INTRODUCTION TO SPATIAL SENSING AND REASONING FROM SENSOR DATA

Dr TIAN Jing

tianjing@nus.edu.sg

Spatial reasoning

- Global (absolute) position
  - Position within general global coordinate reference
  - Global Positioning System or GPS (longitudes, latitudes)
- Relative position
  - Based on selected coordinate reference
  - Distances between sensors (no relationship to global coordinates)
- Symbolic position information
  - “Interaction classroom”, “PGP canteen”

Introduction

Floor pressure

Ultrasonic time of flight

WiFi

Array microphone

Kinect 3D

Laser range-finding

Passive Infrared sensor

Reference:
- http://web.cse.ohio-state.edu/~xuan/courses/5432/5432_localization.ppt.
- https://www.sensorsmag.com/components/smartphone-sensor-evolution-rolls-rapidly-forward

Introduction

- Proprioceptive sensors *(internal)*
  - Measure values internally to the system (robot), e.g. motor speed, wheel load, heading of the robot, battery status
- Exteroceptive sensors *(external)*
  - Information from the external environment, e.g., distances to objects, intensity of the ambient light.
- Passive sensors
  - Measure energy coming from the environment
- Active sensors
  - Emit their proper energy and measure the reaction, but some influence on environment

Reference: https://www.eliko.ee/choose-right-indoor-positioning-system/

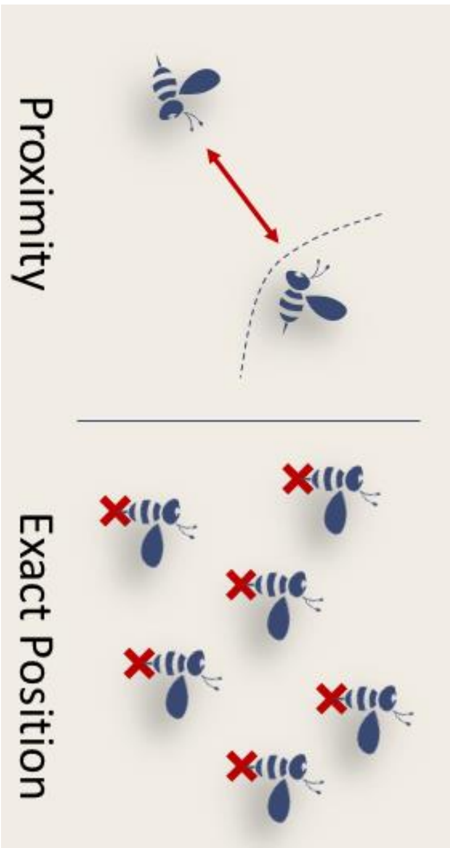
Spatial reasoning

Positioning system consists of Navigation sources (at known locations) and Users (their locations need to be determined)

Information from location sensors	Positioning principle
Binary information if communication is possible or not	Proximity
Quality of communication link • Received signal strength (RSS) • Bit error rate (BER) • (RFID) read success rate	Fingerprinting
Time of arrival (TOA)	Trilateration
Time difference of arrival (TDOA)	Multilateration
Angle of arrival (AOA)	Angulation

