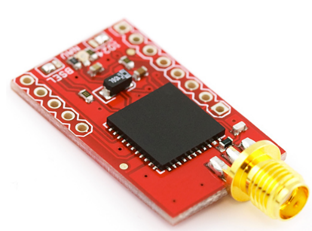
University of Massachusetts Amherst

Lecture 8–Global Positioning System

ECE 197SA – Systems Appreciation

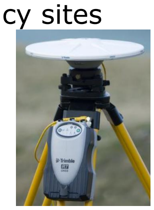
Global Positioning System

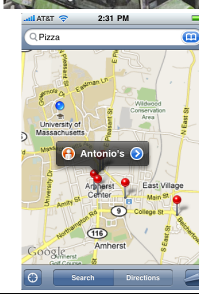
- Many systems require location information
  - Just to be clear:
    - » GPS ≠ car navigation system
    - » GPS is part of car navigation system
- Today's lecture:
  - Determining location
    - » Different techniques
  - Global Positioning System (GPS)
    - » Principles
    - » Implementation



Location-Based Systems

- Many systems require location information
- Navigation
  - Car: Location (2D) + maps + routing
  - Plane: Location (3D), …
  - Military: Troop movement, missile guidance, …
- Emergency response
  - Locate and navigate to emergency sites
- Surveying
  - Determine property boundaries
- Precision agriculture
  - Track yield, adjust fertilization
- Location-based information service





"Where in the world am I?"

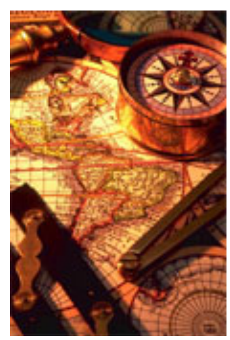
- It is the day after your 21st birthday. You wake up with a headache and you have no idea where you are. What are possible ways of determining you location?

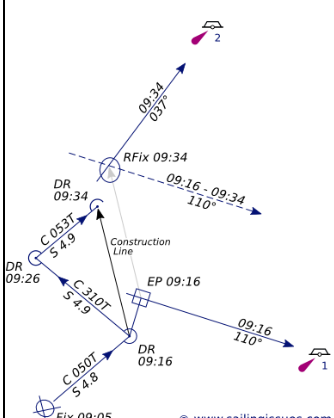
Age-Old Problem

- Hundreds of years ago on a continent far, far away:

Dead Reckoning

- Process
  - Start at known position
  - Keep track of all movements
    - » Heading (from compass)
    - » Distance (from speed and time)



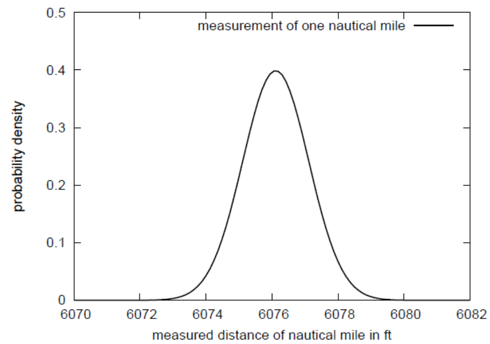


What could possibly go wrong?

What could possibly go wrong?

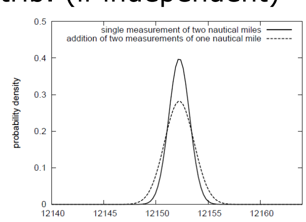
Representation of Errors

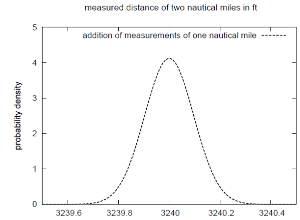
- Measurement error often follows Normal distribution
  - Probability density function $f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{\frac{-(x-\mu)^2}{2\sigma^2}}$
  - Mean μ, standard deviation σ
- Example: measurement of nautical mile
  - Mean: 6,076.1 feet
  - Hypothetical standard deviation: 1 foot
  - 68.2% chance of measuring within +/-1 foot
  - 95.4% chance of measuring within +/-2 feet



