CMPE58C: Sp. Tp. Mobile Location Tracking & Motion Sensing

Introduction

Can Tunca
-
Fall 2022

About Me

- Can Tunca
- Currently R&D Manager at Pointr
  - Founded in 2014
  - Offering an ecosystem around location services (especially indoor positioning)
  - Currently a market leader with close to 100 employees
- MS and PhD in Bogazici University, CMPE, NETLAB
  - MS Thesis on Wireless Sensor Networks (concept currently evolved to IoT)
  - PhD Thesis on Pervasive Healthcare with Wearable Inertial Sensors

About the Course

Purpose

Location Tracking

- Determining initial position and then tracking it in real-time
- Example: Determining where to put the “blue dot” on a consumer map
- We will especially focus on indoor positioning

What are we tracking?

Mobile Devices

- Mainly smartphones
- Any other device that supplements the smartphone ecosystem: e.g. smartwatches
- Any other mobile device with a small form factor: e.g. wearable IMUs
- Devices interacting with humans

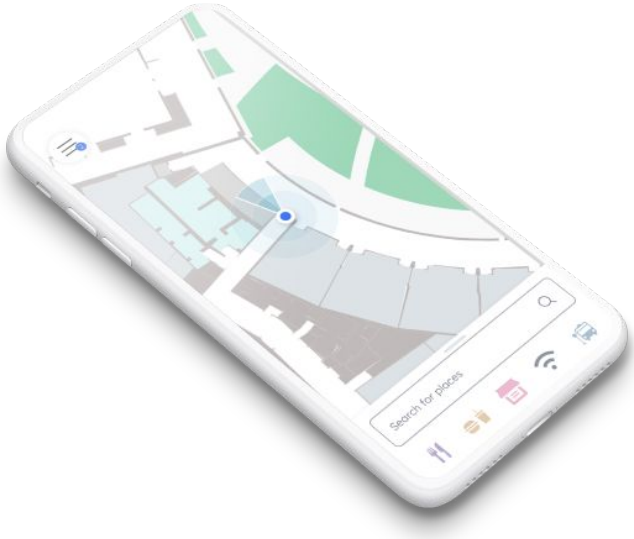
Additionally

Motion Sensing

- Mostly focusing on inertial sensors
- Intricacies of movement in addition to location: e.g. human gait, gestures

About the Course

- Location Tracking is a very broad topic
- This course will favor breadth over depth
  - We will try to cover as many technologies and methods/algorithms as possible
  - Applied context in addition to theoretical background
- Special focus on Indoor Positioning
  - An uncracked problem to this day
  - Outdoor already has a go-to solution: GPS
  - Attracting interest from both the academia and industry



Location Use Cases

- Navigation
  - We are already using it daily
  - Indoor navigation is still unsolved with many unique challenges (e.g., no roads to snap to, turn-by-turn directions should be natural)
- Analytics
  - Common statistics: Footfall (how many people), Dwell time (how much time)
  - Important for POI (point of interest) placement optimization
    - Examples: Which products go on which racks in a supermarket, which flight is assigned to which gate, where to place stores in a mall and in which order?
  - Occupancy management, especially after COVID
    - Smart workspaces, hybrid working schedules

Location Use Cases

- Asset tracking
  - Tracking of mobile valuable assets
  - Examples: Ultrasound machines in a hospital, trolleys and luggages in an airport, pallets in a warehouse (or any other goods really)
- Geofencing
  - Allowing scenarios triggered by location
  - Geofence: Pre-defined regions as small as a room or as big as a country
  - Examples: Sending a message to people in a specific building, activating A/C whenever a person enters a room, A mobile app changing settings based on the user’s current city

Location Use Cases

- Smart cities, buildings, workplaces, homes...
  - Smart <Insert word here>: Definitely a buzzword ... but we are headed there
  - Not possible without location awareness
- Augmented reality (AR)
  - Precise location is required for any meaningful AR application
  - Digital twins (another buzzword!)
- Healthcare
  - Gait analysis: More about how a person moves rather than where he/she is
  - Motion sensing: e.g., Diagnosis and follow-up of motor disorders
  - Contact tracing (especially after COVID)
  - Hospitals may benefit from all other use cases

