16-311: Introduction to Robotics
Mid-term Examination
Spring 2007 Professor Howie Choset

Solutions

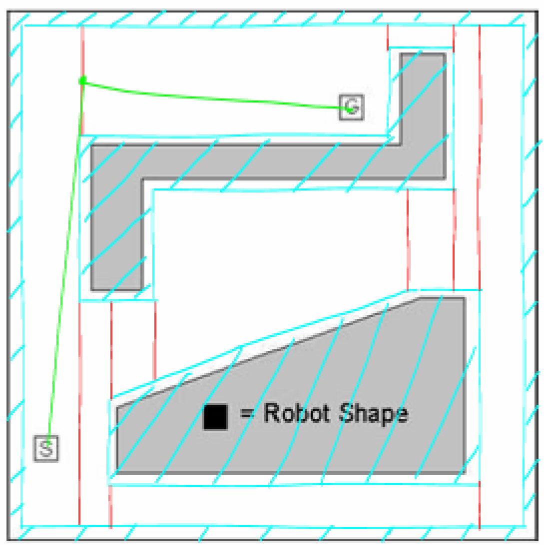
March 7th, 2007

Problem 1 **(25 points)**

(a) Draw the configuration space for the square-shaped robot shown and the trapezoidal decomposition of that configuration space. (15 points)

(b) Using the trapezoidal decomposition, draw a path from start to goal. (5 points)

(c) Is this the optimal path? (5 points) `Optimal with respect to what? (it is not optimal for L1 nor L2)`



Problem 2 **(25 points)**

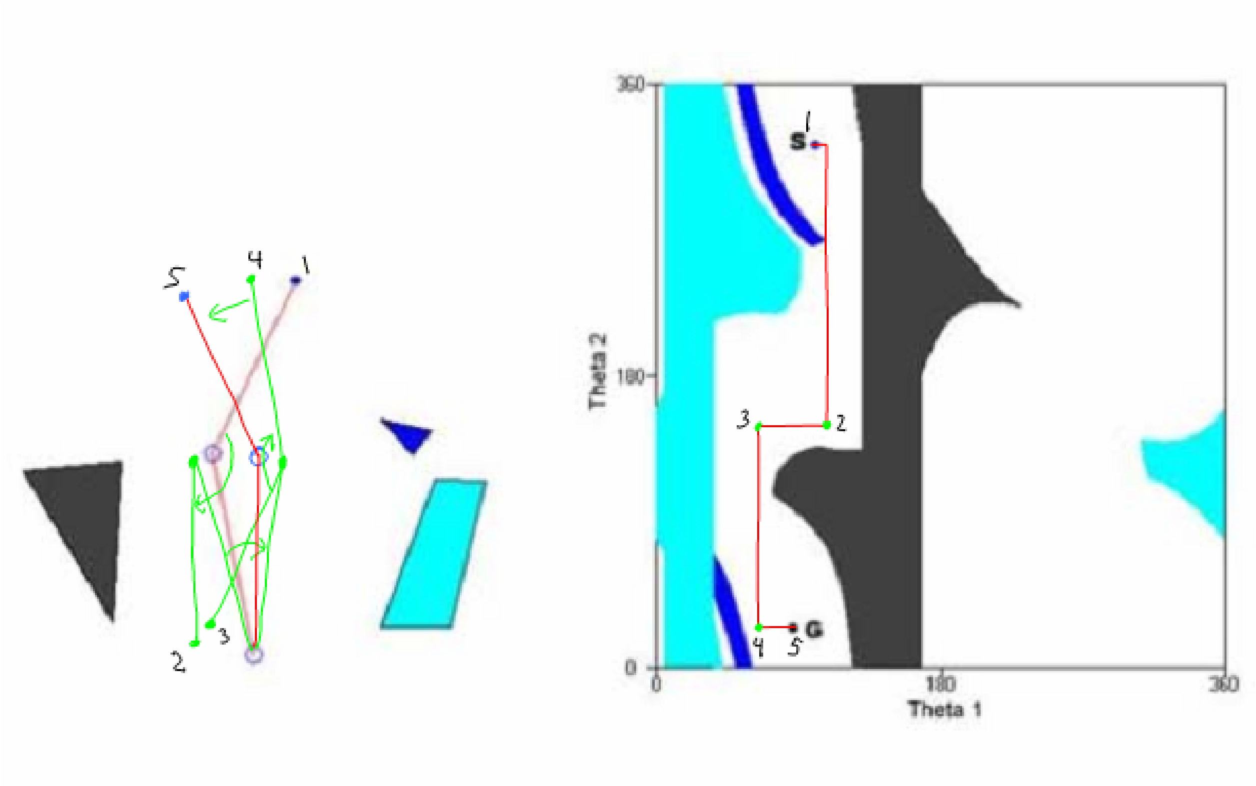
Use the following workspace (with robot shown at the start configuration), configuration space for a two link manipulator with no joint limits, and a distance between two configurations q_a and q_b given as:

