Robot Sensors
An Overview

By Steven D. Kaehler - SRS Secretary/Meeting Organizer
Steve Kaehler - Who Am I?

- EE at Boeing (BCA)
- Instrumentation Engineer
- Specialize in “measuring things”
- >>25 yrs experience
- Design, build & use sensors, signal conditioning, & data acquisition systems
- SRS Sec. & Meeting Organizer
- SRS meeting/event attender since 1997
- Hobby robot builder (time permitting)
Robot Sensors - Outline

• What is a sensor?
• Why do robots need them?
• Sensors layers on robots?
• What kinds of thing can be sensed?
• What sensors are out there?
• What can they do?
• How much do they cost?
• Briefly on signal conditioning…
Robot Sensors - Objectives

- Show a lot of examples
- Try to explain how they work
- Reference Encoder articles
- Point to vendor websites
- Encourage research
- Encourage sensor experimentation
- Move very quickly!
What is a Sensor?

- A device that converts one thing to another
- Something that responds to the environment
- A device that produces an electrical response to some external stimulus
- A transducer
- An electronic device that measures & quantifies something by converting it into a measurable electronic signal
Why Do Robots Need Sensors?

• Provides “awareness” of surroundings
  – What’s ahead, around, “out there”?
• Allows interaction with environment
  – Robo-mower can “see” grass, yard perimeter
• Protection & Self-Preservation
  – Safety, Damage Prevention, Stairwell sensor
• Gives the robot capability to goal-seek
  – Find colorful objects, seek goals, explore
• Makes robots “interesting”
Robot Sensor Layers

• Consider a Robot’s Functional Purpose
  – Security, extending human visibility, cheap staff
  – Surveillance, remote monitoring, tele-presence
  – Exploration (dangerous or far away places)
  – Research & development
  – Contests, amusement, fun,
  – The Challenge of “Can I do it?”
Robot Sensor Layers

- Lines of Defense (of the robot)
  - Distant object detection (e.g. distance)
  - Area sensors (non-directional, object presence)
  - Non-contact, close proximity (a few inches)
  - Physical contact detection (collision detection)
Sensors - What Can Be Sensed?

Just about anything….

But how???
The Ideal Sensor...

- Responds from DC to light
- Detects all electrostatic & electromagnetic radiation
- Can measure anything with infinite resolution
- Can measure everything with absolute accuracy
- Can easily discriminate/filter anything desired
- Produces data that’s easy to analyze
- Is capable of analyzing its own data
- Is cheap, plentiful, easy to use, indestructible
- Does it all…
The Ideal Sensor...

Unfortunately, DOESN’T EXIST...YET
Sensors - What Can Be Sensed?

- Light (visible & invisible)
  - Presence, color, intensity, content (mod), direction
- Sound (audible & inaudible)
  - Presence, frequency, intensity, content (mod), direction
- Heat (invisible light)
  - Temperature, wavelength, magnitude, direction
- Chemicals
  - Presence, concentration, identity, etc.
- Object Proximity
  - Presence/absence, distance, bearing, color, etc.
- Physical orientation/attitude/position
  - Magnitude, pitch, roll, yaw, coordinates, etc.
Sensors - What Can Be Sensed?

- Magnetic (B-Field) & Electric (E-Field) Fields
  - Presence, magnitude (int.), orientation, content (mod)
- Resistance/Conductivity (indirectly via E or I)
  - Presence, magnitude, variation, etc.
- Capacitance (indirectly via excitation/oscillation)
  - Presence, magnitude, variation, etc.
- Inductance (indirectly via excitation/oscillation)
  - Presence, magnitude, variation, etc.
- Other Things?
Passive vs. Active Sensors

- Sensor are usually part of a “system”
  - Electronics make them work
- Passive – Sits (passively) & listens or watches
  - Photo-sensors, microphones, etc.
- Active – emits something; looks for reflections
  - Ultrasonic, laser ranger, etc.
What Sensors Are Out There?