Addition of Errors

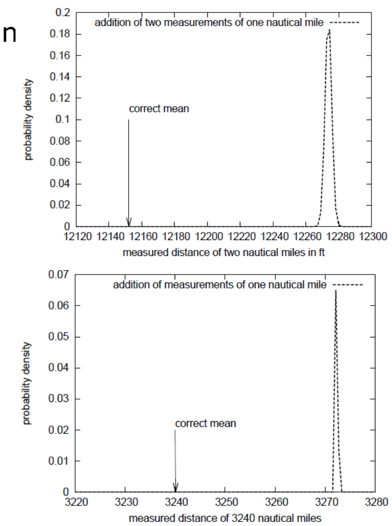
- The good case: errors are independent
- Addition of measurements
  - Measurements X_1, X_2 with distributions $N(\mu_1,\sigma_1^2)$, $N(\mu_2,\sigma_2^2)$
  - Addition of X_1 and X_2 also normal distrib. (if independent)
    - » $X_1+X_2 = N(\mu_1+\mu_2,\sigma_1^2+\sigma_2^2)$
- Two measurements of 1 nautical mile each
  - Std. dev. increases by √2
  - 68.2% chance of measuring within 1.41 feet
- London, UK to Norfolk, VA:
  - Approx. 3240 nautical miles
    - » 3240 measurements
  - Std. dev. of sum σ=√3240 ft=58.5 ft





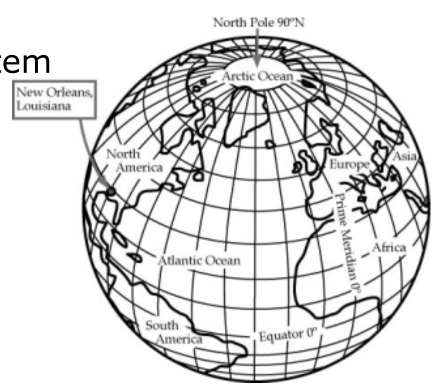
Addition of Errors

- The bad case: errors are systematic
- Addition of measurements
  - Systematic error affects the mean
- Two measurements of 1 nautical mile each
  - Example: measurement is 1% more than real value
  - Mean of sum increases by 1%
- London, UK to Norfolk, VA:
  - 3240 nautical miles measured average 3240+32.4=3272.4 real miles!
- Dead reckoning is difficult since errors add up and are likely systematic



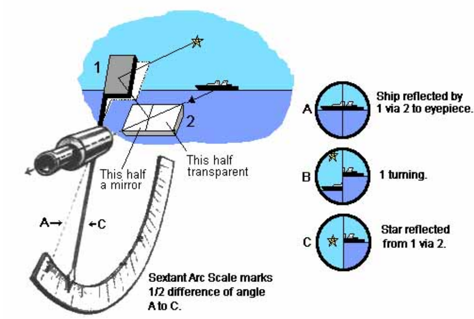
Absolute Position

- Dead reckoning: relative position
  - Difficult to measure precise heading, speed time
  - Errors accumulate
  - More inaccurate with longer journeys
- Better: determine absolute position
  - Independent of "history"
- Geographic coordinate system
  - Longitude and latitude
- How can latitude be determined?
- How can longitude be determined?



Latitude

- Latitude affects position of sky over observer
  - Sun's position
  - Stars' positions
- Sextant to measure angle against horizon



Longitude

- British government offered £20,000 in 1714
  - Accuracy within 30 nautical miles (1/2 degree)

Longitude

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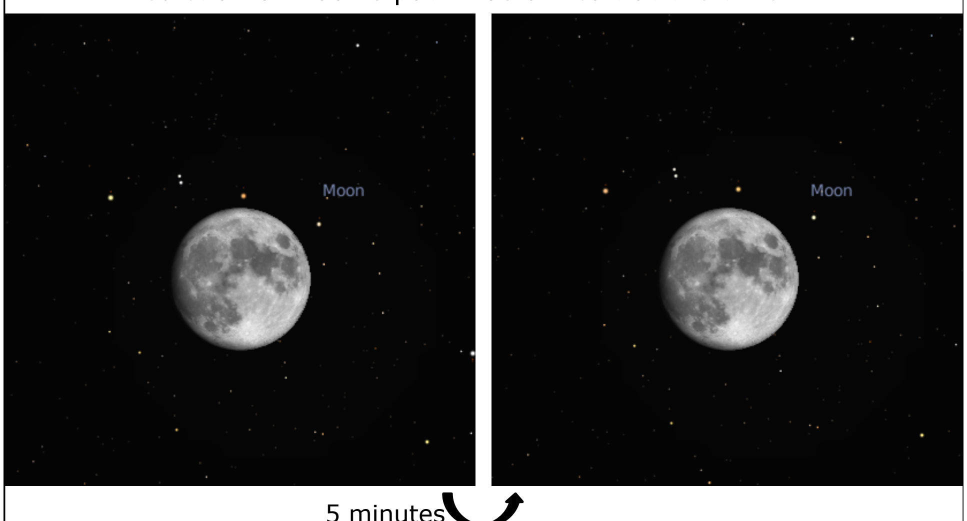
  - Accuracy within 30 nautical miles (1/2 degree)
- Time is key to longitude
  - Sun moves 15° per hour (1/4 degree per minute)
  - Local noon can be observed
- Solutions
  - Lunar distance method
  - Marine chronometer