$$d(q_a, q_b) = \alpha\left(|\texttt{mod}(\theta_{1a} - \theta_{1b})| + |\texttt{mod}(\theta_{2a} - \theta_{2b})|\right)$$

$$\alpha = \begin{cases} 1 & \text{for } 1 < \theta_2 < 359 \\ 4000 & \text{otherwise} \end{cases}$$

$$\alpha\left(|\texttt{mod}(\theta_{1a} - \theta_{1b})| + |\texttt{mod}(\theta_{2a} - \theta_{2b})|\right)$$

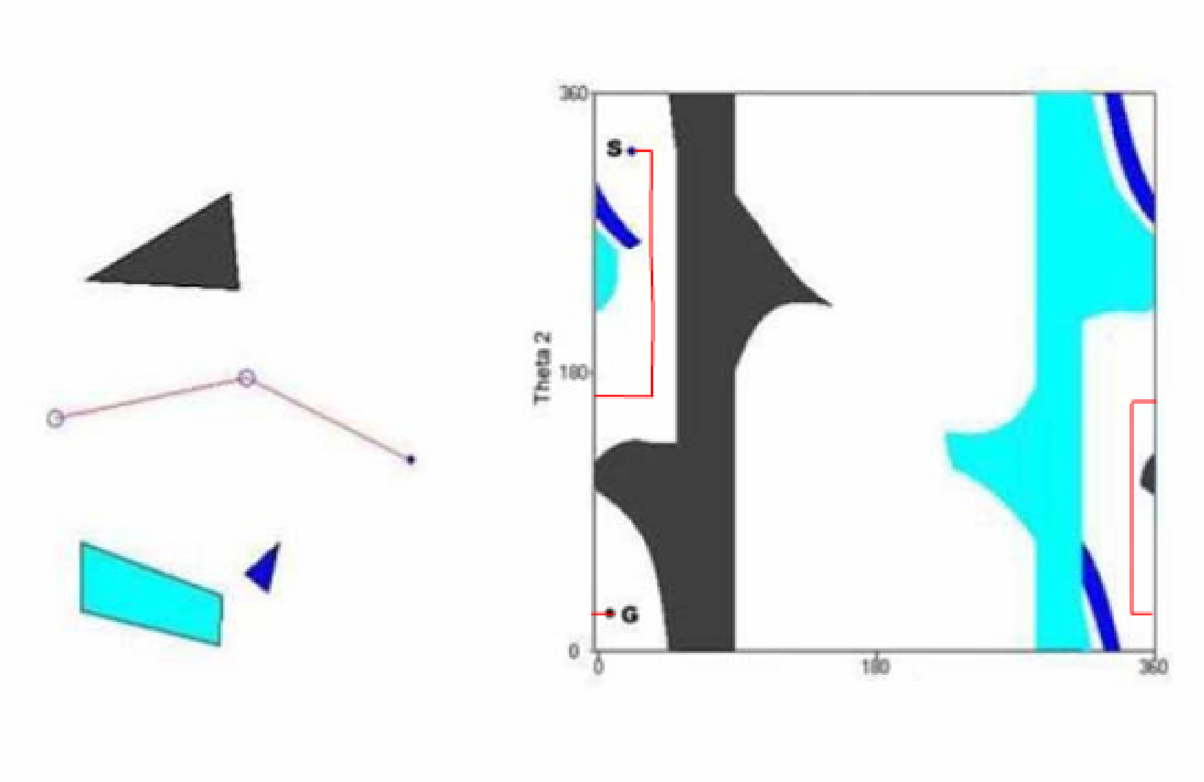
where `mod` is the shortest distance between two angles; e.g., $\texttt{mod}(50 - 20) = 30$, and $\texttt{mod}(5 - 355) = 10$. The $|\cdot|$ guarantees that this difference is always positive. Recall that the cost of a path is the integral of the point-wise distance.



