AI for Mobile Robots
- CSIP5202 -

Sensors

Overview

- Introduction to sensors
- Sensor Characteristics
- Types of sensors
- We will be considering the sensors in the iRobot Create and CoppeliaSim as we go along

Robot Sensors

- Sensors are devices that can sense and measure physical properties of the robot or the environment
  - E.g. temperature, luminance, resistance to touch, weight etc.
- Provide low-level information about the physical variables in the robot or the environment
- Useful information but is noisy (i.e. imprecise)
- Often ambiguous

Sensor Characteristics

- Sensitivity: (change of output) / (change of input)
  - Also referred to as “Gain”
- Linearity: constancy of (output / input)
  - It can be either linear or non-linear in which an explicit transfer function is required to define it.
- Range: the difference between minimum and maximum
  - Technically the difference but sometimes is described with the limits
- Response time: the time required for a change in input to cause a change in the output and thus be detected

Sensor Characteristics

- And these affect the quality of the data gathered
  - Accuracy: the difference between measured and actual values
  - Repeatability: the difference between a number of repeated measures
  - Resolution: smallest observable/measurable increment
  - Bandwidth: how many samples per second can be measured
  - Signal to Noise ratio: This indicates how good is a sensor at providing a value just for the measured variable in comparison with how much noise (random data/errors) is included in such values. It affects/limits directly all the above characteristics.

Sensor Characteristics

- These characteristics have specific ways to be quantified, depending on the variable they measure and how they provide this measurement to the computer (robot). !
  - The measurement of range is often provided just as the start/end of scale values such as (-20) to (+50) C
  - This means, the range of -20 to +50 will be presented to the computer in the form of 0 – 1V for it to convert to a number
  - You have to use these units and ranges to convert the value your software gets to the original units and in the correct range so that you have the correct value

Sensor Characteristics

- Knowing and understanding the characteristics of sensors is one of the most critical aspects in relation to the input in robotics
- It is critical so that proper interpretation of the sensor data is performed
- It is critical so that the limitations can be considered
- It is important to choose the appropriate characteristics for the particular need
- It is critical to know how the different characteristics relate to each other
- Not always more is better!

Sensor Types

- It is difficult for us not to view the world in a humancentric manner
  - Vision is our primary sense
- Other animals see the world in different ways:
  - For dogs, smell is their primary sense
  - Moles don’t even see, they rely mainly on touch and smell
  - Bats rely mainly on the ultrasonic range of their hearing
- There are many other different types of sensors
  - Many sense phenomena that humans cannot detect e.g. magnetism, infra-red, ultra-violet, ultrasound and many more

Sensor Types

- Sensors can be classified according to different aspects relating to the way they work:
  - e.g. active and passive
- How they are used:
  - e.g. internal state and external state
- How they are interpreted:
  - e.g. visual and non-visual

Active Vs. Passive

- Sensors can be classified based on how they work
- Active: radiating some form of energy into the environment e.g.
  - Radar (radio direction and ranging)
  - Sonar (sound navigation and ranging)
  - Active camera (night vision)
- Passive: relying on energy emitted by various objects in the environment e.g.
  - Microphone (hearing, detecting noise)
  - Bumpers (detecting collisions)
  - Camera (normal vision)

Internal Vs. External State

- Sensors can be classified based on how they are used
- Internal state: providing information about internal variables to the robot e.g.
  - Battery level (voltage and energy remaining)
  - Motor position (angles, speed…) – Odometry
  - Time (with respect to an internal clock)
- External state: providing information about variables in the environment
  - External temperature
  - Distance to objects (detecting/avoiding collisions)
  - Camera (vision)

Visual Vs. Non-visual

- Sensors can be classified as we see them
- Non-visual: providing information about non-visual variables e.g.
  - Distance(infrared, ultrasonic or laser-based direction and ranging)
  - Position (GPS or landmark detection)
- Visual: providing information in the form of images e.g.
  - Camera (single image vision)
  - Stereo vision (disparate multiple-image vision)
  - Other spectral cameras (night vision, motion detection)

Tactile Sensors

- There are many different technologies
  - E.g. contact closure, magnetic, piezoelectric, etc.
- For mobile robots, these can be classified as:
  - Tactile feelers (antennae) often some form of a metal wire passing through a wire loop can be active (powered to search for surfaces mechanically)
  - Tactile/contact bumpers solid bar/plate acts on some form of contact switch e.g., mirror deflecting light beam, pressure bladder, wire loops, etc.
  - Distributed surface arrays miniature switches are arranged in a 2D array to provide shape information and sometimes pressure (as skin)

Proximity Sensors

- Tactile sensors allow obstacle detection but proximity sensors are needed for true obstacle avoidance
- Several technologies can detect the presence of particular fields without mechanical contact
  - Magnetic reed switches: 2 thin magnetised strips with an external field close to make contact
  - Hall effect sensors: small voltage generated across a semi-conductor carrying current
  - Inductive sensors, capacitive sensors:
    - Inductive sensors can detect the presence of metallic objects
    - Capacitive sensors can detect metallic or dielectric materials

Infrared Sensors

- Infrared (IR) sensors are probably the simplest type of noncontact sensor
  - widely used in mobile robotics to avoid obstacles or detect beacons
- IR sensors can be both passive or active
- Passive IR sensors simply detect infrared light received from the environment
  - A typical remote control
  - Its possible to measure temperature with no contact
  - Can be used to detect and identify active beacons

