Sensing and Sensors

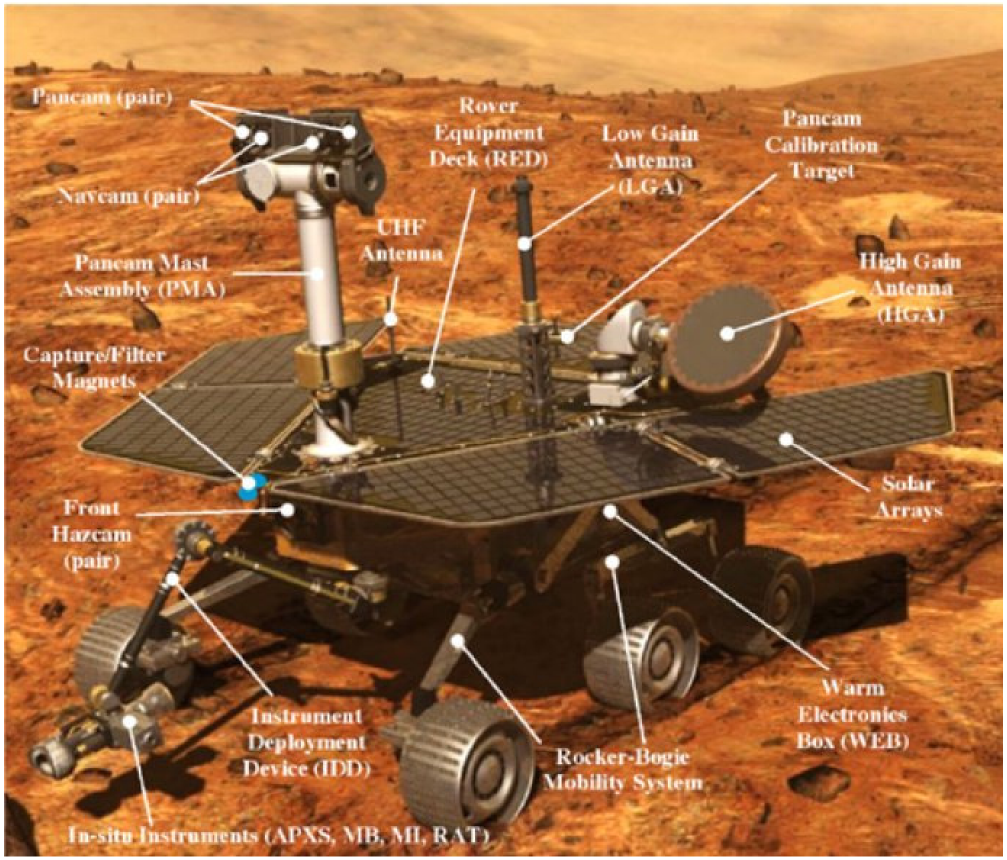
RSS Lecture 4

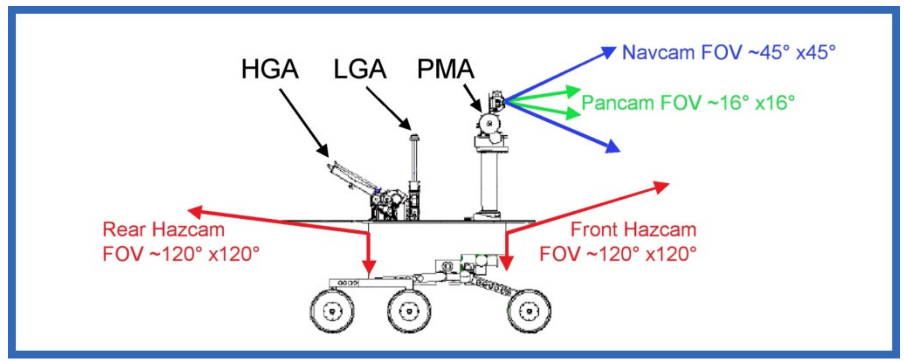
Monday, Feb 14 2011

Cagdas Onal

Lecture Notes Prepared by Daniela Rus

Today: sensors and perception





Outline

- What are sensors?
- Types of sensors (many examples)
- Sensor details
- Examples

Why is robotics hard?

- Sensors are limited and crude
- Effectors are limited and crude
- State is partially-observable
- Environment is dynamic
- Environment is full of potentially-useful (and useless) information

What are sensors

- Sensors constitute the *perceptual* system of a robot
- Sensors are physical devices that *measure* physical quantities
- Sensors do not provide *state*
- Examples:
  - contact -> switch
  - distance -> ultrasound, radar, infra red
  - magnetic field -> compass, hall effect

Examples of Sensors

- More examples:
  - light level -> photo cells, cameras
  - sound level -> microphones
  - strain -> strain gauges
  - rotation -> encoders, switch, potentiometer
  - temperature -> thermometer
  - gravity -> inclinometers
  - acceleration -> accelerometers
  - acceleration -> rate gyroscopes
  - flames -> UV detector

Sensor Types

- Based on energy emission:
  - Passive: received energy only
    - e.g., human vision, hearing
  - Active: emitted energy
    - e.g., sonar, ladar, structured lighting, human touch
- Based on data souce:
  - Proprioceptive: sensing internal properties
    - e.g., battery level, wheel encoders
  - Exteroceptive: sensing external properties
    - e.g., vision, ranging

Signal to Symbol

- Sensors provide signals
  - The bumper switch is depressed
- Acting requires state
  - Stop if we have collided with something
- Reconstruction:
  - Processing
  - *“Given the sensory reading I am getting, what must the world be like to make the sensor give me this reading?”*

Levels of Processing

- Determine position of switch from voltage in circuit => electronics
- Using a microphone, separate voice from noise => signal processing
- Using a camera, find people in the image and recognize “persons of interest” => computation

Example: Detecting People

- temperature: pyro-electric sensors detect special temperature ranges
- movement: if everything else is static or slower/faster
- color: if people wear uniquely colored clothing in your environment
- shape: now you need to do complex vision processing

Example: Measuring Distance

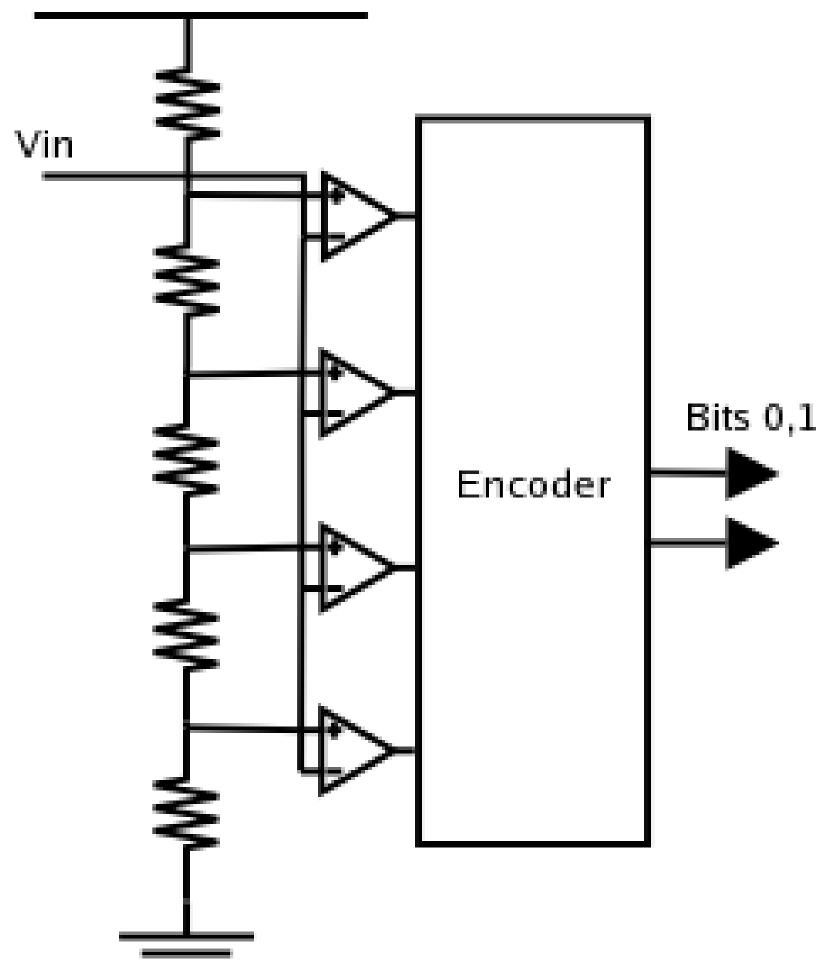
- Two cameras (i.e., stereo) can give you distance/depth
- Ultrasound sensors (sonar) give distance directly (time of flight)
- Infra red provides return signal intensity
- Use perspective projection with 1 camera
- Use structured light; overlying grid patterns on the world

