Module code: **MECH5170M01**
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Module Title: Connected and Autonomous Vehicles Systems

School of Mechanical Engineering **May-June 2024**

Calculator instructions:

- You are allowed to use a non-programmable calculator from the School's list of approved calculators in this examination. No other calculator is permitted.

Dictionary instructions:

- You are not allowed to use your own dictionary in this examination. A basic English dictionary is available to use. Raise your hand and ask an invigilator if you need it.

Exam Information:

- There are **6** pages to this exam.
- You will have 2 hours plus your additional time allowance, if applicable, to complete this exam.
- There are 4 questions to this this examination, each worth 25 marks.
- You must attempt each question.
- The marks available for each question or part of question are given in brackets after the question.
- A formula sheet is provided at the end of the exam paper.
- This assessment is worth **50%** of the overall module mark.
- If you think that any additional data is required, make a reasonable assumption and indicate it clearly in your answer.

 Turn the page over

Q1.

Path planning is one of the most important functions of the autonomous vehicle. Different algorithms have been developed to accomplish this task. Explain the principle, highlight the strengths and weaknesses of each of the following algorithms:

a) Weighted directed graphs algorithm.

[5 marks]

b) Dijkstra algorithm.

[5 marks]

c) Greedy Best-First-Search algorithm.

[5 marks]

d) A* algorithm.

[5 marks]

e) Select one of the above algorithms, which, in your opinion, is the best to find the shortest path, and briefly justify your choice.

[5 marks]

Q2.

The perception system in an autonomous vehicle focuses on precise recognition of the environment surrounding the vehicle in a similar way as a human driver does. A range of sensors and algorithms are used to scan and perceive the surroundings. Please answer the following questions:

a) A human driver is using his senses to recognise the environment around the vehicle. List them in order from most used to least used by humans when driving.

[6 marks]

b) What are the functional requirements for the perception system in an autonomous vehicle.

[6 marks]

c) Each sensor used in the perception system has a different sensing distance range. List the sensors that are used and provide their approximate distance range.

[6 marks]

d) Explain how the distance range of the sensors used in the perception system can be affected by low-lighting conditions, for example, during the night.

[7 marks]

Q3.

Vehicle-to-everything (V2X) is communication between a vehicle and any entity that may affect, or may be affected by, the autonomous vehicle.

a) List the communication protocols that are used in V2X.

[5 marks]

Explain and briefly describe the following types of communications and list protocols that can be used for each of them:

b) V2I communication.

[5 marks]

c) V2N communication.

[5 marks]

d) V2V communication.

[5 marks]

e) V2D communication.

[5 marks]

Q4.

a) An ultrasonic sensor is used to detect the distance between an autonomous vehicle and a parked car. An ultrasound wave has been sent, and it took 18 milliseconds for the signal to return. Calculate the distance between the autonomous vehicle and the parked car, assuming that the speed of sound is 343 m/s.

[5 marks]

b) Assuming that the ultrasound sensor is now 2 meters from the parked vehicle and is connected to a microprocessor that is working at a speed of 8 MHz, sending the signal takes 1000 processor cycles, and receiving and calculating the distance takes 4000 processor cycles. Calculate the maximum frequency of distance measurement that can be achieved with this system.

[5 marks]

c) The wheels on the autonomous vehicle have been fitted with encoders, and the vehicle is negotiating a right-hand turn. The signals from the encoders are presented in Figure Q4.

The vehicle specification is:

Number of teeth on the encoders:	100 teeth per revolution
Wheel rolling radius:	0.5 m
Vehicle track:	2 m

Using the vehicle specification and the information from the graphs in Figure Q4:

i) Calculate the inner wheel speed. **[5 marks]**

ii) Calculate the outer wheel speed. **[5 marks]**

iii) Calculate the radius of the turn. **[5 marks]**

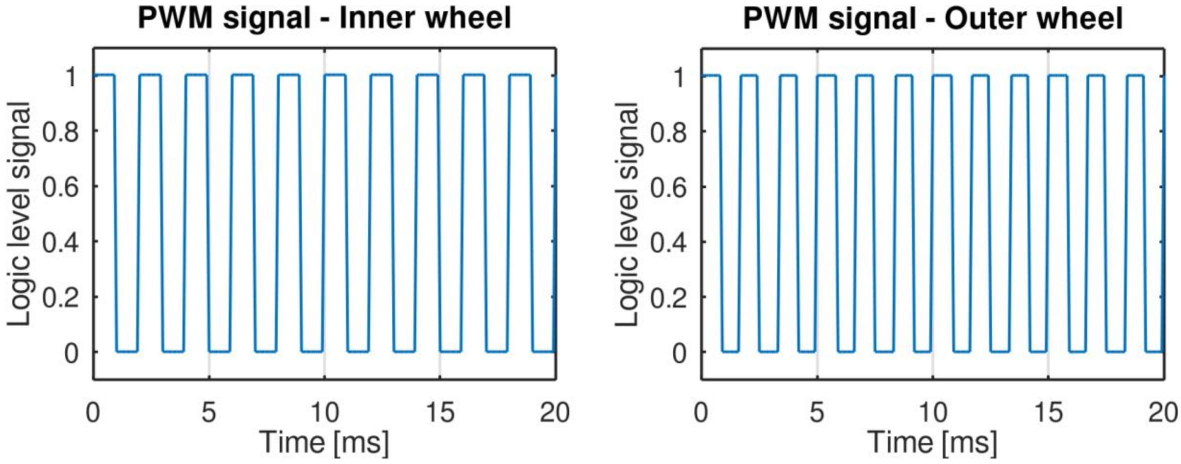

Figure Q4. Signal from encoders of the inner and outer wheel when driving along the turn.

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Formulae sheet

This formulae sheet contains the most commonly used formulae encountered within the MECH5170M01 module. The equations are grouped under the main section headings associated with the delivery of the module. You may assume that all symbols have their usual meaning.

General:

$P = TE\,V$ $\quad P = T\omega$ $\quad A = \frac{\pi d^2}{4}$ $\quad I_x = I_y = \frac{\pi d^4}{64}$ $\quad J = \frac{\pi d^4}{32}$

$D = \frac{1}{2} C_d A \rho V^2$ $\quad R_R = mg\,C_r$ $\quad R_s = 2mg\,C_r$ $\quad G_R = mg\,sin\theta$ $\quad 1mile = 1609m$ $\quad 1\ in\ 3\ slope = 18.4°$

Transmission:

$\Sigma Fx = TE - Rr - Gr - D = 0$ $\quad TE = \frac{Te\,(n_g \cdot n_f)(\eta_g \cdot \eta_f)}{r}$ $\quad TE = \frac{T_w}{r} = \mu N$ $\quad T_w = T_e\,(n_g \cdot n_f)(\eta_g \cdot \eta_f)$

$N_w = \frac{60 \cdot V}{2 \cdot \pi \cdot r}$ $\quad N_w = \frac{Ne}{n_g \cdot n_f}$ $\quad V = 2\pi r\,\frac{N_w}{60}$ $\quad R = \sqrt[(i-1)]{\frac{n1}{n_i}}$ $\quad n_i = n_{i+1} \cdot R$ $\quad m_{eq} = \frac{I_{eq}}{r^2} = \frac{I_w + I_d\,n_f^2 + I_g\,n_g^2\,n_f^2}{r^2}$

Batteries:

Indexes: c - cell, s - string, b - battery, p - pack, r - range

$U = I \cdot R\ \ [V]$ $\quad E = I \cdot U\ \ [Wh]$ $\quad C = I \cdot t\ \ [Ah]$

$E_{bs} = E_{bc} \cdot N_{cs}\ \ [Wh]$ $\quad E_{bp} = U_{bp} \cdot C_r\ \ [Wh]$ $\quad E_{bc} = U_{bc} \cdot C_{bc}\ \ [Wh]$

$N_{cs} = \frac{U_{bp}}{U_{bc}}$ $\quad N_s = \frac{E_{bp}}{E_{bs}}$ $\quad N_c = N_s \cdot N_{cs}$

By-wire steering system:

Kingpin torque $T_k = W \times \mu \times \sqrt{\frac{B^2}{8} + E^2}$ $\quad W = m \cdot g$

Cylinder force $F_C = \frac{T_K}{R_{min}}$

Cylinder surface area $A_c = \frac{F_c}{P}$

Swept volume $V_s = \frac{\pi \times D_B^2}{4} \times S$

LIDAR, Ultrasound sensors:

$d_L = \frac{t \cdot c_L}{2}$ $\quad d_{US} = \frac{t \cdot c_s}{2}$ $\quad f = \frac{1}{t}$ CPU: 1MHz=1 000 000 cycles (ticks) / second

Encoders: Pulse counting: $\omega = 2\pi \frac{n}{N \cdot t}$ Pulse timing: $\omega = 2\pi \frac{n}{N \cdot t}$ (rad/s)

Turn radius: $R = \frac{W_t}{2}\left(\frac{\omega_o + \omega_i}{\omega_o - \omega_i}\right)$ $\quad R = \frac{W_t}{2}\left(\frac{V_o + V_i}{V_o - V_i}\right)$