Embedded Systems
Examination session of January 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) Explain how transactions are signaled on a I^2C bus. [1/20]

   (b) What is the difference between a digital input and a Schmitt trigger? [1/20]

   (c) When is the waiting queue software architecture more appropriate than the round-robin with interrupts? [1/20]

   (d) Why is it important for the scheduler of a real-time operating system to be informed that the processor is currently executing an interrupt routine? Describe two possible mechanisms for providing this information. [2/20]

   (e) Consider two periodic tasks τ_1 and τ_2 with respective periods T_1 and T_2 such that $T_1 < T_2$. Give mathematical expressions for the number of calls to τ_1 in a critical zone of τ_2, and for the number of full periods of τ_1 in a critical zone of τ_2. [1/20]

2. An emergency room electrocardiograph (ECG) machine is organized around a microcontroller that receives amplified heart monitoring signals at dedicated inputs of its analog to digital converter. Those signals must be sampled 100 times per second, with a high timing accuracy. This sampling operation is triggered by sending a start signal to the analog to digital converter, which takes negligible time. After a delay that does not exceed 5 ms, the results of the conversion (taking the form of 10 integer values corresponding each to an input channel) can be read from specific processor registers, where they remain available until the next sampling operation is started.

   In addition, the ECG machine must perform computations on the acquired data, and update the content of a screen with the obtained results. Those computations and screen refresh operations take (in total) at most 8 ms, and have to be performed at least 10 times per second. Finally, the machine communicates with a central unit by a wireless link; the operations needed to manage this communication amount to less than 100 μs of CPU time, and have to be carried out at least 10 times per second as well.

   (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 interrupt routines (if they are present in your solution). [2/20]

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

$$\left\{\tau_1 = \left(1, \frac{9}{2}\right),\ \tau_2 = (\alpha, 2),\ \tau_3 = \left(\frac{1}{2}, \frac{3}{2}\right)\right\},$$

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 hydraulic system driving the rudder of a ship is composed of a pressure pump and a bleed valve, that operate independently from each other. When they are active, the pressure pump increases the pressure in the system at the rate of $3 \,.\, 10^6$ Pa/s, and the bleed valve decreases the pressure by $1 \,.\, 10^6$ Pa/s. These figures are additive, for instance, when both pump and bleed valve are active, the pressure increases by $2 \,.\, 10^6$ Pa/s.

The controller of the pump behaves in the following way: when it detects that the pressure in the system has dropped below $2.8 \,.\, 10^7$ Pa, it waits for a random duration between 1 and 5 s, then activates the pump for a random duration between 1 and 3 s, and then gets back to its initial configuration in which it monitors again the pressure. This cycle goes on endlessly.

The bleed valve activates whenever it detects that the pressure in the system exceeds $3.5 \,.\, 10^7$ Pa. When this happens, the valve remains active for a random duration between 2 and 10 s. It then becomes inactive, and waits for at least 2 s before it is able to become active again.

Initially, the pressure in the system is zero, the pump is active, and the bleed valve is inactive. Note that it is physically impossible for the pressure to become negative during the operation of the hydraulic system.

(a) Model the behavior of the hydraulic system with a hybrid system. [4/20]

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