Analog and Digital Signals

- Sensors may output signals in different formats:
  - Analog level (voltage or resistance)
  - Analog waveform
  - Digital level
  - Digital waveform
  - Examples?
- Modern computers require digital inputs

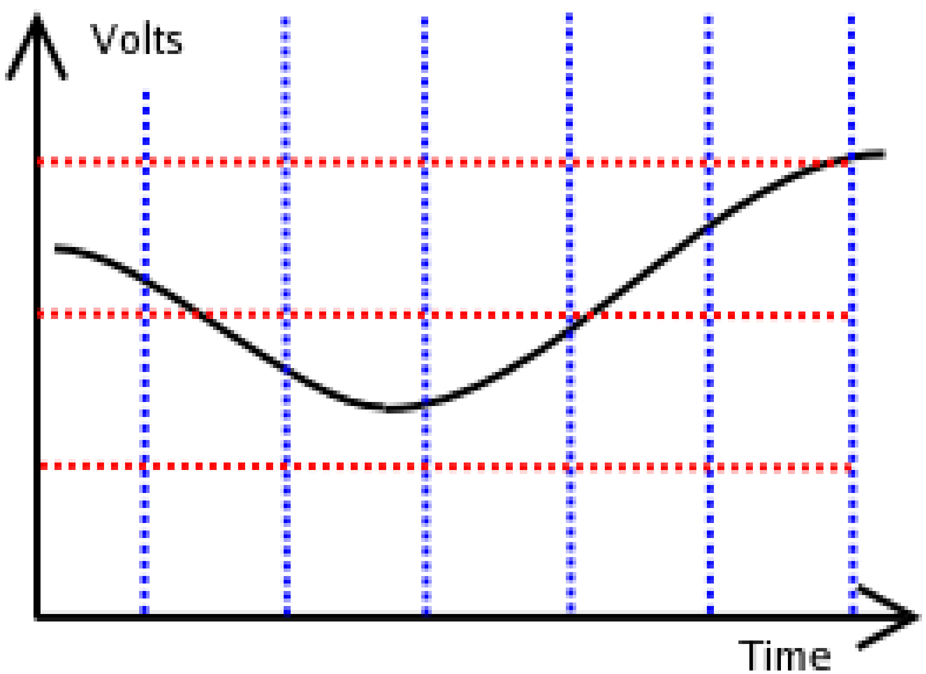
Analog to Digital Conversion

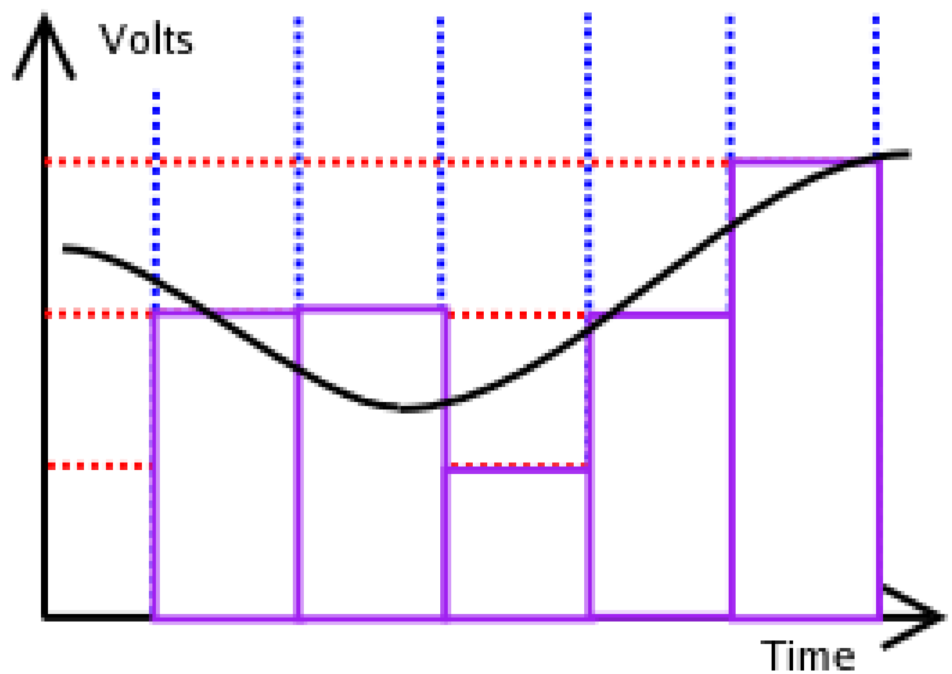
- Analog-to-digital conversion requires specialized circuit (ADC)
- Most circuits based on analog *comparators*



Sampling Rates and Resolution

- Analog waveforms are time-varying signals
- ADC will sample at some fixed *frequency* (x axis)
- ADC will sample at some fixed *resolution* (y axis)
- Nyquist criterion: sample at 2 * max frequency



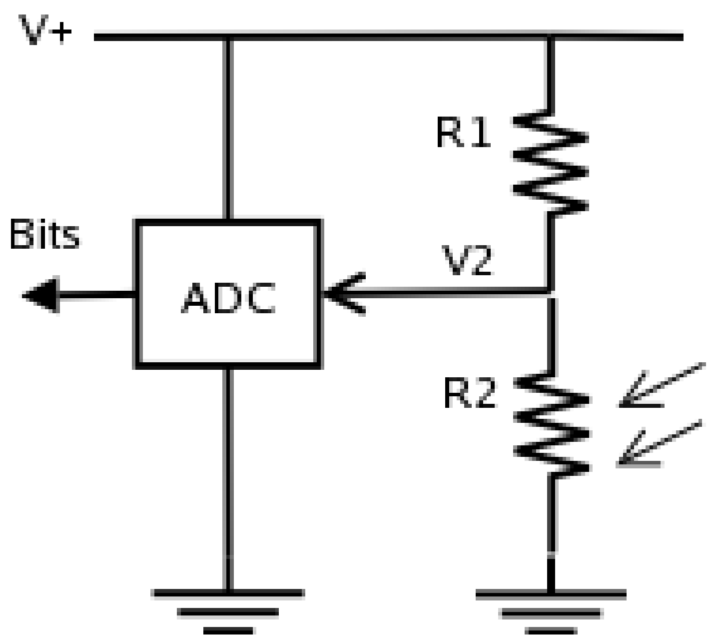


Simple Analog Sensors: Photocells for Light

- Passive sensors for measuring light intensity
- Two technologies:
  - Photoresistor: light-dependent resistor
  - Photodiode: light-dependent diode
- Photoresistor:
  - increasing light => decreasing resistance
- Photodiode (forward bias):
  - increasing light => increasing current

Photocell Circuits

- Light sensors vary current/resistance
- ADC measures voltage
- Sensor must be placed in circuit
- Ohm's Law: V = IR



