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Mobile and Ubiquitous Computing

Location Sensing

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Center

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Session Overview

- Location sensing techniques
  - Triangulation
  - Proximity
  - Scene analysis
- Location sensing systems
  - Properties
  - Examples
  - Challenges

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Location Sensing Techniques

- Triangulation
  - Lateration (using distance)
  - Angulation (using angles)
- Proximity
  - Contact
  - Contactless
- Scene analysis

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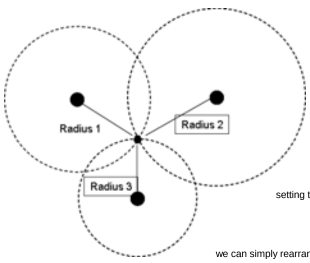
Triangulation

- Compute object locations using the properties of triangles (e.g law of sines, Pythagorean theorem etc)
- Several combinations of distance/angle measurements would work
- Generalization into 3 dimensional objects
- E.g. 3 non-collinear points are needed in 2D and 4 non-collinear points are needed in 3D

Lateration



$$r_1^2 = x^2 + y^2 + z^2$$
$$r_2^2 = (x-d)^2 + y^2 + z^2,$$
$$r_3^2 = (x-i)^2 + (y-j)^2 + z^2$$

subtract the second from the first and solve for *x*

$$x = \frac{r_1^2 - r_2^2 + d^2}{2d}$$

substituting back into the formula for the first sphere produces the formula for a circle, the solution to the intersection of the first two spheres:

$$y^2 + z^2 = r_1^2 - \frac{(r_1^2 - r_2^2 + d^2)^2}{4d^2}$$

setting this formula equal to the formula for the third sphere finds

$$y = \frac{r_1^2 - r_3^2 + (x-i)^2}{2j} + \frac{j}{2} - \frac{(r_1^2 - r_2^2 + d^2)^2}{8d^2 j}$$

we can simply rearrange the formula for the first sphere to find the z-coordinate

$$z = \sqrt{r_1^2 - x^2 - y^2}$$

Lateration Measurements

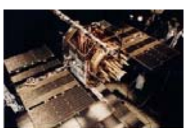
Types of Measurements

- Direct touch
- Time-of-flight (of the radio signal between transmitter and receiver)
  - e.g., sound waves travel 344m/s in 21ºC and so distance = time x speed
- Signal attenuation
  - calculate based on send and receive strength
    - Absorption, scattering, interference
    - Free space loss = 32.4 + 20xLog F(MHz) + 20xLog R(Km)
  - attenuation varies based on environment

Time-of-Flight Problems

- Often requires high time resolution (for accurate light or radio propagation measurements)
  - A light pulse (with 299,792,458m/s) will travel the 5m in 16.7ns
  - 0.001 sec -> 200 miles error!
- Clock synchronization critical
  - Accurate synchronization between reference beacons and receivers
  - Beacons could use atomic clocks (100k cost)
  - Use extra measurements!

Global Positioning System



- 27 satellite constellation
- More than 50 launched since 1978
- Powered by solar energy
- Each carries a 4 rubidium atomic clocks
  - locally averaged to maintain accuracy
  - updated daily by US Air Force Ground control
- Satellites are precisely synchronized with each other
- 400 M USD per year

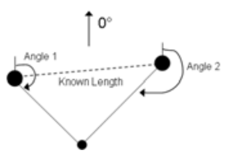
Global Positioning System

- Receiver is not synchronized with the satellite transmitter
- Satellites transmit their local time in the signal
- Receivers compute their difference in time-of-arrival
- Receivers estimate their position (longitude, latitude, elevation) using (at least) 4 satellites
- Accuracy is about 5 meters (20 meters until recently when random error was introduced)
- Differential GPS provides extra accuracy approx. 2 meters

- European solution: Galileo

Angulation

- Location sensing in 2D requires
  - 2 angle measurements from known location
  - 1 distance measurement (between the 2 locations above
- Example system: phased antenna array



Phased Antenna Array

- Multiple antennas with known separation (i.e. distance) – the military is very fond of this!
- Each measures time-of-flight of signal
- Using the difference in times and the (known) geometry of the receiving array, we can calculate the required angle
- If there are enough elements in the array and large separation, angulation can be performed accurately

Scene Analysis

- Compares scenes to reference scenes
  - Image, electromagnetic spectrum
- Construct a signature of a position and apply pattern matching techniques with this signature
- Differential scene analysis
  - Tracks differences in scenes

Scene Analysis Challenges

- Issues
  - the observer needs access to the features of the environment against which it will compare its observed scenes
  - changes of the environment that affects these features may require their reconstruction

Proximity

- Physical contact e.g., with pressure, touch sensors or capacitive detectors
- Within range of an access point e.g. GSM antenna
- Automatic ID systems
  - computer login
  - credit card sale
  - RFID
  - EPC codes

BBC Mobile Location Tag

Location System Properties

- Physical position and symbolic location information
- Absolute versus relative locations
- Localized location computation capability
- Accuracy and Precision
- Scale
- Recognition capability
- Cost
- Limitations

Physical Position and Symbolic Location

- Location information can be
  - Physical (47º39'17'' N by 122 º18'23" W)
  - Symbolic (in the kitchen, next to a mailbox)
- Symbolic location information can be derived by physical position with additional information.
- Using only symbolic location information can yield very coarse-grained physical positions

Absolute vs. Relative

- Absolute location system
  - Shared reference grid for all objects
  - Can be transformed into a relative location
- Relative location system
  - Each object may have own frame of reference
  - Can transform into absolute location from relative location readings
    - Must know absolute position of reference points

Localized Location Computation

- Location computation can happen in:
  - The object being located
    - Ensures privacy
  - The external infrastructure
    - Lower computational and power demands on objects
    - Many more applications possible

Accuracy and Precision

- Accuracy
  - Grain size (e.g. "within 10 meters")
- Precision
  - Probability of achieving a particular accuracy
- Sensor Fusion
  - Tries to improve accuracy and precision through integration of location systems to form hierarchical and overlapping levels of resolution
- Adaptive Fidelity
  - Ability to adjust precision in response to dynamic events like partial failures.

Scale

- Scale assessed by:
  - Coverage area per unit of infrastructure (e.g "1 base station per 10 square meters")
  - Number of objects the system can locate per unit of infrastructure per time interval (e.g. "25 computations per room per second")
- Larger scale achieved by increasing infrastructure

Recognition

- Necessary for applications that take specific actions based on location of object (e.g. airport baggage handling system)
- GUID (Globally Unique ID)
  - Used to provide recognition capability
  - Combined with other contextual information allows for different object interpretations in different settings. (e.g retrieving museum information in a particular language)

Cost

- Time
  - Installation process length
  - System administration needs
- Space
  - Amount of installed infrastructure
  - Hardware size
- Capital
  - Price per mobile unit or infrastructure element
  - Support personnel salaries

Limitations

- Improper functionality in certain environments:
  - Signal strength indoors
  - Exceeding request limits
  - Frequency interference

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