Embedded Systems
Examination session of August 2024

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 started and terminated on a I^2C bus, and how a clock signal is generated during transactions. [1/20]

   (b) Would it be possible to have a real-time preemptive operating system running on a processor that does not have an interrupt mechanism? (Justify your answer.) [1/20]

   (c) Describe the operations that can be performed on a message queue with a capacity equal to zero. [1/20]

   (d) Let $\tau_1, \tau_2, \ldots, \tau_n$ be periodic tasks that fully use the processor, with respective periods $T_1, T_2, \ldots, T_n$ and execution times $C_1, C_2, \ldots, C_n$. Assume that $2T_i \leq T_n$ for some $i \in [1, n]$. How would you modify those periods and execution times into (respectively) $T'_1, T'_2, \ldots, T'_n$ and $C'_1, C'_2, \ldots, C'_n$, in such a way that the tasks still fully use the processor, the processor load factor has not been increased, and one has $2T'_i > T'_n$? (You are only asked to specify the value of $T'_1, T'_2, \ldots, T'_n$ and $C'_1, C'_2, \ldots, C'_n$, and not to prove that this construction is correct.) [2/20]

2. A child's toy takes the form of a stick with 16 LEDs arranged linearly at one of its ends, and is equipped with an accelerometer that is able to detect when the stick is waved. The microcontroller embedded in the toy must perform the following tasks:

   - Querying the accelerometer in order to detect a movement of the stick. This operation must be performed 20 times per second, and takes 2 ms.
   - As soon as movement has been detected, generating a sequence of patterns on the LEDs, so as to display a message in the air thanks to the persistence of vision effect. The sequence contains 128 patterns that must be produced one after the other. Each pattern in the sequence must be displayed during precisely 5 ms. During the time interval when the sequence of patterns is generated, the accelerometer is disabled.

   (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 any). [2/20]

(c) In a future revision of this product, one wishes to add a USB port to the toy in order to be able to update the displayed message by means of an external application. This requires the microcontroller to query at least once per second its integrated UART in order to check whether incoming USB data has been received, and to download this data when that happens. Fully downloading the USB data and writing it into Flash memory takes up to 60 ms. Naturally, the toy remains inactive during this operation. [1/20]

In order to implement this future revision, would you answer (a) differently? (You are not asked to describe in detail the new version of the software, but only to explain your choice of software architecture.)

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

$$\{\tau_1 = (1, 6),\ \tau_2 = (1, 7),\ \tau_3 = (\alpha, 2)\}$$

where α is a parameter.

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

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

4. An apheresis machine used for collecting stem cells has the following components:

- a vessel storing up to 50 ml extracorporeal blood, provided with two sensors that respectively detect when it contains less than 5 ml ("almost empty") and more than 45 ml ("almost full"). Those sensors have an accuracy of ± 1 ml. This means that the actual threshold for detecting an almost empty state is between 4 and 6 ml, and the one for an almost full state is between 44 and 46 ml.
- two peristaltic pumps: one for pumping incoming blood into the vessel, and one for returning blood from the vessel to the patient. Each one of those pumps can operate at either 1 ml/s or 2 ml/s, depending on the value measured by a pressure sensor. The pressure measurements are independent for the two pumps, and can produce any result. They are performed every second, at the same time for both pumps. The speed of the pumps is adjusted after each measurement, and remains constant until the next one.

The principle of operation of the machine is simple: Initially, the vessel is totally empty, the incoming pump is on, and the return pump is off. When the vessel is almost full, the incoming pump turns off and the return pump turns on. When the vessel becomes almost empty, the return pump turns off, the incoming pump turns on, and the cycle repeats itself indefinitely.

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

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