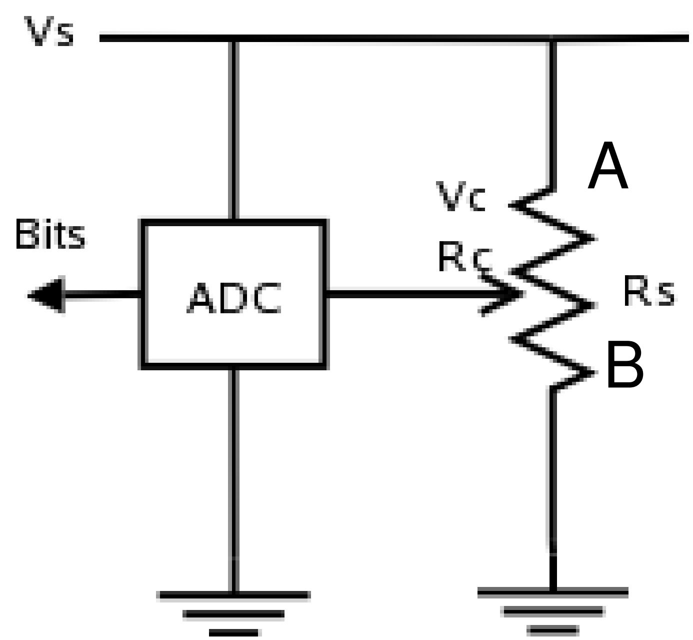
Detecting Position

Simple Analog Sensors: Potentiometers for Position

- Potentiometers (pots) vary resistance with shaft position
  - e.g. volume control on stereo
- Mechanical armature on resistive coil/patter
- Relatively simple sensor: single analog value
- Requires ADC

Potentiometer Circuit

- Pots vary resistance
- Attach wire to A; no voltage drop
- Attach wire to B: big voltage drop
- ADC measures voltage and is converted to digital value
- Uses?



Potentiometer Uses

- Position:
  - Joint angle
  - Shaft angle
  - Linear travel

Detecting Objects

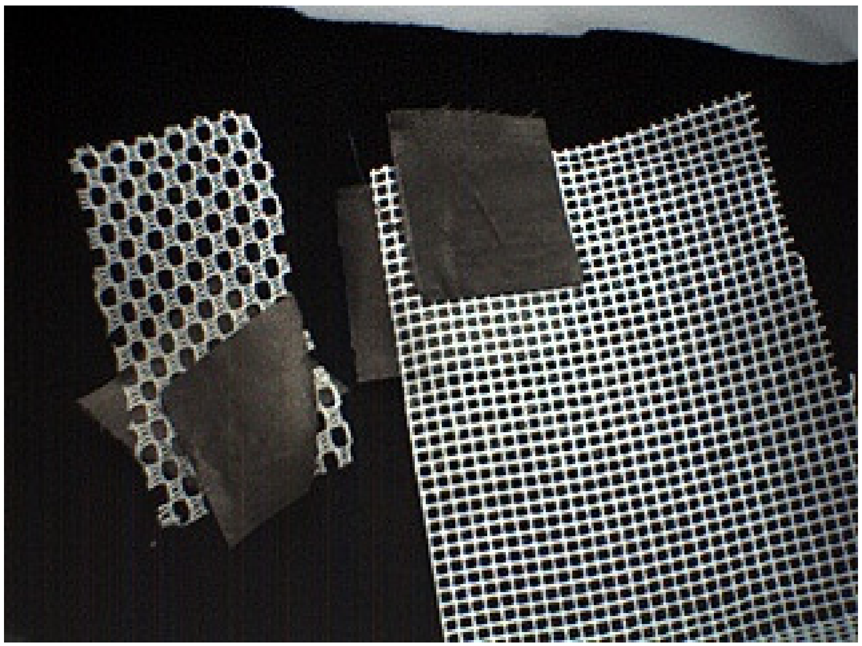
Simple Digital Sensors: Switches for Contact

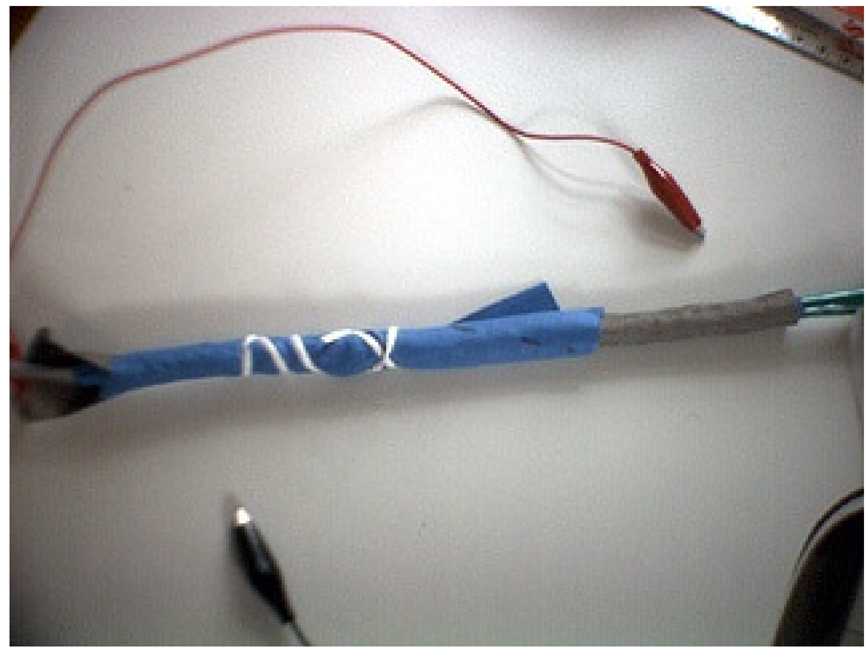
- Simplest sensor: 1-bit digital
- Minimal circuitry, processing
  - De-bounce hardware or software
- Normally open (NO):
  - Current flows when switch is pressed
- Normally closed (NC):
  - Current flows when switch is released
- Many types:
  - Press, toggle, rocker, knife
  - Reed, mercury

Switch Uses

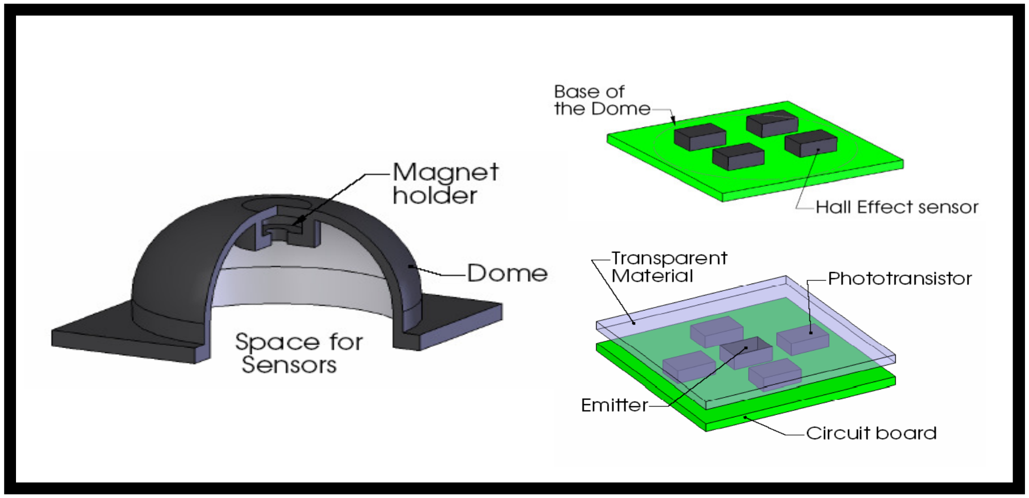
- Contact
  - Trigger on contact with object
- Limit
  - Trigger when joints are at end of range
- Shaft encoder
  - Count revolutions of shaft (reed)
- Orientation
  - Detect if robot is tipped over (mercury)

Skin: Electric-conductive fabric



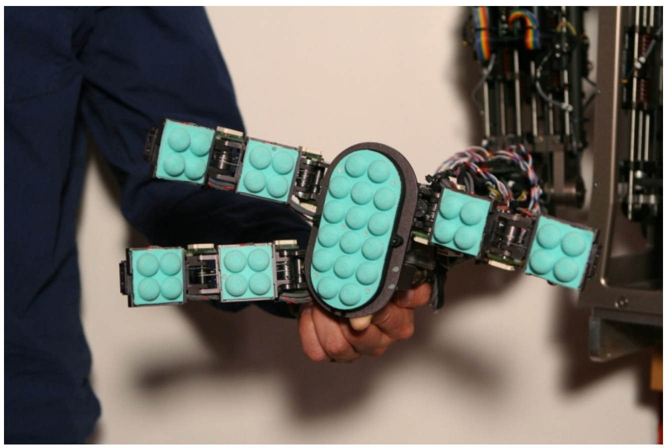


Skin Sensor



- Position of the top of the sensor gives an estimation of the force applied
- Magnetic:
  - A magnet on the dome, 4 hall effect sensors on the base
- Optical version
  - A LED and 4 photo receptors on the base

