THE UNIVERSITY OF MELBOURNE

Department of Electrical and Electronic Engineering

ELEN90066 Embedded System Design

PRACTICE EXAM

Reading/ printing time: 30 minutes, Writing time: 180 minutes

Scanning and submission time: 30 minutes

This examination paper has 8 pages

Authorised materials:

This is a Zoom-supervised, hand-written exam where only the following materials are permitted:

- Printed copy of this exam paper and/or an offline electronic PDF reader.
- Any material available in hardcopy or stored electronically on a device disconnected from communication networks.
- A4 paper, pens, pencils, ruler. Electronic devices may not be used for writing your answers.
- Any calculator model.

Instructions to students:

- This PRACTICE exam is provided purely as an example of the format and sorts of questions that will form part of the final exam for the subject and is for your own study purposes. It is not indicative of the actual content of the final exam.
- The questions carry weight in proportion to the marks stated for each question number. These marks total 100 marks.
- During Reading Time, you may print out a hardcopy of the exam. Alternatively, you may download the exam to an electronic PDF reading device, which must then be disconnected from the internet.
- During Writing Time you may only interact with the device running the Zoom session with supervisor permission. The printed test paper (or offline device containing the test paper) and any other working sheets must be visible to Zoom invigilators.
- Write your exam answers using pens/pencils and A4 paper. Start each question on a new page and write down the question numbers.
- During Scan/Upload Time, assemble your pages in question number order, and use a mobile phone or tablet to scan and combine them into a single PDF file. Check that all pages are included and clearly readable.
- Submit your PDF file to the Gradescope Assignment corresponding to this exam. Confirm with your Zoom supervisor that you have received confirmation of your submission.
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Question 1 (14 marks)

The cliff-edge sensors on the Kobuki robot used in your project were a type of analog distance measuring sensor, using a beam of reflected infrared light to sense the distance between the sensor and a reflective target (i.e. the ground). The range to an object is proportional to the reciprocal of the sensor's output voltage.

An excerpt from the sensor's data sheet is given below

Parameter	Symbol	Conditions	MIN.	TYP.	MAX.	Unit
Measuring distance range	ΔL	(Note 1)	2	-	15	cm
Output terminal voltage	Vo	L=15cm (Note 1)	0.25	0.4	0.55	V
Output voltage difference	Δ Vo	Output change at L change (15cm → 2cm) (Note 1)	1.35	1.65	1.95	V
Average supply current	Icc	L=15cm (Note 1)	-	12	22	mA