(a) Draw (on the figure) the shortest path in configuration space from the start configuration to the goal configuration. (15 points)

(b) Draw four additional configurations along this path (3 intermediate plus goal) on both the workspace and the configuration space. (5 points)

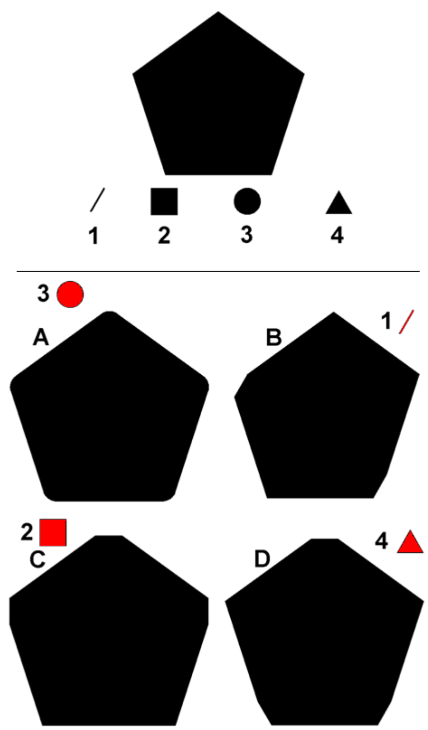
(c) In the configuration space shown below, indicate the path (if it exists) between start and goal (using the same angle conventions). (5 points)


360
S
Theta 2
180
G
0
0
180
360

Problem 3 **(20 points)**

(a) A mobile robot traveling in a plane typically has a three-dimensional configuration space defined by $R^2 \times S^1$; however, when using the wavefront planner for lab 5, you planned in a two-dimensional array. Why was this permissible? (10 points) `You padded the obstacles so that for any robot orientation, it would not overlap the original configuration space obstacle (this is like projecting the obstacles in` $R^2 \times S^1$ `onto` R^2`).  Additionally, when discretizing` R^2`, you considered any grid cell an obstacle if it contained any portion of a padded obstacle.  The result was a suboptimal path through the original configuration space` $R^2 \times S^1$ `(using L1 or L2 metric), but it was much easier to plan in the 2D grid` $\subset R^2$`.`

(b) Given the pentagonal obstacle shown below and the four numbered robot shapes, match each robot shape with the lettered configuration space obstacle for the robot in the configurations shown. (10 points)



Problem 4 **(10 points)**

Answer *five* of the questions below. If you answer more, please mark with a star which five you want to be graded (no extra credit). (2 points each)

A	**B**	**C**	**D**
$\begin{pmatrix} 1 & 1 & 1 \\ 1 & 2 & 1 \\ 1 & 1 & 1 \end{pmatrix}$	$\begin{pmatrix} 1 & 1 & 0 \\ 0 & 0 & 0 \\ -1 & -1 & 0 \end{pmatrix}$	$\begin{pmatrix} 1 & 1 & 1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{pmatrix}$	$\begin{pmatrix} 0 & 1 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{pmatrix}$

(a) Which of the above masks (**A** - **D**) would be best if you wanted to eliminate texture and/or white noise (i.e., small random deviations in pixel values)? `A, a weighted average mask`

(b) Which would be best if you wanted to detect sharp (i.e., not gradual) horizontal edges, assuming the image had no noise? **D**, `a simple first derivative operator`

(c) Which would be best if you wanted to eliminate noise *and* detect horizontal edges simultaneously? **B**, `the result of a smoothing followed by a first derivative`

(d) Which of these, if any, is a Gaussian mask? `none of them really are, but` **A** `is the closest, since it is a weighted averager`