Skin



- 6 tactile sensors on the fingers and thumb
- A tactile sensor has 4 domes with 4 hall effect sensors in each dome
- Palm: 16 domes, each with 4 hall effect sensors

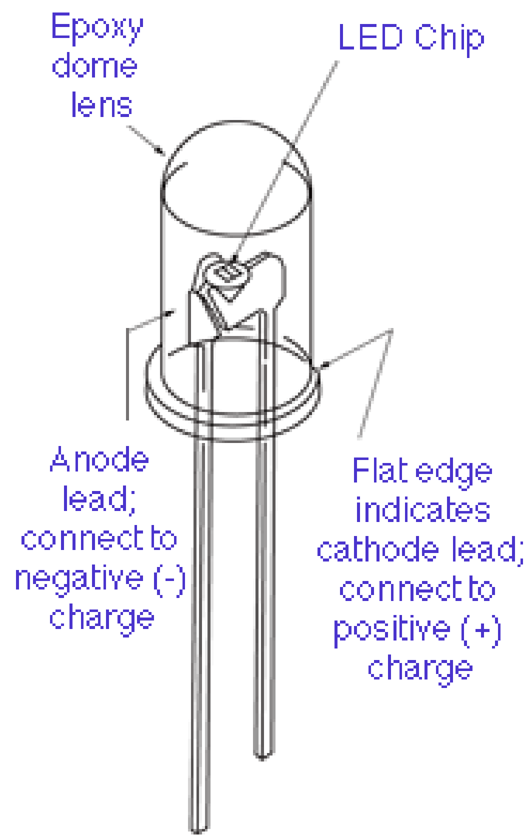
Simple Sensors:
IR for Object Detection

- Optosensors have emitter detector pair in same package (non-contact switch)
- Reflective and break-beam configurations
- Digital and analog versions

- Video

Simple Sensors: Optosensors

- *Active* sensors with emitter-detector pairs (in single package)
- Emitters are light emitting diodes (LEDs)
- Detectors are photodiodes or phototransistors
- Emitter/detector have matched wavelengths, usually in IR



Optosensor Uses

- Reflectance
  - Object proximity
  - Feature detection (e.g., retro reflector)
  - Bar-code reading
  - Shaft encoding
- Break-beam
  - Object presence (e.g., gripper)

Reflectance

- Optosensors measure reflected intensity
- Intensity is a function of range and material properties
- For measuring proximity:
  - Light objects appear closer
  - Dark objects may be invisible
- Require calibration/testing

Measuring Distance

How do we get distance from the measured time-of-flight?

Sound/light travels at a constant speed, which varies slightly based on ambient temperature

At room temperature, sound travels at 331 m/sec, or around 30 cm/msec

Ultrasound

- Ultrasound range sensing is based on the time-of-flight principle
- The emitter produces a "chirp" of sound (at very high frequency)
- Sound travels away from emitter, bounces off barrier, returns to detector
- The time elapsed is measured

Sonar sensor construction

- Some sensors have single emitter/detector pair
- Other sensors have common emitter/detector

- How SONAR works video

Angular Resolution

- Typical sensors have 30 degree angular resolution
- Diffraction limited: wavelength is comparable to emitter size
- e.g., Polaroid transducer:
  - Frequency 50 kHz
  - Wavelength 7 mm
  - Sensor diameter ~ 40 mm
  - Max range ~ 10 m

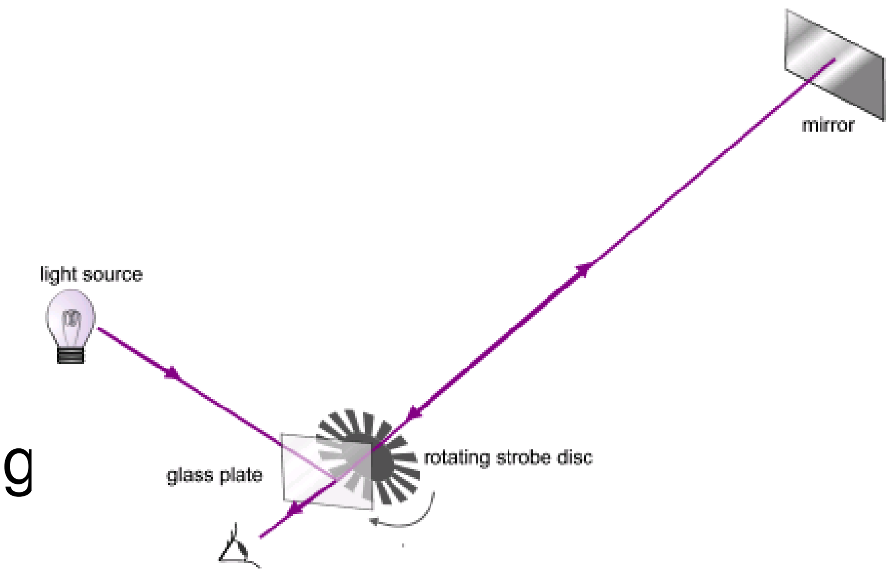
Limitations?
How do we overcome them?

Laser range finders (ladar)

- Sonar sensors measure range using time-of-flight of *sound*
  - Sound: 330 m/sec in air
- Laser range finders measure time-of-flight of *light*
  - Light: 300,000,000 m/sec in vacuum

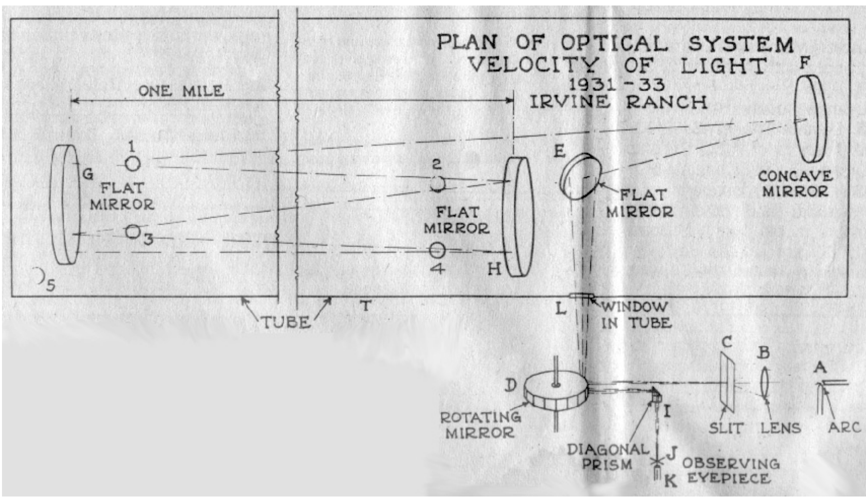
Scanning laser range-finders

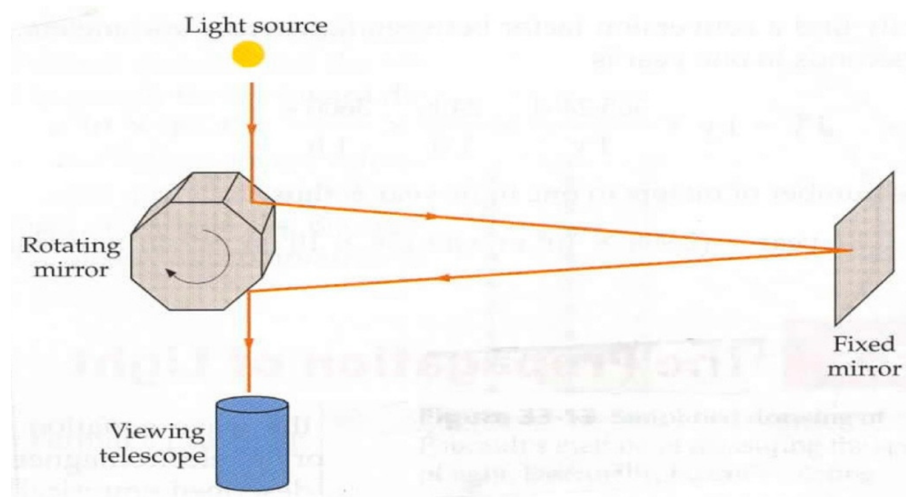
- Scanning laser range-finder:
  - Laser range finder
  - Rotating mirror(s)
- E.g., SICK
  - 3D planar scan, 180 deg FOV
- E.g., Riegl
  - 3D volume scan, 360/80 degree FOV



