ROB 550 Final Exam

Fall 2014
Time: Dec. 17, 4:00-6:00pm
Place: 1200 EECS

This exam is closed-book, closed-notes but you may reference a handwritten double-sided 8.5"x11" page of notes. You have two hours (120 minutes) to complete the exam. You may use a calculator for basic math computations but no other software use is allowed. The exam must be completed individually. Please sign and adhere to the below honor pledge per University of Michigan policy.

I pledge on my honor that I have not given or received any unauthorized assistance on this examination.

____

(Your signature)

Exam Score:

	Points Possible
I. Data Interfaces	**25**
II. Rotation Matrices & Homogeneous Coord. Transforms	**25**
III. ArmLab: Sensing and Serial Manipulation	**25**
IV. FlightLab: Quadrotor & Manipulator Motion & Design	**25**
Total (100 possible points):	**Total: 100 points**

Question I: Data Interfaces (25 points)

1.1 (6 points) Pulse Width Modulation (PWM): Suppose a servo has a range of -90 degrees (maximum counterclockwise (CCW) limit) to +90 degrees (maximum clockwise (CW) limit). Assume a 20 msec PWM period and a full-range PWM signal width between 1 msec and 2 msec. The servo drives a one-DOF revolute arm with the 0 degree position straight up.

a. What duty cycle command (in percent) drives the servo to point straight up?
b. Write a short C code excerpt to smoothly move the arm from straight up to the maximum CW rotation over a duration of 2 seconds. Include variable declarations for context. You may assume code other than any timer or sleep command will run instantaneously, and that simply setting a "duty_cycle" variable (in percent) will drive the servo.

1.2 (6 points) Inertial Measurement Units (IMU): Suppose an IMU is affixed to the servoed arm from the previous problem a distance of 25cm from the servo rotation axis. Suppose the IMU is oriented such that the x-axis points radially outward along the arm, the z-axis points such that a CW rotation is positive, and the y-axis points tangentially to form a right-hand coordinate frame. [Suggestion: you may want to sketch the 1-DOF arm and IMU as a reference.]

a. What does the three-axis accelerometer read (in g units) when the servo is stationary at its full CCW limit?
b. What does the three-axis rate gyro read (in deg/sec units) while the servo is moving steadily along the smooth path commanded in Problem 1.1(b)?
c. What does the three-axis accelerometer read (in g units) when the servo crosses through the midway point between straight up and its maximum CW deflection limit while moving steadily along the smooth path commanded in Problem 1.1(b)?

1.3 (5 points) A/D Calibration: Suppose Channel 0 of an 10-bit A/D converter with 0-5V range is connected to a rate gyro capable of measuring rates ranging from -90 deg/sec to +90 deg/sec.

a. What is the resolution of collected data in (A/D counts) / (deg/sec)? Note that the term "A/D counts" references the raw 10-bit integer value read from the A/D converter.
b. Given a gyro bias of +0.2V, i.e., the zero-rate reading is +2.7V, specify the calibration equation to convert a raw data reading (in A/D counts) to a calibrated value (in deg/sec).

1.4 (8 points) Serial communications for A/D: An RS/232 link provides data from an 8-channel, 16-bit A/D converter unit. A single initialization byte sent to the A/D converter specifies how many channels (1-8) should be read on each subsequent A/D scan. For example, if this byte indicates n=3 channels, the A/D will transmit data from CH0, CH1, and CH2 on each A/D scan.

a. Specify a minimum-size C data structure or array to store and transmit each n-channel A/D scan with no accuracy loss. Your data structure should only store the (n <= 8) channels of data being processed; do <u>not</u> store all 8 channels in your C data structure unless n = 8.
b. Now assume two message ID bytes, one data payload length byte, and a 16-bit Fletcher checksum are added to the A/D data from part a. to form each complete A/D scan message. How many data <u>bytes</u> are transmitted per second given a 100 Hz A/D scan rate and n=5?
c. Given one start bit, odd parity, one stop bit, but no checksum, how many data <u>bits</u> are transmitted over the serial link per second?

Question II: Rotation Matrices and Homogenous Coordinate Transforms (25 points)

2.1. (4 points) Answer True/False (Correct answers are worth +1, incorrect answers are worth -1, and blank answers are worth 0).

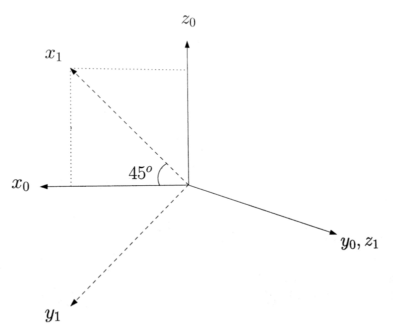
_______ $\begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}$ is a valid right-handed 2D homogenous rigid-body transformation matrix.

_______ $\begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}$ is a valid right-handed 3D rotation matrix.

_______ $\begin{bmatrix} -1 & 0 & 3 \\ 0 & -1 & 4 \\ 0 & 0 & 1 \end{bmatrix}$ is a valid right-handed 2D homogenous rigid-body transformation matrix.

_______ $\begin{bmatrix} -1 & 0 & 3 \\ 0 & -1 & 4 \\ 0 & 0 & 1 \end{bmatrix}$ is a valid right-handed 3D rotation matrix.

2.2. (4 points) Consider the frames $o_0x_0y_0z_0$ and $o_1x_1y_1z_1$ shown below. The rotation matrix R_1^0 specifying the orientation of $o_1x_1y_1z_1$ relative to $o_0x_0y_0z_0$ is given by?