(e) Below (**A2** - **D2**), we have doubled the height and width of each mask, while keeping the same pattern. What would be a <u>benefit</u> of using these doubled masks in the simultaneous edge-detection and noise-elimination scenario? `more noise elimination, detects more gradual edges`

(f) What would be a <u>detriment</u> of using the doubled masks? `blurrier edge detection, more computation`

A2	**B2**	**C2**	**D2**
$\begin{pmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 2 & 2 & 1 & 1 \\ 1 & 1 & 2 & 2 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 \end{pmatrix}$	$\begin{pmatrix} 1 & 1 & 1 & 1 & 0 & 0 \\ 1 & 1 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & -1 & -1 & -1 & 0 & 0 \\ -1 & -1 & -1 & -1 & 0 & 0 \end{pmatrix}$	$\begin{pmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 \end{pmatrix}$	$\begin{pmatrix} 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & -1 & -1 & 0 & 0 \\ 0 & 0 & -1 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$

Problem 5 **(10 points)**

Answer *five* of the questions below. If you answer more, please mark with a star which five you want to be graded (no extra credit). (2 points each)

(a) What was Dr. Efros' take-home message? `Computer vision is hard!`

(b) Dr. Efros stated one main reason vision is easier for humans – what was it? `domain knowledge/experience/"common sense"`

(c) List two of the difficulties associated with computer vision.

Problem	**Potential solution(s)** – not an exhaustive list!
2D→3D reconstruction	domain knowledge, multiple angles of view
occlusion	multiple angles of view
limited computation	approximate methods/heuristics
little info in actual pixels	domain knowledge
noise	smoothing convolution masks
lighting variations	lighting-invariant models
small field-of-view	panoramic stitching

Table 1: Parts (c) and (d)

(d) Where was Dr. Warwick's implant placed? `wrist/forearm`

(e) With what external sensor did Dr. Warwick augment his own senses? He mentioned several in his later talk – just list one. `ultrasonic (sonar) cap`

(f) What are the three D's of robotics? `Dull, Dirty, Dangerous`

(g) State Moore's Law and its implication (or lack thereof) on robots. The number of transistors on a chip doubles every 12 - 18 - 24 months (varies). This increases processing power, improves miniaturization, and reduces power consumption and heat. However, this doesn't affect the mechanical components of a robot, nor the difficult algorithmic problems, so robot capabilities have not kept pace.

(h) What was Hans Moravec's contribution to robotics? early mobile robot pioneer, idea of transhumanism (robots will outstrip humans and/or we'll become cyborgs)

Problem 6 **(10 points)**

Answer *all* of the questions below. (2 points each)

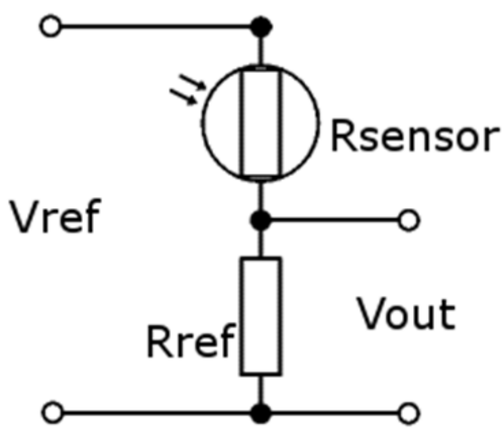
(a) Define transduction. `changing energy from one form to another, such as a sensor takes energy from the environment and outputs a current/voltage`

(b) Assuming sound can travel at 1000 inches/second on some planet, and the time it takes to transmit and receive a signal is 2 seconds, how far away is the obstacle? `1000 inches, since it makes a round-trip`

(c) List one benefit of a laser range finder over an ultrasonic sensor. `much more accurate, higher resolution, greater range`

(d) List one benefit of a switch or bump sensor over a laser range finder. `cheap, passive, not noisy (on or off)`

(e) How do you convert a resistance sensor to a voltage for an A/D input? `use a reference resistor and voltage in a voltage divider, as below; or use a reference current and` $V_{out} = I_{ref} R_{measured}$



$$V_{out} = \frac{V_{ref} R_{ref}}{(R_{sensor} + R_{ref})}$$