Fizeau Experiment
315,000km/s

Michaelson Experiment





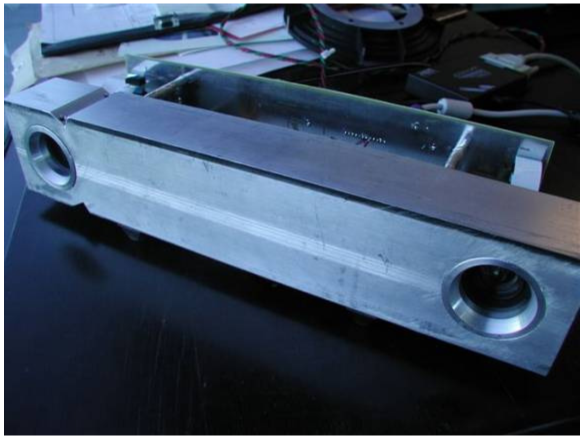
299,796 km/s +/- 4

Same principle used to measure distance

Given speed of light

Imaging Sensors

- Cameras
  - Color, texture give clues about road edges, plant and rock locations
- Stereo/LADAR
  - Provide snapshot of 3-D terrain geometry ahead of vehicle

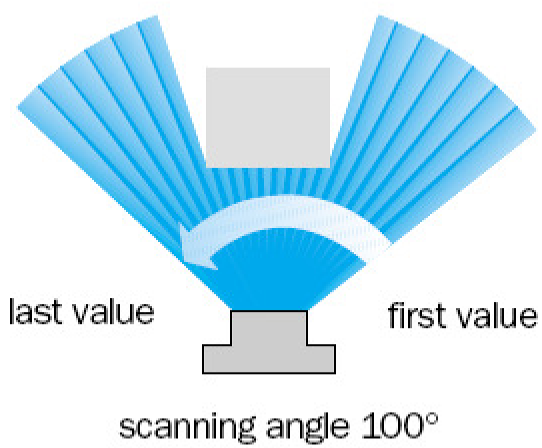


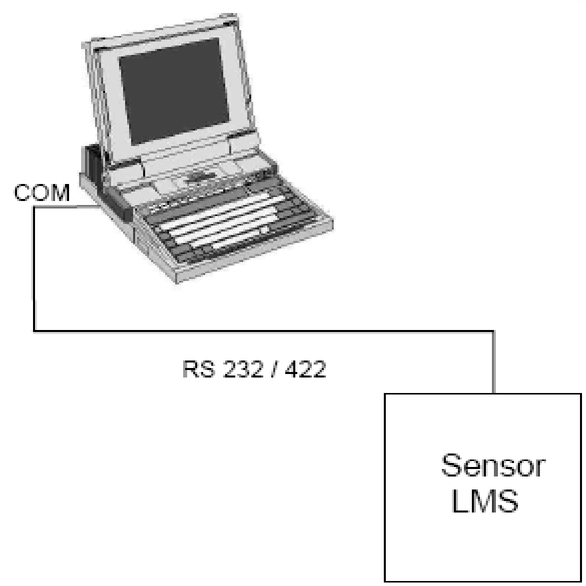
DAD's stereo camera

SICK laser ranger

LADAR

- **LA**ser **D**etection **A**nd **R**anging
  - How it works





LADAR

LMS 291-S05 2D LADAR Scanner; Cost: $3,014

Data Specifications

- Data Interface RS 232 / RS 422 (configurable)
- Transfer Rate 9.6 / 19.2 / 38.4 / 500 kBd

Sensing Specifications

- Scanning Speed: 75 Hz
- Angular View: 100°,180°
- Angular Resolution: 0.25° / 0 .50° / 1.00°
- Measurement Resolution 10 mm

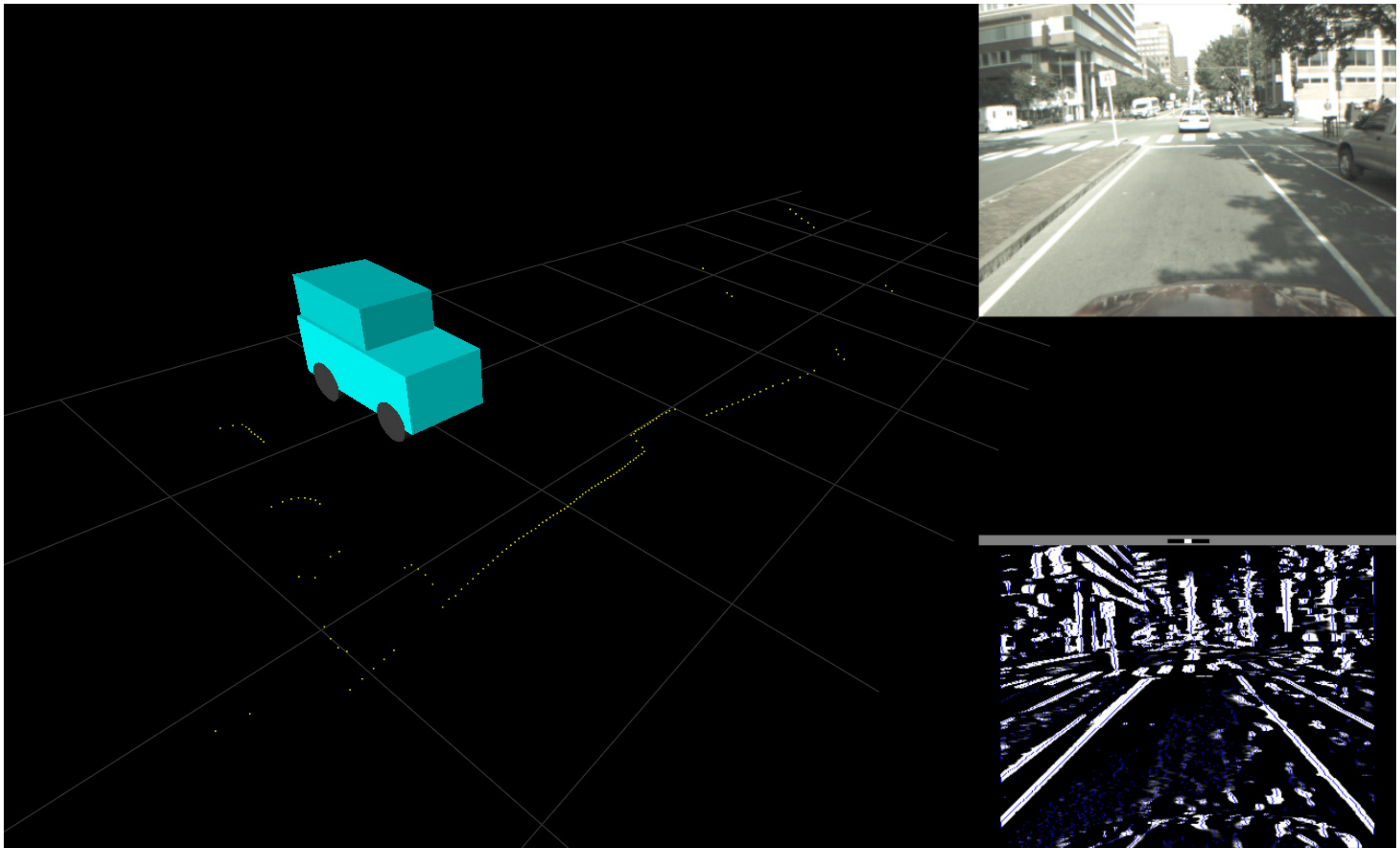
Physical Specifications

- Weight: approx. 19.8 lb
- Environment: Outdoor (Fog Correction)

