SET A

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UNIVERSITI KUALA LUMPUR
Malaysia France Institute

FINAL EXAMINATION

SEPTEMBER 2014 SESSION

SUBJECT CODE	:	**FAB38004**
SUBJECT TITLE	:	**MOBILE ROBOTICS**
LEVEL	:	**BACHELOR**
TIME / DURATION	:	**9.00 AM – 12.00 PM (3 HOURS)**
DATE	:	**9 JANUARY 2015**

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 8 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) Discuss **three (3)** issues for locomotion of mobile robot.

[3 marks]

b) Discuss in what conditions can a legged robot with three or more legs exhibit static stability.

[2 marks]

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

[4 marks]

d) Describe the terms Degree of Mobility, Degree of Steerability and Degree of Maneuverability and complete the Figure 1.

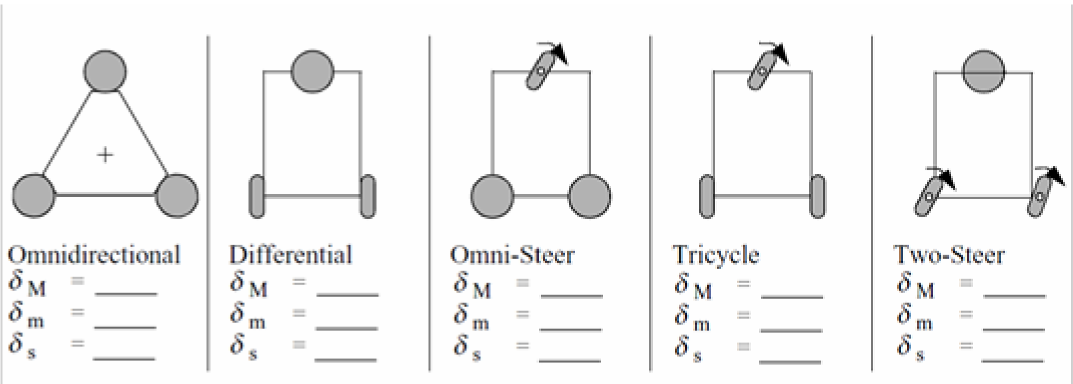

Figure 1 : The five basic types of three wheel configurations

[8 marks]

e) Describe the Instantaneous Center of Rotation (ICR)

[2 marks]

Question 2

a) **Figure 2** shows 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 $\theta = \pi / 2$ 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]

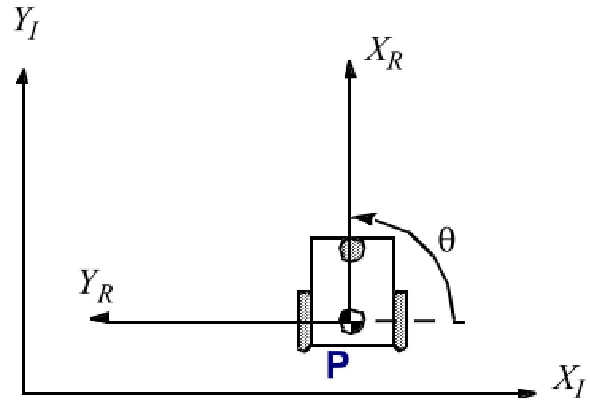

Figure 2: A robot position in global reference frame

b) If the robot velocity is (2 cm/s, 3 cm/s, 5 rad/s) with respect to the global reference frame (ξ_I), determine the velocity with respect to the robot's local reference frame (ξ_R).

[5 marks]

c) Determine the robots velocity with respect to the global reference frame (ξ_I), if the robot velocity is (2cm/s, 3cm/s, 5rad/s) with respect to the robot's local reference frame (ξ_R).

[5 marks]

d) Consider the differential drive fixed standard wheels robot shown in **Figure 3** below. Determine the sliding 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]

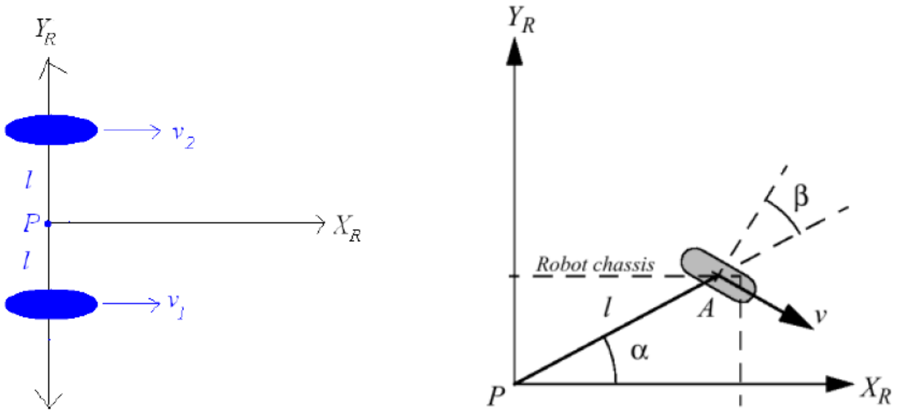

Figure 3: The differential drive fixed standard wheels robot

SECTION B (Total: 60 marks)

