Localization technologies

Two fundamental questions:
- Where am I? (localization)
- What services are available? (service discovery)

Who wants to know and why?
- Public health and safety (especially in US)
  - Extended 9-1-1 system (www.fcc.gov/911/extended)
  - GPS
  - DOT efforts support crash beacons, traffic restoration
- Personal safety
  - Health monitors
- Commercial opportunities leveraging cellphone infrastructure
  - Dominant in Europe, Asia

The client may be phone, computer, PDA, specialized device
- Much of the intelligence will reside in the infrastructure.

Distinctions in localization
- Physical location vs symbolic or functional location
- Locally computed vs location provided by the infrastructure
- Absolute position vs relative position
- Accuracy – distance, % of situations, object speed
- Scale for which the method works

Physical measurement tools:
- Arrival time differences (need synch clocks)
  - Radio 30 m = 100 nsec
  - Ultrasound 3 cm = 10 usec
    - Needs calibration for +- 10% temp, humidity effects
- Signal strength or bearing (either 802.11 or cellphone)
- Direct sensors
  - Dumb – pressure, IR, sound
  - Smart – vision-based
  - Can be either personal, or part of infrastructure

GPS

For a good (not really even dated) survey, see the 1995 RAND policy study http://www.rand.org/publications/MR/MR614

- "accuracy is addictive"
- over $10B spent

History

- Sputnik (1957) could provide intermittent 2D navigation from a few minutes of observation
- US Navy TRANSIT system (1960's) 2D, slow, intermittent
  - First use of atomic clocks
- By 1970's Army, Navy, Air Force all had proposals
- AF lead in 1974-79 NAVSTAR design and development
- By 1980, a receiver fitted into a 25lb backpack
- 1994-95 24 satellites reached full operational status
- (at present, there are 32 US satellites, GLONASS, + European…)
- 2000 SA turned off, because local and wide area DGPS had made it irrelevant.

Commercial uses:

- Surveying – first to succeed
  - Tolerates intermittency, one-hour calibration times Cm accuracy achieved
  - Trimble most successful company
- Truck and package tracking
  - Qualcomm developed hybrid system in late 1980s
- Vehicle navigation
  - FAA executed WAA system by 2002
    - aim to replace surface navigation aids by 2005
    - critical requirement is RAIM
      - 1 sec warning of invalid signal
  - Garmin, others market to hikers, boats, aircraft
  - In-car systems becoming standard in luxury cars

Extended 9-1-1

9-1-1 Systems first defined and executed in the 1970's
- Internal to monolithic Bell system
- PSAPs = public safety answering points
- Caller ID gave automatic location info for wireline calls
- Analog cellphones handled by "virtual phone no"
  - This identifies the antenna location

Extended 9-1-1 (a long history)
- 1993 US studies of future digital communications (PCS)
- 1994 NPRM
- 1996 result: two-phase plan for wireless 9-1-1
  - phase 1 (1997 – 2001) report #, antenna location
  - phase 2 (2001 – 2005) report caller location (lat/lon)
    - 50-100 m precision, high reliability
- 1997 laws passed requiring compliance
- 2001-2 Reviews and mid course corrections

Hatfield report (on fcc website):
- 1990's focused on developing means of localization
  - E-OTD (extended observed time of arrival)
  - A-GPS ("assisted" by base station corrections)
  - No clear winner, multiple ways to succeed
  - Issues in rural deployment
    - Cost, antennas tend to line up along roads
- 2000's issues are dominated by infrastructure concerns
  - PSAP infrastructure an analog "Kluge"
  - Many independent companies now must cooperate
    - Nobody's in charge
    - Standards for protocols, deployment
    - Tests to determine best localization technology

Other examples:

- Aviation
  - VOR system (physical, locally computed, outside)
  - ILS vs GCA (local vs infrastructure computing)
  - Collision avoidance systems (relative coordinates)
  - Inertial navigation (analysis of accuracy very different)
- GPS, possibly augmented as in E911 systems by
  - cellphone infrastructure
  - Outside only ??
- 802.11-based
  - MS-RADAR and some products
- Radio-based, using product ID tags or "active badges"
- Ultrasound-based
  - ATT "bats" (require ceiling receiver arrays)
  - Crickets
- Smart floor with pressure sensors

For further reading (on website),
see IEEE Computer August 2001
and IEEE Pervasive Computing, no. 3

Table 1. Current location sensing technologies.

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
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
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