- Feelers (Whiskers, Bumpers) – Mechanical
- Resistive/Capacitive/Inductive – Active & Passive
- Photoelectric (Visible) – Active & Passive
- Infrared (light) – Active & Passive
- Ultrasonic (sound) – Active & Passive
- Sonic – Active & Passive
What Sensors Are Out There?

- Visual – Cameras & Arrays (Active & Passive)
- Color Sensors (Active & Passive)
- Magnetic (Active & Passive)
- Inertial (Pitch, Roll, Yaw)
- Position (GPS; location, altitude)
- Compass (orientation, bearing)
- Voltage – Electric Field Sensors
- Current – Magnetic Field Sensors
- Chemical – Smoke Detectors, Gas Sensors
A Closer Look…
Feelers - Bumpers & Guards

From Kevin Ross's "Getting Started Article" (SRS Website)
Feelers - Bumpers & Guards

Specifications
• Phosphors bronze springs
• Feather touch operation
• Operates on any voltage
• Maximum current limit 330mA
• 8 pin Dual in line M&F BERG sockets included

From Nex-Robotics.com
Feelers - Bumpers & Guards

- Output response approximately logarithmic
- Standard sensor is very flexible
- Simple interface circuits buffer/amplify/linearize
- Direct connection to uC ADC input feasible

From FlexPoint.com
Sensors – IR

• Active (emitting)
  – Oscillator generates IR reflections off objects
  – Optical & electrical filtering of reflections
  – Pulses may be encoded for better discrimination
  – Typically frequencies around 40KHz
  – Doesn’t work well with dark, flat-colored objects
  – Light easily reflects away from sensor

• Passive (sensor only)
  – Pyro-electric (heat sensor)
  – Look for IR emissions from people & animals
  – Used in security systems & motion detectors
Infrared - Active

$30 from Lynxmotion

July 99 Encoder
Linear Array IR Range Sensors

- Sharp GP2Dxx (one of many)
- ~few to >500cm Ranges
- Fixed range w/discrete or analog output
- Non-linear output-to-distance
- Use 1/distance to linearize
- Easy to Use w/SRSWR

$20 from Acroname.com
Also Nex-Robotics.com
Laser Range Sensors

- USB & RS232 Interfaces
- 240° Field of View
- 0.36° Angular Resolution
- 10Hz Refresh Rate
- 20mm to 4m
- $2375 (cool but pricey)

from Acroname.com
Passive IR – Pyro-Electric

$20 from ElectronicKits.com
Also Nex-Robotics.com

Specifications:
• L: 3" W: 1-7/8" H: 1-1/2"
• Power: 9 - 12 VDC @ 300 mA.
• Range: Up to 18 feet
• Movement Sensitivity Adj.
• Light sensitivity Adj. for Day/Night use.
• Exit delay option.
• Alarm on-time Adj.
• LED indicator when motion is detected
Sensors – Ultrasonic

• Active
  – Emit pulses & listen for echos
  – Times round trip sound travel (~1ft/mS)
  – Reaches far fairly beyond robot (inches to 30-50’)
  – Relatively simple, not cheap, analog output
  – Directional; not everything reflects sound well

• Passive (listens only)
  – Sensor listens for ultrasonic sounds
  – Electronics may translate frequency or modulation
  – Software may perform signal analysis (FFTs, etc.)
Ultrasonic - Active

$27
$49
$134

acroname.com for more information about these & other products.
Search the web for “polaroid ultrasonic sensor” for hacking info on these circuits
Sensors – Resistance

• Passive (sensor only)
  – Measures elec. resistance between objects
  – Measure sensor that varies resistance
  – Use absolute values
  – Use differential readings (from reference)
  – Other ideas?
Sensors – Capacitive

• Passive
  – Only detects “energized” sources or objects
  – Sensor needs amplification & filtering