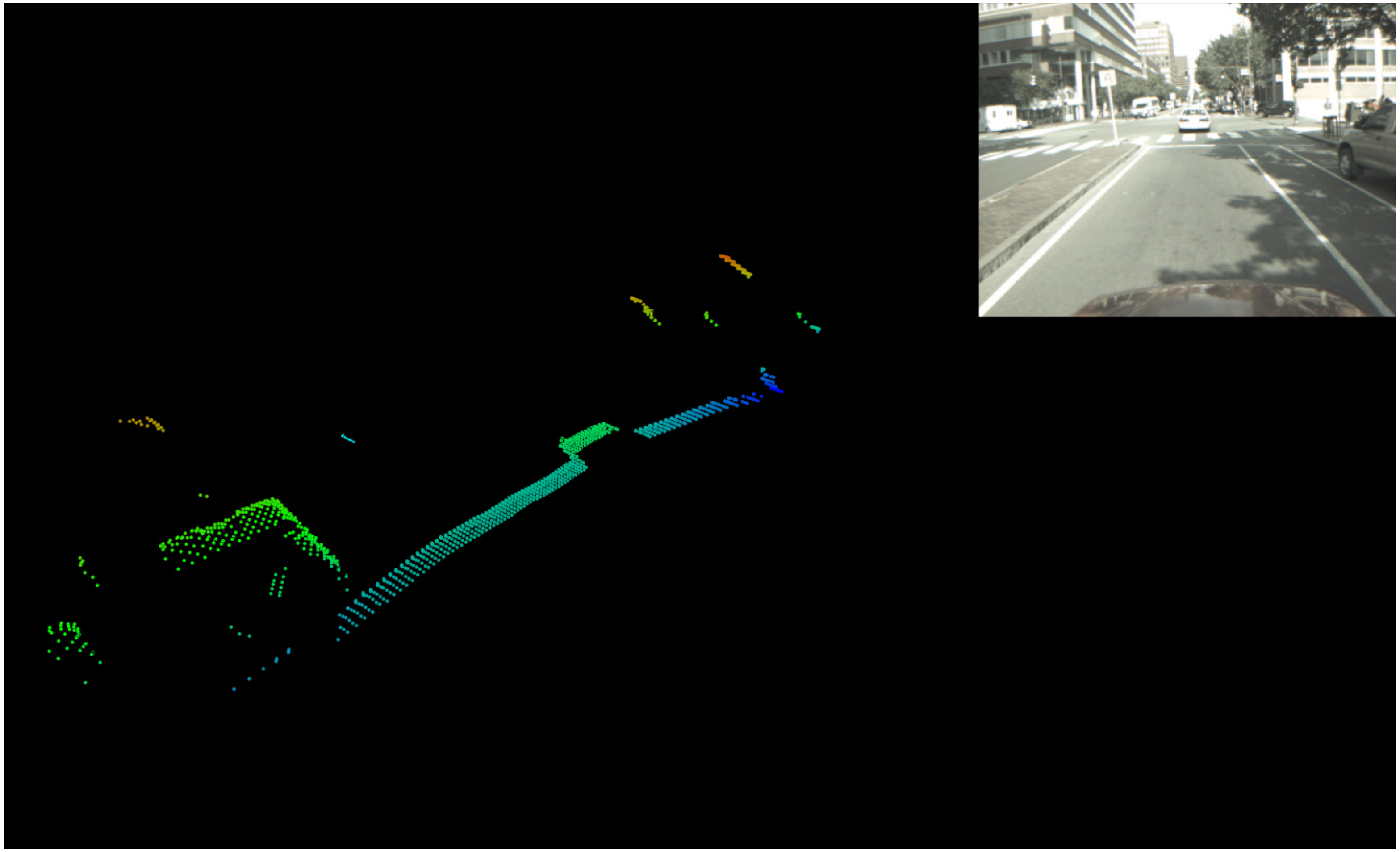
Electrical Specifications

- Supply Voltage: 24 V DC ± 15%

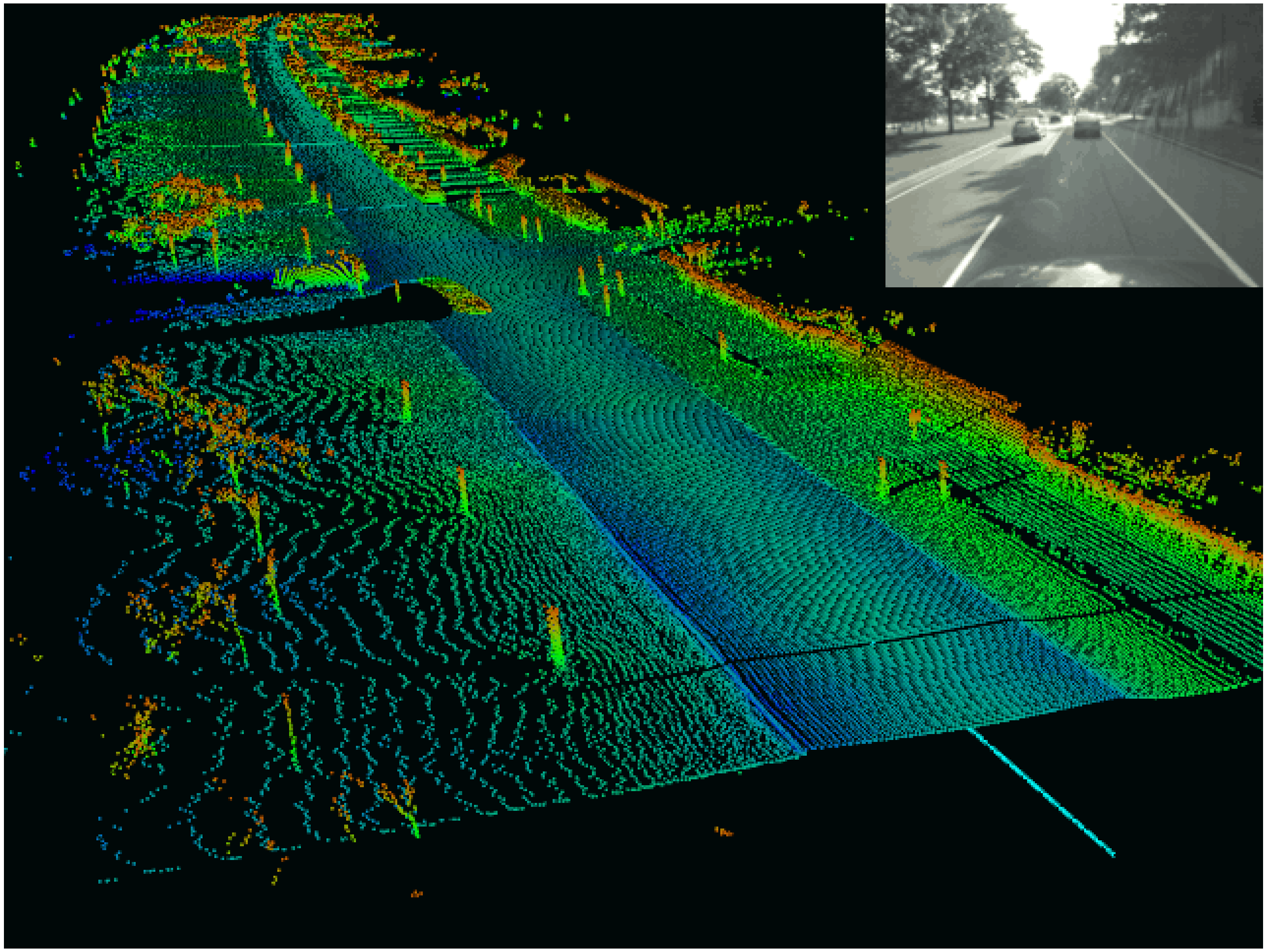
One-scan Data



Several-scan Data



Laser Processing



LADAR (versus SONAR)

