Introduction to Mobile Robots

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Control Models
The Control Cycle

- A fundamental methodology derived in the early days of robotics from engineering principles is the *sense-think-act* cycle.
  - the principle is to continuously attempt to minimise the error between the actual state and the desired state.
    - based on control theory.

```
sense -> compute (think) -> act
```
Control Architectures

- A variety of different approaches have been tried for implementing the *sense-think-act* control cycle.
- These approaches can be categorised as:
  - model-based
  - reactive
  - hybrid
Model Based

- A symbolic internal ‘world-model’ is maintained
  - the sub-tasks are decomposed into functional layers
  - similar to ‘classical’ artificial intelligence approach
Problems with Models

- An **adequate, accurate and up-to-date** model must be maintained at all times
  - this is very difficult in practice!
  - what if sensors detect an object that hasn’t been defined
- A **model-based system** is **extremely brittle**
  - if one of the functional layers fails (e.g. hardware problems, software bugs), then the whole system fails
- **Significant processing power** is required
  - maintaining the model takes time, so slow responses!?
- Despite much effort, **little progress** was made!
Reactive Robotics
Reactive Controllers

- In order to try to overcome the shortcomings of model-based robots, modern approaches have centred predominantly on simple *reactive* systems with minimal amounts of computation.
  - ‘model-free systems’

- More correctly, the models are *simple* and *implicit*.
  - The systems do not use symbolic models but, for example, a rule-set which tells a robot how to react to a corner when following a wall may be considered to be a simple, implicit model fragment.
    - It implicitly encodes assumptions about the environment.
Behaviour Based

- The control system is broken down into horizontal modules, or *behaviours*, that run in parallel
  - each behaviour has direct access to sensor readings and can control the robot’s motors directly

```
sense

identify objects
build maps
explore
wander
avoid objects

act
```
Behaviour Advantages

- It supports multiple goals and is more efficient
  - there is no functional hierarchy between layers
    - one layer does not call another layer
  - each layer can work on different goals in parallel
  - communication between layers is achieved via message passing which need not be synchronised
- The system is easier to design, debug and extend
  - each module can be designed and tested individually
- The system is robust
  - if one module fails, e.g. wander, then other layers, e.g. avoid obstacles, still function and behave correctly
Behaviour Limitations

- It is extremely difficult to implement plans in pure form a behaviour-based robot has no memory (not even an internal state memory) and so is unable to follow an externally specified sequences of actions.

- It can be very hard to predict how a large number of multiple behaviours may interact.
  - *Emergent behaviour* is the term given to unexpected behaviour that comes about through these interactions sometimes it is useful, sometimes it is not!

- The robot can get trapped in a *limit cycle* trapped in a dead-end, repeatedly turning left then right.
Other Approaches
Other Reactive Approaches

- Two other reactive approaches that are popular
- Potential field methods
  - a potential field is a concept from physics
    - e.g. the *gravitational field*
      - you do not need to be told which way to fall
      - planets do not need to plan how to move around the sun
    - obstacles exert hypothetical repulsive forces on the robot
- Motor schema navigation
  - multiple, concurrent schema generate separate behaviours
    which are summed to produce output
  - schema are dynamically created/destroyed as needed
Hybrid Approaches

- The **SSS** three-layer architecture
  - the *servo-subsumption-symbolic* architecture combines Brooks’ architecture with a lower-level servo control level and a higher-level symbolic system [Connell]
  - It provides a neat way to combine the advantages of each architecture:
    - Quick response of servo
    - Robust response of reactive (subsumption)
    - Planning capabilities of model based (symbolic)
Learning Approaches

- Traditional learning techniques
  - rather than attempt to predefine and predict a symbolic model of the ‘real-world’, the robot learns how to operate and how to behave

- Evolutionary algorithms
  - using genetic algorithms to find good network weights
  - significant problems with evolving real solutions in reasonable time on current mobile robot hardware
Introduction to Sensors
Robot Sensors

- Sensors are devices that can sense and measure physical properties of the environment,
  - e.g. temperature, luminance, weight, size, etc.
- They deliver *low-level* information about the environment the robot is working in
- This information is
  - noisy (imprecise) and even contradictory and ambiguous
- Sensors and Detectors are similar but **NOT** equal
Sensor Characteristics

