Module Title: Connected and Autonomous Vehicles Systems

School of Mechanical Engineering **January 2025**

Use of Gen AI (Generative Artificial Intelligence) instructions:
There is a three-tier traffic light categorisation for using Gen AI in assessments.

- This assessment is **red** category. AI tools cannot be used.

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 **7 pages** to this exam.
- You will have **2 hours** plus your additional time allowance, if applicable, to complete this exam.
- The marks available for each question or part of question are given in brackets after the question.
- To get full marks you must explain your reasoning.
- You must show all of your workings in answers to numerical questions.
- All symbols not specifically defined have their normally accepted meanings.
- Do not write or draw with red ink or red pencil.
- 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.

Please do not remove this paper from the exam venue.

Q1.

The Society of Automotive Engineers (SAE) defines different levels of vehicle autonomy.

a) Briefly describe the main features of vehicle autonomy at level 3. Explain under which road conditions a vehicle with level 3 autonomy would be able to drive from the University of Leeds to the Leeds Airport without human driver override.

[5 marks]

b) List the sensors that might be required to create level 3 of vehicle autonomy. Provide a brief explanation for your decision on the inclusion of each listed sensor.

[5 marks]

c) Briefly describe the main features of the level 4 vehicle autonomy.

[5 marks]

d) Explain the main differences between level 4 and level 5 of the vehicle autonomy.

[5 marks]

e) Which level of autonomy is required to develop an autonomous taxi and which level is required to develop an autonomous minibus transporting people between airport terminals. State your answer for both scenarios and briefly justify each answer.

[5 marks]

Q2.

The autonomous vehicles are equipped with many different sensors to perform self-driving functions.

a) Briefly describe the main steps that the autonomous control system will have to perform from the moment of data acquisition by the sensors to the decision point and sending the signals to actuators, for example: to brakes, to steering, etc.

[5 marks]

b) An autonomous vehicle that is driving along a dual carriageway in the nearside lane is approaching a broken-down vehicle blocking this lane. Briefly describe the decision-making process required by the autonomous vehicle control system to pass the broken-down vehicle so that the autonomous car can continue its journey.

[5 marks]

c) What is the sensor fusion and what is its main purpose.

[5 marks]

d) Briefly describe the purpose and logic behind the spatial synchronisation of the camera and LIDAR systems data.

[5 marks]

e) Briefly describe the purpose and logic behind the temporal synchronisation of the camera and LIDAR systems data.

[5 marks]

Q3.

As presented in Figure Q3, an autonomous vehicle is approaching an intersection with a stop sign in front of it and needs to stop before the intersection. Unfortunately, there are no visible lines on the road surface. With the aid of a LIDAR sensor installed in the front of the vehicle, detected distance to the stop sign (6.5 m at an angle 40º) on the left side of the road and to the tree (6.2 m at an angle 70º) on the right side of the road. From its high-resolution map, the vehicle system can read the road width of 6 m, the distance of the stop sign from the edge of the road of 1.5 m, and the distance between the road edge and the tree of 2.5 m.

a) Calculate the distance A that vehicle should travel before stopping in front of the intersection. The front of the vehicle should align with the stop sign position.

[5 marks]

b) Calculate the current position B of the vehicle from the left side of the road.

[5 marks]

c) Calculate the required correction C that the vehicle should do to move to the centre of the left lane of the road.

[5 marks]

d) A LIDAR sensor installed on this vehicle has a field of view of 360 degrees horizontally and 30 degrees vertically, and its angular resolution is 0.4 degrees. The LIDAR processing unit can handle 1.2 million points per second. Calculate the maximum frequency of scanning that can be achieved by this sensor.

[5 marks]

e) If the vehicle is also fitted with an ultrasound sensor, calculate the theoretical maximum signal update frequency of the ultrasound sensor with a range of 9 m, assuming the speed of sound to be c_s = 343 m/s. Under what circumstances can the update frequency be increased?

[5 marks]

Question 3 continues on next page.

