Embedded Systems
Second session, 2025

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, with a schematic, how an I^2C device is electrically connected to the bus lines. What is the main advantage of this scheme? [1/20]

   (b) Show an example of circuit connected to a microcontroller, in which using a digital input with pull-up provides an advantage over an input without pull-up. [1/20]

   (c) When a processor executes a return from interrupt instruction, how does it figure out the location in program memory where it needs to return? [1/20]

   (d) Draw a diagram showing the possible states of a process of a real-time operating system, and the transitions between them. [1/20]

   (e) Prove that the function $U_L(n) = n(\sqrt[n]{2} - 1)$, defined for $n \geq 1$, decreases with n. [2/20]

2. A monitoring system for an aircraft engine controller is built around a microcontroller that receives data from a large number of sensors, processes this data, and sends periodic reports as well as alarm signals through a communication channel.

   The sensors operate asynchronously, meaning that they generate data at unpredictable times, independently from each other. When a sensor has new data available, it sends an interrupt request to the microcontroller, which has to fetch this data as soon as possible. This operation can be assumed to take negligible time. Then, the microcontroller processes the sensor data, which takes between 1 and 20 μs. It is known that in the long run, the microcontroller has enough computing power to process all incoming data and perform all communication duties. However, it may happen that rapid bursts of sensor data force the data processing to be sometimes delayed for a short while. The result of data processing can take two forms: nominally, it consists in updating statistics that are (globally for all sensors) sent every 10 ms through the communication channel. Besides that, if the processing detects a problematic situation, then an alarm message must immediately be sent through the communication channel. Transmitting on the communication channel simply amounts to writing appropriate data to the registers of a dedicated device, which takes at most 1 μs.

   Finally, a key feature of the system is that the sensors are classified in decreasing order of importance as being *life-threatening*, *critical*, *essential*, *auxiliary*, *indicative*, ..., the idea being that data issued by more important sensors must as much as possible be processed before that of less important ones.

   (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. [2/20]

3. Consider the following set of periodic tasks $\tau_i = (C_i, T_i)$:

$$\left\{ \tau_1 = (\alpha, 4),\ \tau_2 = \left(\frac{1}{2}, 11\right),\ \tau_3 = \left(\frac{1}{2}, 3\right) \right\},$$

where α is a parameter.

(a) Compute the largest value of α that makes this set of tasks schedulable. [2/20]

(b) Verify your answer with a graphical simulation. [1/20]

(c) For this value of α, compute the processor load factor. [1/20]

4. The servo mechanism of a hard-disk drive is responsible for positioning at all times the read-write head over the appropriate track. There are 200 000 tracks, each identified by an integer number from 0 to 199 999, and the physical distance between two consecutive tracks is equal to 100 nm.

The number identifying the target track to be reached is modified unpredictably, with a delay of at least 1 ms between successive updates. Whenever the current position of the head does not match the target track within a margin of 10 nm or less, the servo initiates a move in the appropriate direction. If the distance between the current and target positions is more than 10 μm, then the head moves at a speed between 25 and 35 m/s; if this distance is less than or equal to 10 μm, then the speed is between 5 and 30 m/s. Initially, the head is stationary, and the target and current positions can take arbitrary values.

(a) Model the behavior of the hard-disk drive servo with a hybrid system, including a mechanism for detecting whether it is possible for the target position to be updated in a situation where the read-write head has not yet reached its previously intended position. [4/20]

(b) Give the first three steps of the state-space exploration of this model. [2/20]