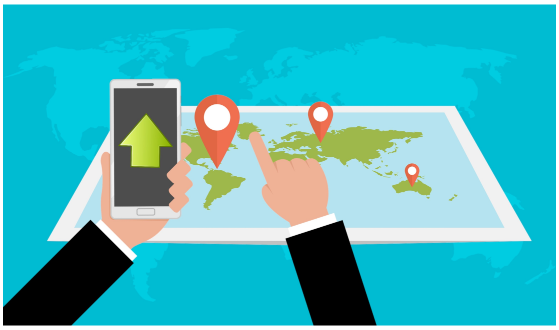
Sistemas de Computação Móvel e Ubíqua

2021/2022

Context and Location

2021/2022

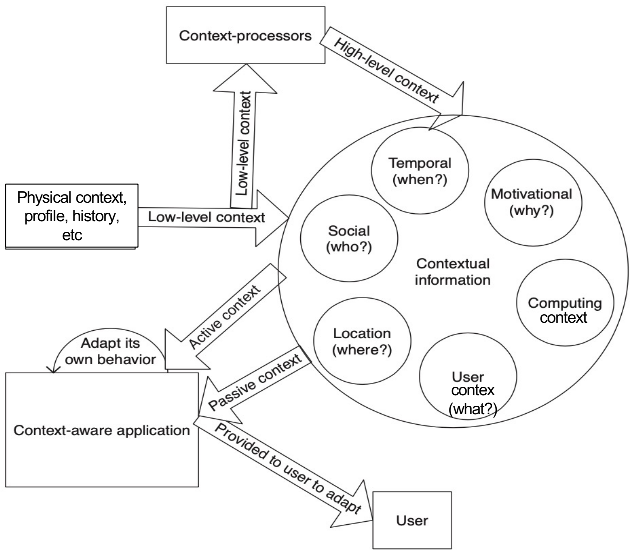


Context-aware systems

Adaptation is key to mobile and ubiquitous computing, usually for resource adaptation
- Application transparent (the SO, network stack, libs, take care)
- Application aware (notify application to adapt)

Context-ware application also uses all environment and contextual information that may improve the user experience
- Examples: who is near, time of day, location, user intent, etc
- Using: sensors, talking to other devices, using historical data, user profile, etc

Various types of contexts



Who?

What?

Where?

When?

Why?

Context-aware systems

Main Characteristics of context-aware systems

- Context sensing: detect environmental information to present to the user (eg. detect location to show user in a map)
- Context adaptation: the application adapts (changes behavior) depending on the context (eg. use interface dark mode at night)
- Contextual resource discovery: the application discover available resources to user needs (eg. discover neighbor's phone to exchange files)
- Contextual augmentation: contextual information is added to some other data (eg. add GPS info to photos)

Localization Systems

Knowing the physical location of people and things can allow the creation of novel services/applications and augment existing ones.

Examples:

- Getting the location of lost persons, items, etc.
- Finding nearby restaurants, etc.
- Finding the best paths
- View information on my mobile device about a panting that is ahead of me ...

Localization Systems

Positioning or localization: determination of position of devices, persons or other objects.
- In some Absolute Reference (e.g. geographic coordinate) or in a Relative Reference (e.g. relative to some wifi antenna)

Physical Position or geographic location: exact point in space
- E.g. GCS 47º39'17''N, 122º18'23''W

Symbolic Location (or semantic location): area with assigned *semantics*
- E.g. "Lab 128 Ed.II FCTUNL"
- Usually inferred from physical position with additional information

When no confusion arise, position and location are used interchangeably

Location system properties

Different Location Sensing techniques are used to create location systems with different properties

Properties:
- physical position vs. symbolic location
- absolute vs. relative
- client-based vs. infrastructure-based
- accuracy and precision
- scale
- recognition
- cost

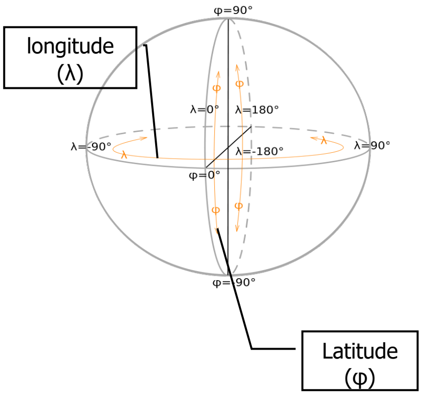
Different techniques have different properties

Different systems have different requirements

Physical position vs. symbolic location

Physical position provides coordinates in a given coordinate system

- ellipsoid coordinate system to model locations on earth
- geodetic data used to map to earth positions (earth is nor a perfect ellipsoid)
- in limited areas (e.g., city), Cartesian coordinates can be used, by projecting latitude/longitude coordinates on a Euclidean plane



