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SET A

UNIVERSITI KUALA LUMPUR
Malaysia France Institute

FINAL EXAMINATION

JANUARY 2014 SESSION

SUBJECT CODE	**:**	**FAB 38004**
SUBJECT TITLE	**:**	**MOBILE ROBOTICS**
LEVEL	**:**	**BACHELOR**
TIME / DURATION	**:**	**(3 HOURS)**
DATE	**:**	

INSTRUCTIONS TO CANDIDATES

1. **Please read the instructions given in the question paper CAREFULLY.**
2. **This question paper is printed on both sides of the paper.**
3. **Please write your answers on the answer booklet provided.**
4. **Answer should be written in blue or black ink except for sketching, graphic and illustration.**
5. **This question paper consists of TWO (2) sections. Section A and B. Answer ALL questions in Section A. For Section B, answer THREE (3) questions only.**
6. **Answer all questions in English.**

THERE ARE 9 PAGES OF QUESTIONS AND 1 PAGE OF APPENDIC, EXCLUDING THIS PAGE.

SECTION A (Total: 40 marks)

INSTRUCTION: Answer ALL questions.
Please use the answer booklet provided.

Question 1

a) Describe the meaning of Locomotion in mobile robot. Give **three (3)** most important issues in locomotion.

[4 marks]

b) Calculate the number of distinct event sequences (gaits) for a walking machine with 2 legs. List all the possible different events.

[4 marks]

c) Explain the meaning of holonomic and non-holonomic wheel systems. Give an example for each type of wheel systems.

[4 marks]

d) Describe the Instantaneous Center of Rotation (ICR).

[2 marks]

e) Draw the general control scheme of mobile robotics. Explain with an example each of the components.

[6 marks]

Question 2

a) Consider the differential drive fixed standard wheels robot shown in **Figure 1** below. Determine the rolling constraints of the wheels in the robot reference frame. Assume the radius, r of both wheels is 1cm, distance, $\ell = 20cm$ and orientation, θ = 90°.

[5 marks]

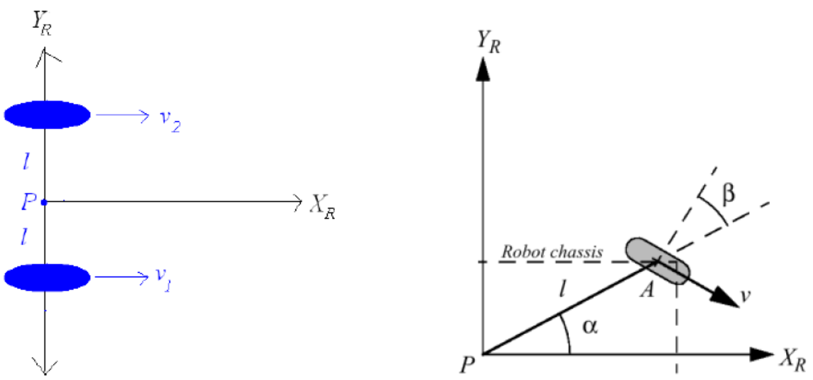

Figure 1: The differential drive fixed standard wheels robot

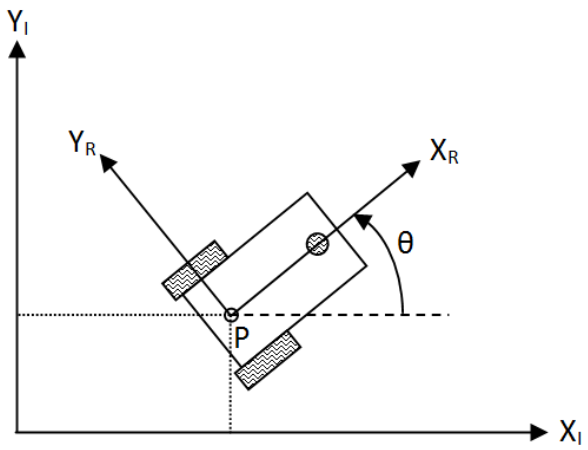

Figure 2: A robot position in global reference frame

b) **Figure 2** show a robot position in global reference frame. If a robot velocity has a velocity of $(\dot{x}, \dot{y}, \dot{\theta})$ in the global reference frame and positioned at *P* and orientation $\theta = \pi/3$ with respect to the global reference frame. Determine the motion along X_R and Y_R due to θ with respect to the robot reference.

