CS550 Midterm Exam

Fall 2002

Due in class Thursday, November 5th

The Rules

This is a take-home, open-book exam. You can use any resources that you like to answer the questions, but you *must* acknowledge all sources that are not the class notes or textbook. You are not allowed to discuss your answers with anyone else. Copying someone else's work will result in a negative grade for the whole exam for both parties. We are also going to be strict about the deadline for this exam. If you hand it in after class (*i.e.* after 1pm), it will cost you 10% of the total value of the exam for each day (or part of a day) that you're late.

If you have any questions about any of the problems, send mail to `wds@cs.wustl.edu`. Read over the questions and make sure you understand them early. Don't leave things to the last minute, since I will be out of town the weekend of the 1st, and might not have regular access to email.

If you need more space, then feel free to attach extra sheets of paper. There is a 10 point penalty for not writing your name on this exam. Yes, this has happened in the past.

Name:

Question 1	**/ 10**
Question 2	**/ 15**
Question 3	**/ 15**
Question 4	**/ 15**
Question 5	**/ 20**
Question 6	**/ 25**
Total	**/ 100**

Question 1 [10 points]

Briefly describe the differences between the control systems in Braitenberg's vehicles, Brooks' subsumption architecture, and the Sense-Think-Act architecture used by Shakey. What are the major benefits and disadvantages of each approach. Come up with two tasks that each control strategy would be better suited for.

Question 2 [15 points]

For this question, consider four sensors covered in class: active sonar, active laser range-finder, bumpers, and GPS.

For each of the sensors, state the advantages and disadvantages of each. Discuss the use of each sensor in the context of three different robots: a small Mars rover (like Sojourner), an autonomous land vehicle (basically a car driven by a robot subsystem), and an underwater autonomous vehicle. Address questions such as how useful each sensor would be, how it might be used, and and problems that might be associated with using it for each application.

Question 3 [15 points]

Write down the probability of an occupancy grid square being occupied, given than something is sensed in it, $P(Occ|s)$, in terms of quantities that can be calculated directly from sensor data and prior assumptions about the sensors and the world. Describe, in English, what each of the terms in this equation represents. Be sure to say where the actual values of each of these quantities would come from.

Is it ever possible for a grid cell to be occupied with certainty, *i.e.* $P(Occ|s) = 1$? If no, why not? If yes, under what conditions? Show that your assertions are true using the equation that you wrote down. Explain, in English, what the mathematics relates to in terms of a real sensor.

Question 4 [15 points]

(a) [5 points]

Briefly describe the basic ideas behind Markov localization. Be sure to explain, in English, what each grid cell represents, what it contains and how this is updated as new information comes in. What are the assumptions behind this approach.

(b) [5 points]

Why is Monte-Carlo localization generally considered to be superior to Markov localization? Describe the situations in which Markov localization will succeed, but Monte-Carlo localization will fail.

(c) [5 points]

Although localization is considered to be a solved problem, it is still not a robust technology. Describe why practical implementations of the two algorithms above might fail in real-world situations. Suggest some possible fixes for these problems.

Question 5 [20 points]

The forward model for a differential drive robot can be given by

$$
\begin{aligned}
x_{diff}(t) &= \frac{l}{2}\frac{v_r + v_l}{v_r - v_l}\sin\left(\frac{t}{l}(v_r - v_l)\right) \\
y_{diff}(t) &= -\frac{l}{2}\frac{v_r + v_l}{v_r - v_l}\cos\left(\frac{t}{l}(v_r - v_l)\right) + \frac{l}{2}\frac{v_r + v_l}{v_r - v_l} \\
\theta_{diff}(t) &= \frac{t}{l}(v_r - v_l)
\end{aligned}
$$

where v_r is the velocity of the right wheel, v_l is the velocity of the left wheel, and l is the distance between the wheels along the axle.

Similarly, the forward model of a synchronous drive robot can be given by

$$
\begin{aligned}
x_{synch}(t) &= \int_0^t v_t \cos(\omega t)\, dt \\
y_{synch}(t) &= \int_0^t v_t \sin(\omega t)\, dt \\
\theta_{synch}(t) &= \int_0^t \omega\, dt
\end{aligned}
$$

where v_t is the translation velocity and ω is the rotation velocity. We are going to assume that v_l, v_r, v_t, and ω are constant over the time period that we're looking at.

