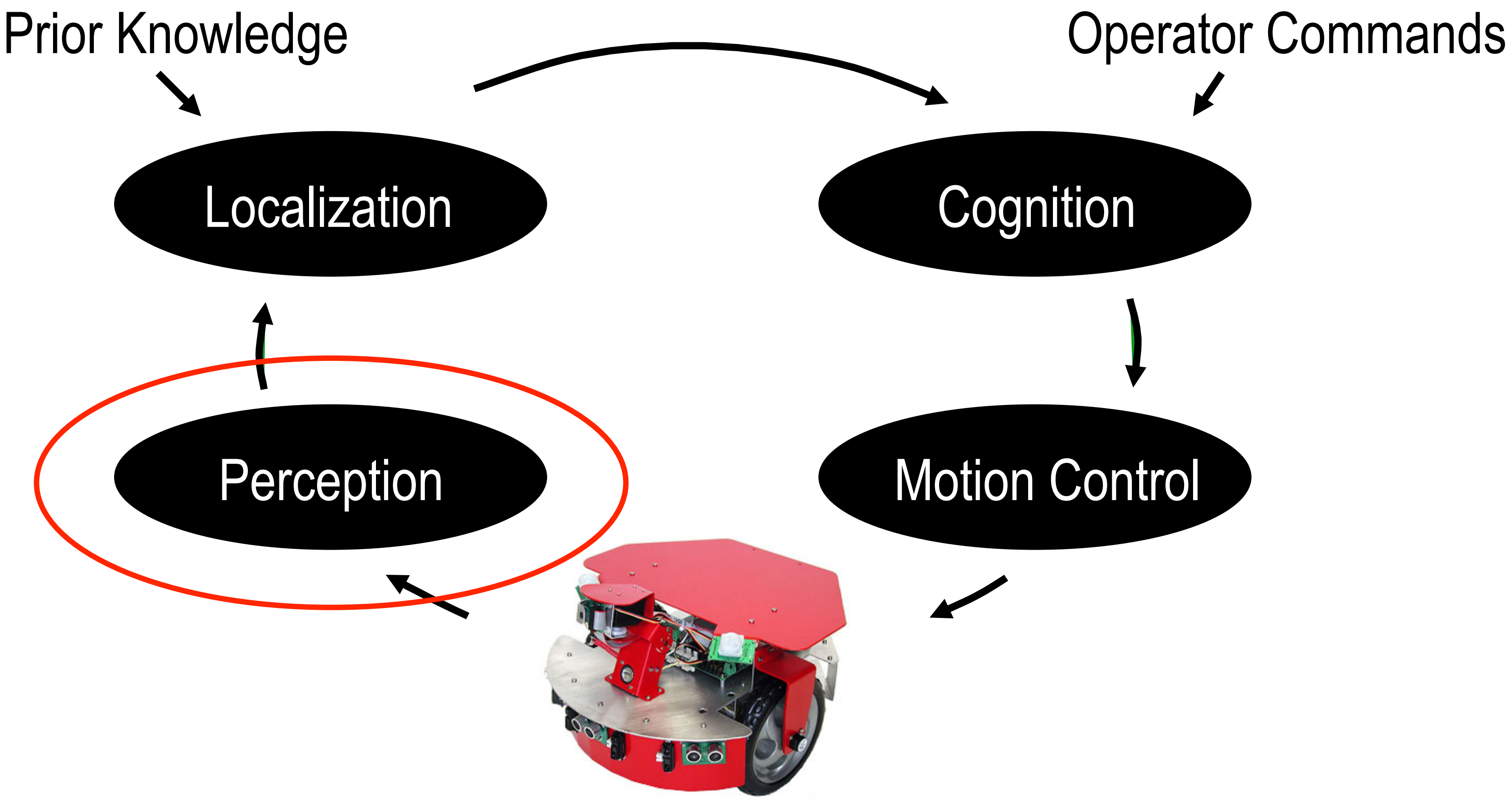
COS 495 - Lecture 9
Autonomous Robot Navigation

Instructor: Chris Clark

Semester: Fall 2011

Figures courtesy of Siegwart & Nourbakhsh

Control Structure



Outline

- Sensor examples II
  1. Doppler Effect Sensing
  2. Beacon Positioning Systems
  3. GPS