[5 marks]

c) Determine the robots velocity with respect to the local reference frame (ξ_R), if the robot velocity is (3 cm/s, 4 cm/s, 5 rad/s) with respect to the robot's global reference frame (ξ_I).

[5 marks]

d) A robot is positioned at a 60° angle with respect to the global reference frame and has wheels with a radius of 1 cm. These wheels are 2 cm from the center of the chassis. If the speeds of wheels 1 and 2 are 4 cm/s and 2 cm/s respectively, determine the robot velocity with respect to the global reference frame (ξ_R).

[5 marks]

SECTION B (Total: 60 marks)

INSTRUCTION: Answer only THREE (3) questions.
Please use the answer booklet provided.

Question 3

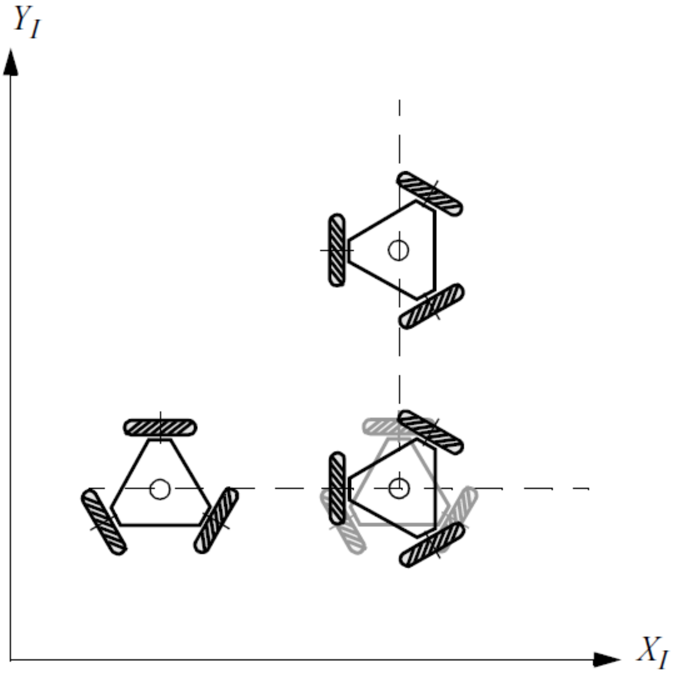

Figure 3: A robot trajectory with omnidirectional robot

a) **Figure 3** shows a robot trajectory of omnidirectional robot. A robot has a goal trajectory in which the robot moves for 1 second with constant speed of 1 m/s along axis X_I. Then the robot changes the orientation counterclockwise 90 degree in 1 second. Finally the robot moves for 1 second with constant speed of 1 m/s along axis Y_I. Based on the movement of robot above, plot the appropriate parameter involved in trajectory in relation to time (e.g. x, y, θ).

[3 marks]

b) **Figure 4** shows a differential steering robot in the global frame with ℓ = 5 cm starts at (x_0, y_0) = (10 cm, 10 cm), θ = 0°, t = 0 second. Answer the following questions:

i. The robot moves both wheels at 3 cm/sec and moves for 15 seconds. Determine the location of the robot at t = 15 seconds.

[3 marks]

ii. From the new location in question 3b(i), the robot sets the right wheel to 4 cm/s and the left wheel to 3 cm/s and moves for 20 more seconds. Determine the location of the robot at t = 35 seconds.

[4 marks]

iii. After 35 seconds, set the robots right wheel to 3 cm/s and the left wheel to -3 cm/s for 5 seconds. Determine the location of the robot at t = 40 seconds.

[3 marks]

iv. Now set the robot's right wheel to 3 cm/s and the left wheel to 3.5 cm/sec for 10 seconds, where is the robot at t = 50 seconds.

[3 marks]

v. Finally, the robot sets the right wheel to 0 cm/s and the left wheel to 3 cm/s for 10 second, determine the final location of the robot at t = 60 seconds.

