TEST 1

1) Clear your desk top of all books, papers and personal notes. You may keep only your cheat sheet, the test paper, a calculator and a pencil.

2) Read through the test completely and work the problems you can, leave the difficult ones till last.

3) Keep your eyes on your own paper. Cheating will not be tolerated

4) Work problems on the back of the previous page if necessary.

5) Show your work!

NAME: _____________________________________________ _________________________
Question 1

i) Different types of robot locomotion include: (check all that apply)
   a) Crawling.
   b) Rolling.
   c) Flying.
   d) Localizing.

ii) Issues that affect robot locomotion include: (check all that apply)
   a) The robot’s stability.
   b) The robot’s work environment.
   c) The robot’s sensors.
   d) The robot’s type of contact with the environment.

iii) We are considering mounting a laser range finder (e.g. SICK) on our BirPi iRobots.
     a) What advantages and disadvantages would the laser range finder provide over three sharp infra-red range sensors? (Provide minimum 4 total)

     - Higher horizontal resolution (angular)
     - Wider range
     - Viewing angle
     - Good throughput
     - More accurate

     vs.

     - More expensive
     - Heavier
     - Surface absorption
b) Describe how laser range finding sensor works when phase shift measurements are used to obtain the distance to an object. Be sure to use a diagram.
c) What would be the drawback of rotating a sonar 180 degrees back and forth instead of a laser? Explain.

- Sound is "slow" and hence, the rotation speed can't be too high or low
  bandwidth/throughput
- Speed would also have to be determined by desired range and in a way that
  minimizes cross-talk
iv) Ultrasound range sensors are useful sensors but must be used with care. Answer the following questions regarding these sensors.

a) Explain the basic principles on how the sensor works in 4 sentences or less. Be sure to use a diagram, labeling variables on the diagram. Give the equation used to calculate range.

\[
d = \frac{c \cdot t}{2}
\]

where:
- \(d\) is the distance
- \(c\) is the speed of sound
- \(t\) is the time for the sound to travel forth and back

\[
c \approx 343 \text{ m/s}
\]

\[
f = (40 - 180 \text{ kHz})
\]

Transmitter = Receiver

Range: 12 cm to 5 m

Accuracy = 98 - 99%

Resolution = 2 cm (depth)
b) Compare the use of sonars above water versus underwater. Provide 2 issues of comparison. For each issue, explain why the issue arises in 2 sentences or less.

- Speed of sound > underwater

- Absorption under water, specially in seawater > than air. The higher the freq — higher the absorption — small range
Question 2

Consider the differential-drive robot shown below, where a passive sphere is used as the third wheel. Assume that we want to impose to the spherical wheel a velocity $V_c$ directed as in the figure. Compute the angular speeds $\omega_L$ and $\omega_R$ required to achieve this objective, using the following numerical data: $L = 0.3 \text{ m}$, $d = 0.4 \text{ m}$, $r = 0.15 \text{ m}$, $\alpha = 45^\circ$, $V_c = 0.1 \text{ m/s}$.

[CAREFUL!! Do NOT rely on the letters/symbols that we used in class, but instead on what these letters/symbols mean.]

First, the relationship between robot velocities & wheel velocities (using the notation above) is:

$$
\begin{bmatrix}
\dot{x}_R \\
\dot{y}_R \\
\dot{\theta}
\end{bmatrix}
= 
\begin{bmatrix}
\frac{r\omega_R}{2} + \frac{r\omega_L}{2} \\
\frac{r\omega_R}{2} & -\frac{r\omega_L}{2} \\
0 & 0 & 0
\end{bmatrix}
$$
\[
\begin{pmatrix}
\frac{1}{2} \left( \frac{r \omega_R}{2} + \frac{r \omega_L}{2} \right) \\
0 \\
\frac{r \omega_R}{d} - \frac{r \omega_L}{d}
\end{pmatrix}
= \begin{pmatrix}
\cos \alpha & \sin \alpha & 0 \\
-\sin \alpha & \cos \alpha & 0 \\
0 & 0 & 1
\end{pmatrix}
\begin{pmatrix}
V_c \\
0 \\
\frac{V_c \sin \alpha}{L}
\end{pmatrix}
\]

