UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 7 Examination in Engineering: May 2023

Module Number: ME 7216 **Module Name: Mobile Robot Design**

[**Three** Hours]

[Answer **all** questions, each question carries **10** marks]

Clearly state any assumptions, made in answering. Also, make sure to use standard notations and SI units where necessary.

Q1. a) The choice of wheel types for a mobile robot is strongly linked to the choice of wheel arrangement or wheel geometry. The mobile robot designer must consider these two aspects simultaneously when designing the locomoting mechanism of a wheeled robot.

i) Why does wheel type and wheel geometry matter for the choice of wheel types for a mobile? Explain using **three** fundamental characteristics of a mobile robot.

ii) Figure Q1(a) shows icons of different wheel types used in a mobile robot. Sketch **three** configurations or wheel arrangements of a mobile robot with four number of wheels. Briefly describe the purpose of each configuration with respect to the wheel types.

[5 Marks]

b) Figure Q1(b) shows a differential drive robot in its global reference frame (I): $\xi_I = [x \quad y \quad \theta]^T$. This differential drive robot has two wheels, each of diameter $\boldsymbol{r}$. Given a point P centered between the two drive wheels, each wheel is a distance $\boldsymbol{l}$ from P. If the spinning speeds of right and left wheels are $\dot{\varphi}_1$ and $\dot{\varphi}_2$, respectively and the pose of the mobile robot in the global reference frame.

i) Write down the relationship between the speed of the mobile robot in local reference frame $\dot{\xi}_R$ and $\dot{\xi}_I$, using the rotation matrix $R(\theta)$.

ii) Obtain the kinematic model of the differential drive robot using the parameters given above.

iii) In a given moment, the location of the robot is defined by $\theta = {}^{\pi}/_{2}$ rad, $r =$ 1 cm and $l =$ 1cm. If the robot engages its wheels unevenly at speeds of $\dot{\varphi}_1 = 4$ cm/s and $\dot{\varphi}_2 = 2$ cm/s, respectively, show that the mobile robot speed is $[0 \quad 3 \quad 1]^T$.

[5 Marks]

Q2 a) Describe **four** key features of an autonomous mobile robot.

[2 Marks]

b) By referring an application in the field, explain how a mobile robot reaches a pre-set target location in an unknown environment (hint: you may follow the "SEE-THINK-ACT" cycle).

[3 Marks]

c) Figure Q2(c) shows the current position of a mobile robot and the position of the goal that it should reach eventually.

i) Let α denote the angle between the X_R axis of the robot reference frame and the vector connecting the centre of the axle of the two rear wheels and the goal of the robot. Derive expressions for ρ, α and β using parameters given in Figure Q2(c).

ii) Taking control laws for v and ω as $v = K_1.\rho$ and $\omega = K_2\alpha + K_3\beta$ where K_1, K_2 and K_3 are control gains, show that the feedback control system of the mobile robot is given by the following matrix.

$$\begin{bmatrix}\dot{\rho}\\ \dot{\alpha}\\ \dot{\beta}\end{bmatrix} = \begin{bmatrix}-K_1\rho\cos\alpha\\ -K_1\rho\sin\alpha - K_2\alpha - K_3\beta\\ -K_1\sin\alpha\end{bmatrix}$$

[5 Marks]

Q3 a) With the aid of figures, briefly explain the reason for using probability in mobile robotics.

[2 Marks]

b) With the aid of figures and equations, explain why the Markov approximation is important for mobile robots. Here, you should also state any underlying assumptions and their implications in real-world applications.

[3 Marks]

b) For a stream of observations $Z_1, Z_2, \ldots Z_t$ and a stream of corresponding actions $u_1, u_2, \ldots u_t$, the posterior of the state of a robot is given by the following expression.

$$bel(X_t) = P(X_t/u_1, Z_1, u_2, Z_2 \ldots u_t, Z_t)$$

Apply the Baye's filter recursively to obtain the simplified total probability of state X_t, if Markov approximations are valid for this robot.

[5 Marks]

Q4 a) State **two** types of motion models and briefly explain **two** mobile robot applications for each of the motion model. Also, incorporate suitable sensors for each of your applications.

[3 Marks]

b) When a robot executes the "press button" action while the button is not pressed, the robot has a certainty of 90% being successful. The probability of the button being in the "pressed" state initially is 5%. Clearly indicating any assumptions made, draw the state transition diagram and calculate the probability of the button remaining in the "not pressed" state after executing "press button" action.