[4 marks]

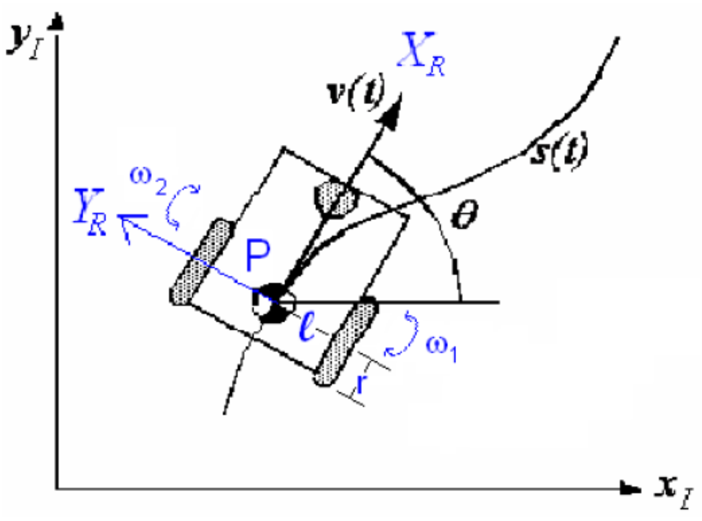

Figure 4: A differential steering robot

Question 4

a) Define systematic error and random errors.

[2 marks]

b) Describe the meaning of Active sensors and Passive sensors. Give an example for each sensor.

[4 marks]

c) **Figure 5** shows a robot with multi-sensor system. Classify all sensors.

[4 marks]

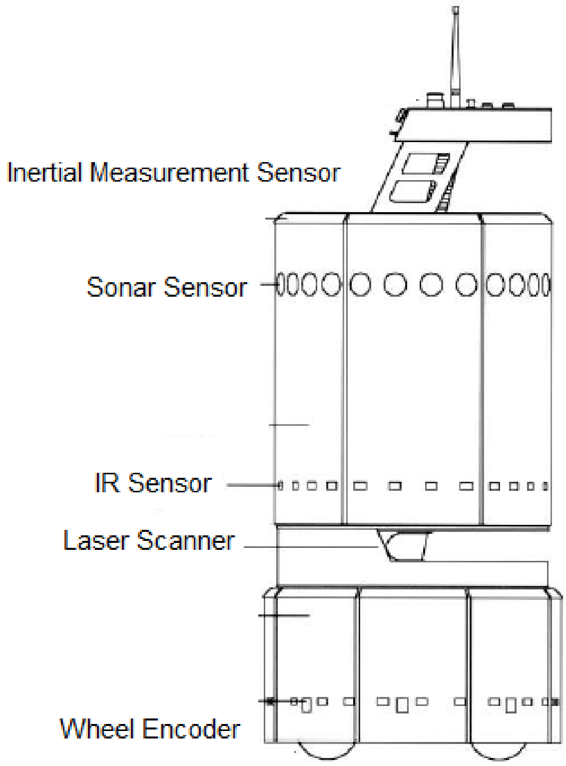

Figure 5: A robot with multi-sensor systems

d) Typical beacon based navigation system require signals from more than one beacon signal to compute the robot position. Explain why more than one beacon signal are required and comment on the limitation when used with mobile robot.

[3 marks]

e) A laser rangefinder transmitting a 10MHz modulated signal uses phase-shift to measure distance. If the measured phase shift is π/10 radians, determine the measured distance. (c = 0.3 m/ns).

[3 marks]

f) Exteroceptive ranging sensors are the most popular sensors used for obstacle detection, obstacle avoidance and localization. Explain the challenge of used this sensors. Give **two (2**) examples of this sensor type.

[4 marks]

Question 5

a) Draw the process flow of updating robot position. Explain the two-step processes of updating robot position based upon encoder and observation sensors.

[6 marks]

b) **Figure 6** shows the real map of a building. Explain **three (3)** methods that can be used to localize the robot to move from point A to point B. [hint: sketch the map to help your explanation]

[6 marks]

Figure 6: A real map of building

c) Explain behaviour-based localization and their challenge.

[4 marks]

d) Explain **four (4)** methods of mobile robot localization.

[4 marks]

Question 6

a) Describe obstacle avoidance path planning in navigation.

[3 marks]

b) Describe **three (3)** algorithms of global path planning for a mobile robot.

[3 marks]

c) List **two (2**) methods of graph search in path planning.