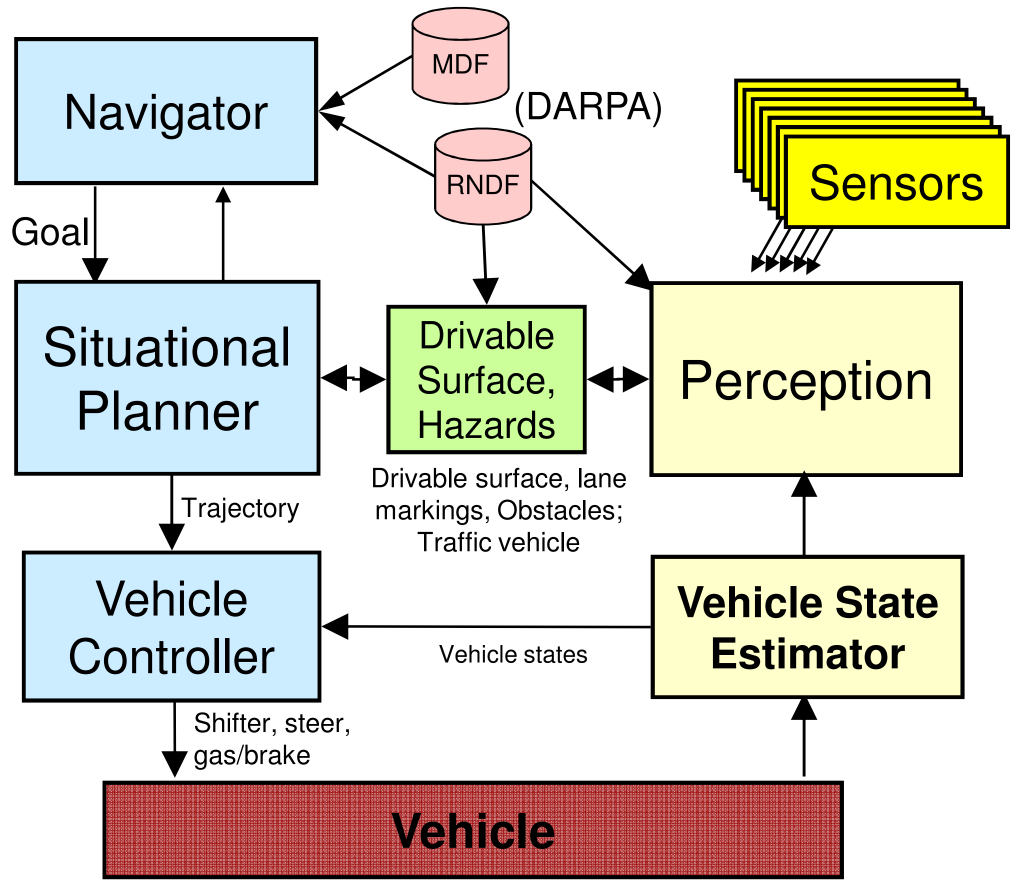
- Pros:
  - Small spot size (good angular resolution)
  - High sample rate
  - Short wavelength (fewer specular reflections)
- Cons:
  - Large/heavy
  - Complex/expensive

MIT Vehicle: Talos (Land Rover LR3)

- Approach: Perception-based navigation and planning
- Power: 6 kW gas-fueled generator
- Computation: blade cluster (40 processing cores)
- Sensing: 13 lidars, 15 radars, 5 cameras
- Planning and control: rapidly-exploring random tree (RRT), pure-pursuit
- Software: powerful new UDP messaging, visualization architecture

System Architecture

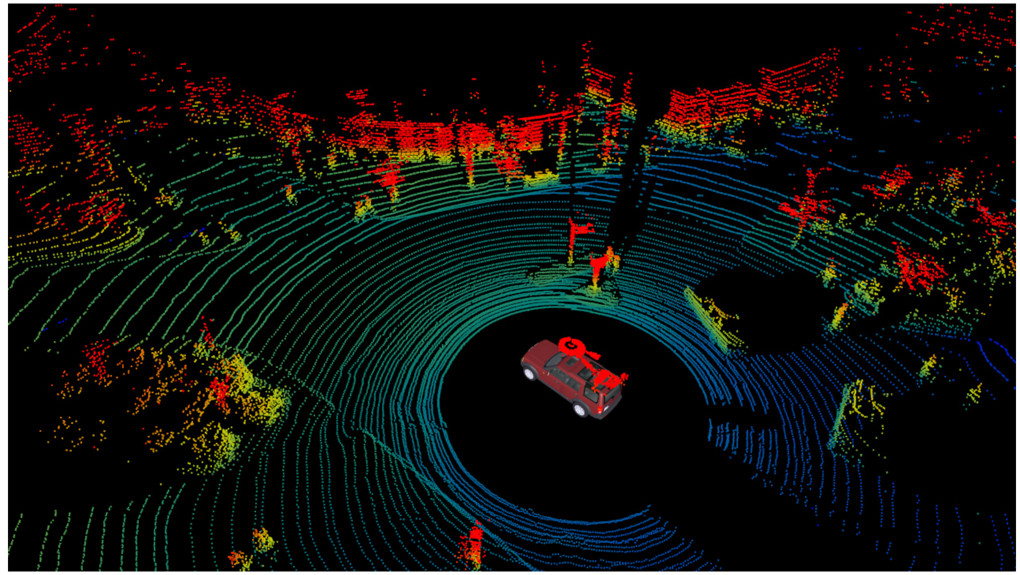
- Perception
  - Vehicle surroundings
  - Vehicle location w.r.t. surroundings, RNDF
- Planning & Control
  - Codified driving rules
  - How to reach the goal



- AEVIT Vehicle Conversion (EMC) control unit
  - Continuous signal (steering, gas/brake)
  - Discrete signal (turn signals, gear shift)