Spatial reasoning: Proximity

- Proximity: User's position = position of closest navigation source



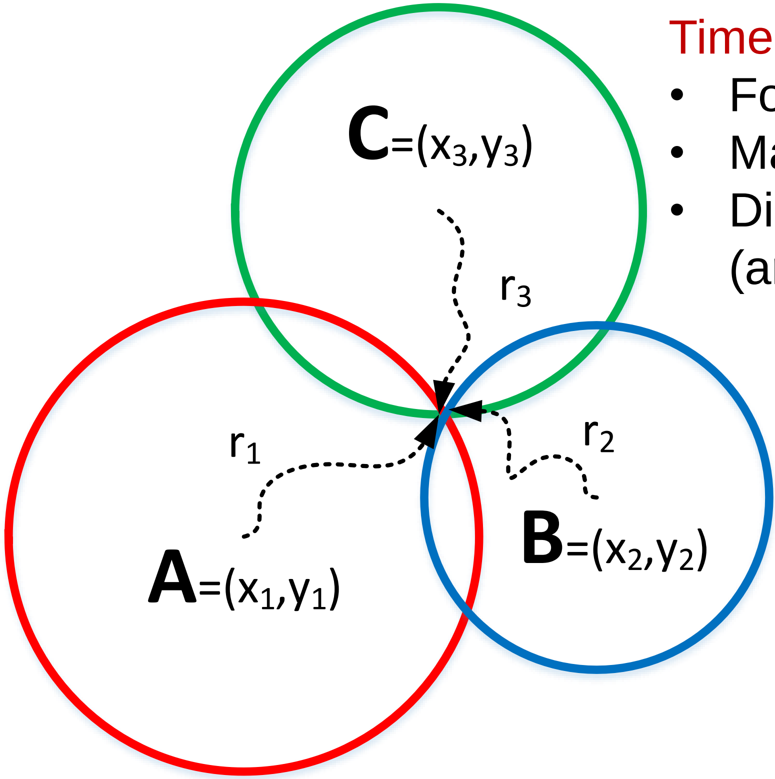
	GPS	WI-FI	NFC
Recommended for	Macro-location and out of store use-cases	In-store use-cases	Close proximity, secure interaction
Some potential uses	Near-store notifications and offers, pre-arrival customer 'check-in'	In-aisle notifications and offers, in-store navigation, hands-free payment	Payments, product tagging
Ease of set up and maintenance	Medium-high	Medium	Medium
Range	Long	Medium-low	Close
Accuracy	Medium-low	Medium	High
Ease of use for consumer	Medium	Medium-high	Medium-high
Energy efficiency on consumer device	Medium-low	Medium-high	High

Reference:
- https://www.accenture.com/us-en/insight-beacons-location-based-technology-revolutionizing-how-retailers-business
- https://nanotron.com/EN/2017/04/19/professional-location-awareness-is-presence-proximity-and-tracking/

Spatial reasoning: Fingerprinting

- Use an n-dimensional space containing *received signal strength* (RSS) vectors $(rss_1, rss_2, \cdots, rss_n)$ of reference points; n = number of navigation sources.
- Nearest neighbour
  - Find reference point ref for which the RSS is the largest.
  - Decision: $POS_{user} := POS_{ref}$
- Multiple nearest neighbour
  - Find k (e.g., three) “closest” reference points
  - Decision: $POS_{user} := center(POS_{ref1}, \cdots, POS_{refk})$
- Interpolation
  - Find three “closest” reference points
  - Use interpolation algorithm on triangle to obtain POS_{user}

Spatial reasoning: Trilateration



Time of Arrival (TOA)

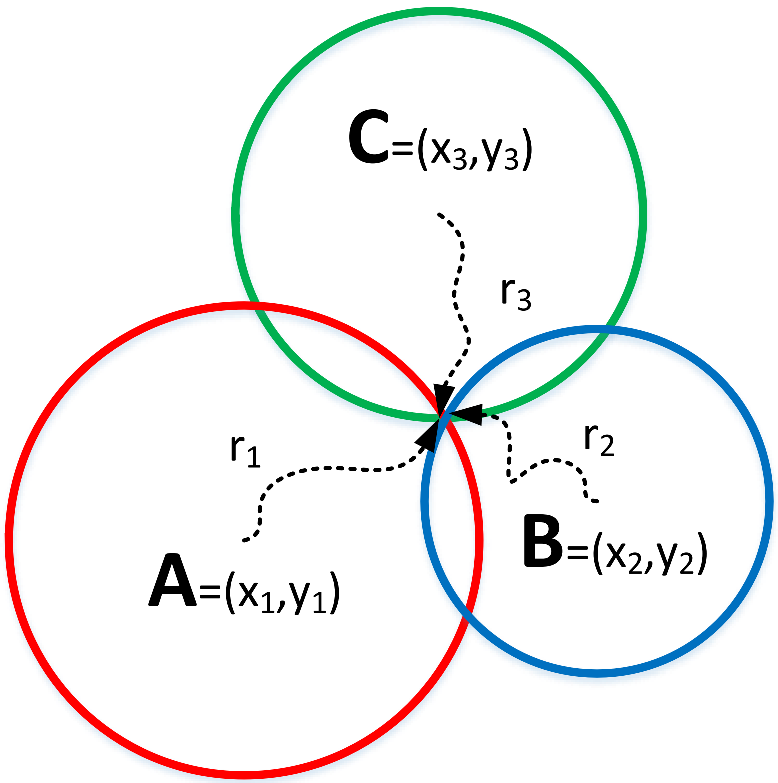
- Foghorn is sounded precisely on the minute mark
- Mariner has an exact clock and notes elapsed time
- Distance = propagation time * speed of sound (around 335 meter/second)