Lunar Distance Method

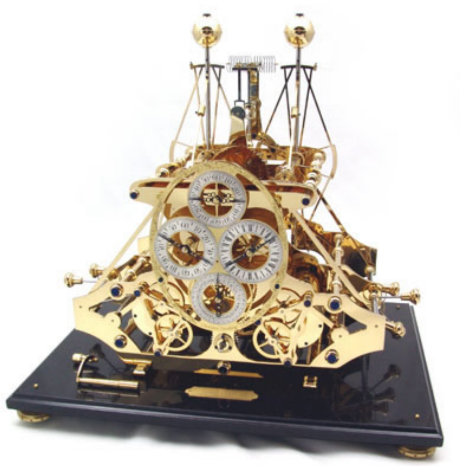
- Position of Moon relative to background stars
  - Prediction of Moon's path was difficult at the time



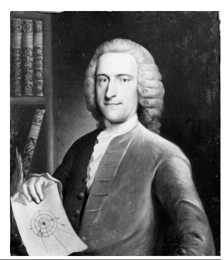
5 minutes

Marine Chronometer

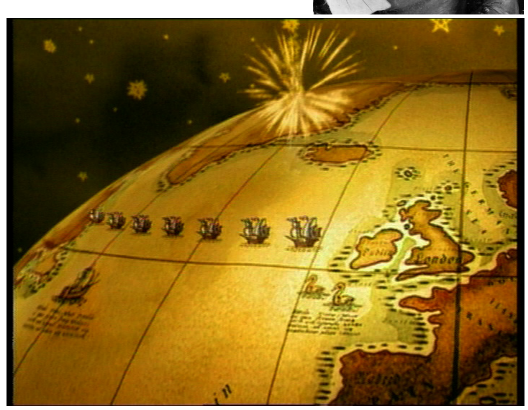
- John Harrison's chronometers
  - Compensate for ship's movement, environmental conditions



Other Approaches



- William Whiston
- Solution I (with Humphrey Ditton)
  - Rockets from known location
  - Difference between light and sound determines distance
  - Allows for trilateration
- Solution II
  - Geomagnetic inclination as unique characteristic
  - Developed inclination map
- Many others



And the winners are…

Significant recipients

[edit]

Many persons benefited from the awards offered by the Board. In total, over £100,000 was given in the form of encouragements and awards. Significant among these are:[3][4]

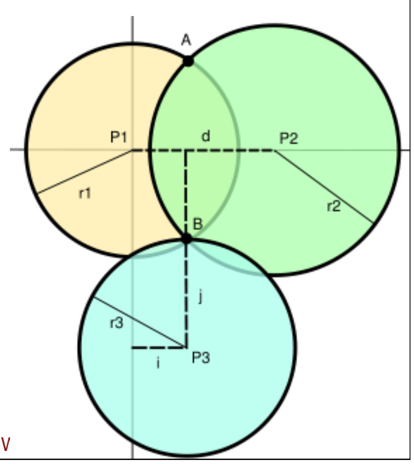
Name	Amount	Reason
John Harrison	£14,315	Received in several payments. £4,315 was awarded during his work on his chronometers from 1737 to 1764 with the remaining £10,000 provided in 1765.
Tobias Mayer	£3,000	Contributions to the lunar distance method. His widow received the money due to Mayer's untimely death.
Thomas Mudge	£3,000	Construction of chronometers with improvements to Harrison's designs.
John Arnold	£3,000	Design and improvements to chronometers.
Thomas Earnshaw	£3,000	Design and improvements to chronometers.
Charles Mason	£1,317	Various contributions and improvements on Mayer's lunar tables.
Jesse Ramsden	£615	Design and construction of a superior dividing engine (£300) and publishing the design (£315).
Larcum Kendall	£500	Construction of a copy of Harrison's *H-4*.
Leonhard Euler	£300	Contributions to the lunar distance method in aid of Mayer.
Nathaniel Davies	£300	Design of a Lunars telescope for Mayer