Doppler Effect Sensing

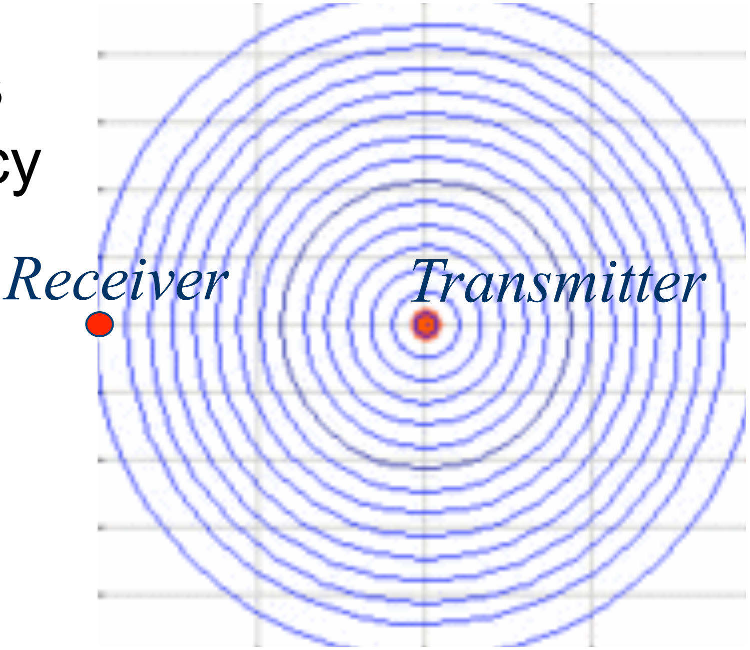
- What is the Doppler effect?

Doppler Effect Sensing

- What is the Doppler effect?

Doppler Effect Sensing

- Stationary transmitter and receiver
  - Receiver detects wave as having the same frequency as the transmitter

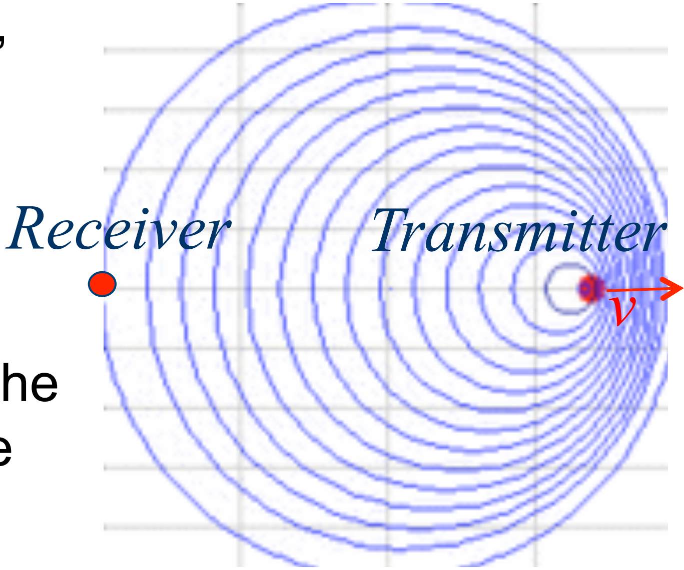


$$f_t = f_r$$

Doppler Effect Sensing

- Tracking moving objects
  - For every period the transmitted wave, the transmitter moves away from the receiver a distance

$$d = v / f_t$$



  - This lengthens the effective period of the transmitted wave by an amount of time

$$d/c = v/(f_t c)$$

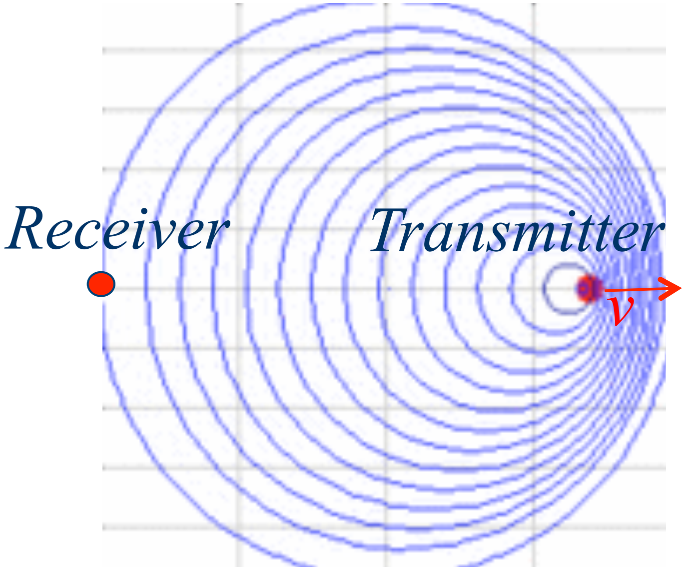
  - So the period of waves at the receiver is