[3 Marks]

c) Probability of reading distance measurement value of 10 from a sensor, which measures through a door is 0.6, if door is open. If the door is closed, the probability of same sensor reporting measurement value of 10 is 0.3. In a given moment, it is unknown whether the door is open or closed and the sensor has reported a measurement result of 10. Show that the measurement improved the knowledge about state of door.

[4 Marks]

Figure Q1(a): Icons of different wheel types

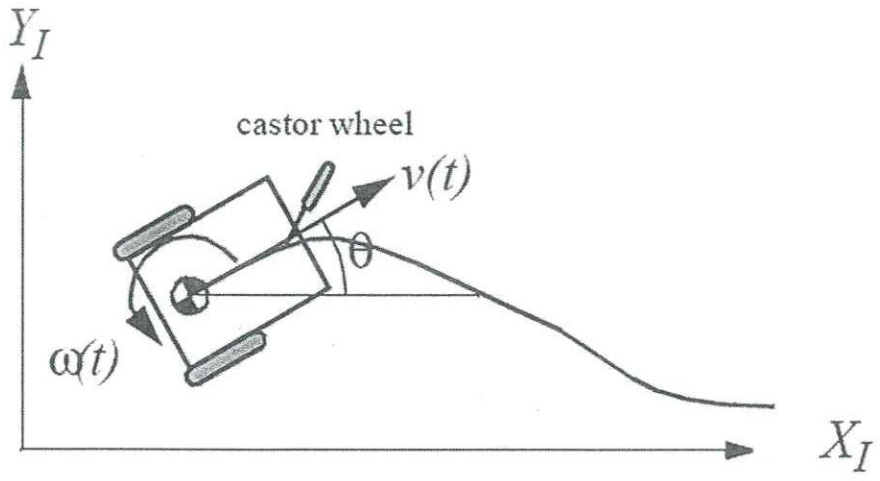

Figure Q1(b): A differential drive robot in its global reference frame

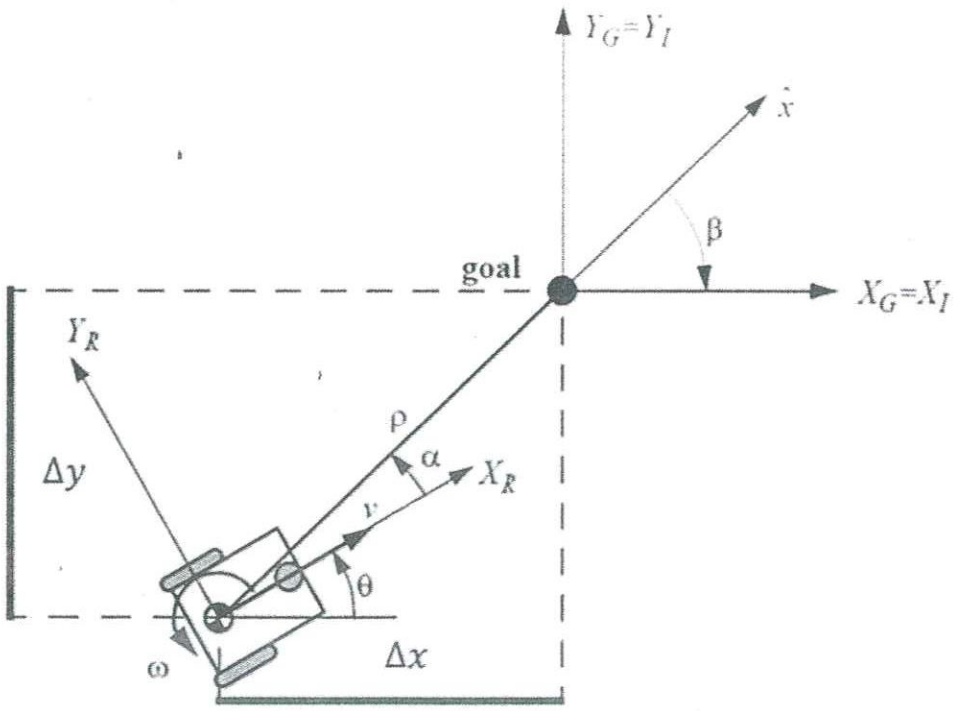

Figure Q2(c): Current and target position of a mobile robot