With three measurements, we have

$$(x - x_1)^2 + (y - y_1)^2 = r_1^2$$
$$(x - x_2)^2 + (y - y_2)^2 = r_2^2$$
$$(x - x_3)^2 + (y - y_3)^2 = r_3^2$$

<Taken 2>, Locating Dad,
https://www.youtube.com/watch?v=WWeYvvN-F5s

Spatial reasoning: Trilateration



Time Difference of Arrival (TDOA)

- Uses propagation delay between mobile terminal and multiple base stations
- No global time
- Only time differences are known

The travel time of a signal from a reference station to the current position is given by the distance divided by the signal propagation speed v, we can obtain the time difference of arrival Δt_{AB} (between source A and B) and Δt_{BC} (between source B and C) as:

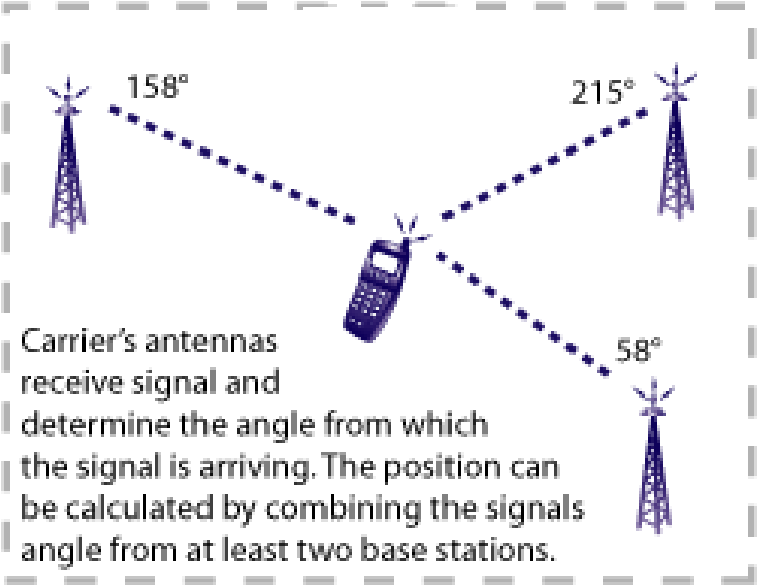
$$\Delta t_{AB} = \frac{1}{v}\sqrt{(x-x_1)^2+(y-y_1)^2} - \frac{1}{v}\sqrt{(x-x_2)^2+(y-y_2)^2}$$

$$\Delta t_{BC} = \frac{1}{v}\sqrt{(x-x_2)^2+(y-y_2)^2} - \frac{1}{v}\sqrt{(x-x_3)^2+(y-y_3)^2}$$