$$1/f_r = 1/f_t + v/(f_t c)$$

Doppler Effect Sensing

- Tracking moving objects
  - Isolating the frequency of the received wave results in

$$f_t = f_r(1 + v/c)$$



  - One can determine the velocity of the transmitter with

$$v = \Delta f\, c / f_r$$

where the doppler shift is

$$\Delta f = f_t - f_r$$

Doppler Effect Sensing

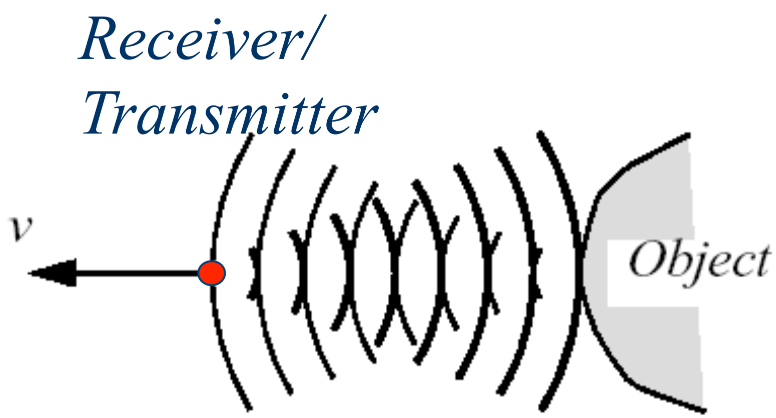
- Tracking moving objects
  - If the receiver is moving

$$v = \Delta f \, c \, / \, f_t$$

Doppler Effect Sensing

- Consider a reflected wave
  - The Doppler shift will be doubled on a round trip, so velocity must be halved.