Physical position vs. symbolic location

With information about boundaries/extent of symbolic location, may be possible to map physical positions to symbolic location and vice-versa

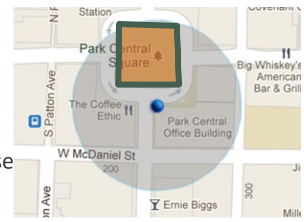
challenges:

physical position -> symbolic location

- accuracy on determining physical location

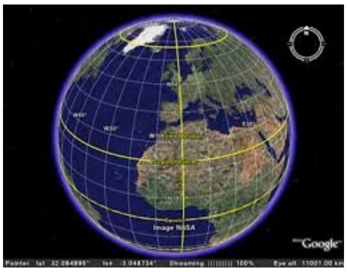
symbolic location -> physical position

- low accuracy of mapped physical position – which point to se



Absolute vs. Relative

Absolute location system uses the same reference for all objects



Relative location systems provide location information relative to a given reference or landmark

- e.g., behind me (current observer), 50 meters west of the library

Client-based vs. infrastructure-based

Client-based systems, clients actively determine their position. (e.g., GPS)

Advantage:

- location information under control of object - **privacy**

Infrastructure-based systems, it is the infrastructure that determines objects' position (e.g., cell-id location)

Advantages:

- simpler devices – no special hardware/software needs to be running on objects to be located

Accuracy and precision

Accuracy is the error in location determination

Precision is how often we can expect some given accuracy

e.g. GPS can locate positions to within 10 meters (accuracy) for 95 percent of measurements (precision)

Scale

Scale has several facets:

- geographic scope where the system can be used
  e.g. worldwide, campus
- number of objects that can be located in a given area
  e.g., xbox kinect can track a limited number of people in a room
- number of objects that can be located for a given period of time
  e.g., radio-frequency based techniques have limited bandwidths

Scale

Increasing the scale may be complex due to physical limitations and software issues

Different technique may have inherently different scale potentials

- e.g., indoor vs. outdoor location systems

Recognition

For some applications, besides knowing location of an object, it may be required to recognize/identify the object

One general technique is to assign globally unique identifiers to objects – e.g., using RFIDs, QR-codes, MAC addresses, etc.

QR-code

Cost

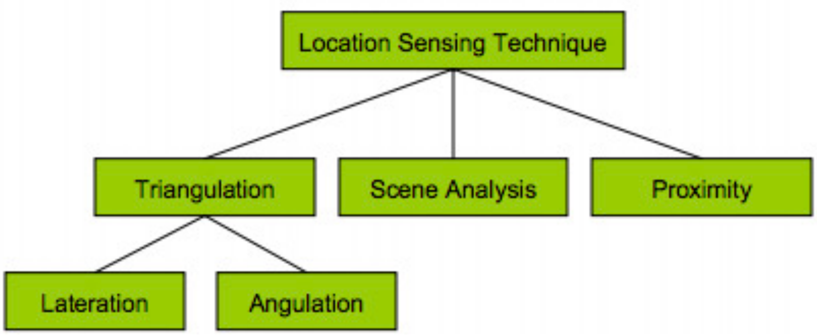
Time cost:

deployment and administrative needs

Spatial cost:

cost per device plus infrastructure cost

Location Sensing Techniques



Location Sensing Techniques

Triangulation: is the process of determining the location of a point by forming triangles to it from known points, using the geometric properties of triangles to compute position

- **Lateration**: using multiple distance measurements to known points
- **Angulation**: using angle measurements relative to points with known separation

Location Sensing Techniques

Proximity: measures nearness to a known set of points

- Example: cell-ids in cellular networks

Scene analysis: examines a view from a particular vantage point to determine own location or location of other things

- Example: painting in a museum

Proximity

Proximity entails determining when an object is near a given location

Three basic techniques:
- **Detecting physical contact** - using special sensors
- **Monitoring wireless access points** - within range of cellular cell, wi-fi access point, bluetooth access point, etc.
- **Observing automatic ID systems** - e.g. login in some computer, etc.

Note: Proximity may need to be combined with identification systems if the method used to detect proximity does not provide identification directly.

Scene analysis

Use features of the scene observed to infer the location of the observer or other things, the observer needs access to the features of the environment against which it will compare its observed scenes
- NOTE: does not necessarily means using images

In static scene analysis, observed features are looked up in a predefined dataset that maps them to location
- E.g. map with signal strengths in different locations

Differential scene analysis tracks the difference between successive scenes to estimate location

Scene analysis: signal strength fingerprinting

Off-line step
- Build a map that records the signal strength readings at given positions
- Problems: orientation, device, etc.

