Embedded Systems
Examination session of January 2023

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

Each question must be answered on a different sheet with your name and section.

1. (a) What are the parameters that influence the latency of interrupts? [1/20]

   (b) Describe the operations involving the stack of the processor that are performed during a context switch. [1/20]

   (c) For which purpose does µCOS-III manage a counter `OSIntNestingCtr` that keeps track of the number of interrupt routines that are currently executing? [1/20]

   (d) When does a hybrid system have the Zeno property? Why is it problematic? [1/20]

2. The embedded firmware of an event-based camera needs to manage the following tasks:

   - A task that acquires data from an image sensor between 5 and 60 times per second, depending on the frame rate selected by the user. The delay between two data acquisitions must be precisely respected. Copying the data from the sensor to memory takes up to 2 ms.
   - A task that processes the data received from the sensor after each acquisition, which takes up to 5 ms.
   - A task that manages a USB connection, in order for an external computer to be able to set the value of parameters (such as the frame rate), and receive processed image data. This connection is handled by an internal peripheral of the microcontroller, that sends an interrupt request whenever a byte of incoming data has been received, as well as when a byte of outgoing data has finished to be emitted. The total time needed to send processed data for one image frame is 5 ms. The operations of the CPU during this time interval, as well as those needed to modify the value of a parameter of the camera, can be considered to take a negligible amount of time.

   (a) What is the best software architecture for this system? Justify carefully your answer. [3/20]

   (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. [3/20]

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

$$\{\tau_1 = (1, 12),\ \tau_2 = (\alpha, 2),\ \tau_3 = (1, 7)\},$$

where α is a parameter.

(a) Compute the maximum value of α for this set of tasks to be schedulable. [3/20]

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

4. A pick-and-place robot is composed of two articulated arms that move in a shared environment. The system works as follows:

- Each arm repeatedly alternates between an extension and a retraction phase. During the extension phase, the length of the arm grows from 15 to 85 cm at a rate between 8 and 12 cm/s. During the retraction phase, the length of the arm decreases from 85 to 15 cm at a rate between -20 and -15 cm/s.
- After an extension, each arm waits between 1 and 3 s before retracting. Similarly, after a retraction, there is a delay between 1 and 2 s before the next extension.
- The two arms move independently from each other, except that whenever one arm reaches a length that is greater than or equal to 50 cm, the other one cannot extend further. (This means that if this arm is currently in its extension phase, it must stop immediately and move to the retraction phase, after the suitable delay has elapsed.)

(a) Model the behavior of this device with a hybrid system. [3/20]

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

(c) Explain how you would compute the maximum total extension of the two arms, i.e., their total combined length at any moment during the operation of the system. (You are not asked to perform the computation, but only to explain how you would carry it out.) [1/20]