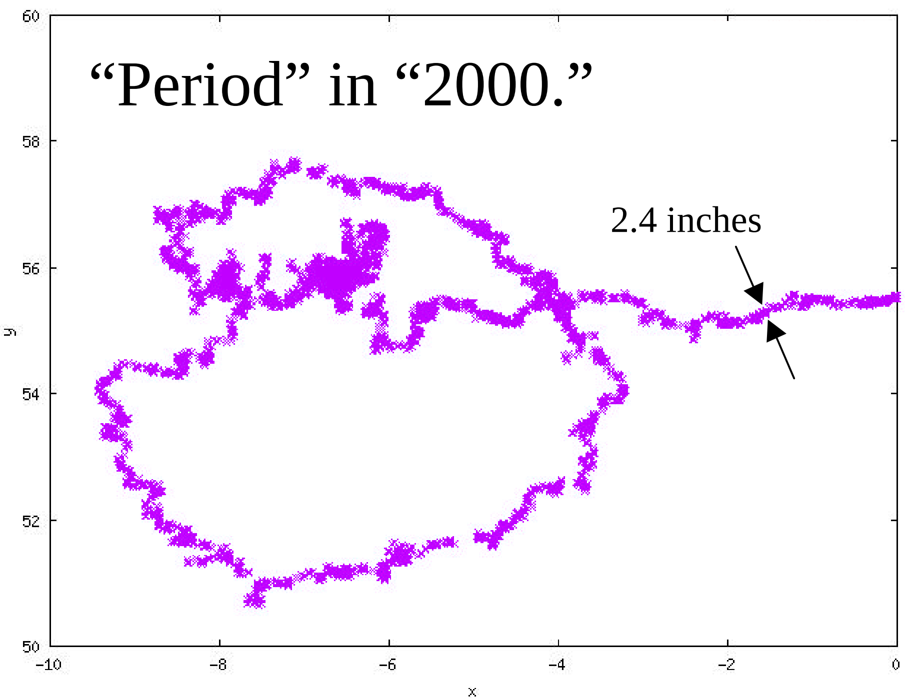
Outdoor UWB Geolocation Experiment





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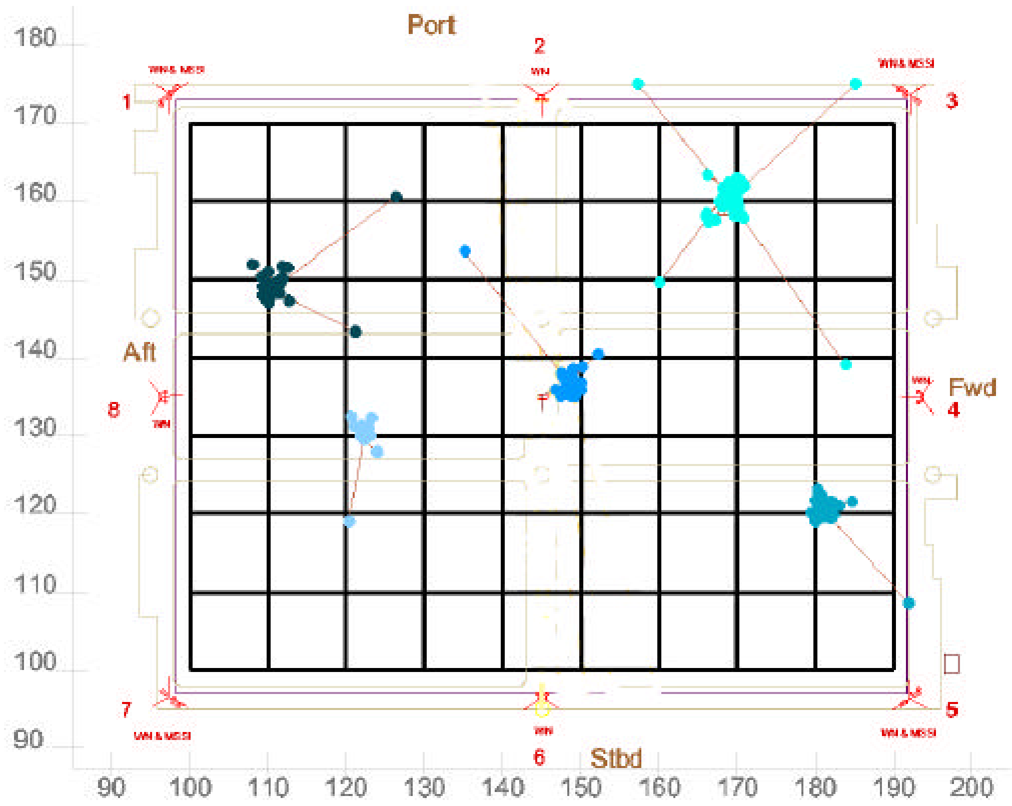
UWB Geolocation