Location step
- Get reading at some position
- Use the map to find the closest records
  - Distance: Euclidean, *Manhattan*, …
  - How many points to use: best, k-best – average position, …

Scene analysis: images

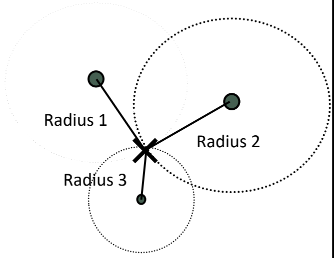
Process images to determine what is being observed
- E.g. Google goggles, Nokia point & find can be used to provide location
- Museum applications can recognize paintings and provide user with location

Often used in conjunction with augmented reality

Triangulation - Lateration

Lateration: computes the position of an object by measuring its distance to reference positions

- In 2D, distances from 3 non-collinear points are required;
- In 3D, distances from 4 non-coplanar points are required



Position of **reference points** must be known.

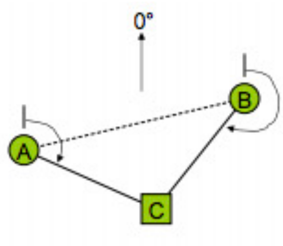
Additional information/constraints may reduce requirements, e.g., when determining position in a room, if all reference points are in the ceiling, only 3 distances are required for 3D positioning.

Triangulation - Angulation

Angulation:

- Angles used to determine object position
- 2D requires 2 angles and one length
- 3D = 2D + azimuth

- Angulation technologies
  - Phase antenna arrays different arrival times at antenna array
  - VOR aircraft navigation system measure phase shifting of reference and secondary signals pulse



Angulation Technique

Advantages

- It only needs two measuring units for 2D positioning and 3 for 3D. It doesn't need synchronization between the measuring units.

Disadvantages

- Works well in situations with LoS (Line of Sight) but the accuracy and precision decrease when there are signal reflections (so it is not good for indoor).
- Large and complex hardware.
- The accuracy also decreases when the mobile target moves further from the measuring units.

Measuring Angles

Phase 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 separation, the angulation can be performed

Measuring Distances

Techniques

- Direct
- Attenuation
- Time-of-Flight (or Time of Arrival)

Measuring Distances - Direct

Direct

Uses a physical action or movement

e.g. extend a probe until touch something or tape measure.

- Easy to understand.
- Difficult to obtain automatically due to complexity involved in coordinating physical movement.

Measuring Distances - Attenuation

Attenuation

The decrease in the intensity of an emitted signal with the distance from the emission position

- e.g. in free space, radio signal attenuation is proportional to $1/r^2$, with r the distance from the emission point

Challenges:

Reflections, refraction, multi-path make it difficult to accurately measure distances

- Problematic in spaces with lots of obstacles (walls, buildings, etc.)

Measuring Distances - ToF

Time-of-flight (or time of arrival ToA)

Measures the time it takes to travel between two points at a known velocity

- e.g., sound waves velocity ≈ 344 m/s @ 21ºC
  An ultrasound pulse sent by an object and arriving at point P 14.5ms later => Object is 5 m away from point P
- Light and radio waves are also used but require clocks with higher resolution than ultrasound.
  (light velocity = 299 792 458 m/s, 5 m => 16.7 ns)
- Depending on objects, it may be necessary/possible to measure a round-trip delay. (e.g. laser beams for reflective objects, radar)

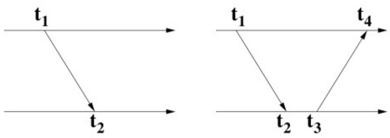
Measuring Distances - ToF

One Way ToA

One way propagation of the signal

$dist_{ij} = v\,(t_2 - t_1)$

- Requires highly accurate synchronization of sender and receiver clocks



Two Way ToA (or ToF)

Round-trip time of signal is measured at sender device

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

Measuring Distances - ToF

Time-of-flight challenges (1)

It is necessary to ignore pulses arriving via indirect paths caused by reflections, these multipath propagations introduce significant measurements errors

- Aggregate and statistically prune reflective results

Clock precision

- For round-trip sound, laser or radar reflection, needed precision will depend on the used technique

Measuring Distances - ToF

Time-of-flight challenges (2)

Clock agreement - Clock synchronization is a key aspect in every ToA system. The transmission and reception time must be known using a common time base in order to deduce accurate measurements.

Clock synchronization is of particular importance in one-way ToA methods. Two-way methods exhibit an advantage over the one-way method since each node operates its own clock, hence its own timing system.