Spatial reasoning: Angulation

Angle of arrival (AOA): Base station measures angle to mobile terminal

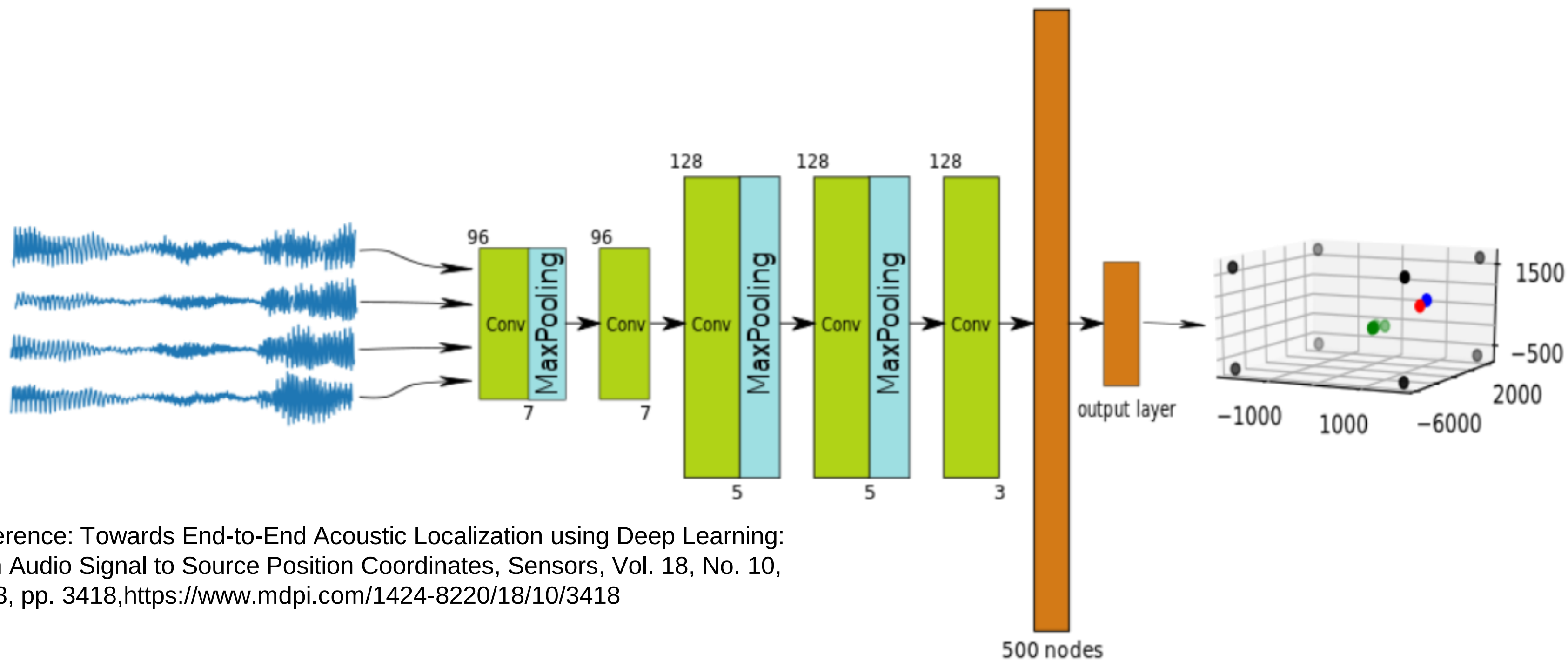
- Rotate antenna to the highest RSS value
- Derive angle from RSS values of individual antennas in an antenna array.



Reference: http://www.e-cartouche.ch/content_reg/cartouche/LBStech/en/html/LBStechU2_poslabel1.html

