Embedded Systems
Examination session of January 2022

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) Explain the purpose of the first 9 bits exchanged during an I^2C transaction. In which direction with respect to the master and slave of the transaction are those bits sent? [1/20]

   (b) By which mechanism is the kernel of a real-time operating system informed that an interrupt routine is being executed? Why is this mechanism essential? [1/20]

   (c) In a real-time operating system, what is an idle task, and why is it useful to have such a task? [1/20]

   (d) If a set of 5 periodic tasks has a processor load factor strictly greater than $5(\sqrt[5]{2}-1)$, can it be schedulable? (Justify your answer.) [1/20]

2. A marine research buoy contains sensors for measuring water temperature and salinity. It is equipped with an embedded system whose processor performs the following tasks:

   - Starting a new round of measurements every hour. This operation takes negligible time. The measurements are carried out by a separate data acquisition peripheral, and take a few seconds. An interrupt request is send by this peripheral when the results of the measurements are available.
   - Processing the measurements results, which is done each time that they are obtained, and takes up to 500 ms of CPU time. The results are written into flash memory. A write operation takes up to 10 ms, and is performed by a peripheral. This peripheral sends an interrupt request when the write is complete.
   - Sending by radio the last processed measurements. This operation should be performed once every 24 hours, and takes up to 30 s.

   Since the amount of onboard power is limited, it is important to put the processor in a low-power sleep mode whenever possible.

   (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, with interrupt routines, and with peripherals. [2/20]

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

$$\{\tau_1 = (1, 14),\ \tau_2 = (\alpha, 10),\ \tau_3 = (2, 3)\},$$

where α is a parameter.

(a) Compute the maximum value of α for this set of tasks to be schedulable. [2/20]

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

4. A windshield wiper is controlled by a switch with three positions. In the first one, the wiper is off. In the second one, it operates in intermittent mode, in which it performs one wiping cycle, then waits 5 seconds, then repeats the same sequence endlessly. In the third position of the switch, the wiper works continuously, which means that it performs wiping cycles repeatedly without pausing between them.

A wiping cycle is carried out by moving the blades of the wiper from 0 to 90 degrees at a constant speed, and then moving them back from 90 to 0 degrees at the same speed. The speed of the blades is controlled by a binary switch: in its "slow" position it is equal to 45 degrees per second, and in the "fast" position to 120 degrees per second.

Initially, the two switches are respectively in the "off" and "slow" positions, and the blades are at a 0 degree angle. We do not make any hypotheses about the behavior of the user; in other words, the state of each switch may potentially change at any time.

(a) Model the behavior of this device with a hybrid system. [5/20]

(b) Give the first three steps of the state-space exploration of this system. [3/20]