• Active (emitting)
  – Generate AC or DC voltage
  – Apply to external environment
  – Measure current to determine Resistance
  – Short range applications
Sensors - Capaciflector

http://www.edcheung.com/job/hrsdm/cap.htm
Sensors - Capaciflector

http://www.edcheung.com/job/hrsdm/cap.htm
Sensors - Capaciflector

http://www.edcheung.com/job/hrsdm/cap.htm
Sensors - Inductive

• Passive
  – Only detects energized (current flow) “sources”
  – Sensor needs ampl. & filtering
  – Sens. to B-field orientation

• Active (emitting)
  – Metals affect sensor
  – Current flows through inductor
  – Magnetic field mostly ignores non-metals
  – Inductance changes with metallic proximity
  – Short range applications (~cm or mm)
Sensors – Visual

• Active (emitting)
  – Camera with field of view illumination
  – Looks for particular reflections
  – Filter removes non-significant light sources
  – Linear array senses single axis of motion

• Passive (camera only)
  – Scans field of interest
  – Looks for objects, artifacts, features of interest
  – Processes digital data to simplified interpretation
Sensors – Visual

- CMUCam
- Linear Optical Array
Sensors – Visual

Kinect
- Color Camera
- IR Emitter/Detector
- Four Microphones
- DC Accelerometer
Inside the case:

- An RGB camera stores three channel data at 1280x960 resolution.
- An infrared (IR) emitter and an IR depth sensor.
- A multi-array microphone (four provide source direction)
- A 3-axis accelerometer to determine the current orientation of the Kinect.
## Specifications for the Kinect

<table>
<thead>
<tr>
<th>Kinect</th>
<th>Array Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viewing angle</td>
<td>43° vertical by 57° horizontal field of view</td>
</tr>
<tr>
<td>Vertical tilt range</td>
<td>±27°</td>
</tr>
<tr>
<td>Frame rate (depth and color stream)</td>
<td>30 frames per second (FPS)</td>
</tr>
<tr>
<td>Audio format</td>
<td>16-kHz, 24-bit mono pulse code modulation (PCM)</td>
</tr>
<tr>
<td>Audio input characteristics</td>
<td>A four-microphone array with 24-bit analog-to-digital converter (ADC) and Kinect-resident signal processing including acoustic echo cancellation and noise suppression</td>
</tr>
<tr>
<td>Accelerometer characteristics</td>
<td>A 2G/4G/8G accelerometer configured for the 2G range, with a 1° accuracy upper limit.</td>
</tr>
</tbody>
</table>

The resolution of the depth stream is dependent on the frame rate, and is specified by the `DepthImageFormat Enumeration` enumeration. Similarly, the resolution of the color stream is specified by the `ColorImageFormat Enumeration` enumeration.

See the `depth space range` section to see the depth data ranges as well as values for out-of-range data.
Sensors – Color

• Active (emitting)
  – Selective field illumination (specific color(s))
  – Sensor is calibrated for each color
  – Sensor filter removes extraneous light sources
  – Output can be analog (prop.) or digital (on/off)

• Passive (sensors only)
  – Different sensors for different colors
  – Color filter removes extraneous light sources
  – Output can be analog (prop.) or digital (on/off)
Sensors – Color

http://robotroom.com/ColorSensor.html

- Activate one LED at a time
- Measure the photocell resp. to reflection
- Repeat for all LEDs
- Compare individual readings with table
Sensors – Magnetic

• Active (emitting)
  – Metal detectors
  – Follows metallic strips on or under the floor
  – Magnetometer
  – Magnetic Resonance Imaging (MRI)

• Passive (sensors only)
  – Compass
  – Magnetic field sensor (→oscillating current)
  – Coil
Sensors – Orientation

• Rate Gyros
  – Output proportional to angular rotational speed
  – Integrate to get position
  – Differentiate to get angular acceleration
  – Use to control dynamic motion (e.g. balance)

• DC Accelerometer
  – Minimum output when perpendicular to gravity
  – Maximum output when parallel to gravity
  – Output proportional to sine of vertical angle
Sensors – Motion