\[
\begin{pmatrix}
1 \text{ m/s} \\
1 \text{ s/m}
\end{pmatrix}
= \begin{pmatrix}
\frac{15 \omega_R}{2} + \frac{15 \omega_L}{2} \\
\frac{15 \omega_R}{40} - \frac{15 \omega_L}{40}
\end{pmatrix}
= \begin{pmatrix}
0.7 & 0.7 & 0 \\
-0.7 & 0.7 & 0 \\
0 & 0 & 1
\end{pmatrix}
\begin{pmatrix}
10 \\
0 \\
-10 + 0.7 \\
-30 \text{ cm}
\end{pmatrix}
\]
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\[
\begin{align*}
W_R + W_L &= \frac{14}{15} \\
\frac{15W_R}{40} - \frac{15W_L}{40} &= -\frac{7}{30}
\end{align*}
\]

\( W_R = 0.311 \text{ rad/s} \)
\( W_L = 0.622 \text{ rad/s} \)

Another way to solve it:

Also, for a fixed wheel:
\( \alpha = 90^\circ \quad \beta = 0^\circ \)
\( \alpha_1 = -90^\circ \quad \beta_1 = 180^\circ \)
\[ \dot{\phi} = \begin{bmatrix} \dot{\phi}_1 \\ \dot{\phi}_2 \end{bmatrix} \]

\[ J_2(\beta) = \begin{bmatrix} J_{11} \\ J_{12} \end{bmatrix} = \begin{bmatrix} \sin(\alpha + \beta_1) & -\cos(\alpha + \beta_1) & -\cos(\beta_1) \\ \sin(\alpha + \beta_2) & -\cos(\alpha + \beta_2) & -\cos(\beta_2) \end{bmatrix} = \begin{bmatrix} 1 & 0 & l \\ 1 & 0 & -l \end{bmatrix} \]

\[ J_2 = \begin{bmatrix} I_1 & 0 \\ 0 & I_2 \end{bmatrix} \]

\[ C_1(\beta) = \begin{bmatrix} C_{11} \\ C_{12} \end{bmatrix} = \begin{bmatrix} \cos(\alpha + \beta_1), \sin(\alpha + \beta_1) & l \sin(\beta_1) \\ \cos(\alpha + \beta_2), \sin(\alpha + \beta_2) & l \sin(\beta_2) \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 0 & 1 \end{bmatrix} \]

\[ \begin{cases} \dot{J}_2 \dot{\phi} - J_1(\beta) R(\theta) \ddot{x}_i = 0 \\ C_1(\beta) R(\theta) \ddot{x}_i = 0 \end{cases} \]

\[ \begin{bmatrix} \ddot{x}_1 \\ \ddot{x}_2 \\ \ddot{x}_3 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} R(\theta) \]

\[ \begin{bmatrix} 0 \ 0 \\ \cos(\alpha) \ \sin(\alpha) \\ -\sin(\alpha) \ \cos(\alpha) \end{bmatrix} \begin{bmatrix} \ddot{x}_1 \\ \ddot{y}_1 \end{bmatrix} \]

\[ \dot{\psi}_1 = \omega_e \quad \dot{\psi}_2 = \omega_l \quad \dot{\theta} = \frac{d}{2} \quad \dot{\alpha} \]

\[ \begin{bmatrix} 1 & 0 & d/2 \\ 0 & 1 & -d/2 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos(\alpha) \ \sin(\alpha) \\ -\sin(\alpha) \ \cos(\alpha) \end{bmatrix} \begin{bmatrix} x \ y \ z \end{bmatrix} \]

\[ -V_c \sin(\alpha) \]

\[ V_c \]