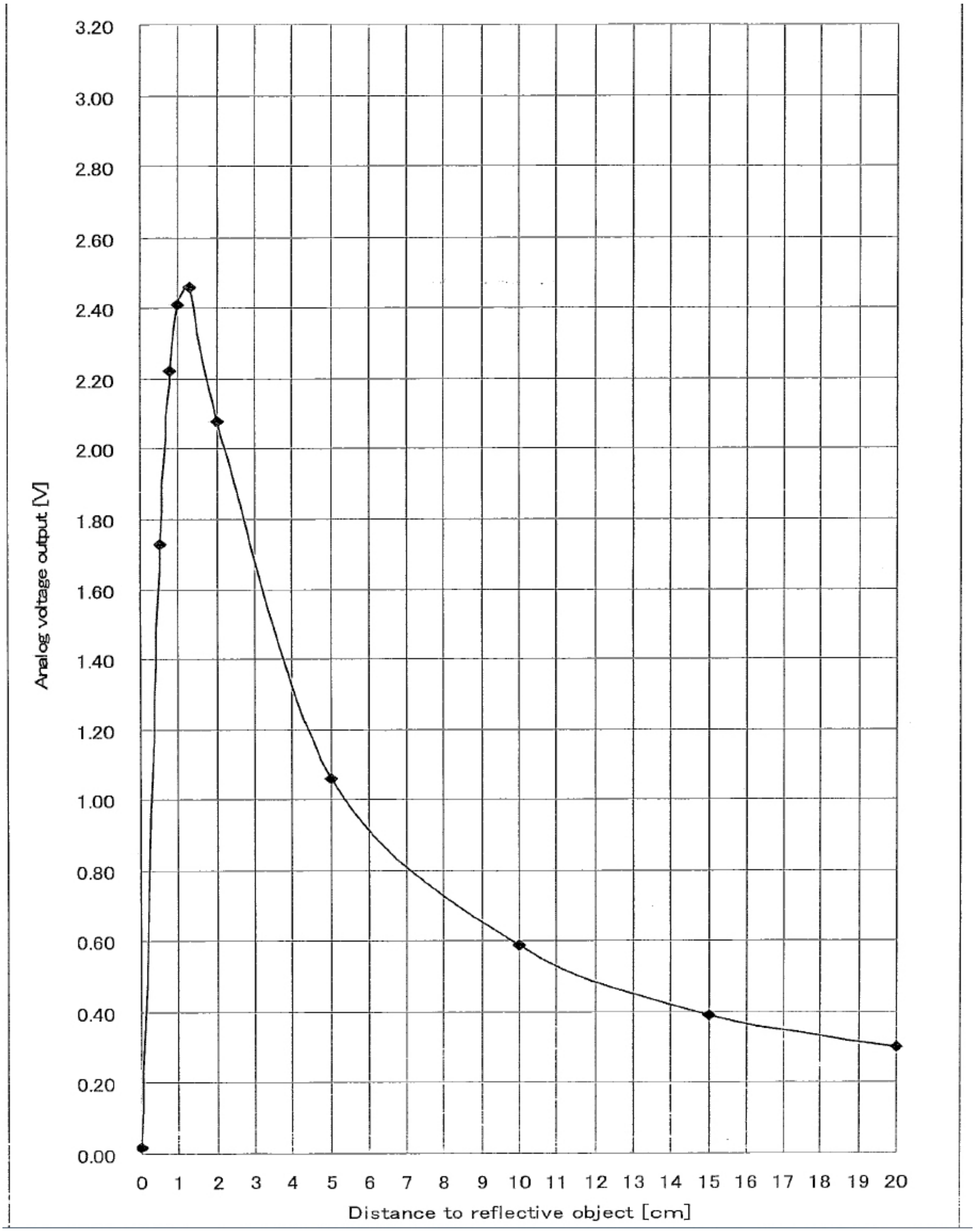
※ L : Distance to reflective object

(a) **[2 marks]** What are the typical output voltages for the cliff-edge sensor at both ends of its stated measuring range?

(b) **[2 marks]** Using ONLY the data from the table above and assuming an *affine* model for the sensor, is it possible to determine the *bias* and *sensitivity* parameters of the sensor? If yes, explain how to determine them. If no, explain why not.

Question 1 (continued)

(c) **[5 marks]** Some testing data for the sensor, using a particular surface, is given in the figure below



Question 1 (continued)

The equation mapping the sensor voltage V_O back to the physical range R (cm) is given by

$$R = K_s \left(\frac{1}{V_O} \right) + K_o$$

where K_s and K_o are parameters characteristic of the sensor.

Use the data in the graph to estimate K_s and K_o over the normal operating range of the sensor.

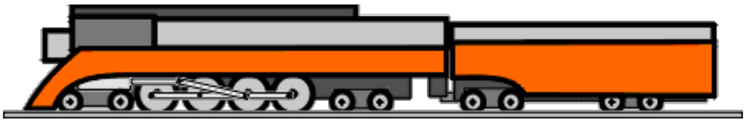
(d) Assume now that the output terminal voltage of the cliff-edge sensor, V_O, can range between 0V and 3.3V. The output signal from the cliff-edge sensor is converted to a 12-bit binary number via an Analog to Digital Converter for use in an obstacle avoidance algorithm by dividing this voltage range into equally spaced voltage steps.

(i) [**2 marks**] What is the precision of this sensor?

(ii) [**3 marks**] What is the dynamic range of the sensor, expressed in dB?