- Sound and radar reflections easy because transmitter and receiver are the same
- For one-way techniques (e.g. GPS), it is necessary for sender and receiver to agree on time.
- In GPS, satellites have their clocks synchronized; 4 satellites are required for solving position + time

Location Systems Examples

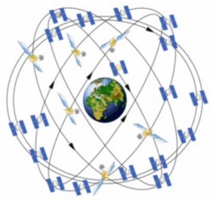
GPS - Global Positioning System

GPS (Global Positioning System) most widely known location-sensing system.

- NAVSTAR GPS (Navigation Satellite Timing and Ranging Global Positioning System) — US based military navigation system was specially designed to support armed forces.
- Developed for navigation and outdoor environment.
- Started in 1973, fully operational in 1995, allowed for civilian use in 1980.

GPS signals are not available in indoor environment because, it does not penetrate in the hard surface and inside buildings -> not well suitable for indoor applications.

GPS

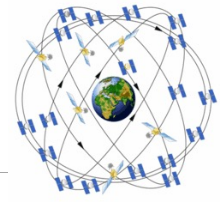


satellites
- 32 satellites (24+spares) uniformly distributed in six orbits (as of 12/2012)
- altitude = 20.200 km
- time of circulation = 12h
- min 5, max 11 satellites visible from each point on earth

control
- 5 earth stations monitor satellite signals, create **correction** data

GPS receivers
- compute location based on **lateration** using one-way **time-of-flight**

accuracy
- standard : ~3m (horiz.) 15m (vert)



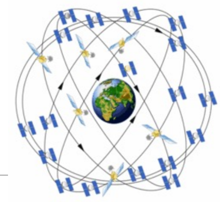
GPS

Three segments:

Space (GPS space vehicles (SV) - satellites)

Control (earth stations)

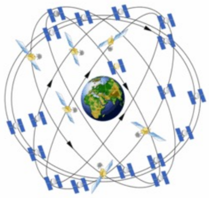
User (civilian and military)



GPS

Control:

- SVs are controlled by five system tracking stations.
- Stations monitor and measure signals from each of the satellites.
- Compute precise orbital data and SV clock corrections for each satellite.
- The Master Control station uploads updated orbital and clock data to the SVs.



GPS

Users - two levels of service:

Standard Positioning Service (SPS)

- available to all users, no restrictions or direct charge
- high-quality receivers have accuracies of 3 m and better horizontally

Precise Positioning Service (PPS)

- used by US and Allied military users
- uses two signals to reduce transmission errors

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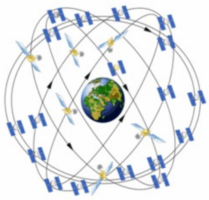
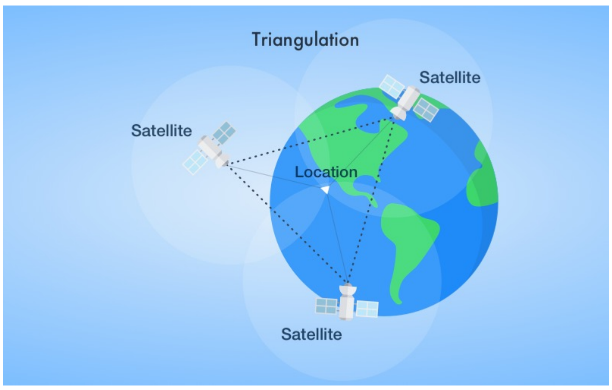


GPS



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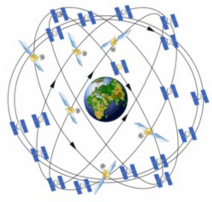
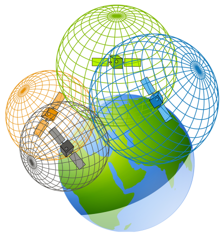
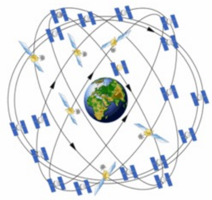


GPS

With four satellites, accurate localization is possible:

- accurate positioning relies on accurate timing
- small timing errors lead to large position errors
  - example: clock error of 1ms translates to a position error of 300km
- fourth sphere would ideally intersect with all three other spheres in one exact location





GPS

Accuracy

- Depends on factors such atmospheric effects, sky blockage, and receiver quality
- High-quality GPS receivers provide better than 3 meter horizontal accuracy.
- Higher accuracy is attainable by using GPS in combination with augmentation systems.
  - These enable real-time positioning to within a few centimeters, and post-mission measurements at the millimeter level.

