Location, Location, Location

Terminology of Location Systems

- Position type
  - Symbolic versus physical
    - Abstract idea versus latitude/longitude
  - Absolute versus relative
    - GPS versus beacons or bluetooth
- Accuracy
  - How close to the accurate position the system says you are
- Precision
  - How often it is accurate… 99%?

Ranging Techniques

- Time of Arrival (ToA, Time of Flight) (requirement?)
  - Signal propagation time
  - Signal velocity
- Radio signal versus sound signal (which "better"?)
- One-way time of arrival method (requirement?)

  $dist_{ij} = (t_2-t_1)*v$
- Two-way time of arrival method

  $dist_{ij} = ((t_4-t_1)-(t_3-t_2))*v/2$

Ranging Techniques

- Time Difference of Arrival (TDoA)
  - 2 signals with different velocities (example?)

  dist = $(v_1-v_2) * (t_4-t_2-t_{wait})$
  - Advantage? Disadvantage?
  - Alternative: sender sends one signal to multiple receivers where receivers have known locations

Ranging Techniques

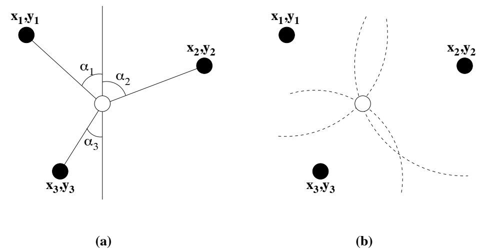
- Angle of Arrival (AoA)
  - Using antenna or microphone array
  - Angle between propagation direction and reference direction
  - Disadvantage?

Ranging Techniques

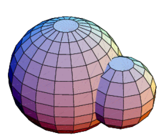
- Received Signal Strength (RSS)
  - RSSI: Received Signal Strength Indicator
  - RSS degrades with square of distance from sender

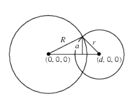
$P_r/P_t = G_t G_r \lambda^2/((4\pi)^2 R^2)$

Triangulation - Trilateration



Trilateration





Scene Analysis

Features of an observed scene from a particular vantage point used to infer location.

- Static: observations matched to features recorded in a database with corresponding locations.
- Differential: examine differences between two successive scenes to calculate location.

Requires compiling a database of features: extensive infrastructure.

Proximity

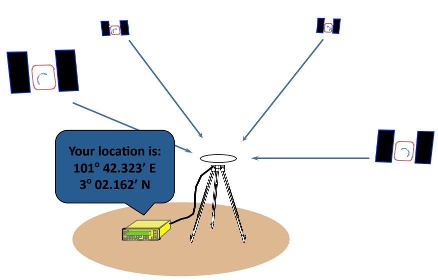
Detecting an object when it is near a known location through observed changes at that location.

- Physical contact: pressure sensors, capacitance field detector, … (Smart Floor)
- Monitoring access point = 'in-range' proximity (Active Badge)
- Automatic ID Systems: RFID badges, UPC scanning, phone & computer logs. Location of scanner, badge, computer, phone, identifies location of object.

GPS

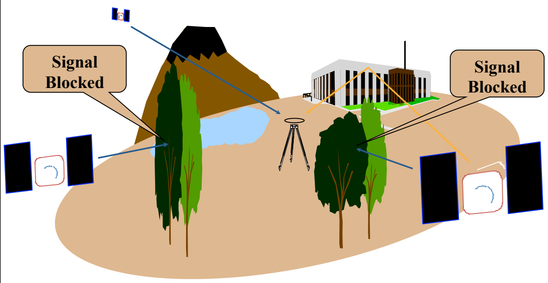
- Global Positioning System, example of GNSS (Global Navigation Satellite System)
- At least 24 satellites orbiting Earth at 11,000 miles
- The orbit altitude is such that the satellites repeat the same track and configuration over any point approximately each 24 hours
- Powered by solar energy (also have backup batteries on board)
- GPS is a line-of-sight technology: the receiver needs a clear view of the satellites it is using to calculate its position
- Each has 4 rubidium atomic clocks
  - locally averaged to maintain accuracy
  - updated daily by a Master Control facility

GPS

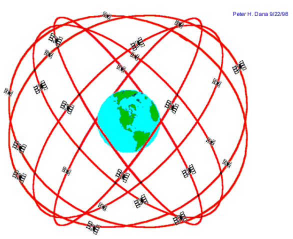


GPS

Multipath, Signal Obstruction (Buildings, Mountains, Foliage, etc)



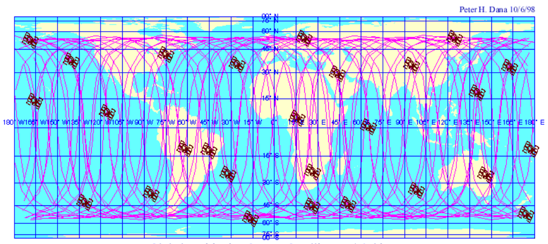
Satellites Orbits



GPS Nominal Constellation
24 Satellites in 6 Orbital Planes
4 Satellites in each Plane
20,200 km Altitudes, 55 Degree Inclination