Asset Tracking

UWB Tagging System

Raw Data



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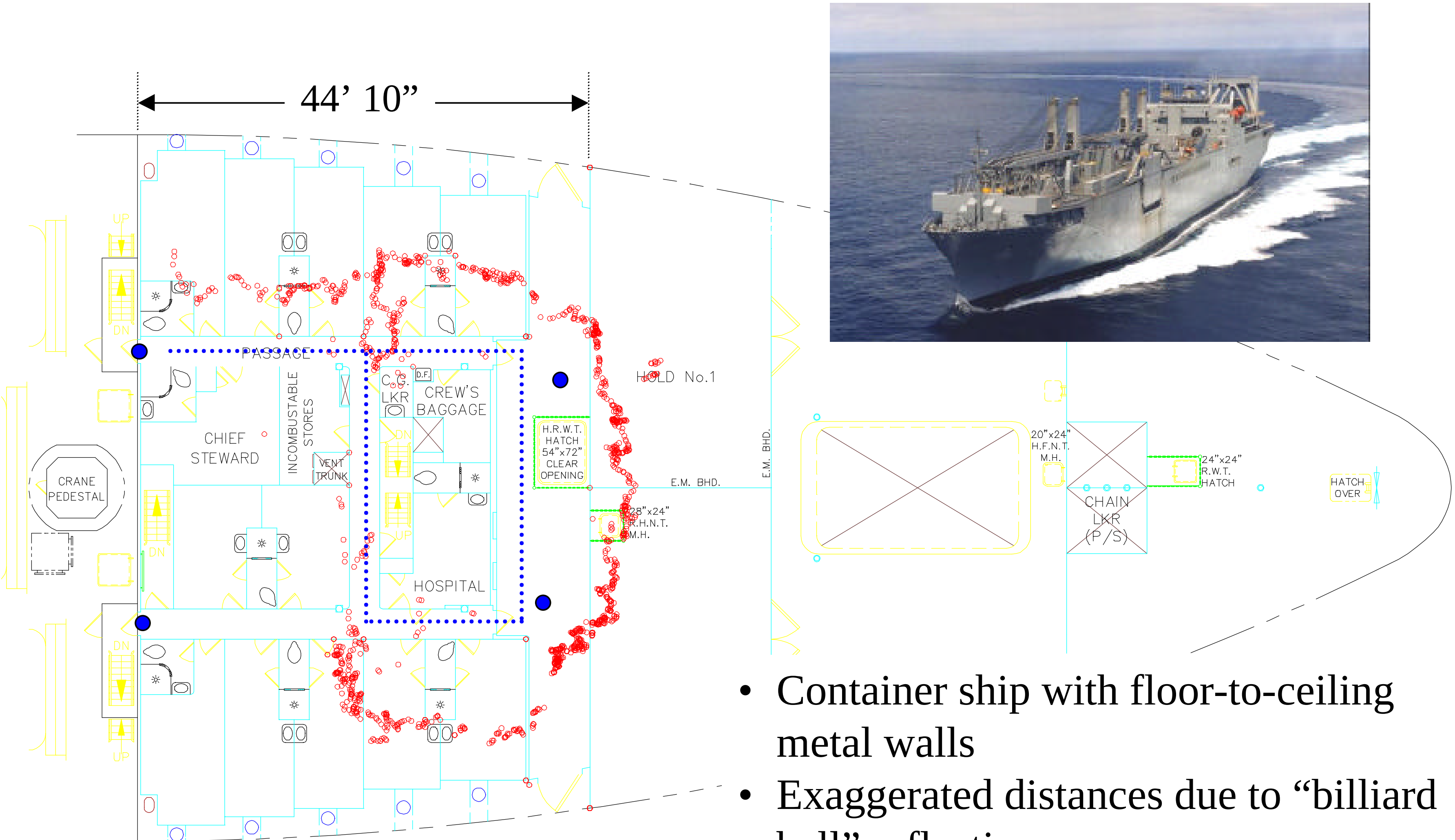
An Unique Propagation Environment



- Container ship with floor-to-ceiling metal walls
- Exaggerated distances due to “billiard ball” reflections

.... True path

● UWB Beacon Location

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Conclusions & Recommendations

- Demonstrated feasibility of UWB technology for precision tracking within and outside of a building
- Performance
  - Maximum range
    - typically 300+ feet (in commercial buildings)
    - > 2 km demonstrated (line-of-sight outdoors/indoors - omnidirectional antennas)
  - RMS error (400 MHz BW system)
    - 0.5 to 3 feet (indoors) – geometric dilution of precision
    - < 0.5 feet (outdoors)
- Areas for further system improvement
  - Increase transmitter power for extended range
    - Currently 2.5W/0.25W ERP
    - FCC issues for Part 15 operation
  - Decrease pulsewidth for better resolution
    - Currently 2.5 ns (400 MHz instantaneous BW)
  - Optimize frequency selection for better building penetration
    - Currently L-band (1.5 GHz)
    - FCC issues for Part 15 operation
  - Optimize antenna design for coverage
    - Vertical polarization
    - Circular polarization with squinted vertical beam pattern