$$v = \Delta f\, c \,/\, (2\, f_t)$$

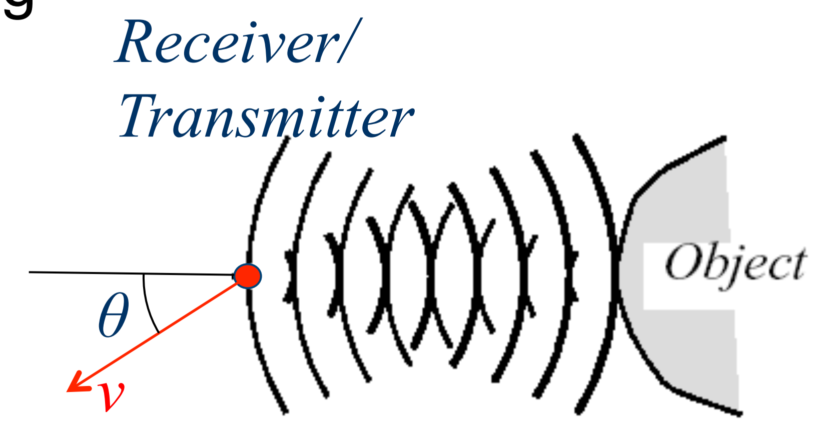


Doppler Effect Sensing

- Consider a reflected wave

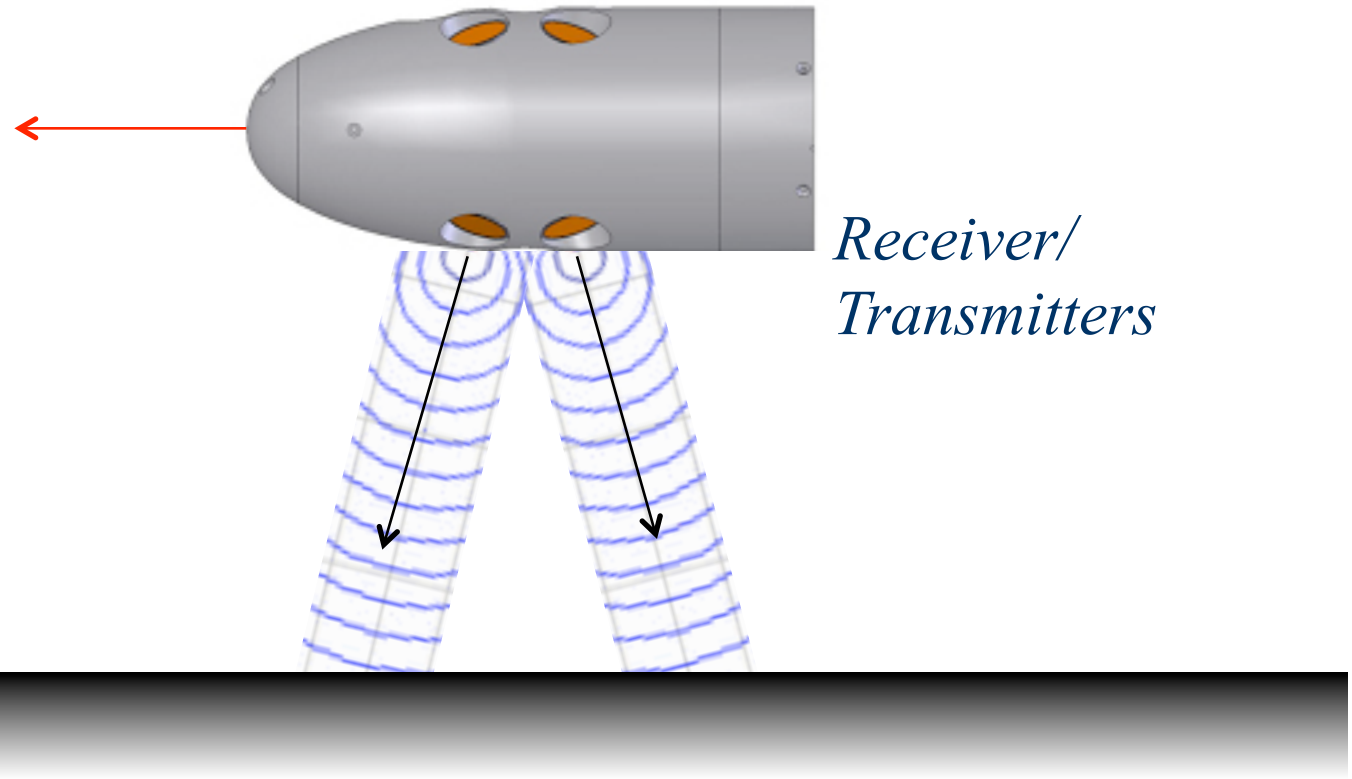
  … and if the R/T is moving away at relative angle θ