[2 marks]

d) **Figure 7** shows an exact cell decomposition of a room. Construct the path planning for the robot to move from **start** to **goal** using appropriate algorithm

[6 marks]

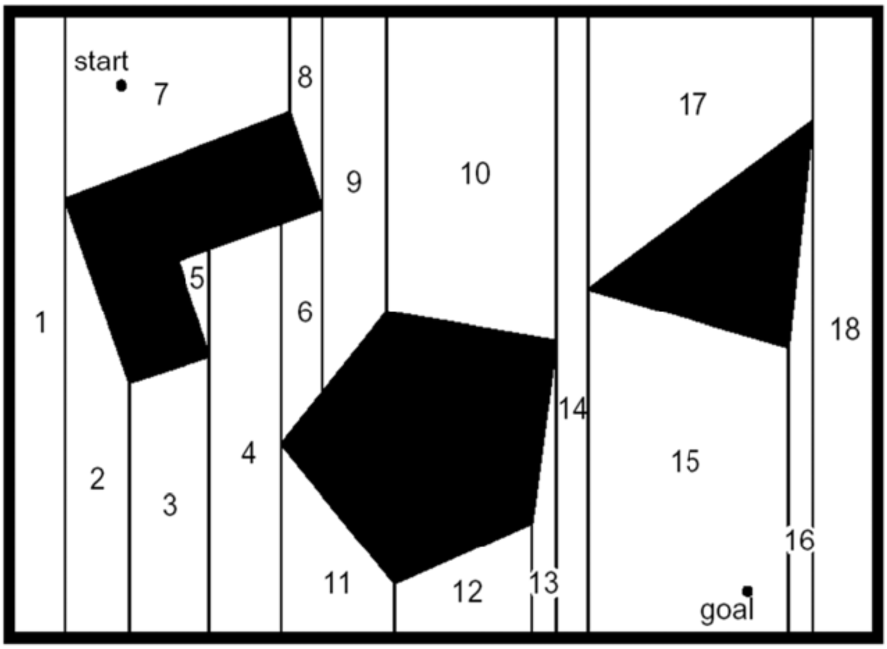

Figure 7: Exact cell decomposition

e) Draw and explain the architecture for map-based (or model-based) navigation method.

[4 marks]

f) Give **two (2)** advantages of using map-based navigation approach.

[2 marks]

END OF QUESTION

APPENDIX

Trigonometry

θ (radians)	0	$\frac{\pi}{6}$	$\frac{\pi}{4}$	$\frac{\pi}{3}$	$\frac{\pi}{2}$
θ (degrees)	0°	30°	45°	60°	90°
$\cos(\theta)$	1	$\sqrt{3}/2$	$\sqrt{2}/2$	$1/2$	0
$\sin(\theta)$	0	$1/2$	$\sqrt{2}/2$	$\sqrt{3}/2$	1

$$\sin(-\theta) = -\sin(\theta) \qquad \cos(-\theta) = \cos(\theta)$$
$$\sin(\theta - \tfrac{\pi}{2}) = -\cos(\theta) \qquad \cos(\theta - \tfrac{\pi}{2}) = \sin(\theta)$$

$$\begin{aligned} \cos(a+b) &= \cos a \cos b - \sin a \sin b \\ \sin(a+b) &= \sin a \cos b + \cos a \sin b \end{aligned}$$

Kinematics

$$\boldsymbol{R}(\theta) = \boldsymbol{R_{cw}}(\theta) = \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

The rolling constraint for a fixed standard wheel:

$$[\sin(\alpha+\beta) \;\; -\cos(\alpha+\beta) \;\; (-l)\cos(\beta)]\, \boldsymbol{R}(\theta)\dot{\boldsymbol{\xi}}_{\boldsymbol{I}} - r\dot{\phi} = 0$$

The sliding constraint for a fixed standard wheel:

$$[\cos(\alpha+\beta) \;\; \sin(\alpha+\beta) \;\; l\sin(\beta)]\, \boldsymbol{R}(\theta)\dot{\boldsymbol{\xi}}_{\boldsymbol{I}} = 0$$

$$\dot{\xi}_R = R(\theta)\dot{\xi}_I$$

Forward kinematics (linear displacement)

$$\begin{aligned} x(t+\Delta) &= x_t + v_t \Delta \cos\theta_t \\ y(t+\Delta) &= y_t + v_t \Delta \sin\theta_t \\ \theta(t+\Delta) &= \theta_t \end{aligned}$$

Forward kinematics (Turning)

$$\begin{aligned} R &= \ell(v_1 + v_2)/(v_1 - v_2) \\ \omega &= (v_1 - v_2)/2\ell \\ x(t+\Delta) &= R\cos(\omega\Delta)\sin(\theta_t) + R\sin(\omega\Delta)\cos(\theta_t) + x_t - R\sin(\theta_t) \\ y(t+\Delta) &= R\sin(\omega\Delta)\sin(\theta_t) - R\cos(\omega\Delta)\cos(\theta_t) + y_t + R\cos(\theta_t) \\ \theta(t+\Delta) &= \theta_t + \omega\Delta \end{aligned}$$