Rate Gyro – Silicon Sensing Systems
Servo Accel – SensorLand.com
Sensors – Position/Location

• Rotary Sensors & Encoders
  – Relative & absolute position & motion
  – Quadrature outputs for speed & direction
  – Integrate/Differentiate for other parameters
  – RVDTs (analog output proportional to angle)

http://webstore.melexis.com/mlxstore.asp?family=MLX90316
Wheel Encoders

- Nubotics.com, $27
- Jun 98, Oct 2000 Encoder
Sensors – Position/Location

• Global Positioning System
  – Absolute position/location/elevation on earth
  – Local differential error correction
  – Integrate/Differentiate for other parameters
  – Use compass for static orientation
Sensors – Compass (Orientation)

- Track bearing & distance to determine position
- L: Parallax.com, $30
- R: DinsmoreSensors.com, $13-$37
Sensors – Compass (Orientation)

- Voltage: 5V only Required
- Current: 20 mA Typical
- Resolution: 0.1 Degree
- Accuracy: 3-4° approx. after cal.
- Output 1: Timing Pulse 1mS to 37mS in 0.1mS inc
- Output 2: I2C Interface, 0-255 (0-3599)
- SCL speed up to 1MHz
- Size: 1.26 x 1.38 in.
- 32 x 35 mm

- Measure bearing to determine position
- From Robot-Electronics.co.uk
- From RoboticsConnection.com
Sensors – Voltage

- Passive – Senses electric fields

$24
Sensors – Current

Package LC

Pin 1: IP+
Pin 2: IP+
Pin 3: IP−
Pin 4: IP−
Pin 5: GND
Pin 6: VCC
Pin 7: VOUT

Pins 6 and 7 are internally connected in shipping product. For compatibility with future devices, leave pin 6 floating.
Sensors – Current

- Components:
  - Voltage Regulator
  - Dynamic Offset Cancellation
  - Gain
  - Temperature Coefficient
  - Offset
  - Trim Control

- Connections:
  - IP+ Pin 1, IP+ Pin 2
  - VCC Pin 8
  - To all subcircuits
  - GND Pin 5

- Notes:
  - Pins 6 and 7 are internally connected in shipping product. For compatibility with future devices, leave pin 6 floating.
Sensors – Chemical

• Passive (sensors only)
  – Sensor must be energize & amplified
  – Requires flow of chemical past sensor
  – Carbonizes gas as it passes

• Active (optical emitter/photo sensor)
  – Emits beam into path of chemical/particles
  – Requires flow of chemical past sensor
Sensors – Chemical

- Detect ammonia, CO, methane, combustible gases
- Conductivity increases with gas concentration in the air
- Sensors that detect carbon atoms
- Use a heater to “burn” gas
- Downside: Eventually “plugs up”
Sensors – Chemical

MOS Sensor Operating Principles:
- Gas adsorption on surface of the metal oxide changes electrical resistance
- Reducing gas donates electrons and oxidizing gas "grabs" electrons.
- Change in resistance is a surface reaction and dependent upon the amount of surface area.
- Surface interactions occur at elevated temperatures

Synkera NanoMOS™ sensors features/benefits
- Three unique sensor architectures:
  - Planar sensors prepared via a thick film screen printing process
  - Multilayer sensors
  - MEMS sensors for low power and advanced operating modes
- Small size
- Improved sensitivity
- Low cost
- Fast Response

Operation of Planar and Multilayer MOS Sensors
- Sensor Resistance is a function of analyte concentration
- Log (resistance) is proportional to Log (concentration)
- Power required for heater operation of 100 mW to 1W.
Sensors – Chemical

- Smoke Detectors - Cheap, readily available, $5
- Can use radioactive to ionize smoke particles in the air
- Can use optical reflection from smoke particles in the air
- Oxygen concentration sensors - CO, H₄S, CH₄, pricey
- See HowStuffWorks.com
Parallax Sensor Sampler - $159