Other satellite systems

Galileo (European Union)

- December 2016, 18 of 30 satellites in orbit; is expected to reach Full Operational Capability in 2019; the complete 30-satellite Galileo system (24 operational and 6 active spares) is expected by 2022.
- Accuracy: < 4 m horizontal, < 8m vertical (open service)

Differential GPS

- Reference station on earth compute error based on GPS reading and propagate information to receivers
- Increases accuracy up to 1-3 m

Indoor Position Systems

Indoor Position System

GPS technology uses the signals of satellites in orbit. These signals are seriously degraded when there is no direct visibility, which makes indoor location finding difficult.

Indoor Challenges:

- Smaller dimensions
- High or none line of sight
- Obstacles (like: walls, equipment, humans, doors, ...)
- Noise interference

Indoor Position System

An IPS is usually composed of two different elements: **Anchors** and location **Tags**.

- Anchors are devices placed in the building;
- Tag is carried by the person or object whose location is of interest.

Indoor Position System

- IMU
- Infrared Light
- Ultrasound
- Radio Frequency
  - RFID
  - WiFi and Bluetooth
  - Zigbee

https://www.bitbrain.com/blog/indoor-positioning-system

Indoor Position System

IMU (Inertial Measurement Unit)

IMU information about relative movement of a tag, that has several sensors (accelerometer, magnetometer and gyroscope).

Can provide an estimation of the relative movement regarding a previous position.

Advantage of this technology is that it does not require the use of anchors in the environment.

Disadvantage is the accuracy, as the error accumulates over time and can be on the order of meters after just a few seconds.

Usually used in combination with other technologies to smooth the results and reject outliers.

Indoor Position System

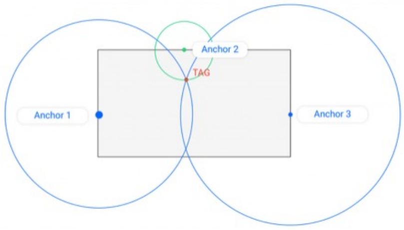
Ultrasound System

Ultrasound systems use sound instead of light. It does not interfere with electromagnetic waves and does not require line of sight.

Uses Time of Flight, that is, the time required by sound to travel from an anchor to a tag or vice versa, to estimate the distance between them (position can be computed using trilateration).

Require the placement of multiple anchors and time synchronization between anchors and tags.

Ultrasound signals are affected by interference from solid objects and consequently accuracy can be poor if these are not considered.



Indoor Position System

Infrared Light

Require an unobstructed Line of Sight (LOS) between the anchor and the tag.

This type of system can be used as a very reliable room detector, because it is not possible for a tag to detect light from an anchor without being in the same room.

For precise localization, they require installing many anchors and can struggle due to the low quality of the signal strength measurements required to compute the position from multiple anchors.

Indoor Position System

Radio Frequency Technologies

The most common IPS are based on radio frequency signals:

- use technology that is already deployed (WiFi, Bluetooth, and mobile phones).
- These signals can traverse obstacles, they can work in real-world settings where obstacles are unavoidable.

Indoor Position System

RFID (Radio Frequency Identification)

Uses electromagnetic fields to identify and track tags attached to people or objects.

Readers send pulses that are detected by tags. Tags respond to the request of a reader by sending back a small amount of information, such as an ID.

- The simplest RFID systems use **passive** tags that obtain the power necessary to send the answer directly from the reader's pulse. Passive tags are very cheap, can only store a few kb of memory, and the reader has to be within around 1 meter of the tag to get the information.

Indoor Position System

WIFI & Bluetooth

Advantage is that they use the pre-existing network infrastructure and that both WI FI and Bluetooth are available in mobile phones and other wearable devices (-> easy to deploy and cheaper than ad-hoc installations).

Operating principle consists of using the Received Signal Strength (RSS).

- By measuring the RSS of the tag (e.g. a mobile phone) to multiple WiFi access points or Bluetooth beacons (which act as anchors), it is possible to estimate the position of the mobile phone using trilateration.

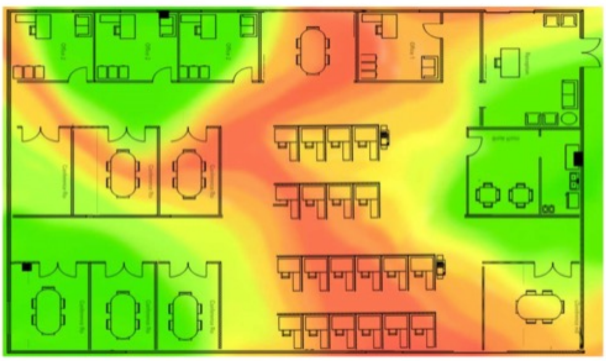
The main difficulty for these systems is that WIFI and Bluetooth signals vary enormously in the presence of obstacles and moving people. Also, different materials affect the signals differently which affects accuracy.

