

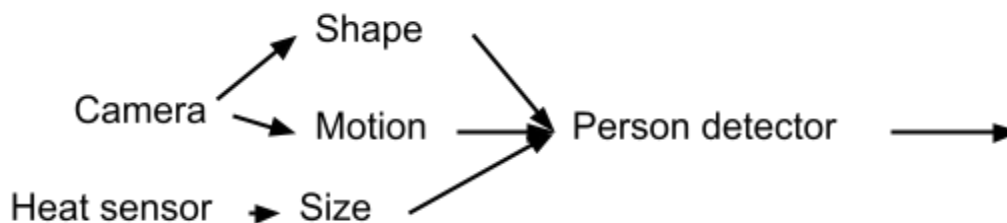
1. (a) Explain, with an example, the concept of a virtual sensor. [3 marks]

Virtual sensors provide feasible and economical alternatives to costly or impractical physical measurement instruments. It uses information available from other measurements and parameters to calculate an estimate of the quantity of interest.

example..

I think the slides would answer this perfectly no?

Virtual, or “logical”, sensors are an abstraction over the physics of specific sensors. Modularise (multiple) sensors and processing into a single output vector allowing you to independently redesign, restructure and improve modules. E.g.:



(b) Explain, with an example, the concept of a sensor model. [3 marks]

A sensor model is a set of values which govern how the probability of an uncertain measurement varies in space. E.g. ultrasonic sensors can be imprecise/uncertain, and so a mixture of:

- measurement noise
- unexpected obstacles
- random measurements
- and max range

error sources are combined as a mixture density.

(c) Steels (1990) defines emergence as a robot function achieved “indirectly by the interaction of more primitive components among themselves and with the world”. List three advantages and three disadvantages of obtaining a desired robot functionality this way. [3 marks]

Advantages:

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Disadvantages:

- Function is achieved indirectly, may not be that accurate
- Accuracy depends on how the components are combined
- A change/error in one component could drastically affect the results of the function

(d) What simple strategies used by desert ants can be used by a robot to relocate its home position? Describe one algorithm that has been proposed to explain

ant navigation. [4 marks]

- Snapshot model?
- Image subtraction from home image
- **Integration of outbound path:**

by integrating velocity over time,
should be able to keep track of current position
relative to starting position.

e.g.

$$x(t + \Delta t) = x(t) + \cos(\Theta(t))s(t)\Delta t$$

$$y(t + \Delta t) = y(t) + \sin(\Theta(t))s(t)\Delta t$$

Where

Δt is the time step, $\Theta(t)$ the heading angle and $s(t)$ the
speed during that time step.

(e) Your robot has been provided with a map showing the layout of obstacles in a large arena and its start and goal location. Describe how you can calculate an efficient path from the start to the goal. You can assume the robot is able to rotate on the spot. [5 marks]

Using the grid method, a topological map can be made which divides the area into equally spaced nodes. A number of paths which avoid the object can then be created, with an algorithm such as A* deciding which is the most efficient:

$$f^*(n) = g^*(n) + \epsilon h^*(n)$$

$$\epsilon = 1$$

$f^*(n)$ = 'goodness' of path via node n

$g^*(n)$ = distance between start and n

$h^*(n)$ = distance between n and goal

$c(n, n')$ is cost from node n to adjacent node n'

- (f) A Bayes filter for updating the belief Bel about a robot's state x is given by $Bel(x_t) = \eta P(z_t|x_t) \int P(x_t|u_t, x_{t-1}) Bel(x_{t-1}) dx_{t-1}$ where z is the sensor information, u the control action and η a normalisation factor. Your robot has a simple topological map consisting of three states (figure 1):

in the hall; outside the door; in the room. The action “go through door” succeeds 0.9 of the time to move the robot from outside the door to in the room or vice versa; taking this action in the hall has no effect. The probability of the robot's sensors reporting that it is the hall, outside the door, or in the room, given its actual state, are given in the following table:

	In hall	At door	In room
Sensing hall	0.6	0.1	0.3
Sensing door	0.1	0.8	0.1
Sensing room	0.2	0.1	0.7

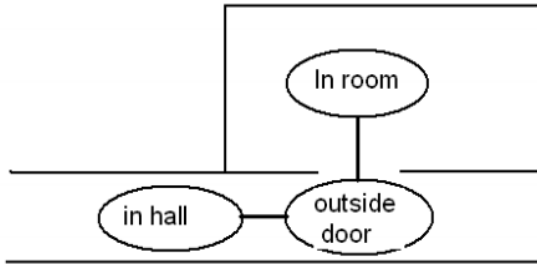


Figure 1: Topological map for robot in question 1 f

If your belief at time $t - 1$ about the robot's state is that there is probability 0.8 of being outside the door, otherwise equal probability of being in the hall or the room, calculate the updated belief after taking the action “go through door” and sensing that it is in the room. [7 marks]

$$Bel(x_{t-1} = \text{Hall}) = 0.1$$

$$Bel(x_{t-1} = \text{Door}) = 0.8$$

$$Bel(x_{t-1} = \text{Room}) = 0.1$$

$$P(x_t = \text{Room} \mid u_t = \text{“go through door”}, x_{t-1} = \text{Room}) = 0.1$$

$$P(x_t = \text{Door} \mid u_t = \text{“go through door”}, x_{t-1} = \text{Room}) = 0.9$$

$$P(x_t = \text{Door} \mid u_t = \text{“go through door”}, x_{t-1} = \text{Door}) = 0.1$$

$$P(x_t = \text{Room} \mid u_t = \text{“go through door”}, x_{t-1} = \text{Door}) = 0.9$$