2.3. (4 points) Suppose that three coordinate frames $o_1x_1y_1z_1$, $o_2x_2y_2z_2$, and $o_3x_3y_3z_3$ are given, and suppose

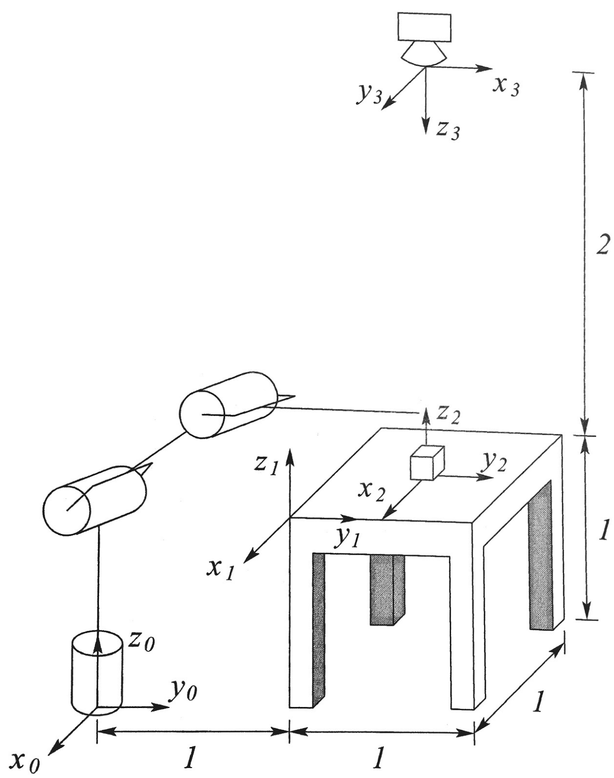
$$R_2^1 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \frac{1}{2} & -\frac{\sqrt{3}}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{1}{2} \end{bmatrix}, R_3^1 = \begin{bmatrix} 0 & 0 & -1 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \end{bmatrix}.$$

Find the matrix R_3^2.

2.4. (13 points) Consider the setup shown below. A robot is set up 1 meter from a table. The table top is 1 meter high and 1 meter square. A frame $o_1x_1y_1z_1$ is fixed to the edge of the table as shown. A cube measuring 20 cm on a side is placed in the center of the table with frame $o_2x_2y_2z_2$ established at the center of the cube as shown. A camera is situated directly above the center of the block 2 meters above the table top with frame $o_3x_3y_3z_3$ attached as shown.

a. Find the homogenous transformations relating each of the frames to the base frame $o_0x_0y_0z_0$ (i.e., H_1^0, H_2^0, H_3^0).

b. Find the homogeneous transformation relating the frame $o_2x_2y_2z_2$ to the camera frame $o_3x_3y_3z_3$ (i.e., H_2^3). In order to receive full credit, find this transform using your answers from part a).



Question III: ArmLab: Sensing and Serial Manipulation (25 points)

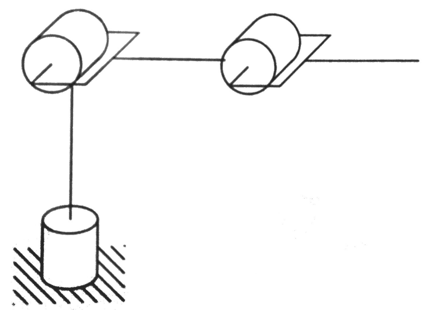
3.1. (3 points) Given a monochrome `uint8_t` image with data buffer `*buf`, `int height`, `int width`, `int stride`, write an expression giving the value of the pixel at `col=32, row=115`.

```
uint8_t pixel =
```

3.2. (5 points) When performing template matching, decimating the template and search image by an (integer) factor of N will speed up the matching by a factor of what? Explain your answer.

3.3. (12 points) Consider the three-link manipulator show below. Derive the forward kinematic equations using the DH convention by filling in the table below. You MUST draw and annotate your coordinate frame assignments in order to receive full credit.

link	a_i	α_i	d_i	θ_i
1				
2				
3				



3.4. (5 points) For the same manipulator, provide a symbolic expression for the manipulator Jacobian evaluated at a floating point o_f located at the midpoint of link 2.

Question IV: FlightLab: Quadrotor and Manipulator Motion & Design (25 points)

4.1 (5 points) Quadrotor Translation: As described in lecture, a quadrotor is actuated by varying the speed at which four counter-rotating propellers are driven. Suppose a quadrotor weighing 5 kg is commanded to hold a constant altitude but finds itself commanded to a constant 5 degree left bank (roll) orientation. What is the direction and magnitude of the quadrotor's lateral acceleration at this roll angle? You may assume a zero pitch angle.

4.2 (5 points) Delta Arm Kinematics: Consider a Delta arm with the following dimensions (written here as specified in the provided inverse kinematics code):

```
const float e = 5.0;     // end effector
const float f = 20.0;    // base
const float re = 10.0;
const float rf = 5.0;
```

Assume dimension units are cm, and that the servos can rotate to any angle. You may ignore structural interference in this problem. What is the vertical range of motion for this delta arm? Specify minimum and maximum end effector heights with zero height (z=0) referenced to the delta arm base plate and +z oriented up.

4.3 (15 points) End Effector Design: Suppose the FlightLab competition is modified so that the quadrotor/manipulator system was tasked to "clean up a playroom". Specifically, the manipulator must retrieve a child's blocks (all cubes with edge length approximately equal to one ping pong ball diameter). Analogous to our competition, blocks would be retrieved one at a time and dropped off in a storage bin. Describe and sketch a compact lightweight end effector concept to accomplish this "block pick-and-place" task. Clearly describe the mechanism and illustrate how a single servo can drive pickup/dropoff. You may reference your FlightLab team's design (in which case summarize this design in one sentence) or you may propose a different solution.