- Some IPS create a map of RSS specific for a given area based on ad-hoc calibrations.

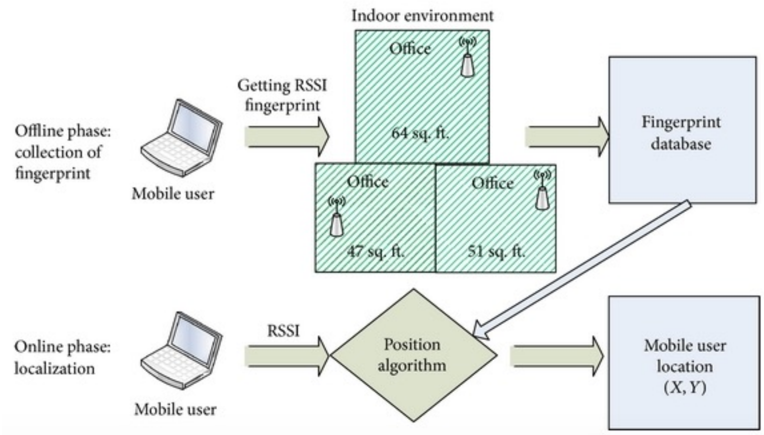
The accuracy obtained with this type of systems can reach 1-2m.

Indoor Position System

WIFI & Bluetooth



Fingerprinting Based Indoor Localization



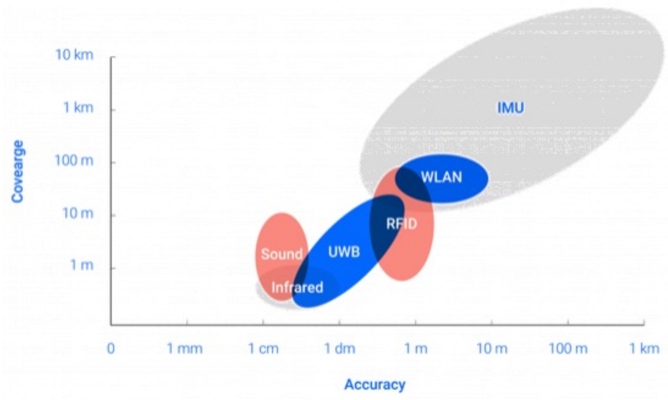
https://www.hindawi.com/journals/jcnc/2013/185138/

WiFi-Based Indoor Localization

Strengths	(i) Found in almost every building, fairly good available signal strengths. (ii) WiFi signals are able to penetrate walls in where GPS fails. (iii) Targeted location fingerprints available.
Weaknesses	(i) Site surveying time consuming and labor intensive. (ii) Multipath influenced by presence of Physical objects. (iii) Signal strength changes in variations due to time. (iv) Interfere possible with other appliances in the 2.4 GHz ISM.
Opportunities	(i) Fingerprinting does not need geometric surveys. (ii) Fingerprinting only necessary at selected places.

https://www.hindawi.com/journals/jcnc/2013/185138/

Indoor Position System



Active Bat

Indoor location system

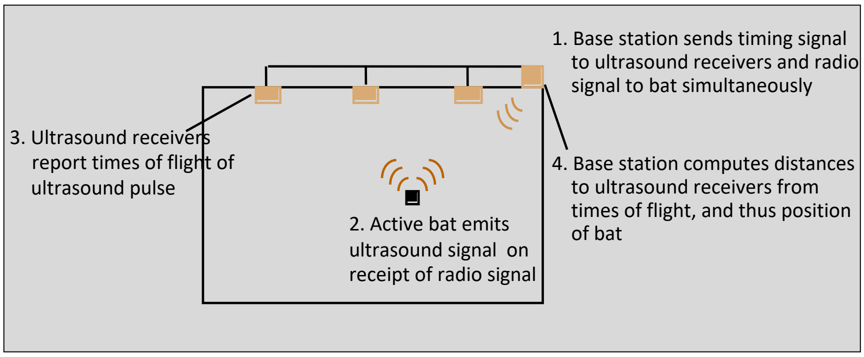
User has a mobile "Bat"

- responds to radio request with ultrasonic beacon
- ceiling sensors measure time-of-flight
- central system determines location using lateration

