CMSC 479/679: Assignment 4

Movement Error & Localization

Turnin: Blackboard.

Please submit all parts together as a **single PDF file** named *lastname*_hw3.pdf, with parts clearly marked and delineated. **All** files must start with your last name and have your full name(s) in the file, at/near the top. This assignment **may be done in groups of up to 4 people**. In this case, make sure *everyone* understands *every* part—don't split the work by person!

PART I. ERROR (16 PTS.)

Consider a small robot navigating in a room. This robot has two-wheel differential drive movement and a single ultrasonic range sensor. The wheels have a specified diameter of 6 cm and are mounted on servos that use really cheap encoders. Using a sweeping motion, the range sensor spans an arc of 90° in front of the robot. The sensor is operating at 200Hz. A camera mounted above the robot gives the actual ground truth of its movement and distances. You observe the following:

a. When the robot gets within about 45 cm of walls, the sensor starts returning erratic results—readings may be correct, or they may return unexpectedly low or high numbers. These return values aren't consistent, even if the robot is not moving. The part of the sweep that is parallel to the wall or pointed outward is fine.

b. The robot doesn't move forward as precisely as the control signal indicates. When told to move 20cm, it moves somewhere in the range of 18.82 cm and 21.18 cm. This error is zero-mean and symmetric.

c. As the robot moves, it's always tugging slightly to the left. When it's told to move 3 meters in a straight line, it transcribes a long, shallow curve, ending up about 10cm to the left of where it should be.

Assignment:

For *each* of a, b, and c:

1. *(3 pts)* What is the *most likely* cause of the observed error?
2. *(1 pt)* Can you calibrate the system to remove this error? Why or why not?

Now consider this case. A second robot with identical listed specs, but for which there are no calibration readings, receives a control signal to turn in a wide circle that spans 90° of arc (that is, it starts out pointing west, and ends up pointing north).

3. Can we apply any calibration we've done for the first robot to the second robot? Why or why not? (This is the same as asking if it has the same errors.)
4. With respect to the intended position, is this robot most likely to end up… (choose one):

a.	North and east of it	North of it	NE and N are equally likely
b.	South and east of it	South of it	SE and S are equally likely
c.	North of it	South of it	N and S are equally likely

Part II. Belief Representations (6 pts.)

We've discussed three major characteristics of a belief representation (how a robot's belief about its position is stored):

- Discretized vs. continuous beliefs
- Single-hypothesis or multiple-hypothesis beliefs
- Probabilistic, bounding-box based, or point beliefs

Assignment:

5. Consider the following English descriptions of a belief state. For each, how is the belief state represented (using the three characteristics listed above)?

d. "The robot's in either room 331 or 333. I don't know which because they're identical. It's definitely somewhere in the triangle between the sink, the wall, and the corner, but it could be anyplace in there."

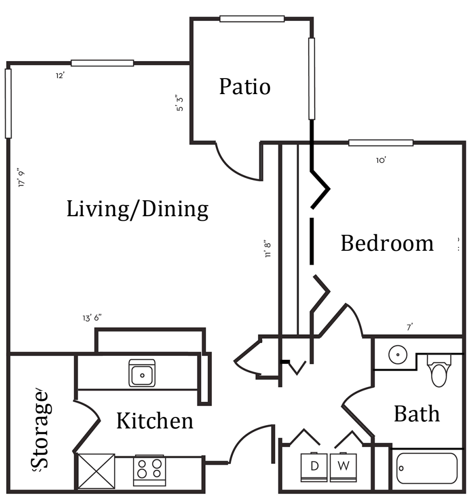
e. "Since it's a maze, we're storing its location in a matrix. We aren't always entirely sure where it is, so we store standard deviations in different cells of the matrix—it's 68% likely to be in the cell we wanted, 14% likely to be in the adjacent cells, and 2% likely to be in the cells one step further out."

Part III. Map Representations (12 pts.)