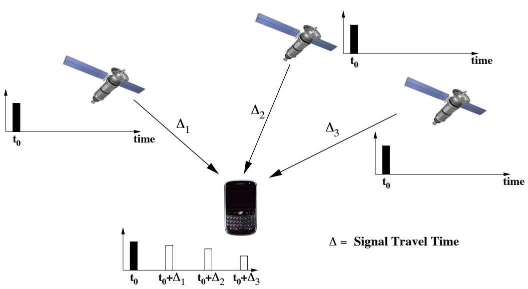
Satellites Positions and Orbits

Peter H. Dana 10/6/98



Global Positioning System Satellites and Orbits
for 27 Operational Satellites on September 29, 1998
Satellite Positions at 00:00:00 9/29/98 with 24 hours (2 orbits) of Ground Tracks to 00:00:00 9/30/98

GPS

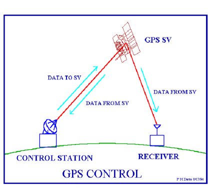


GPS

- 3 satellites sufficient for localization
- 4^{th} is needed to obtain accurate position
- Clock errors can be significant, e.g., error of 1ms results in localization error of 300km
- Typical positioning error: 1-5m (95-99%)

GPS

- Master Control Station (MCS, Colorado Springs) and at least six monitor stations monitor the satellites
- Computes precise orbital data (i.e., ephemeris) & clock corrections for each satellite



GPS Satellite Signals

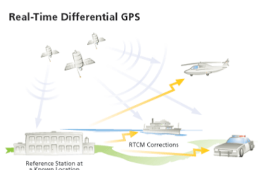
As light moves through a given medium, low-frequency signals get "refracted" or slowed more than high-frequency signals.

Satellites transmit two microwave carrier signals:

1. L1 frequency (1575.42 MHz) carries the navigation message (satellite orbits, clock corrections & other system parameters) and a unique identifier code
2. L2 frequency (1227.60 MHz) is used to measure the ionospheric delay
3. By comparing the delays of the two different carrier frequencies of the GPS signal L1 & L2, we can deduce what the medium is (i.e., atmosphere) and can correct for it

Differential GPS (DGPS)

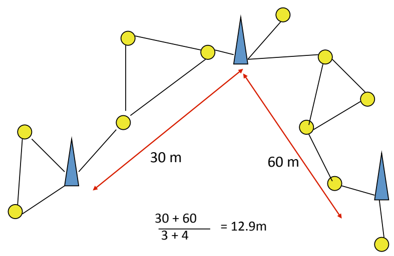
- Underlying assumption: any two receivers that are relatively close together will experience similar atmospheric errors
- Requires reference station: a GPS receiver been set up on a precisely known location
- Reference stations calculate their position based on satellite signals and compare this location to the known location



Ad-Hoc Positioning System

- Multihop localization schemes (APS); uses a distance-vector flooding technique to determine the minimum hop count and average hop distance to known beacon positions.
  - Each beacon broadcasts a packet with its location and a hop count, initialized to one.
  - The hop-count is incremented by each node as the packet is forwarded.
  - Each node maintains a table of minimum hop-count distances to each beacon.

Ad-Hoc Positioning System



Phased Antenna Array

- Multiple antennas with known separation
- Each measures time of arrival of signal
- Given the difference in time of arrival and the geometry of the receiving array, we can compute the angle from which the emission was originated
- If there are enough elements in the array and large enough separation, angulation can be performed

Cricket system

- Beacon:
  - Consists of a micro-controller running at 10MHz, with 68 bytes of RAM and 1024 words of program memory
  - Lower power RF-transmitter, and single-chip RF receiver, both in 418MHz unlicensed band
  - Ultrasonic transmitter operating at 40Hz
  - All of these are assembled on a small-board and mounted on a ceiling
- Receiver:
  - Similar to the beacon but with also an interface to the host device (e.g., laptop, printer)

Cricket system

- Beacon sends concurrently an RF message (with info about the space) and an ultrasonic pulse
- When the listener hears the RF signal, it uses the first few bits as training information and then turns on its ultrasonic receiver
- Then, it listens for the ultrasonic pulse, which will usually arrive a short time later
- It determines the distance to the beacon from the time difference between the receipt of the first bit RF information and the ultrasonic distance

Cricket Problems

- Lack of coordination can cause:
  - RF transmissions from different beacons to collide
  - A listener to wrongly correlate the RF data of one beacon with the ultrasonic signal of another yielding false results
- Ultrasonic reception suffers from severe multi-path effect
  - Order of magnitude longer in time than RF multi-path because of the relatively long propagation time for sound waves in air