$$v = \Delta f\, c \,/\, (2\, f_t \cos\theta\,)$$



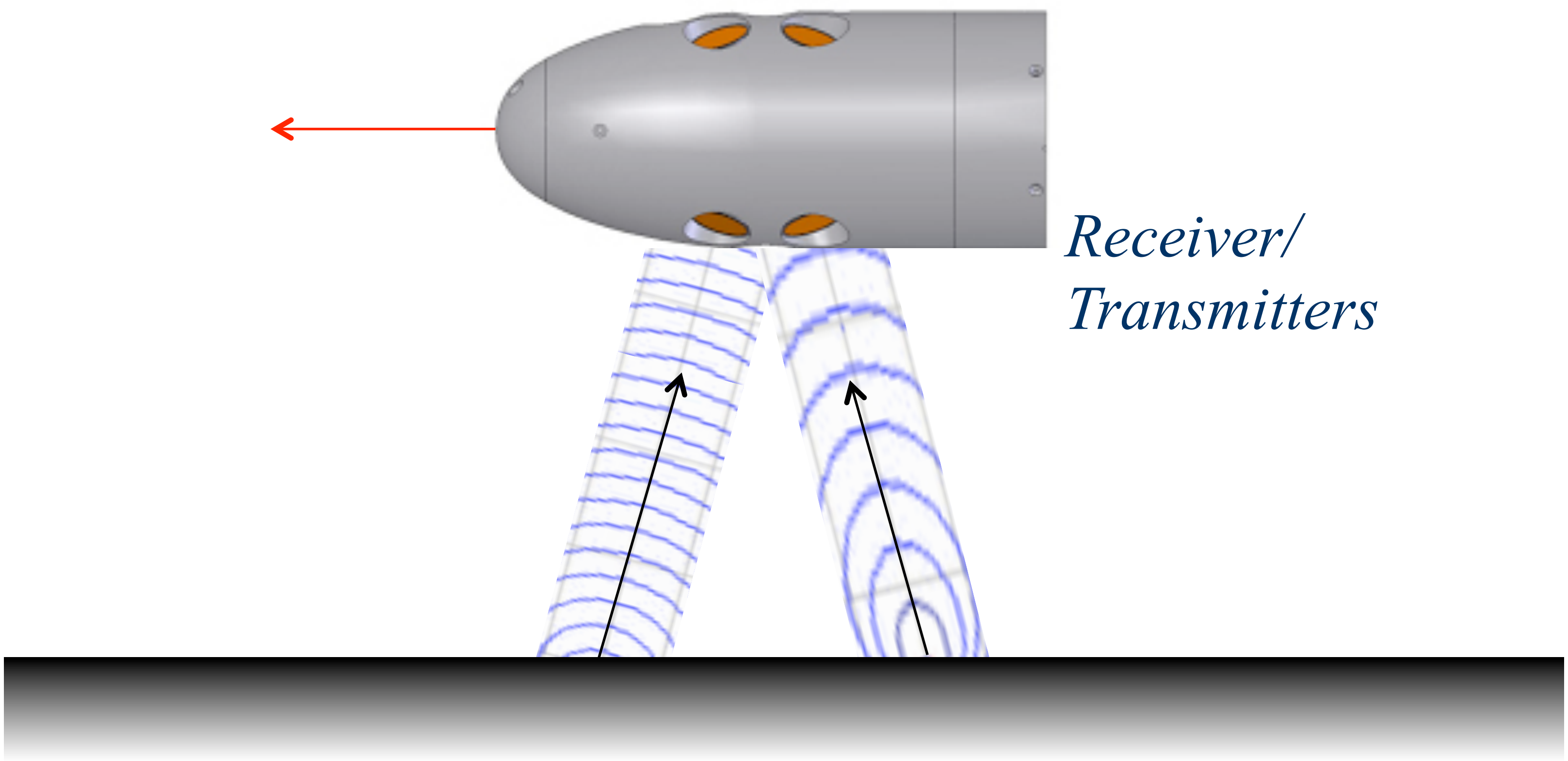
Doppler Effect Sensing

- Consider a DVL – Doppler Velocity Logger



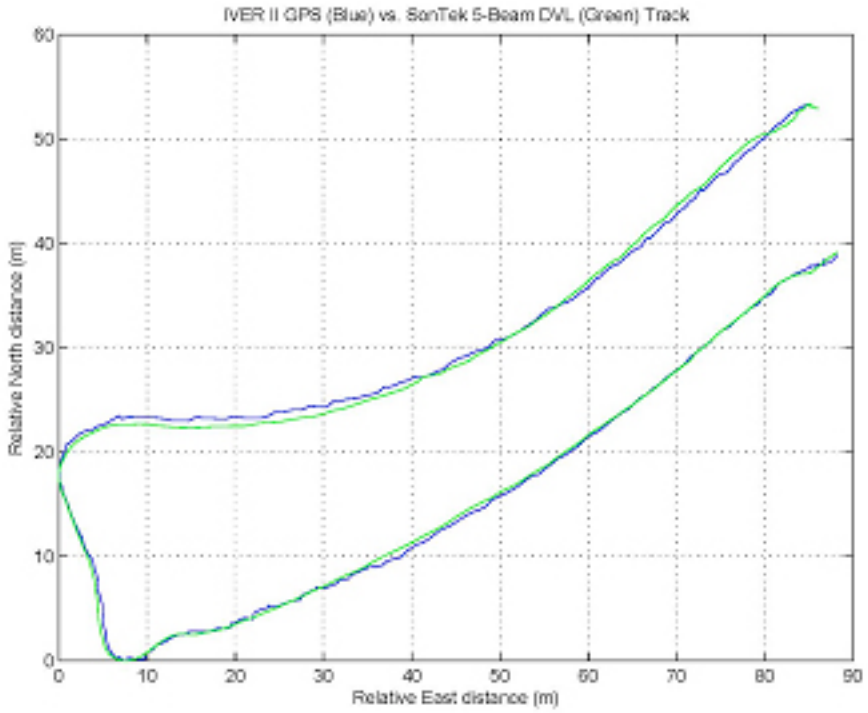
Doppler Effect Sensing

- Consider a DVL – Doppler Velocity Logger



Doppler Effect Sensing

- Iver2 DVL

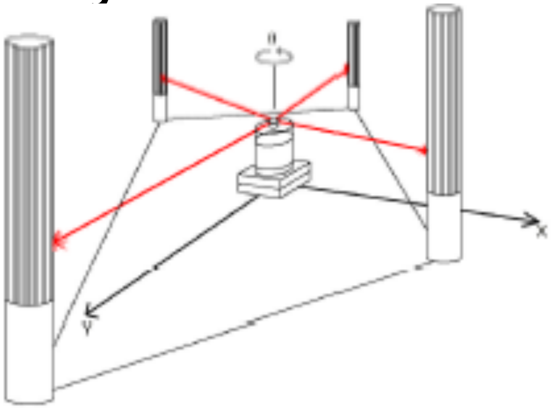


Outline

- Sensor examples II
  1. Doppler Effect Sensing
  2. Beacon Positioning Systems
  3. GPS