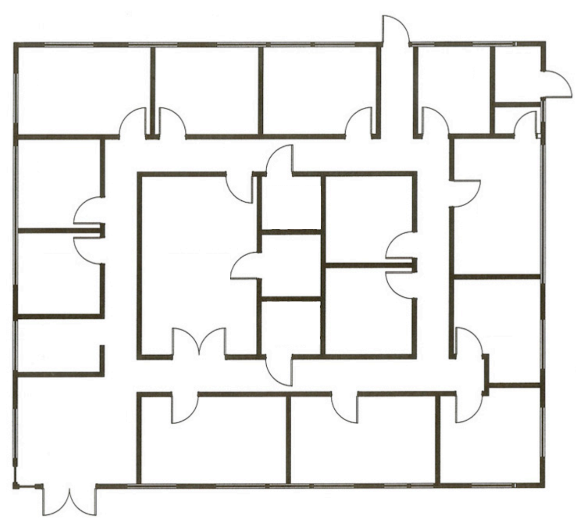
We've discussed a number of different ways maps can be stored in memory as robot-usable structures. Consider a robot trying to do localization in a map of the following areas. What kind of map representation would work best for the task? What features do you extract? (If you use a representation with cells don't forget to say what kind of cell decomposition you would use.)

Assignment: Given the following three maps, what would the best choice of belief representation be? *Do not use the exact same representation twice*. Explain your choices.

6. Apartment building:[1]



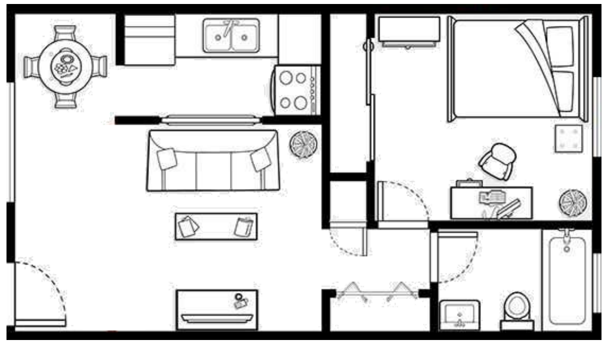
7. Offices:[2]



---

[1] https://stanfordwest.stanford.edu/prospective-residents/living-here/floor-plans
[2] http://rotunda.info/executive-home-plans/executive-home-plans-office-floor-plans-office-space-is-available-for-rent-or-lease-offices-executive-ranch-home-plans/

8. Furnished apartment:[3]



PART IV. LOCALIZATION AND SLAM (6 PTS.)

Assignment:

9. We've considered a number of methods for localization, but gone into the most detail for Markov localization and Kalman filter-based localization. For both approaches, give an example of situations that would "break" the algorithm and explain what the failure would be and why it would occur.

10. Explain the different steps of Kalman filters. Divide them into prediction and correction and give an explanation on how the state and uncertainty evolves.

PART V. MAPPING (22 PTS.)

Consider the following case. A robot is trying to localize in an area it has mapped, containing only two possible locations, a room and a corridor. Based on sensor data, it believes it is in the corridor initially; it can also sense whether it is in a room. Unfortunately, there is both actuation and sensor noise. You know that the robot succeeds in entering rooms with a probability of:

$$p(x_{t+1} = \texttt{room} \mid x_t = \texttt{corridor}, u_{t+1} = \texttt{enter\_room}) = 0.9$$

where $xt+1$ is the location after executing an action, $ut+1$ is the control command that transitions between t and $t+1$, and x_t is the location before performing the action. The prior on the un-normalized[4] sensor model is:

$$p(z = \texttt{in\_room} \mid x = \texttt{corridor}) = 0.2$$
$$p(z = \texttt{in\_room} \mid x = \texttt{room}) = 0.7$$

Unfortunately, you don't know where the robot started. However, after the robot was given the command `enter_room`, the sensor gives the reading $z = \texttt{in\_room}$.

Assignment:

11. List the three possible pairs of value that $\{x_t, x_{t+1}\}$ can have.

12. Use a Bayes filter to find the probability that the robot is in the corridor. Use an appropriate prior distribution and justify your choice. Show all work.

---

[3] http://theenz.com/floor-plan-for-1-bedroom-apartment/floor-plan-for-1-bedroom-apartment-bath-house-room-size-2018-and-stunning-enjoyable-plans-with-ideas-about-apartments-on-rooms-rent-furnished/

[4] Remember, the normalization constant exists to make probabilities add up to one.