Active Badge

- Users wear infrared badges
  - badge emits user ID every 10 seconds
- Building equipped with IR sensors
- Issues
  - fluorescent lights
  - accuracy limited by IR range

Active Bat

- User has a mobile "Bat"
  - responds to radio request with ultrasonic beacon
  - ceiling sensors measure time-of-flight
  - central system determines location using lateration
- Issues
  - requires large infrastructure

RADAR

- Uses existing 802.11 infrastructure
- Scene Analysis Version
  - 3-meter accuracy / 50% precision
- Lateration Version
  - 4.3-meter accuracy / 50% precision

MotionStar Magnetic Tracker

- Used in virtual reality systems
- Generate axial DC magnetic-field pulses from a fixed transmitting antenna
  - Computes position and orientation of receiving antennas by measuring the response to the transmitted pulse in 3 orthogonal axes
  - 1mm spatial, 1ms time, 0.1° orientation resolution

Easy Living

- Uses 3D cameras
- Provides stereo-vision position capabilities
- Designed for home use

Smart Floor

- Pressure sensor grid installed in all floors
- Can accurately determine positions of everyone in a building
- Users do not need to wear a tag or carry a device
- Cannot specifically identify an individual

E911

- FCC is requiring wireless phone providers to locate any phone that makes an E911 call
- Different approaches
  - proximity
  - angulation with phased antenna arrays
  - GPS-enabled handsets
- Will lead to numerous new consumer services

Survey of Location Systems

Technology	Technique	Physical	Symbolic	Absolute	Relative	LLC	Recognition	Accuracy and precision if available	Scale	Cost	Limitations
GPS	Radio time-of-flight lateration	•		•		✓		1-5 meters (95-99 percent)	24 satellites worldwide	Expensive infrastructure $100 receivers	Not indoors
Active Badges	Diffuse infrared cellular proximity		•	•			✓	Room size	1 base per room, badge per base per 10 sec	Administration costs, cheap tags and bases	Sunlight and fluorescent light interfere with infrared
Active Bats	Ultrasound time-of-flight lateration	•		•			✓	9 cm (95 percent)	1 base per 10 square meters, 25 computations per room per sec	Administration costs, cheap tags and sensors	Required ceiling sensor grid
MotionStar	Scene analysis, lateration	•		•			✓	1 mm, 1 ms, 0.1° (nearly 100 percent)	Controller per scene, 108 sensors per scene	Controlled scenes, expensive hardware	Control unit tether, precise installation
VHF Omni-directional Ranging	Angulation	•		•		✓		1° radial (≈ 100 percent)	Several transmitters per metropolitan area	Expensive infrastructure, inexpensive aircraft receivers	30-140 nautical miles, line of sight

Survey of Location Systems

Technology	Technique	Physical	Symbolic	Absolute	Relative	LLC	Recognition	Accuracy and precision if available	Scale	Cost	Limitations
Cricket	Proximity, lateration		•	◦	◦	✓		4 × 4 ft. regions (≈ 100 percent)	≈ 1 beacon per 16 square ft.	$10 beacons and receivers	No central management receiver computation
MSR RADAR	802.11 RF scene analysis and triangulation	•		•			✓	3-4.3 m (50 percent)	3 bases per floor	802.11 network installation, ≈ $100 wireless NICs	Wireless NICs required
PinPoint 3D-iD	RF lateration	•		•			✓	1-3 m	Several bases per building	Infrastructure installation, expensive hardware	Proprietary, 802.11 interference
Avalanche Transceivers	Radio signal strength proximity	•			•			Variable, 60-80 meter range	1 transceiver per person	≈ $200 per transceiver	Short radio range, unwanted signal attenuation
Easy Living	Vision, triangulation		•	•			✓	Variable	3 cameras per small room	Processing power, installation cameras	Ubiquitous public cameras
Smart Floor	Physical contact proximity	•		•			✓	Spacing of pressure sensors (100 percent)	Complete sensor grid per floor	Installation of sensor grid, creation of footfall training dataset	Recognition may not scale to large populations

Survey of Location Systems

Technology	Technique	Physical	Symbolic	Absolute	Relative	LLC	Recognition	Accuracy and precision if available	Scale	Cost	Limitations
Automatic ID systems	Proximity		•	◦	◦		✓	Range of sensing phenomenon (RFID typically <1m)	Sensor per location	Installation, variable hardware costs	Must know sensor locations
Wireless Andrew	802.11 proximity		•	•			✓	802.11 cell size, (≈ approx. 100 m indoor, 1 km free space)	Many bases per campus	802.11 deployment, ≈ $100 wireless NICs	Wireless NICs required, RF cell geometries
E911	Triangulation	•		•			✓	150-300 m (95 percent)	Density of cellular infrastructure	Upgrading phone hardware or cell infrastructure	Only where cell coverage exists
SpotON	Ad hoc lateration	•			•		✓	Depends on cluster size	Cluster at least 2 tags	$30 per tag, no infrastructure	Attenuation less accurate than time-of-flight