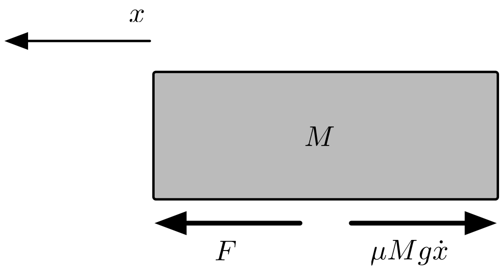
Question 2 (10 marks)

Consider a model of a train shown in the figure below.



Assuming that the train only travels in one dimension (along the track), we want to model the train so that it starts and comes to rest smoothly, and so that it can track a constant speed command with minimal error in steady state.

The train will be considered as one rigid mass, represented as M. The force F represents the force generated between the wheels of the engine and the track, while μ represents the coefficient of rolling friction. The free-body diagram is shown below.



From Newton's second law, the sum of the forces acting on a body is equal to the product of the mass of the body and its acceleration. In this case, the forces acting on the train in the horizontal direction are the rolling resistance, and the force generated at the wheel/track interface.

The rolling resistance forces are modelled as being linearly proportional to the product of the corresponding velocities and normal forces (which are equal to the weight forces).

Applying Newton's second law in the horizontal direction based on the above free-body diagram leads to the following governing equation for the train system.

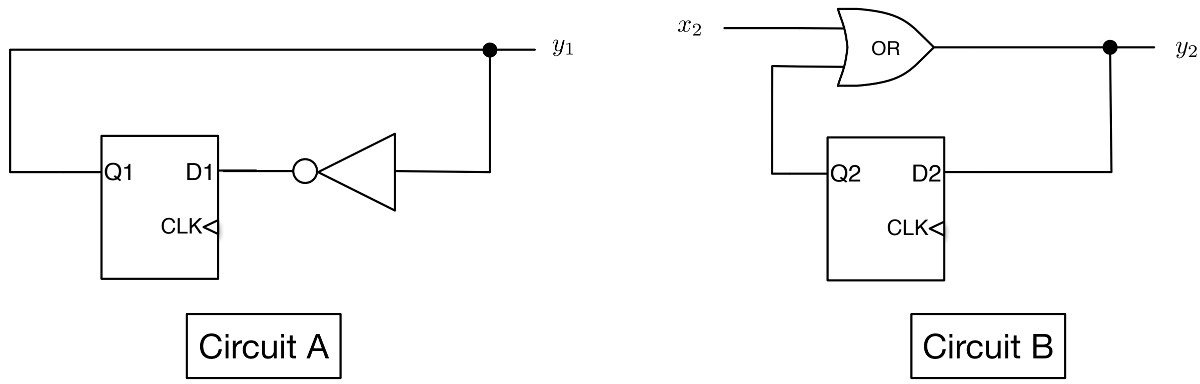
$$F - \mu M g \dot{x} = M \ddot{x}$$

(a) **[3 marks]** Assuming that the train is initially at rest, rewrite the train system equation above as an *integral* equation for $x(t)$.

(b) **[7 marks]** Assuming that $x(t)$ is an output, construct an actor model (a block diagram) that models the train. You should use only primitive actors such as *integrators* and basic arithmetic actors such as *scale* and *adder*.

Question 3 (24 marks)

(a) Consider the following two synchronous logic circuits below, Circuit A and Circuit B.



Note that the clock inputs on the D flip-flops are not explicitly shown, but the flip-flops react on the positive edge of the clock in the normal fashion (e.g. $Q <= D$).

(i) [**2 marks**] Construct a Finite State Machine diagram representing the behaviour of Circuit A.