Harrison also received £8,750 from Parliament in thanks for his work, bringing his total lifetime award to £23,065.

from wikipedia.com

Global Position System

- Satellites on known orbits send periodic signals
  - Signal contains very accurate time information
- Distance to satellite
  - Propagation delay
- Trilateration to determine coordinates
  - Requires at least 4 satellites
- Provides location and time



GPS Satellites

GPS Satellite Orbits

- Different orbits
  - Sufficient satellites visible at any time

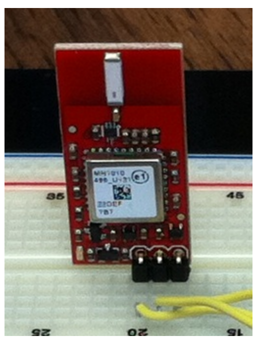
GPS Receiver

- Traditional receiver with antenna

- Embedded receiver

GPS Demo

- GPS receiver very small
- GPS interface very easy to use
  - Simple serial connection
  - 3 wires for data and power
  - Can connect directly to computer or microcontroller
- Example:

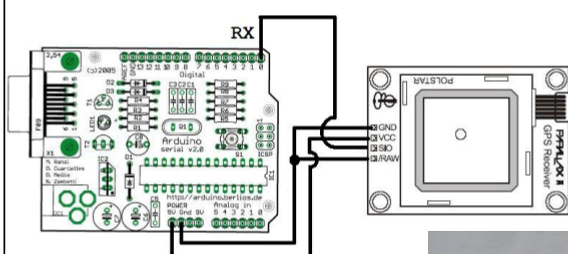


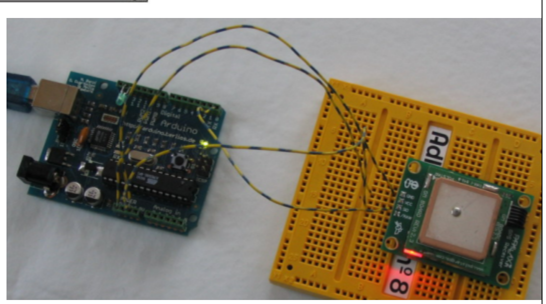
GPS Demo

- GPS sends information periodically
- GPS messages
  - Location, precision, time, speed, etc.
- Example:
  - **`$GPRMC,225446,A,4916.45,N,12311.12,W,000.5,054.7,191194,020.3,E*68`**
  - Interpretation:
    - » **`225446`** Time of fix 22:54:46 UTC
    - » **`A`** Navigation receiver warning A = Valid position, V = Warning
    - » **`4916.45,N`** Latitude 49 deg. 16.45 min. North
    - » **`12311.12,W`** Longitude 123 deg. 11.12 min. West
    - » **`000.5`** Speed over ground, Knots
    - » **`054.7`** Course Made Good, degrees true
    - » **`191194`** UTC Date of fix, 19 November 1994
    - » **`020.3,E`** Magnetic variation, 20.3 deg. East
    - » **`*68`** Mandatory checksum

GPS in Embedded Systems

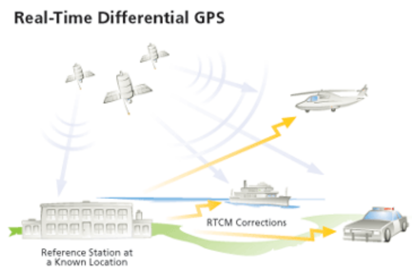
- Very easy to use integrate





GPS Limitations

- Requires view of sky
  - Does not work in buildings
  - Difficult with foliage, high-rise buildings
- Accuracy limited
  - Horizontal accuracy in the order of 10s of ft
- Differential GPS
  - Reference to known location
  - Correction broadcast via UHF
- Wide Area Augmentation System (WAAS)
  - Reference to know location
  - Correction broadcast via satellites
  - WAAS-enabled receivers can compensate



Courses in ECE Curriculum

- ECE 415 – Senior Design Project I
- ECE 416 – Senior Design Project II

Upcoming…

- Next week: digital camera
  - Image sensors
- Moodle quiz