$$P(x_t = \text{Hall} \mid u_t = \text{“go through door”}, x_{t-1} = \text{Hall}) = 1$$

$$P(z_t = \text{Room} \mid x_t = \text{Door}) = 0.1$$

$$P(z_t = \text{Room} \mid x_t = \text{Hall}) = 0.2$$

$$P(z_t = \text{Room} \mid x_t = \text{Room}) = 0.7$$

$$\begin{aligned} \text{Bel}(x_t = \text{Room}) &= \eta * P(z_t = \text{Room} \mid x_t = \text{Room}) * [P(x_t = \text{Room} \mid u_t = \text{"go through door"}, x_{t-1} = \text{Room}) \text{Bel}(x_{t-1} = \text{Room}) \\ &+ P(x_t = \text{Room} \mid u_t = \text{"go through door"}, x_{t-1} = \text{Door}) \text{Bel}(x_{t-1} = \text{Door}) \\ &+ P(x_t = \text{Room} \mid u_t = \text{"go through door"}, x_{t-1} = \text{Hall}) \text{Bel}(x_{t-1} = \text{Hall})] \\ &= \eta * 0.7 * ((0.1 * 0.1) + (0.9 * 0.8) + (0 * 0.1)) \\ &= \eta * 0.511 \end{aligned}$$

$$\begin{aligned} \text{Bel}(x_t = \text{Door}) &= \eta * P(z_t = \text{Room} \mid x_t = \text{Door}) * [P(x_t = \text{Door} \mid u_t = \text{"go through door"}, x_{t-1} = \text{Door}) \text{Bel}(x_{t-1} = \text{Door}) \\ &+ P(x_t = \text{Door} \mid u_t = \text{"go through door"}, x_{t-1} = \text{Room}) \text{Bel}(x_{t-1} = \text{Room}) \\ &+ P(x_t = \text{Door} \mid u_t = \text{"go through door"}, x_{t-1} = \text{Hall}) \text{Bel}(x_{t-1} = \text{Hall})] \\ &= \eta * 0.1 * ((0.1 * 0.8) + (0.9 * 0.1) + (0 * 0.1)) \\ &= \eta * 0.017 \end{aligned}$$

$$\begin{aligned} \text{Bel}(x_t = \text{Hall}) &= \eta * P(z_t = \text{Room} \mid x_t = \text{Hall}) * [P(x_t = \text{Hall} \mid u_t = \text{"go through door"}, x_{t-1} = \text{Hall}) \text{Bel}(x_{t-1} = \text{Hall}) \\ &+ P(x_t = \text{Hall} \mid u_t = \text{"go through door"}, x_{t-1} = \text{Room}) \text{Bel}(x_{t-1} = \text{Room}) \\ &+ P(x_t = \text{Hall} \mid u_t = \text{"go through door"}, x_{t-1} = \text{Door}) \text{Bel}(x_{t-1} = \text{Door})] \\ &= \eta * 0.2 * ((1 * 0.1) + (0) + (0)) \\ &= \eta * 0.02 \\ \eta &= 1.82... \end{aligned}$$

Is updated belief just the probability of being in each state?

$$\text{Bel}(x_t = \text{Room}) = 0.932..$$

$$\text{Bel}(x_t = \text{Door}) = 0.036..$$

$$\text{Bel}(x_t = \text{Hall}) = 0.031..$$

2. You have a robot that needs to dock in its recharging station by stopping at a specific distance from a wall.

(a) Describe three different sensor systems that could be used to detect distance and briefly summarise their relative advantages for range, accuracy, cross sensitivity and cost. [6 marks]

- IR
 - high accuracy, can be used to detect ambient light and other things (cross-sensitivity)
- Ultrasonic
 - Optical reflectance properties do not affect measurement - includes dust, fog,
- Vision
 - not as accurate

(b) You mount two of the above sensors and discover that both provide readings with Gaussian noise centred on the true distance, one with variance 1 cm^2 and one with variance 5 cm^2 . What is your best option to determine the distance with minimal error? [2 marks]

Combine to find true range?

(c) You decide to use only the better sensor and to improve the estimate by successive updates as you approach the wall. Explain, with equations, how a Kalman filter can be applied to this problem. [8 marks]

(d) Explain in what circumstances a particle filter would be preferred to a Kalman filter for this problem. [2 marks]

(e) Given the initial problem specification, suggest a method of solving it that does not require the robot to explicitly estimate its distance from the wall. [2 marks]

Locate docking station, navigate to it?

(f) Discuss, with examples, the relative advantages and limitations of using simple physical solutions to solve robot control problems. [5 marks]

Adv.

- Can use gravity to conserve energy
- using shape of robot and environment to force diversion towards or away from something

Lim.

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3. You are asked to design an autonomous spy robot that will enter and map an area. If it detects anything moving (e.g. a person that might see it) it will retreat

to its entry point as quickly as possible. You are also asked to design a guard robot that will patrol an area, and chase down any spy robot that has infiltrated.

(a) Describe the physical design you would use for each robot, including size, shape, sensors, actuators etc., justifying each design decision. [8 marks]

- Both would need to quick.
- Spy would need to be small to avoid detection
- Guard may be larger for a greater field of view
- Multiple sensors would detect the other one, e.g. ultrasonic, microphone?
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(b) What kind of intelligence would each robot need? Give an outline of the robot architecture you would choose and how it would be implemented, including some explicit algorithms for the behaviour. [12 marks]

(c) What problems might arise for the robustness of the map-building by the spy robot? Suggest some solutions. [5 marks]

Spy robot is not as likely to map places further away from it's entry point, as many of the times it will only map a small amount before retreating.