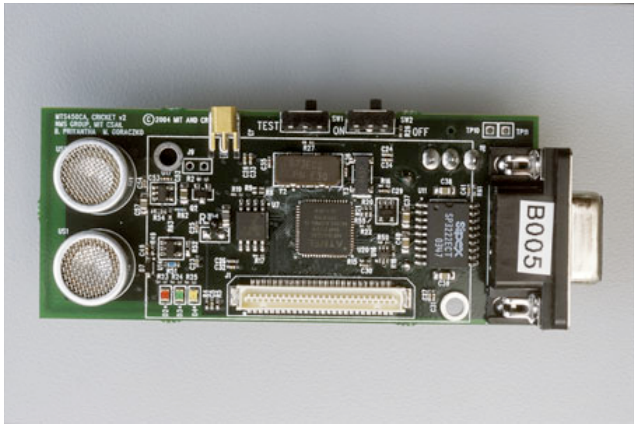
Sensors: Ground-Based Beacon Systems

- Used for localization
- Used by humans (e.g. stars, lighthouses)
- Beacons can be active or passive
- Known location of beacons allows localization
- Problem is that they aren't flexible



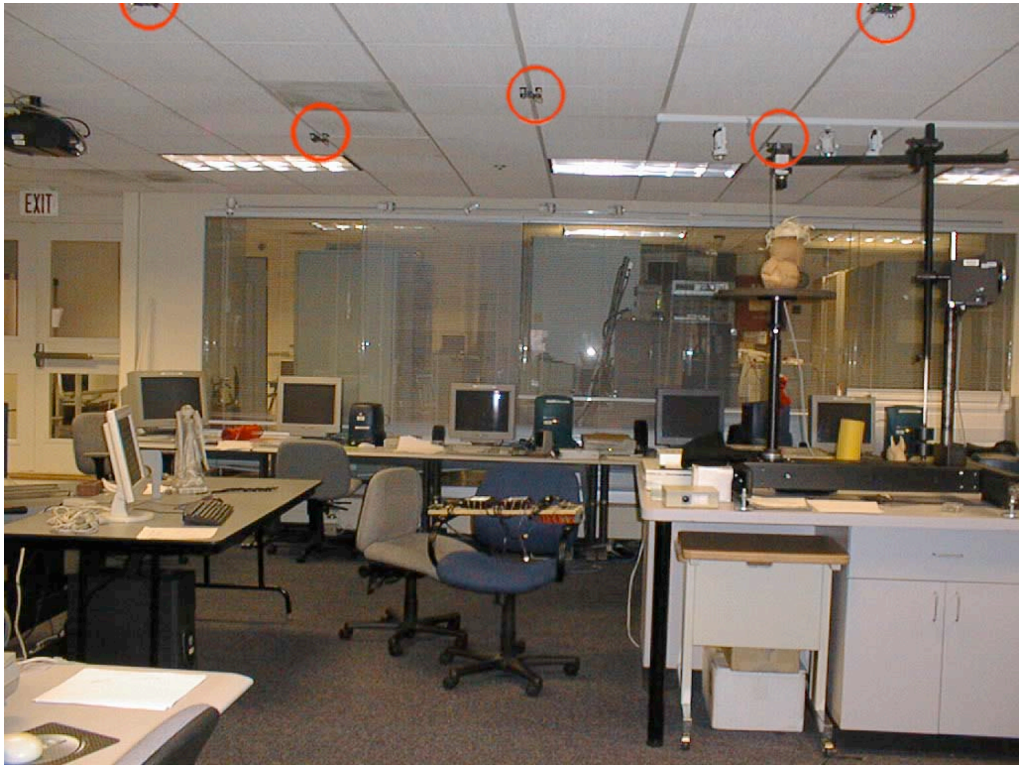
Sensors:
Ground-Based Beacon Systems

- MIT "Crickets" for Localization
  - Use acoustic beacons that allow for time-of-flight (then distance) measurements to a mobile transceiver.