Issues

- requires large infrastructure

Active Bat



Active Bat - Main Concept

- Controller sends simultaneously a radio signal and a synchronized reset signal to the ceiling sensors using a wired serial network
- Bat responds to the radio request with a ultrasonic beacon
- Ceiling sensors measure time-of-flight (from reset to ultrasonic pulse)
- Central system determines location using lateration
- Statistical pruning eliminates erroneous sensor measurements caused by a a ceiling sensor hearing a reflected ultrasound pulse instead of one that traveled along the direct path from the Bat to the sensor

https://www.researchgate.net/figure/Active-Bat-AT-T-Laboratories-Cambridge_fig4_228772814

Cricket

Ultrasound emitter infrastructure

Nodes have embedded receivers

Each node calculates its own position

Issues

- Provides privacy
- High power consumption due to localized calculations

http://cricket.lcs.mit.edu

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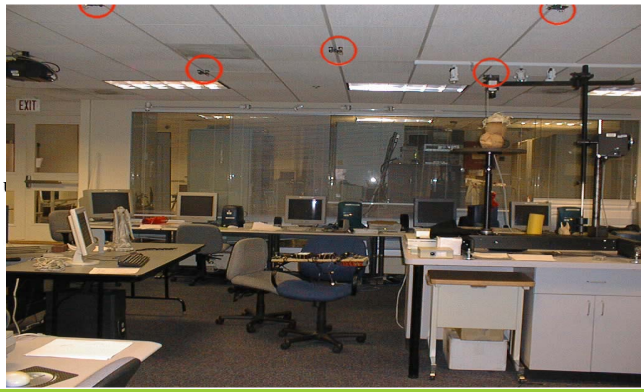
Cricket

Ultrasound emitter infrastructure; nodes have embedded receivers. Each node computes its own position



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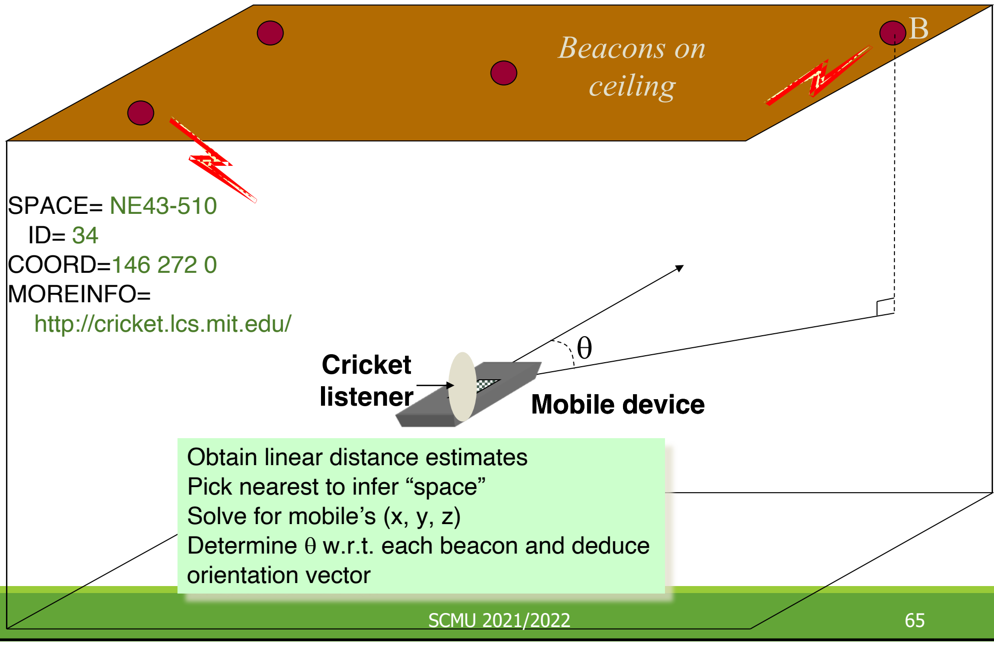
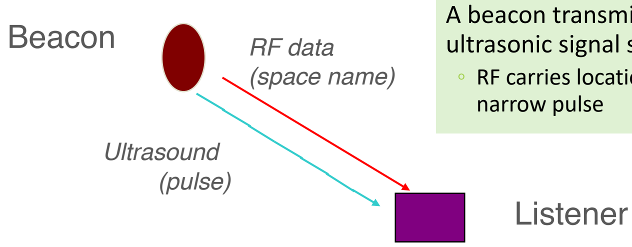
Machinery



Obtain linear distance estimates
Pick nearest to infer "space"
Solve for mobile's (x, y, z)
Determine θ w.r.t. each beacon and deduce orientation vector