Infrared Sensors

- Active IR sensors work by emitting infrared light
  - To differentiate emitted IR from ambient IR (e.g. lights, sun, heat, etc.), the signal is modulated with a particular known frequency (e.g. 400 Hz)
  - It detects the reflections off nearby surfaces
- In certain environments, with careful calibration, IR sensors can be used to measure object distance
  - requires uniform surface colours and structures

Infrared Sensors

- The iRobot Create has an Omnidirectional IR receiver (passive)
- This sensor can receive IR signals from an external transmitter, which can be a virtual wall, or a home beacon (charging station)

Sonar Sensors

- The fundamental principle of robot sonar sensors is the same as that used by bats
  - Emit a chirp (e.g. 1.2 milliseconds): a short powerful pulse of a range of frequencies of sound
  - Its reflection off nearby surfaces is detected
- As the speed of sound in air is known (≈ 330 m·s-1) the distance to the object can be computed from the elapsed time between chirp and echo
  - minimum distance = 165 t $chirp$(e.g. 21 cm at 1.2 ms
  - maximum distance = 165 t $wait$(e.g. 165 m at 1 s)
- Usually referred to as “Ultrasonic Sensors”

Sonar Problems

- There are a number of problems and uncertainties associated with readings from sonar sensors
  - it isn't easy to be sure in which direction an object is because the 3D sonar beam spreads out as it travels
  - specular reflections give rise to erroneous readings
    - the sonar beam hits a smooth surface at a shallow angle and so reflects away from the sensor
    - only when an object further away reflects the beam back does the sensor obtain a reading but distance is incorrect
  - arrays of sonar sensors can experience crosstalk
    - one sensor detects the reflected beam of another sensor
  - the speed of sound varies with air temperature and pressure
    - a 16°C temp. change can cause a 30cm error at 10m!

Sonar Sensors

- Both the iRobot Create simulator and the CoppeliaSim Pioneer have sonars
- The iRobot Create simulator has 4 sonars, one at each cardinal side (these are not actually available in the real robot)
- The pioneer has 8 sonars in the front half. These sonars are the primary sensors in the Pioneers

Laser Range Finders

- Laser range finders commonly used to measure the distance, velocity and acceleration of objects
  - also known as laser radar or LIDAR
- The operating principle is the same as sonar
  - a short pulse of (laser) light is emitted
  - the time elapsed between emission and detection is used to determine the distance (using the speed of light)
- Due to the shorter wavelengths of lasers, the chance of specular reflections is much less
  - accuracies of millimetres (16 - 50mm) over 100m
  - 1D beam is usually swept to give a 2D planar beam
- May not detect transparent surfaces (e.g. glass!)
- The iRobot Create simulator has LIDARs, in CoppeliaSim you can add a LIDAR sensor to the Pioneer robot

Inertial Measurement Units

- Measure RELATIVE velocity and orientation using:
  - Gyroscopes (rotation)
  - Accelerometers (acceleration)
- Aligned along an orthogonal axis
- Measurements are noisy and relative
- Needs complex filters to make sense of the data (e.g. Kalman filter)
  - see it in a CCI project: HERE

Gyroscope

- A gyroscope is a spinning wheel with most of its mass concentrated in the outer periphery
  - e.g. a bicycle wheel
- Due to the law of conservation of momentum
  - the spinning wheel will stay in its original orientation
  - a force is required to rotate the gyroscope
- A gyro. can thus be used to maintain orientation or to measure the rate and direction of rotation
- In fact there are different types of mechanical gyro.
  - and even optical gyro's with no moving parts: these can be used in space probes to maintain orientation

GPS

- Started in 1973 as a US DoD program.
- In 1989 Block II the first satellite of the current generation was launched.
- In 1995 the system was declared to be of ‘full operational capability’
- Global Positioning System (GPS) is based on a constellation of 21 orbiting satellites. They orbit the Earth in six orbital planes so at least five of them would be visible at any time from any point on the Earth’s surface.
- The system operates by measuring the difference in time of flight for a radio signal to arrive from a combination of satellites.

GPS

- The US government-controlled GPS is not the only GNSS in existence
- The Russians have their own “ Glonass ”
- And now we also have Galileo, Europe’s own global navigation satellite system
- “A defining characteristic of Galileo is that, unlike GPS and Glonass, it was conceived and developed and will always remain under civilian control.”

Robot Sensors

- Study the iRobot simulator's guide (iRobotSimulator_UserGuide.pdf), specifically the sensor functions list (pages 7 - 10), and the Pioneer robot in the scene hierarchy in CoppeliaSim
- Check which sensors it has (including the ones in the real robot which are not used in the simulator and vice versa)
- Try to find out how to add a sensor to the CoppeliaSim Pioneer robot
- Discuss some of these sensors in terms of the classification and characteristics, e.g.:
  - Which are the internal state and which external state?
  - How would you asses a characteristic, such as range or accuracy?

Robot Sensors

- Discussion board:
  - Remember that your contribution to the discussion board will make part of the final mark
  - Make sure you contribute with your discussions relating to the topics flagged in the lessons
  - And with your experience and problems/limitations/etc… from the labs.

Recap

- Sensors can be classified according to different aspects relating to the way they work:
    - e.g. Active vs. Passive
- The use we give them:
    - e.g. Internal state vs. External state
- The way we interpret them:
    - e.g. Visual vs. Non visual
- We need to understand the characteristics of each sensor to understand the limitations of the robot and how to deal with the uncertainty the combination of sensors will provide.

Questions?