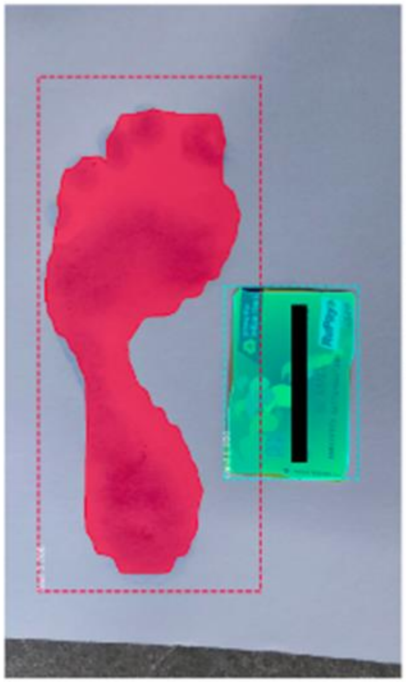
Spatial reasoning: Acoustic

Our system obtains the position of an acoustic source from the audio signals recorded by an array of M microphones. Given a reference coordinate origin, the source position is defined with the 3D coordinate vector $\mathbf{s} = \begin{pmatrix} s_x & s_y & s_z \end{pmatrix}^\top$. The microphones positions are known and they are defined with coordinate vectors $\mathbf{m}_i = \begin{pmatrix} m_{i,x} & m_{i,y} & m_{i,z} \end{pmatrix}^\top$ with $i = 1, \ldots, M$. The audio signal captured from the i^{th} microphone is denoted by $x_i(t)$. This signal is discretized with a sampling frequency f_s and is defined with $x_i[n]$. We assume for simplicity that $x_i[n]$ is of finite-length with N samples. This corresponds to a small window of audio with duration $w_s = N/f_s$, which is a design parameter in our system.



Reference: Towards End-to-End Acoustic Localization using Deep Learning: from Audio Signal to Source Position Coordinates, Sensors, Vol. 18, No. 10, 2018, pp. 3418,https://www.mdpi.com/1424-8220/18/10/3418