Determining Distance



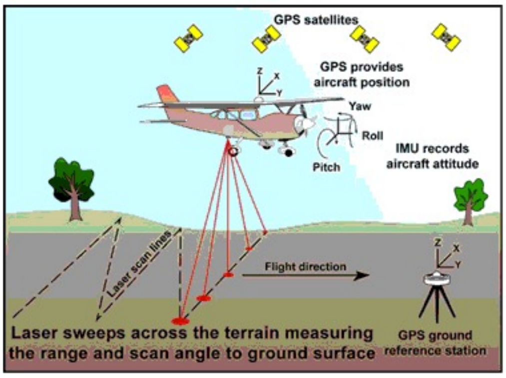
A beacon transmits an RF and an ultrasonic signal simultaneously
- RF carries location data, ultrasound is a narrow pulse

- The listener measures the time gap between the receipt of RF and ultrasonic signals
  - A time gap of x ms roughly corresponds to a distance of x feet from beacon
  - Velocity of ultrasound << velocity of RF
- May lead to incorrect readings. Solution: make RF signals long

LiDAR (Light Detection and Ranging)

It is sometimes called “laser scanning” or “3D scanning.”

The technology uses eye-safe laser beams to create a 3D representation of the surveyed environment.



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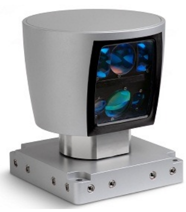
LiDAR (Light Detection and Ranging)



Uses a laser + imaging sensor to detect time-of-flight of IR light pulses.

Applications: remote sensing, autonomous driving/flying

- eg. Velodyne LIDAR Module

http://www.lidar-uk.com/how-lidar-works/

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LiDAR (Light and Radar)

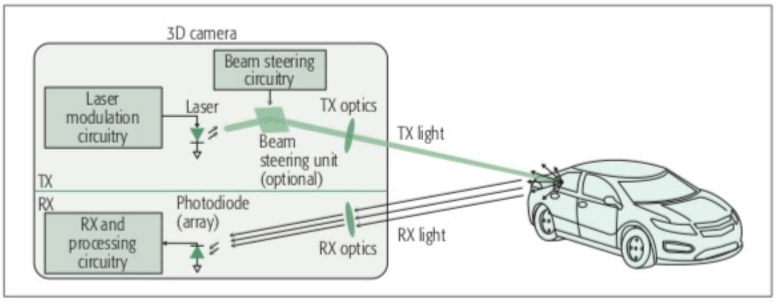

Figure 1. Basic lidar-based 3D camera architecture.

"Lidar System Architectures and Circuits"
https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8067701

LiDAR - Videos

https://www.youtube.com/watch?v=EBgdskiWlO8

https://www.youtube.com/watch?v=bUVtT7Gp2Z4

https://www.youtube.com/watch?v=DLj1HWNO5e4&spfreload=10

(basic explanation)

https://www.youtube.com/watch?v=EYbhNSUnIdU

KINECT 2

Uses CMOS array technology that measures time-of-flight.

IR light is pulsed at very high frequency and the return delay is measured by counting photons received in a given time window interval.

Made possible by advances in sensor technology.

For the targeted ranges, the tolerances are very small, in the nanosecond time scale.

A custom form of LiDAR

KINECT 2 - Videos

https://www.youtube.com/watch?v=OWzjn656kb4

https://www.youtube.com/watch?v=49FUfFkHRnQ

Technical details about Kinect 2

http://www.gamasutra.com/blogs/DanielLau/20131127/205820/The_Science_Behind_Kinects_or_Kinect_10_versus_20.php

Bibliography

Main:

- Book: Frank Adelstein, et. al. Fundamentals of Mobile and Pervasive Computing. McGraw-Hill. 2005. Chap 4.
- J. Hightower, et. al. A" Survey and Taxonomy of Location Systems for Ubiquitous Computing". TR UW-CSE 01-08-03, 2001. Section 1,2,3, 4.1-4.4. (http://www.csd.uoc.gr/~hy439/lectures11/hightower2001survey.pdf)
- Fundamentals of Wireless Sensor Networks: Theory and Practice (Wireless Communications and Mobile Computing) (chap. 10)
- "Evolution of Indoor Positioning Technologies: A Survey"
- (http://downloads.hindawi.com/journals/js/2017/2630413.pdf)

Complementary:

- http://webarchiv.ethz.ch/geometh-data/downloads/GPSBasics_en.pdf
- https://ieeexplore.ieee.org/document/4796924/
- https://www.accuware.com/blog/bluetooth-beacons-tracking/
- http://www2.egr.uh.edu/~ychen11/PUBLICATIONS/p118-chen.pdf