

# Embedded Systems

## January 2026

*Notes or documents of any kind forbidden. Duration: 3 h 30.*

*The problems must be answered on different sheets labeled with your name and student ID.*

1. (a) Describe what happens electrically and logically when two devices connected to an I<sup>2</sup>C bus send conflicting values on the SDA or SCL line (in other words, when one sends 0 while the other sends 1). [1/20]
  - (b) Explain how one can connect a push button to a digital input of a microcontroller without employing any additional component. (Illustrate your answer with a schematic, and describe its principle of operation.) [1/20]
  - (c) A set of  $n \geq 1$  periodic tasks has a processor load factor equal to  $U$ . How can one determine whether this set of tasks is schedulable if [2/20]
    - i.  $U = 0.5$ ?
    - ii.  $U = 0.7$ ?
  - (d) Give an example of a mechanism implemented by Real-Time Operating Systems for identifying efficiently the non-blocked task that has the highest priority. [1/20]
  - (e) Why is it problematic for a hybrid system to satisfy the Zeno property? [1/20]
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2. A smart thermostat works by monitoring indoor and outdoor temperatures, and drives a heater with the goal of reaching a target comfort level specified by the user. The user interacts with the thermostat via a mobile application connected by Wi-Fi.
    - The indoor temperature is measured by reading the voltage across a temperature-dependent resistor, by means of an analog-to-digital conversion (ADC). A new conversion is started by the processor of the thermostat by raising a dedicated flag. When the conversion is finished, an interrupt is raised by the ADC peripheral, and the result is made available in a specific register. Such an ADC conversion takes at most 5 ms, and must be performed once per second.
    - The outdoor temperature is measured by an external module connected to a wireless link. This link is managed by a peripheral that sends an interrupt request whenever a new data packet is received, which occurs approximately twice per minute. This data packet must be fetched from the peripheral before the reception of the next one. The fetch operation takes negligible time.
    - The Wi-Fi connection with the user application is managed by a network peripheral, according to the following protocol. The processor of the thermostat first initiates a transaction by writing a specific value in a register of the peripheral, which prompts this peripheral to send a block of data to a server, then download incoming data from this server, and finally trigger an interrupt when this data has been fully received. It is then the responsibility of the processor to copy this data from the peripheral registers into memory. A complete transaction, including the time needed to copy the data, takes at most 1 ms, and there can be up to 10 transactions per second.

- The heater is driven by setting the duty cycle of a PWM generator, which must be done each time that a new indoor temperature is received. The computation of this duty cycle based on the temperature measurements and the user input takes less than 1 ms.
- (a) What is the best software architecture for this system? Justify carefully your answer. [2/20]
- (b) Using pseudocode, give the global structure of this software, with enough details to show data communication between tasks, as well as with peripherals and interrupt routines. [3/20]
3. Consider the following set of periodic tasks  $\tau_i = (C_i, T_i)$ :

$$\{\tau_1 = (1, 5), \tau_2 = (\alpha, 7), \tau_3 = (3, 11)\},$$

where  $\alpha$  is a parameter.

- (a) Compute the largest value of  $\alpha$  that makes this set of tasks schedulable. [2/20]
- (b) Verify your answer with a graphical simulation. [1/20]
4. A DC/DC converter is in charge of regulating the supply voltage of an electronic device. It is designed around a two-position switch that connects the device either to a battery or to ground. The switch is operated according to the following logic:
- When the supply voltage gets above 3.35 V, the switch connects the device to ground.
  - When the supply voltage gets below 3.25 V, the switch connects the device to the battery.
  - There must be a minimum delay of 100  $\mu$ s between two transitions of the switch. This means that every time that the switch position is modified, further changes are inhibited during 100  $\mu$ s.

The supply voltage of the device obeys the following rules:

- When the device is connected to the battery, the voltage increases at a rate between 0.5 V/ms and 1.5 V/ms.
- When the device is connected to the ground, the voltage decreases at a rate between  $-2.5$  V/ms and  $-0.5$  V/ms.

Initially, the supply voltage is at 3.3 V, and the device is connected to ground.

- (a) Model the behavior of the DC/DC converter and its connected device with a hybrid system, including a mechanism for estimating the minimum and maximum voltages experienced during operation of the system. [4/20]
- (b) Give the first three steps of the state-space exploration of this model. [2/20]