If you are given a command for a differential drive robot, consisting of v_l and v_r, is it possible to come up with commands for a synchronous drive robot, v_t and ω that will cause it to follow the same path? That is, for any assignment to v_r and v_l, can you come up with an assignment to v_t and ω, such that

$$
\begin{aligned}
x_{diff}(t) &= x_{synch}(t) \\
y_{diff}(t) &= y_{synch}(t) \\
\omega_{diff}(t) &= \omega_{synch}(t)
\end{aligned}
$$

What we're looking for here is essentially for you to define v_t and ω as functions of v_l and v_r

$$
\begin{aligned}
v_t &= f_1(v_l, v_r) \\
\omega &= f_2(v_l, v_r)
\end{aligned}
$$

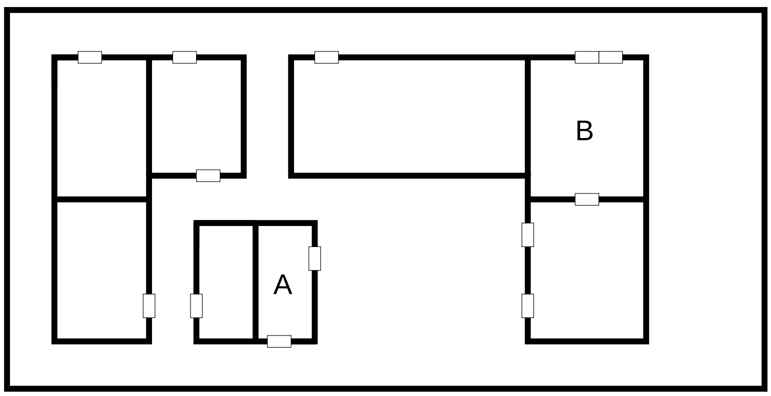
such that the above equalities hold. Show all the steps of your working, and comment on the final answer that you get (*i.e.* does is seem reasonable?).

Question 6 [25 points]

This question deals with path-planning in an office environment. Walls are solid black lines, and doors are open rectangles. Assume that the robot is capable of opening doors if they are closed.

(a) [5 points]

Segment the environment into a convex meadow map, and use this to design a topological map. Draw the regions and the map on the building plan.

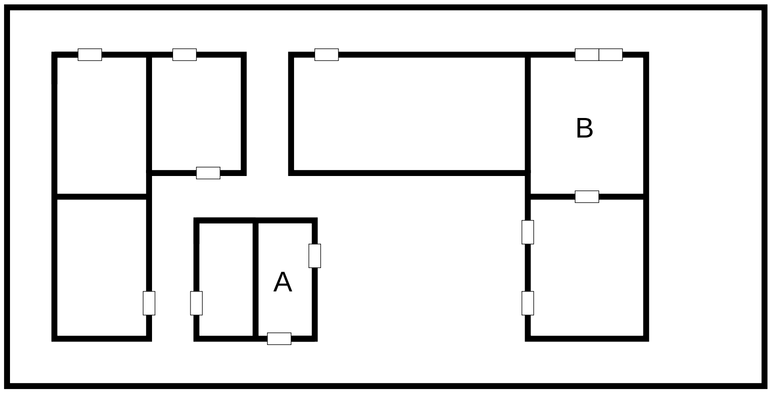


(b) [5 points]

Draw the map again, and assign costs to the links. Explain the costs that you assigned.

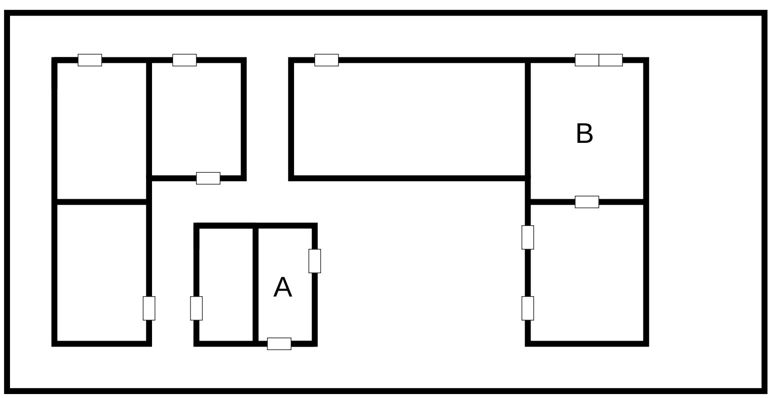
(c) [5 points]

Plan a path from point A to point B in the map. Assume that you have perfect, deterministic actions, and that you are trying to minimize costs. Show the path, and the total cost. Show the path in the graph, and also draw it on the building plan.



(d) [5 points]

Explain what a Vornoi path is. Show the Vornoi paths on the building plan. You don't have to calculate the exact paths, a freehand approximation is good enough. Assume that all doors are open for the purpose of drawing the paths.



(e) [5 points]

Assume that the cost of a path is it's total length. Plan a path from point A to point B in the map, using the Vornoi paths. Assume that you are capable of following the path exactly. Draw the path on the building plan.