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

Question 3

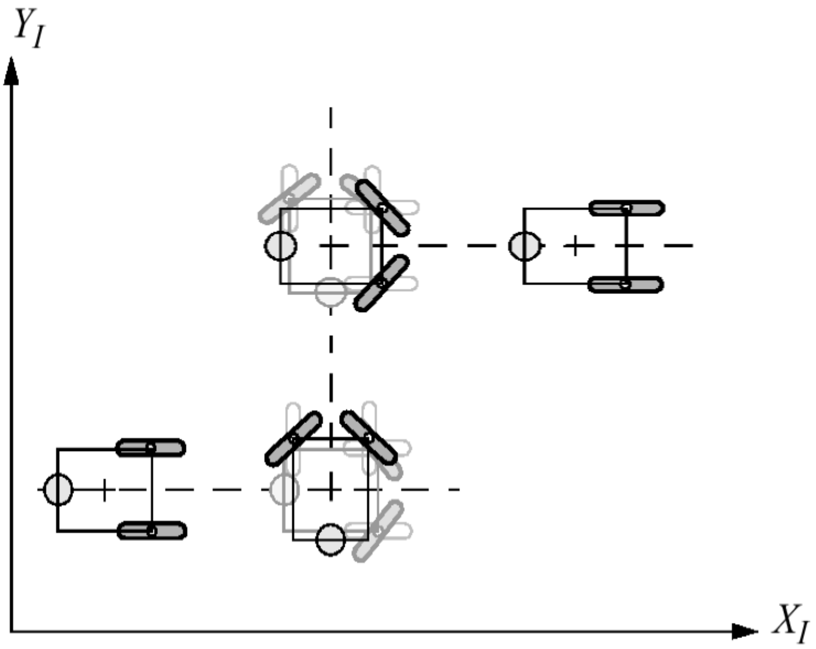

Figure 4: A trajectory of two steered wheels robot

a) **Figure 4** shows a robot path of two steered wheels mobile 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 rotate steered wheels -60 / 60 degree respectively for 1 second, and then change orientation counterclockwise 90° in 1 second. Rotate steered wheels 60 / -60 degree respectively for 1 second and move for 1 second with constant speed of 1 m/s along axis Y_I. At this location, the steered wheels rotate about -60 / 60 degree and turn clockwise at -90 in 1 second. Finally, the steered wheels rotate 60 / -60 degree for 1 second and moves parallel to axis X_I for 1 final second. Based on the movement of robot above, plot the appropriate parameter involved in trajectory in relation to time (e.g. x, y, θ, β_{s1} and β_{s2}).

[8 marks]

b) **Figure 5** shows a differential steering robot in the global frame with ℓ = 5.3 cm starts at (x_0 , y_0) = (20 cm, 20 cm), θ = 0°, t = 0 second. Answer the following questions:

i. The robot moves both wheels at 2 cm/sec and moves for 10 seconds. Determine the location of the robot at t = 10 seconds.

[3 marks]

ii. From the new location in question 3(b), the robot sets the right wheel to 3 cm/s and the left wheel to 2 cm/s and moves for 10 more seconds. Determine the location of the robot at t = 20 seconds.

[5 marks]

iii. After 20 seconds, set the robots right wheel to 2 cm/s and the left wheel to -2cm/s for 5 seconds. Determine the location of the robot at t = 25 seconds.

[4 marks]

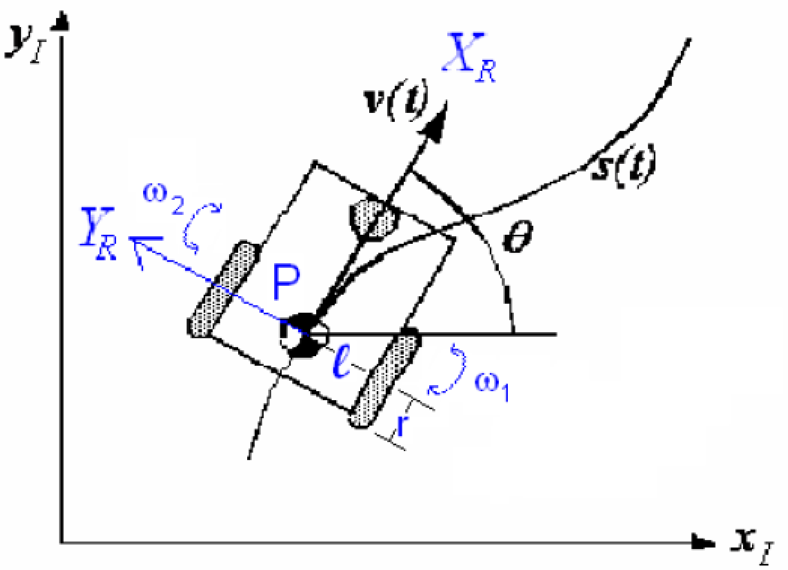

Figure 5: A differential steering robot

Question 4

a) Define deterministic and non-deterministic errors.