Question 3 continued

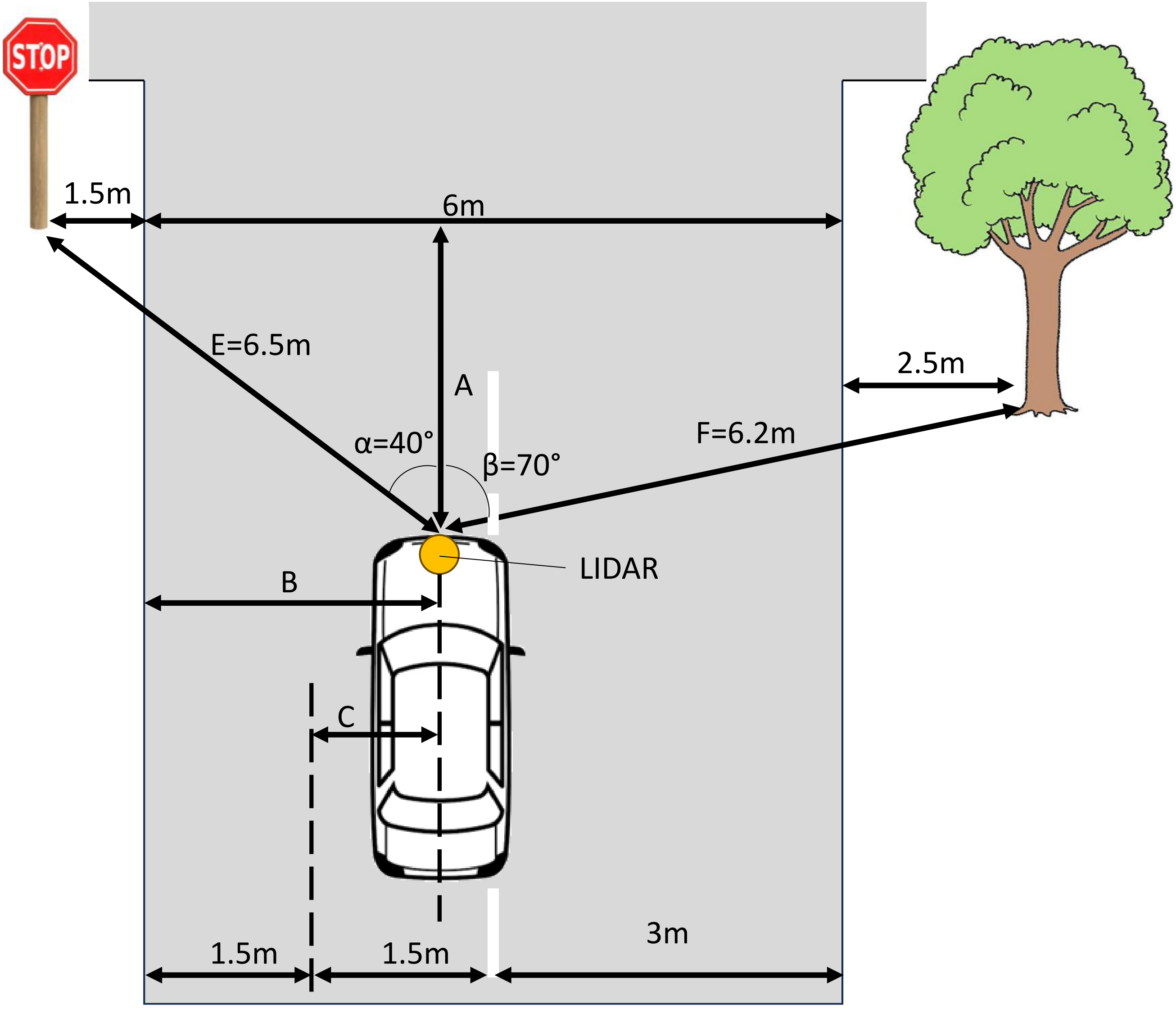

Figure Q3:
Road layout with an autonomous vehicle approaching a stop sign in front of an intersection.

Q4.

Introduction of autonomous vehicles on the public roads requires new regulations and a requirement framework.

a) What are the main pillars of the UK safety framework for autonomous vehicle operation.

[5 marks]

b) List and briefly describe new legal actors that need to be created as a part of the new legal framework for the autonomous vehicles.

[5 marks]

c) Briefly describe the potential benefit to society and the public that wide adoption of autonomous vehicles is expected to bring.

[5 marks]

d) Human error is the main cause of traffic accidents on the roads involving human operated vehicles. In a case of a road traffic accident caused by an autonomous vehicle, what are the main parties involved in the operation that could possibly be to blame for the cause of the accident.

[5 marks]

e) Briefly describe two main cybersecurity vulnerabilities that autonomous vehicles can be exposed to and propose solutions to prevent it from happening.

[5 marks]

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

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