Sensors: Ground-Based Beacon Systems

- MIT Crickets (cont')



Sensors: Ground-Based Beacon Systems

- MIT Crickets (cont')

Outline

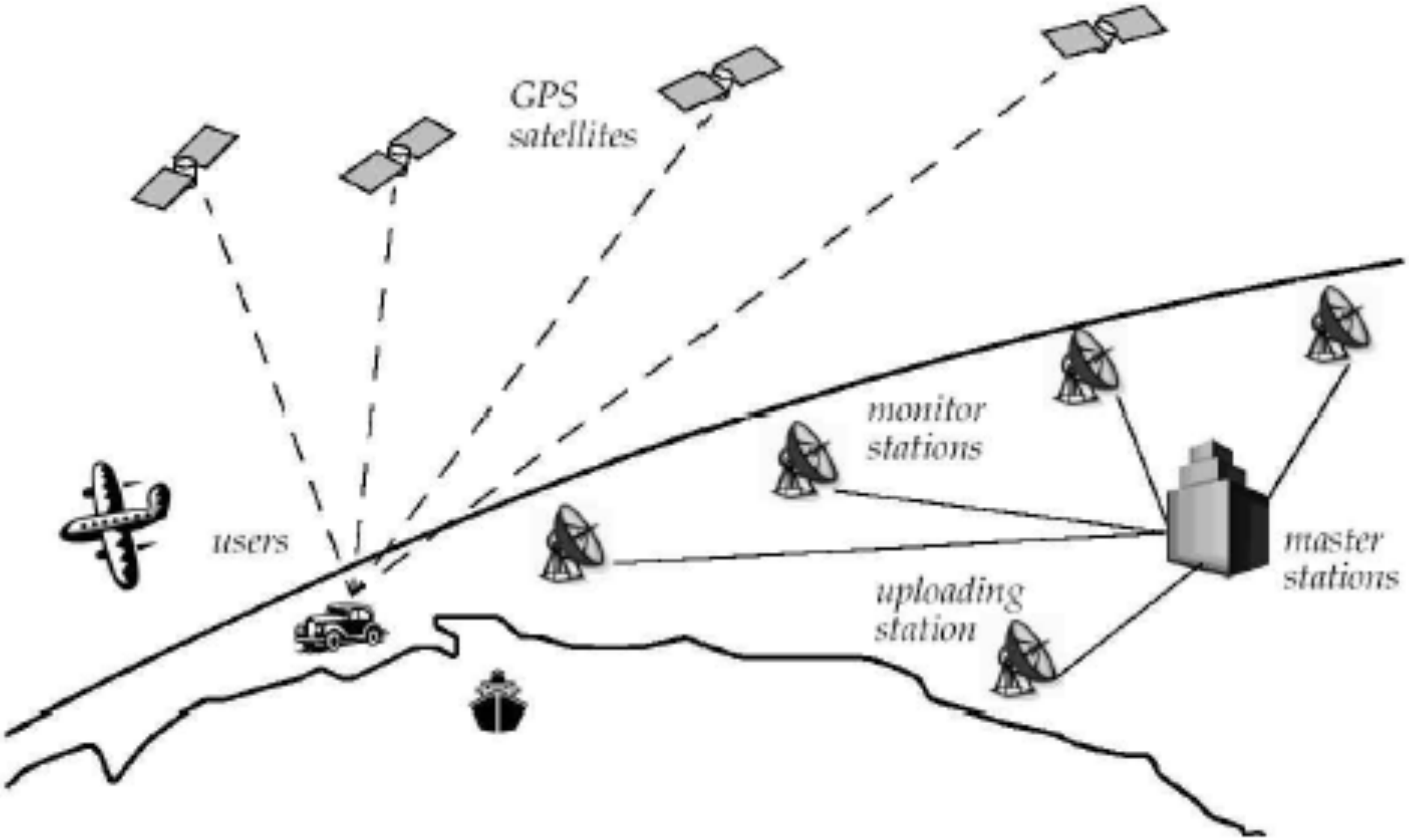
- Sensor examples II
  1. Doppler Effect Sensing
  2. Beacon Positioning Systems
  3. GPS

Global Positioning System (GPS)

- Developed for military use
- Now accessible for commercial use (e.g. hiking, flying, …)
- There are 24 satellites orbiting the earth every 12 hours at height of 20+ km.
- There are 4 satellites located in each of 6 planes inclined at 55 degrees to the equator.

Garmin Image

Global Positioning System (GPS)



Global Positioning System (GPS)

- Use a GPS receiver to measure time of flight from several satellites to receiver.
- The system requires:
  - Time synchronization between satellites and receiver
  - Known position of satellites
  - Precise measurement of time of flight
  - Overcoming interference with other signals

Global Positioning System (GPS)

- Time Synchronization:
  - Atomic clocks on each satellite are monitored from ground stations
- Known location of satellites
  - A number of widely distributed ground stations monitor the satellites
  - A master station analyses measurements and transmits position to each satellite

Global Positioning System (GPS)

- Precise Measurement:
  - Satellites transmit (at the same time) their current time and location.
  - Arrival time differences inform the receiver of relative distance to each satellite.
  - Use four satellites to solve for (x,y,z) and receiver clock correction T