Spatial reasoning: Vision



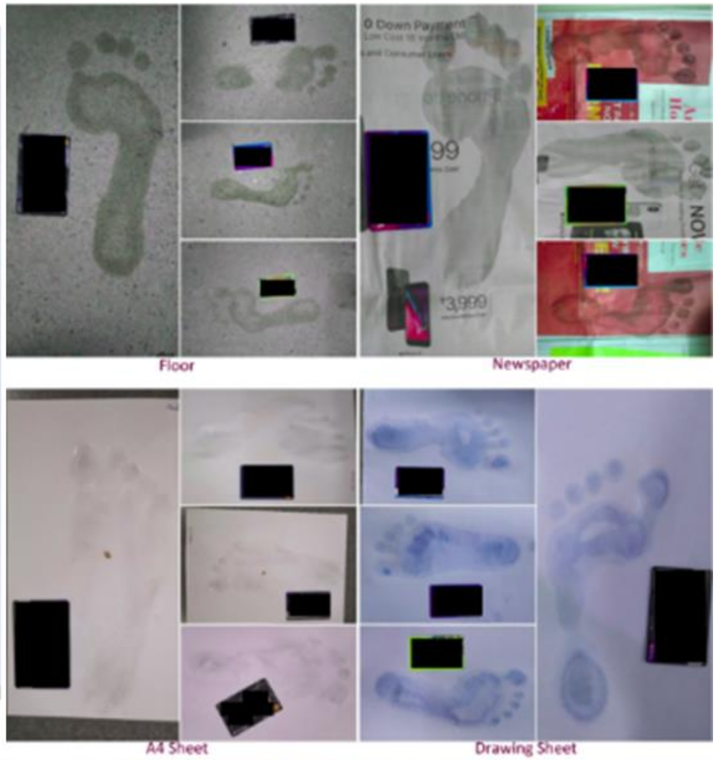


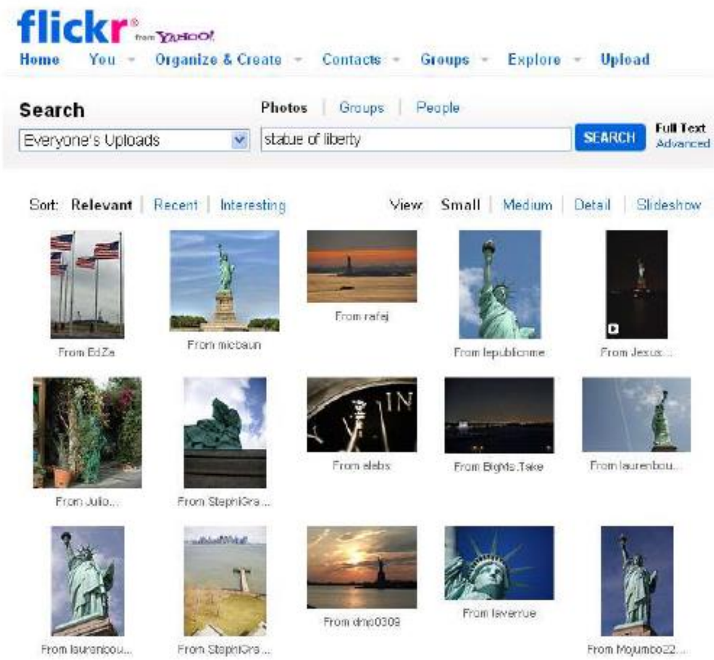
Fig-2: Impressions of wet feet on different background

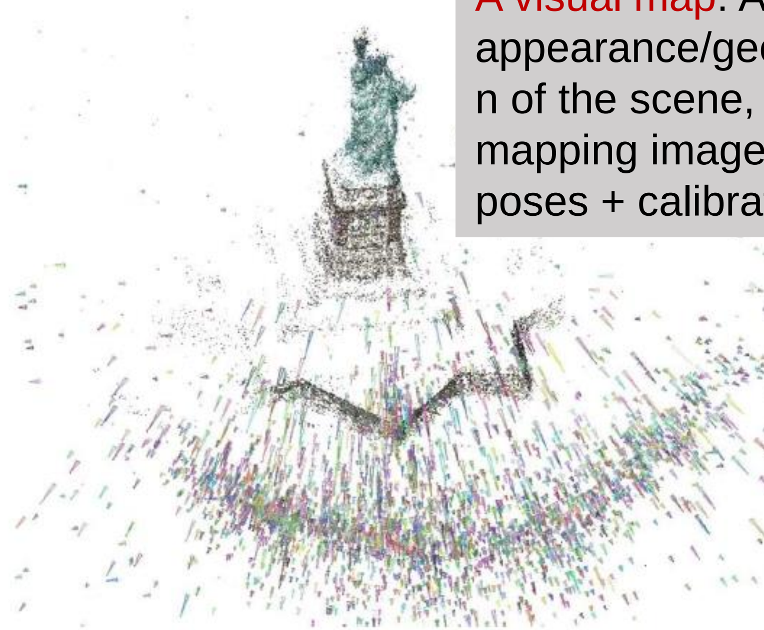
Use A4 paper as a reference

Height: 8.08 inches
Breadth: 3.41 inches
Arch type: High

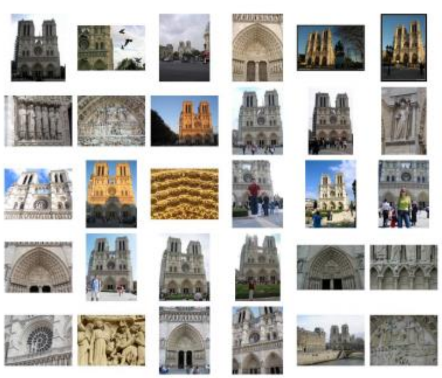
Reference: https://labs.imaginea.com/post/measuring-feet-using-deep-learning/

Spatial reasoning: Vision





A visual map: A representation of appearance/geometry/description of the scene, including a set of mapping images with camera poses + calibration.



Reference:

- M. Goesele, et al., Multi-View Stereo for Community Photo Collections, ICCV 2007, https://grail.cs.washington.edu/projects/mvscpc/
- N.Snavely, et al., Exploring Photo Collections in 3D, SigGraph 2006. http://phototour.cs.washington.edu/

Thank you!

Dr TIAN Jing
Email: tianjing@nus.edu.sg