- All sensors are characterised by a number of properties that describe their capabilities
  - Sensitivity: \((\text{change of output}) \div (\text{change of input})\)
  - Linearity: constancy of \((\text{output} \div \text{input})\)
  - Measurement range: difference between min. and max.
  - Response time: time required for a change in input to cause a change in the output
  - Accuracy: difference between measured & actual
  - Repeatability: difference between repeated measures
  - Resolution: smallest observable increment
  - Bandwidth: range of frequencies it can respond to
Sensor Types

- It is impossible for us not to view the world in a human-centric manner, but this is not absolute:
  - vision is our main sense, as the human brain is dominated by a large visual cortex
  - the dog brain is dominated by an olfactory cortex, with 125 to 220 million smell-sensitive receptors in the olfactory bulb
  - cockroaches have 30,000 wind-sensitive hairs on legs

- There are many different types of sensor
  - many sense phenomena that humans cannot detect
    - e.g. magnetism, infra-red, ultra-violet, ultrasound, phase of light (e.g. polarised sun-glasses), etc.
Active vs. Passive

- Sensors can be broadly classified as either
  - *active*
    - radiating some form of energy into the environment
    - e.g.
      - radar (radio direction and ranging)
      - sonar (sound navigation and ranging)
      - lidar (light direction and ranging)
  - *passive*
    - relying on energy emitted by various objects in environment

- It is tempting to imagine that passive sensors do not interfere with the environment
  - *ANY sensor may affect the environment*
Internal State vs. External State

- The variable that a Sensors reads can provide information either
  - About the internal state of the Robot
    - Internal variables, e.g. battery level
    - Self measurements, e.g. odometry
    - Time
  - About the external environment
    - External variables, e.g. outside temperature
    - Position relative to external objects, e.g. obstacles
    - Communications
Non-Visual Sensors
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:
    - Two thin magnetic strips of opposite polarity not quite touching.
    - An external magnetic field closes the strip & makes contact.
  - Hall effect sensors:
    - Small voltage generated across a conductor carrying current.
  - Inductive sensors, capacitive sensors:
    - Inductive sensors can detect presence of metallic objects.
    - Capacitive sensors can detect metallic or dielectric materials.
Infrared Sensors

- Infrared sensors are probably the simplest type of non-contact sensor
  - widely used in mobile robotics to avoid obstacles

- They work by
  - emitting infrared light, (to differentiate emitted IR from ambient IR - e.g. lights, sun, etc.- , a code is added)
  - detecting any reflections off nearby surfaces

- In certain environments, with careful calibration, IR sensors can be used for object distance
  - requires uniform surface colours and structures
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
Visual Sensors
Visual Sensors

- Visual sensors are based on light. They consist of two main components:
  - An optical system
  - An optoelectrical system
Visual Sensors

- A digital image is a collection of samples representing the visual content of the environment.
- Each individual sample is represented in the form of a pixel or picture element. Each pixel is a point on rectangular lattice with finite resolution encoding some form of intensity.
- For the image to look unbroken (continues) a minimum number of samples should be taken. The minimum sampling frequency is known as the Nyquist frequency:
  - The signal should be sampled ‘at a rate at least twice as great as the highest frequency in the signal’
Stereoscopic Vision

- Viewing the world with two cameras (eyes) allows a three-dimensional representation to be formed
  - unfortunately the signal is complex and noisy
- Each camera receives a slightly different view
  - the distance between corresponding points in an image is known as the *stereo disparity*
Object Recognition

- Much research has gone into the field of object recognition (it seems so easy for us humans!), but the problem has not been solved yet
  - it seems humans use a combination of techniques

- Edge detection
  - fairly simple filter operations can detect clean edges
    - e.g. the discrete Laplace filter
  - reliable detection of all edges is much more difficult

- Area based techniques
  - connected regions of similar colour, texture or brightness probably belong to the same object
Actuators

Locomotion
Mobility Considerations

- Issues impact selection of drive
  - manoeuvrability: ability to alter direction/speed
  - controllability: practical and not too complex
  - traction: sufficient to minimise slippage
  - climbing ability: traversal of minor discontinuities, slope rate, surface type, terrain
Mobility Considerations

- **stability**
  - mustn't fall over!