What is required of you

- Paper Review & Presentation - 20%
- Course Project - 40%
- Final Exam - 40%

Paper Review & Presentation

- Review a paper of your own choosing
  - Should be recent (last 5 years)
  - Journal papers preferred, but could be a conference paper from select conferences
  - Journal/conference recommendations will be shared in the coming weeks
  - Selected papers should be confirmed by me
- A short presentation to explain the paper to the class
  - 15-20 minutes
  - A deck of ~10 slides
  - Will allow the class (and me) to ask questions and discuss
- Timeline to be announced... (Likely to start around week 5)

Course Project

- A hands-on project to demonstrate application of theory
  - Could be a mobile app implementing a solution discussed in class, or found in a paper, or a novel idea
  - Could be a solution on a pre-recorded dataset found on web
  - Comparison to some ground truth or some other approach, test results in numerical and/or visual form
- Two stages: Project Proposal (10%) and Final Report/Presentation (30%)
- Project Proposal (around middle of the term, exact time TBA)
  - 1-2 pages proposal document, outlining idea and method
  - 10 minutes presentation
- Project Final Report/Presentation (end of the term)
  - Final report
  - 20-30 minutes final presentation + demo (if applicable)

What this course is NOT about

- You won't be taught anything on mobile app development
  - Do not be misled by "Mobile" on the course title, it does not mean "Mobile Apps"
  - There are quite a lot of resources on the web (if you choose to build a mobile app for your course project)
- This is not a hardware course
  - We will not go into too much detail on the physical layer of radio technologies
  - We will mostly focus on what hardware can provide us in terms of building algorithms
- This is not a robotics course
  - Robotics have a whole different set of goals and technologies/sensors
  - We are mostly interested in devices that are interacting closely with humans
  - Though there will be some overlap in the covered algorithms

Syllabus Overview

- Introduction (Covered in this deck)
  - Brief history of location tech and mobile devices
  - Overview of positioning architectures and approaches
- Technology Overview
  - GPS, Bluetooth, WiFi, 5G, UWB, RFID, Inertial, Camera-Based, VLC, Geomagnetic, Sound...
- Outdoor Positioning
  - GPS (Global Positioning System)
  - Time-of-flight
  - Trilateration
  - Challenges of working with the globe (geo-coordinates, datum and projections)

Syllabus Overview

- Radio-Based Positioning
  - Radio fingerprinting
  - RSSI-based methods
  - Bluetooth, WiFi, UWB
- Cellular Positioning
  - 5G positioning
  - Angle-of-arrival
  - Beamforming
  - Pico-cells, femto-cells
- Inertial Sensors
  - IMUs: accelerometer, gyroscope, magnetometer
  - Sensor fusion basics
  - Attitude (3D-orientation) estimation
  - Barometer, altitude/floor tracking
- Pedestrian Dead Reckoning
  - Human gait basics
  - Inertial navigation

Syllabus Overview

- Indoor Positioning
  - Combining different positioning schemes
  - Fusion: Bayesian filters (Linearized Kalman filters, particle filters)
  - Making use of context/map information
  - Challenges, open problems

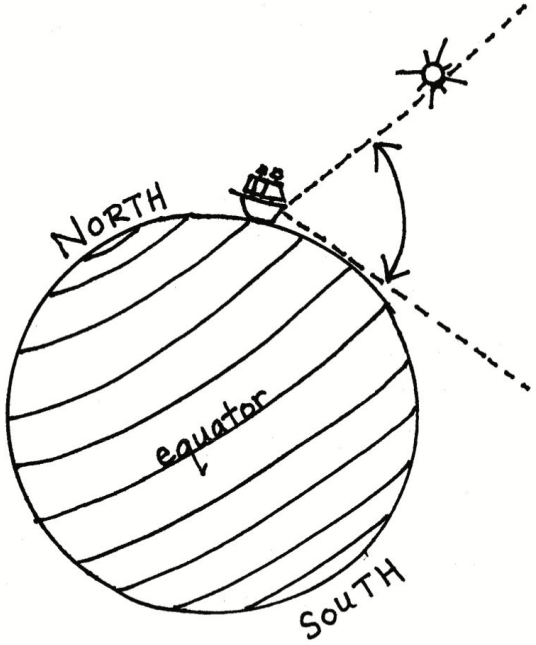
Syllabus Overview

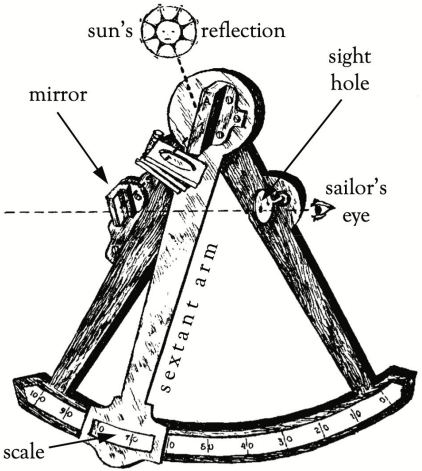
If time permits...