- Memsic 2125 Accelerometer
- Sensirion Temperature and Humidity Sensor
- Flexiforce Demo Kit
- PING))) Ultrasonic Sensor
- PIR Sensor ("heat" sensor)
- Hitachi HM55B Compass Module
- Hitachi H48C Tri-Axis Accelerometer Module
- Piezo Film Vibra-Tab Mass
- TCS230-DB Color Sensor

- Parallax.com
Parallax Sensor Sampler - $159
Interfacing to Analog Sensors

• Wire to sensors & electronics
• Energize sensor electronics (locally or remotely)
• Route analog signal controlled by sensor
• Buffer & amplify analog signal
• Isolate, remove DC offsets, single-end signal
• Feed to ADC or uController analog input

• Atmel.com
Instrumentation Amplifiers

- Gain = 1 + \(\frac{2R_1}{R_{gain}}\)
- Linear.com & Maxim-ic.com (free to $$)
Instrumentation Amplifiers

Pin numbers are for DIP packages.

\[ V_O = G \cdot (V_{IN} - V_{IN}) \]
\[ G = 1 + \frac{50k\Omega}{R_G} \]

<table>
<thead>
<tr>
<th>DESIRED GAIN</th>
<th>( R_G (\Omega) )</th>
<th>NEAREST 1% ( R_G (\Omega) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No Connection</td>
<td>No Connection</td>
</tr>
<tr>
<td>2</td>
<td>50.00k</td>
<td>49.9k</td>
</tr>
<tr>
<td>5</td>
<td>12.50k</td>
<td>12.4k</td>
</tr>
<tr>
<td>10</td>
<td>5.556k</td>
<td>5.62k</td>
</tr>
<tr>
<td>20</td>
<td>2.632k</td>
<td>2.61k</td>
</tr>
<tr>
<td>50</td>
<td>1.02k</td>
<td>1.02k</td>
</tr>
<tr>
<td>100</td>
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<td>511</td>
</tr>
<tr>
<td>200</td>
<td>251.3</td>
<td>249</td>
</tr>
<tr>
<td>500</td>
<td>100.2</td>
<td>100</td>
</tr>
<tr>
<td>1000</td>
<td>50.05</td>
<td>49.9</td>
</tr>
<tr>
<td>2000</td>
<td>25.01</td>
<td>24.9</td>
</tr>
<tr>
<td>5000</td>
<td>10.00</td>
<td>10</td>
</tr>
<tr>
<td>10000</td>
<td>5.001</td>
<td>4.99</td>
</tr>
</tbody>
</table>
Robot Sensors - Summary

• What are sensors?
• Why do robots need them?
• Implementing sensor layers
• What can be sensed?
• What sensors are out there (some)?
• How do they work?
• How much they cost?
• How to interface to them
Sensors… Conclusion

• There are lots of them
• Almost anything can be sensed
• Provide for human & robot protection
• Enable goal-seeking (finding things)
• Enable closed-loop interaction (approaching)
• Make robots interesting (& fun)
• Make programming “challenging”
• Lots of data to process & interpret
• Are pretty cool!
Sensor Vendor/Info Links

http://www.acroname.com
http://www.dinsmoresensors.com
http://www.electronickits.com
http://www.fluke.com
http://www.howstuffworks.com
http://www.lynxmotion.com
http://www.magnetometer.org
http://www.nex-robotics.com
http://www.nubotics.com
http://www.raztec.co.nz
Sensor Vendor/Info Links

http://www.robotics.com
http://www.roboticsconnection.com
http://www.robotroom.com
http://www.sensorland.com
http://www.sensorsmag.com
http://www.seattlerobotics.org/encoder
http://www.seattlerobotics.org/encoder/index-old.html
http://www.solarbotics.com
http://www.synkera.com/
http://www.tedlarson.com
Sensors

Q&A

Comments & Discussion