Global Positioning System (GPS)

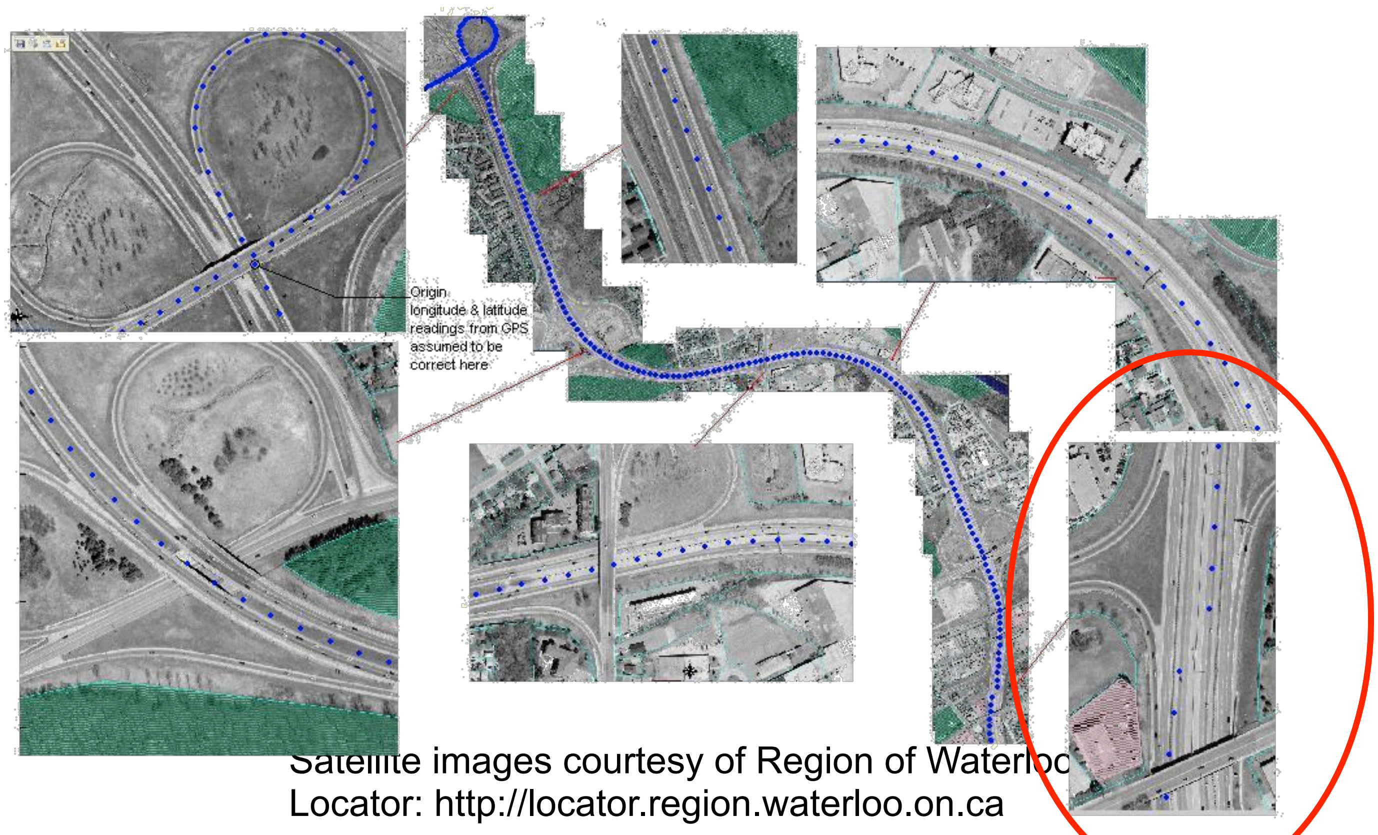
- Error Sources
  - Atmospheric conditions vary
  - Number of satellites with line of sight
  - Ephemeris Errors (position of satellite)
  - Satellite Geometry
  - Signal Multi-Path
  - Receiver Clock Errors

Sensors: Global Positioning System (GPS)

- Regular GPS, can get accuracy 10-15 m.
- With a second receiver of known location, differential GPS (i.e. DGPS) can resolve down to 1 m.
- Carrier-phase can get resolution down to 1cm.

Sensors: Global Positioning System (GPS)

- Example:



Satellite images courtesy of Region of Waterloo
Locator: http://locator.region.waterloo.on.ca

Sensors: Self-Calibrating PseudoLites

K9-SCPA field trial at the Marscape 02/11/04