- Mapping Basics
  - Digital maps
  - Automated ML-based map digitization
  - Wayfinding and navigation
  - SLAM basics
- Augmented Reality on Mobile Phones
  - AR basics
  - ARKit, ARCore
  - LIDAR
- Case Study: Human Motion Tracking for Pervasive Healthcare
  - Gait analysis basics
  - ML for human motion tracking
  - Fall risk assessment

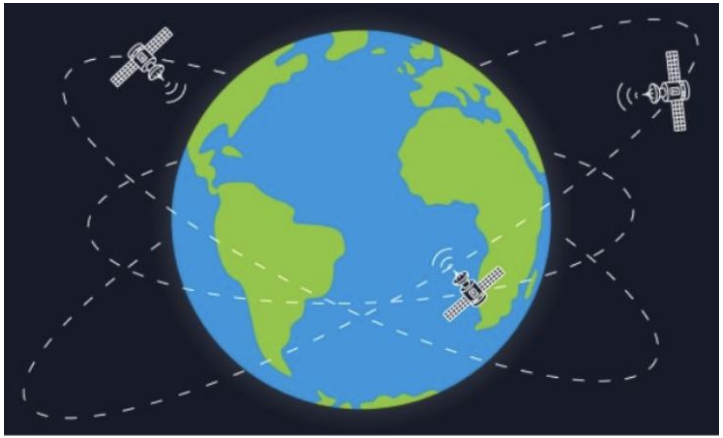
Brief History: Back in the day...

- Sextant and clock to determine latitude and longitude
- Compass for bearing
- Dead reckoning via ship speed
- Lighthouses, navigation beacons
- Principles still apply today!





Brief History: Modern Age

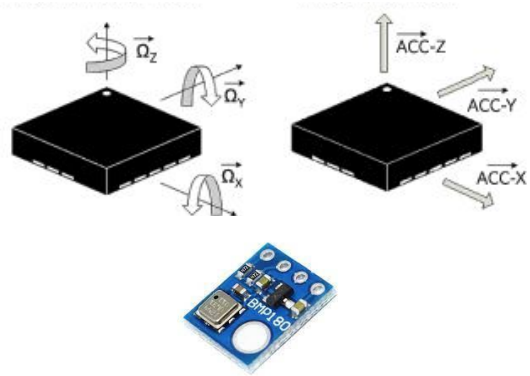


- 1933: Radar
- 1978: **GPS** is born
  - First satellite launched in 1978
  - Fully operational in 1995
  - First consumer devices appeared around 1999
- 2005: Google Maps
  - A big step towards making location tech mainstream
- 2007: Smartphones with GPS
  - A-GPS (Assisted-GPS): GPS + Cellular + WiFi + anything else

Brief History: Era of Smart Devices

- GPS is still the standard for outdoors, but not suitable for indoors

  (or any place without line-of-sight to overhead satellites)
- Other radio technologies to the rescue
  - WiFi, Bluetooth, UWB...
  - Cellular networks (precise location to improve service)
- Sensors
  - Inertial (motion) sensors: accelerometer, gyroscope
  - Magnetometers (compass really)
  - Barometer (good for tracking altitude)
  - Camera, microphone and anything else...



Location Architectures

DEVICE-BASED

- Location calculated on the device
- e.g. Smartphone calculating its own location
- **Pros:** Simpler (not distributed), potentially less delays, no reliance on a data network (no need to transfer location to the device), more privacy
- **Cons:** Limited by the device resources, limited by what the device can sense
- **Examples:** GPS, BLE beacons

INFRASTRUCTURE-BASED

- Location calculated on the infrastructure
- e.g. Multiple base stations calculating the location of a smartphone
- **Pros:** Allows more sophisticated hardware and algorithms, target device could be simpler (e.g. tracking a tag instead of a smartphone)
- **Cons:** Complex distributed system, need to relay calculated location to device
- **Examples:** Radar, cellular positioning

Positioning Modes

ABSOLUTE

- Location anchored on the World or a floor plan
- Examples:
  - You are at latitude, longitude: 42.0° N, 120.2° W
  - You are at Room 3 on Level 1
- Best computed via signals from outside