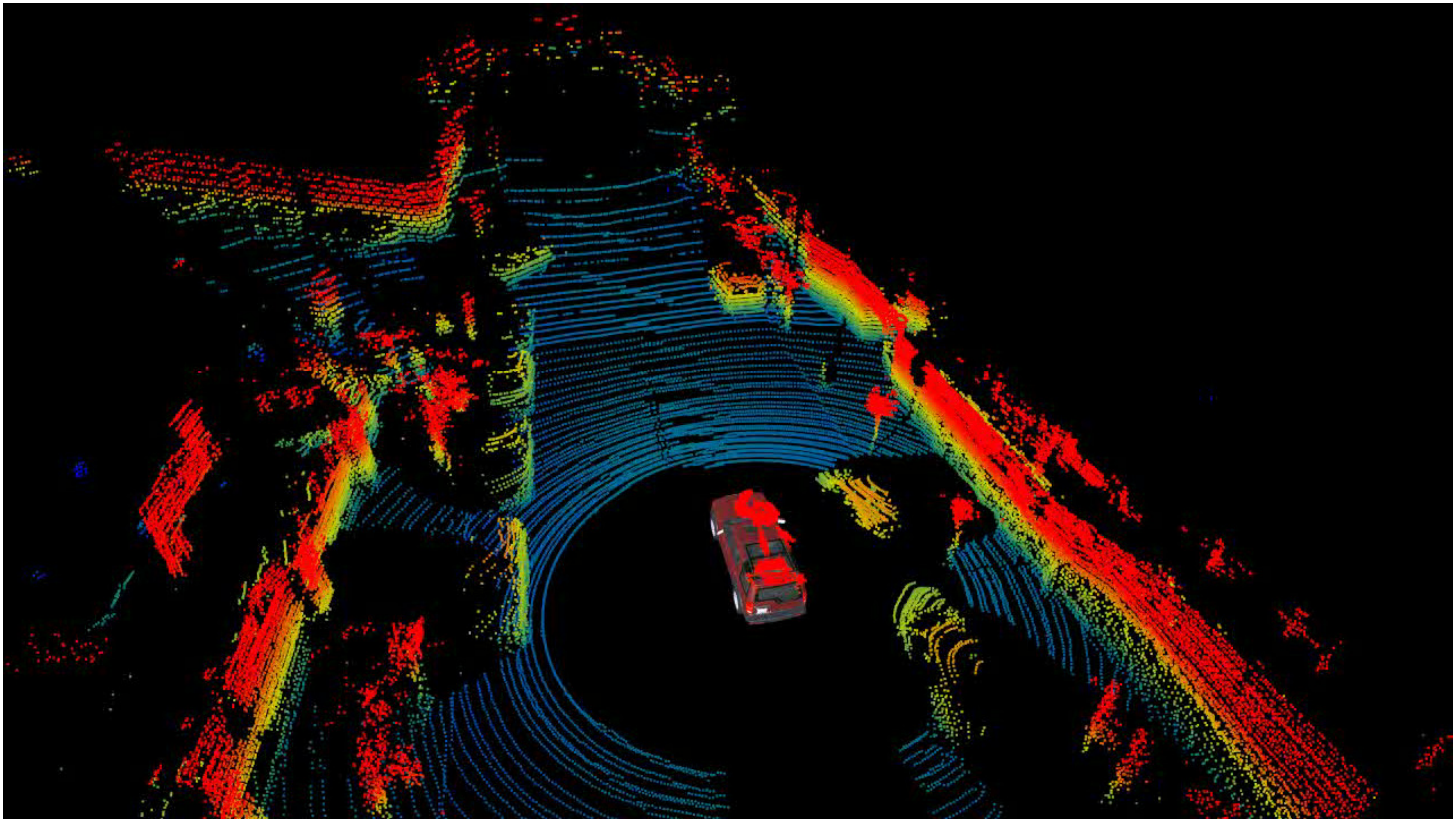
One (64x) Velodyne Lidar

- 64 lasers, 360° HFOV
- Unit spins at 15 Hz
- Vertical FOV
  -24°, +2°
- Redundant (albeit relatively noisy) lidar



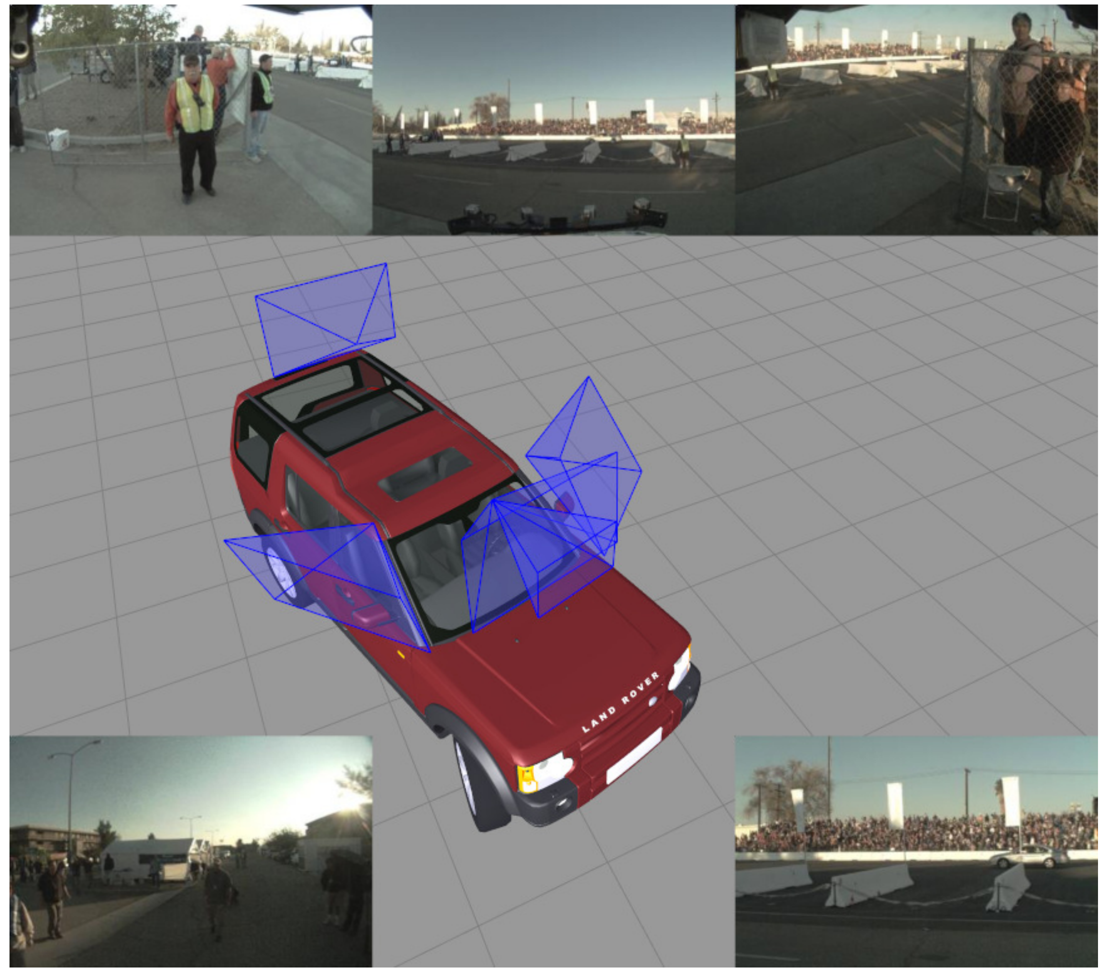
Sample Velodyne Data

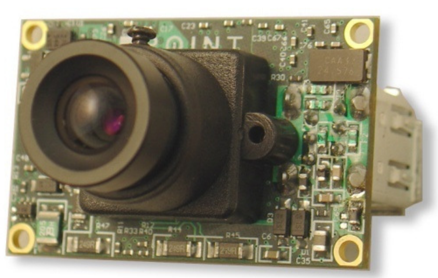
False colored by height



Video Cameras

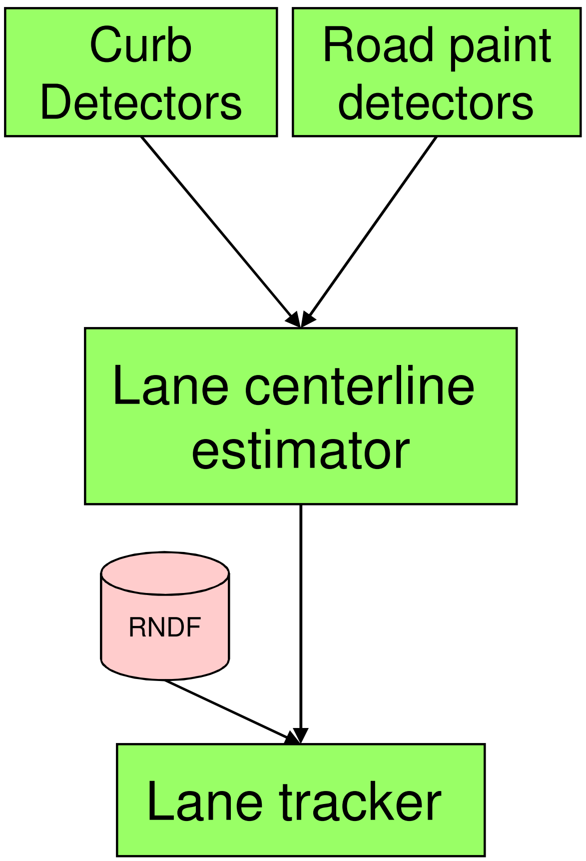
- 5 Firewire Cameras
  - Point Grey Firefly MV
- 720x480 8bpp Bayer pattern @ 22.8 fps
- ~40 MB/s (2.5 GB/min)
  - Significant I/O Bandwidth
- Purpose: Detection of painted lane markings





Multi-sensor Lane Discovery and Path Estimation

- **Sensor-rich, CPU-intensive architecture**
- **Multiple complementary sensor types**
- **Robust to coarse map, degraded/denied GPS**



Detecting Location

Position Sensors

- GPS (global positioning system)
  - May provide sub-meter resolution, but can be blocked by urban landscape

courtesy of NavCom

- Vehicle attitude
  - Gyroscopes, accelerometers (IMUs) can be used to get/update compass heading, pitch, roll of vehicle