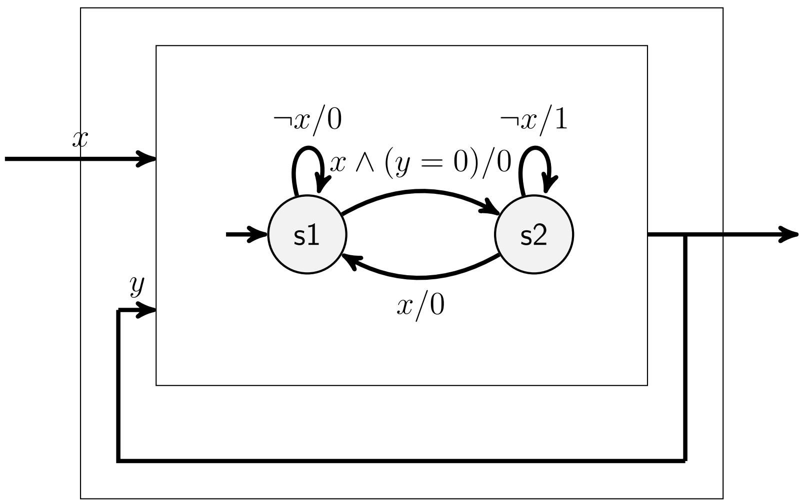
(ii) [**5 marks**] Construct a Finite State Machine diagram representing the behaviour of Circuit B.

(iii) [**4 marks**] It is claimed that Circuit B could potentially 'get stuck' forever with $y_2 = 1$, independent of the input x_2.

Write this proposition in Linear Temporal Logic (LTL) and then either prove or disprove it.

(iv) [**10 marks**] Consider the *synchronous composition* of the cascaded connection of Circuits A and B – that is the output of Circuit A (y_1) is connected to the input of Circuit B (x_2). Construct a Finite State Machine diagram representing this composition.

(b) Consider the following synchronous feedback composition shown below:



(i) [**3 marks**] Is the feedback composition *constructive*? Explain your answer.

Question 4 (26 marks)

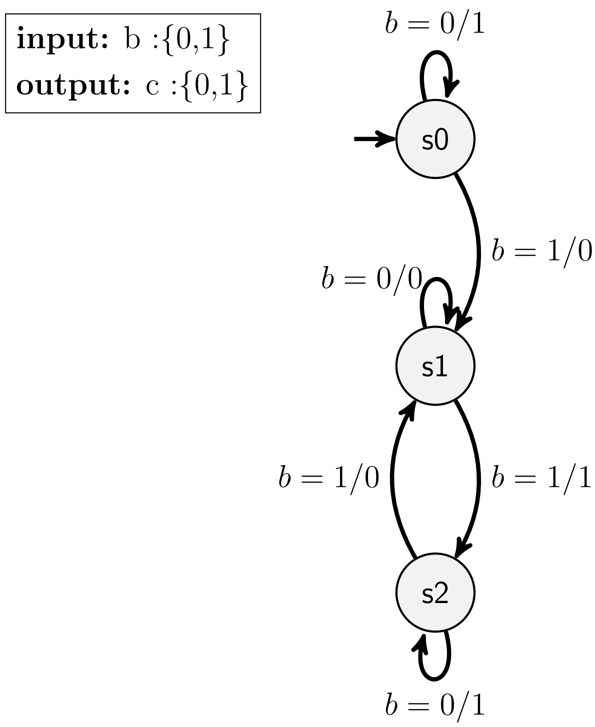
(a) Suppose that a finite state machine has a periodic sequence 0101010101 . . . as its only input. For each of the infinite sequences below, either construct a state machine (specify the state transition diagram and the initial state) that will yield the sequence as output, or argue that it is impossible to do so.

(i) [**2 marks**] ababababab...

(ii) [**5 marks**] aaaaababababababababab...

(iii) [**2 marks**] abaabbaaabbbaaaabbbb...

(b) The finite state machine shown below has the property that it outputs 1 if an input string of bits has *even parity*, that is the total number of 1s in the string is even.



(i) [**6 marks**] For each of the following LTL formulae, determine whether it is TRUE or FALSE. You **MUST** give an explanation for your answer. If FALSE, give a counterexample.

