Embedded Systems
Examination session of January 2024

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

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

1. (a) If two devices connected to an I^2C bus attempt to start a transaction at the same time, how will such a conflict be resolved? [1/20]

   (b) How does a processor react to an interrupt request? (Briefly describe each operation that it performs in this situation.) [1/20]

   (c) What does it mean for a function to be reentrant? [1/20]

   (d) How can a real-time operating system identify efficiently the tasks that need to be resumed after being suspended for a definite amount of time? Describe a possible mechanism for solving this problem. [1/20]

   (e) The function $f(n) = n\left(\sqrt[n]{2} - 1\right)$ gives the lowest possible value of the processor load factor for sets of n periodic tasks that fully use the processor. Prove that this function is decreasing with n. (You can either provide a formal development, or an informal argument.) [1/20]

2. A guitar tuner works by sampling the signal sensed by a microphone, applying signal processing algorithms to the samples, and displaying the current frequency estimate together with other data on an OLED display. More precisely, the microcontroller that drives the tuner is carrying out the following tasks:

   - A task τ_1 that acquires the signal from an analog to digital converter, at the rate of 48000 samples/s, and stores them in a circular buffer. The availability of a new sample is indicated by an interrupt request emitted by the A/D converter.
   - A task τ_2 that processes every 1/5 s the samples contained in the circular buffer, and computes a frequency estimate, a confidence measure, and the intensity of the sound.
   - A task τ_3 that refreshes the contents of the screen whenever new data has been produced by τ_2.
   - A task τ_4 that monitors the state of two buttons that can be pressed in order to change the current mode of operation of the tuner. This mode of operation affects the computations performed by τ_2, as well as the format of the display generated by τ_3. The buttons have to be monitored at least 20 times per second.

The operations of Tasks τ_1 and τ_4 take negligible time. The computations performed by Task τ_2 take up to 120 ms. Task τ_3 needs up to 4 ms to refresh the screen.

(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. *Note:* You are not asked to implement the internal details of the circular buffer. [3/20]

(c) If the screen is replaced by a LCD display that needs to be refreshed 10 times per second, would this change your answer to (a)? [1/20]

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

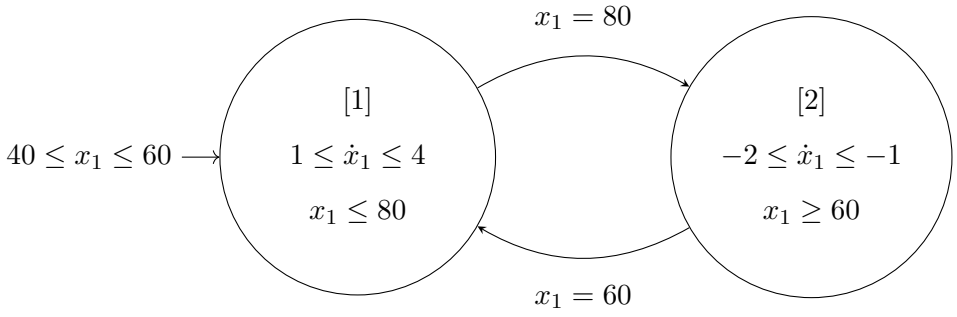
$$\{\tau_1 = (1, 7),\ \tau_2 = (1, 5),\ \tau_3 = (1, \alpha)\}\,,$$

where α is a parameter.

(a) Compute the smallest value of α that makes this set of tasks schedulable. [3/20]

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

4. A thermostat is modeled by the following hybrid system, in which the control locations [1] and [2] of its single process represent (respectively) the heating and non-heating modes of operation.



(a) Does this hybrid automaton have the Zeno property? (Justify your answer.) [1/20]

(b) Compute all the reachable states of this hybrid system. [2/20]

(c) Create an additional process for this hybrid system, that moves to a dedicated control location whenever the first process stays continuously in the heating mode of operation for at least 10 time units, and remains in other control locations otherwise. *Note:* You cannot modify the first process, except for adding (if you wish) synchronization labels of your choice to its transitions. [2/20]