- **efficiency**
  - power consumption reasonable

- **maintenance**
  - easy to maintain, reliable

- **environmental impact**
  - does not do damage

- **navigation**
  - accuracy of dead-reckoning
Legs

- Two legs seems the most familiar configuration
  - But balance is an incredibly difficult problem
  - Need very fast and supple joints to move and balance
  - Standing still is an active task (uses energy!!)
- Four legs are much easier to balance and move … are they?
- Six legs are much easier to balance and move
  - Stable when not moving
  - Can work with simple cams and rigid legs
  - Processing is much simpler!
Wheels

- Again, any number of wheels is possible
  - there are many different configurations that are useful
- Two individually driven wheels on either side
  - usually with one or more *idler wheels* for balance
  - independently driven wheels allows zero *turning radius*
    - one wheel drives forwards, one wheel drives backwards
- Rear wheel drive, with front wheel steering
  - the vehicle will have a non-zero turning radius
  - for two front wheels, turning geometry is complex
  - the rear wheels need a *differential* to prevent slippage
- 4WD is possible, but it is even more complex
Exotic Wheels and Tracks

- Tracks can be used in the same way as 2 wheels
  - good for rough terrain (as compared to wheels)
  - tracks must slip to enable turns (*skid steering*)
- In *synchro drive* three or more wheels are coupled
  - drive in same direction at same rate
  - pivot in unison about their respective steering axes
  - allows body of robot to remain in the same orientation
- Tri-star wheels are composed of 3 *sub-wheels*
  - entire wheel assembly rolls over a large obstacle
- There are many other exotic wheel configurations
  - multiple-degrees-of-freedom (MDOF), e.g. Kilough
Wheels and Tracks

If \( v_L = -v_R \):
\[
\Delta P_0 = \{
\begin{align*}
|\Delta P_0| &= 0; \\
\Delta P_0 \to &= |v_L \Delta t| / R\omega;
\end{align*}
\}
\]

If \( v_L \neq v_R \) and \( \Delta t \) is small:
\[
\Delta P_0 = \{
\begin{align*}
|\Delta P_0| &= |v_L + v_R|/2 \cdot \Delta t; \\
\Delta P_0 \to &= (|v_L - v_R|/2 \cdot \Delta t) / R\omega;
\end{align*}
\}

Exotic Wheels and Tracks
Actuator Types

- Electric
  - DC motor is most common type used in mobile robots
  - stepper motors turn a certain amount with a voltage pulse

- Pneumatic
  - operate by pumping compressed air through chambers: slow.

- Hydraulic
  - pump pressurised oil: usually too heavy, dirty and expensive to be used on mobile robots

- Shape memory alloys (SMA’s)
  - metallic alloys that deform under heat and then return to their previous shape: *used for artificial muscles*
Arms and Grippers

- Degrees-of-freedom
  - independently controllable components of motion

- Arms
  - convenient method to allow full movement in 3D
  - more often used in fixed robots due to power & weight
  - even more difficult to control!
    - due to extra degrees of freedom

- Grippers
  - may be very simple (two rigid arms) to pick up objects
  - may be complex device with fingers on end of an arm
  - probably need feedback to control grip force
    - e.g. picking up an egg!
Measuring Motion
Odometry

- If wheels are being used, then distance traveled can be calculated by measuring number of turns
  - *dead-reckoning* or *odometry* is the name given to the direct measure of distance (for navigation)
- Motor speed and timing are very inaccurate
  - measuring the number of wheel rotations is better
  - *shaft encoders*, or *rotation sensors*, measure this
- Can be used in Mobile Robots as well as Manipulators
Odometry

- There are many different types and technologies of shaft encoder
  - Optical encoders (relative)
  - Potentiometers (absolute for each turn)
- In practice, slippage means that dead-reckoning is unreliable over all but very short distances
- And is a relative measurement at the end, so...