[2 marks]

b) Describe the meaning of Proprioceptive sensors and Exteroceptive sensors. Give an example for each sensor.

[4 marks]

c) **Figure 6** show a robot with multi-sensor system. Classify all sensors.

[4 marks]

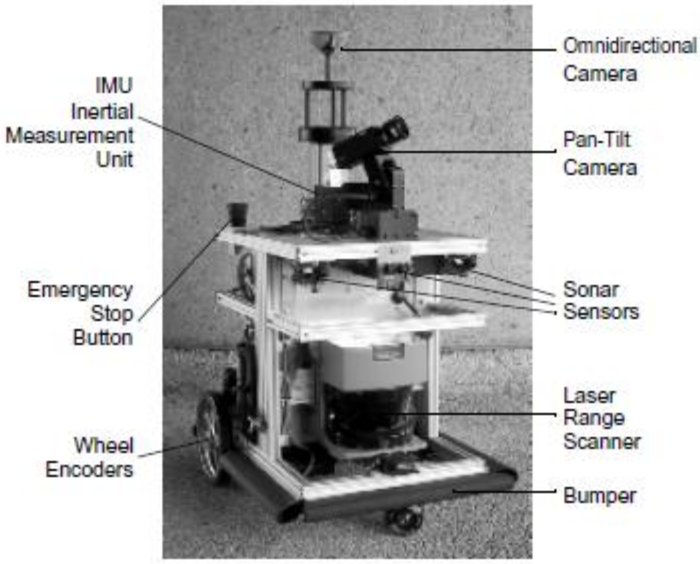

Figure 6: A robot with multi-sensor systems

d) Typical GPS receivers require signals from four satellites to compute position. Explain why **four (4)** are required and comments on the limitation when used in 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 $\pi/10$ radians, determine the measured distance. ($c = 0.3$ m/ns).

[3 marks]

f) Active ranging sensors are the most popular sensors used for obstacle detection, obstacle avoidance and localization. Explain the challenge of used this sensors in terms of quality of time of flight. 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 proprioceptive and exteroceptive sensors.

[6 marks]

b) **Figure 7** 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 7: A real map of building

c) Explain map-based localization and their challenges.

[4 marks]

d) Give **two (2)** advantages of using Markov Localization method.

[2 marks]

e) Give **two (2)** advantages of using Kalman Filter Localization method.

[2 marks]

Question 6

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

[3 marks]

b) List **two (2)** method of graph search in path planning.

[2 marks]

c) Describe local path planning in navigation.

[3 marks]

d) **Figure 8** 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]

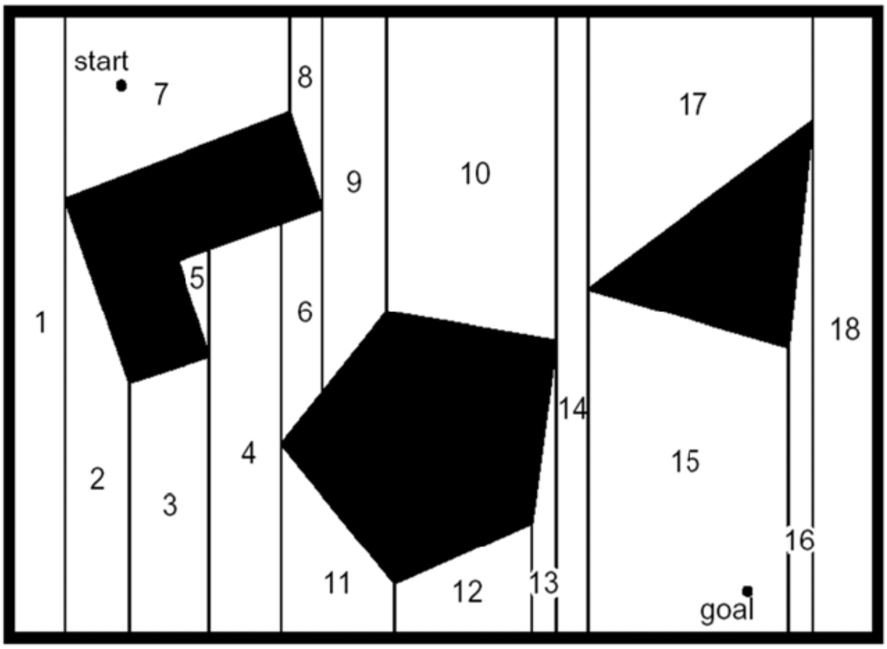

Figure 8: Exact cell decomposition

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)

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