$\mathbf{G}(b = 1) \implies \mathbf{F}\text{s2}$

$\mathbf{GF}(b = 0) \implies \mathbf{FG}\text{s0}$

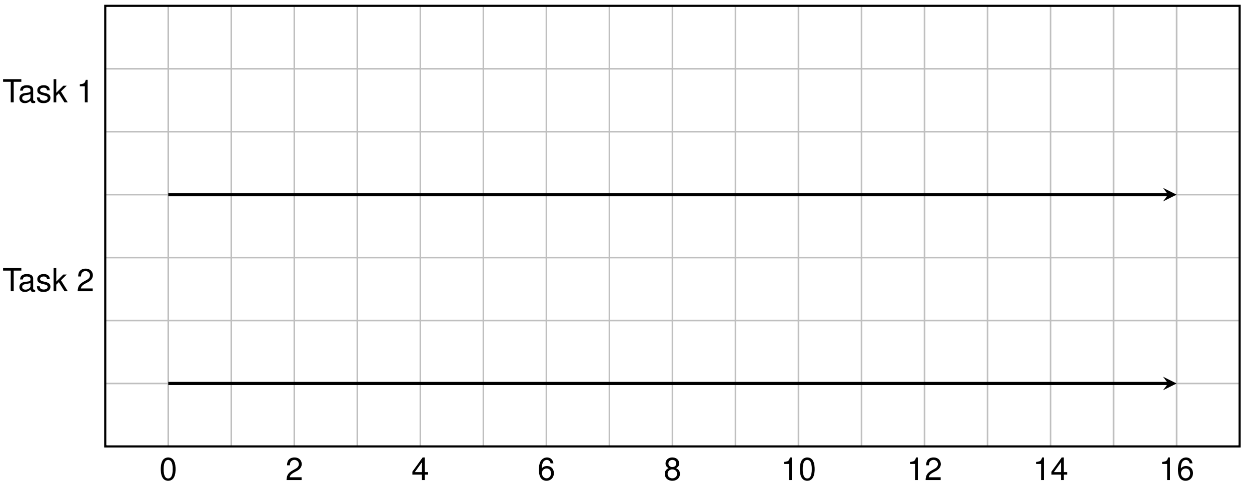
(ii) [**8 marks**] Construct a **two-state** state machine that *simulates* this one and preserves its behaviour. Give the simulation relation.

(iii) [**3 marks**] Is your machine from part (ii) *bisimilar* to the original one? Explain your answer.

Question 5 (13 marks)

Consider two tasks to be executed periodically on a single processor, where Task 1 has period $T_1 = 5$ and Task 2 has period $T_2 = 7$. Assume Task 1 has Worst Case Execution Time (WCET) $C_1 = 2$, and Task 2 has WCET $C_2 = 4$.

(a) [**6 marks**] Choose a scheduling algorithm covered in the lectures (RMS or EDF) that ensures that the two tasks have a *feasible schedule*. Using the axes below as a guide, sketch the schedule for the tasks for 15 time units.



(b) [**2 marks**] What is the relationship between threads and processes?

(c) [**2 mark**] Could threads within the same process share data with one another by passing pointers to objects on their stacks? Explain why / why not.

(d) [**3 mark**] Interrupt disabling and enabling is a common approach to implementing *mutual exclusion*. What are its advantages and disadvantages?

Question 6 (13 marks)

(a) [**2 marks**] Explain the concept of *pipelining* with respect to microprocessors in embedded systems. What benefits does it provide?

(b) [**3 marks**] The security of embedded systems is notoriously behind that of desktop computing and consumer mobile devices. Give three reasons why this is the case.

(c) [**4 marks**] Name an additional sensor you would add to the Kobuki robot in order for it to perform better with either obstacle avoidance or hill climbing / descending? Explain how the sensor data would be used by your main navigation algorithm.

(d) [**4 marks**] Give an example of a *safety* requirement and a *liveliness* property satisfied by your Kobuki robot algorithm.

END OF PRACTICE EXAMINATION