RELATIVE

- Position relative to device's initial location/orientation
- Examples:
  - You traveled 10 meters straight
  - You rotated 30 degrees to your right
- Best computed via data from sensors on the device

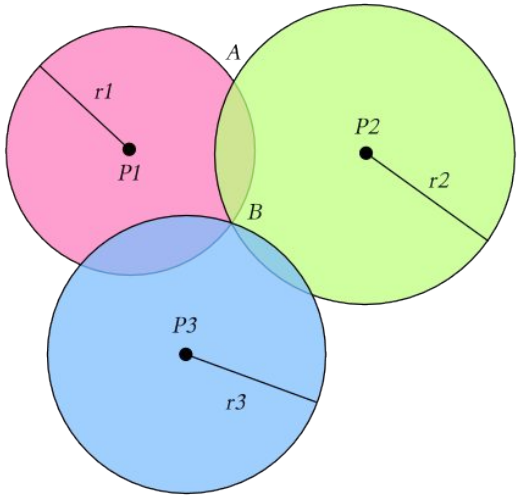
Both have their strengths/weaknesses,
but it is possible to combine them! (Spoiler: Sensor Fusion!)

Positioning Approaches: Proximity/Identity Based

- **Concept:** Device is detected to be near a known location
- Scanning an ID card (RFID), your momentary location would be known
- Being connected to a WiFi AP, rough location would be known
- Being near a Bluetooth beacon

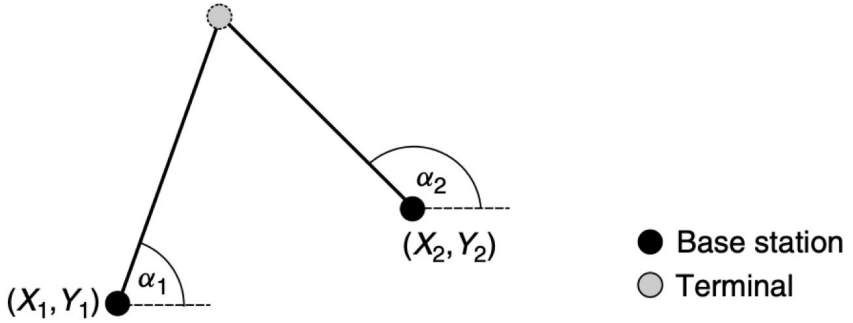
Positioning Approaches: Lateration

- **Concept:** Obtaining distances to anchors with known locations, then building a geometrical model
- GPS uses lateration!
- Trilateration: Lateration with 3 anchors
- How to estimate distance:
  - Time-of-flight (TOF)
  - Radio signal strength (aka RSSI)
  - Time difference of arrival (TDOA): Time difference between multiple anchors



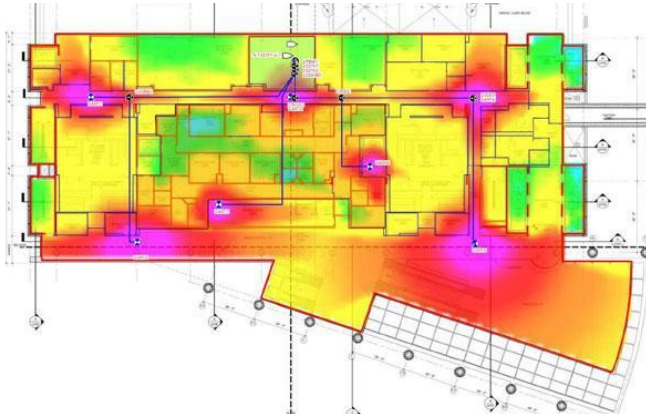
Positioning Approaches: Angulation

- **Concept:** Rather than using distances to multiple anchors, use angles
- May require fewer anchors if readings are accurate enough
- Directional antennas, antenna arrays
- Usually requires more complex hardware



Positioning Approaches: Fingerprinting

- **Concept:** Match currently observed context to some pre-built database, aka pattern matching
- Example: Build a radiomap of WiFi access points on a floor,
  then the device scans APs around and tries to match to this radiomap
- Requires training/survey of the environment
- The environment may change!



Positioning Approaches: Dead Reckoning

- **Concept:** Tracking relative movement starting from a known position
- Example: Accumulate velocity readings from a start location
- Typically done with inertial sensors
- May decay over time, unless corrected with absolute location estimates (can be used for “filling the gaps” between absolute location estimates)