INFO0064 - Embedded Systems
Examination session of January 2017

Notes or documents of any kind forbidden. Duration: 3 h 30.
Each problem must be answered on a different sheet with your name and section.

1. (a) [*1 point*] Describe the arbitration mechanism of the I^2C bus.

   (b) [*1 point*] What is the latency of an interrupt routine? How can it be made as small as possible?

   (c) [*2 points*] In a real-time operating system, what is the context of a task? How is this context initialized when the task is created?

   (d) [*2 points*] What is the value of the best lower bound of the processor load factor for sets of n tasks that fully use the processor? Explain why this best lower bound does not increase with n.

2. [*6 points*] A quadcopter contains a microcontroller for controlling its four motors. This microcontroller is responsible for stabilizing the spatial position and orientation of the aircraft during flight, and for processing the orders sent by the pilot via a remote control. In order to do this, it has to perform the following tasks:

   - Reading, processing and filtering data received from various sensors such as accelerometers and gyroscopes. This task has to be performed at a rate of 200 Hz, and takes 2 ms.
   - Implementing a control loop. This task has to be performed at a rate of 100 Hz, and takes 1 ms.
   - Communicating with the remote control. This task has to be performed at a rate of 50 Hz, and takes 0.2 ms.
   - Writing a flight log in flash memory. This task has to be performed at a rate of 10 Hz, and takes 15 ms. The operations carried out by the task essentially amount to waiting for the flash memory component to trigger an interrupt signalling the end of the write operation.

   (a) What is the best software architecture for this system? (Carefully justify your answer.)

   (b) Using pseudocode, give the global structure of this embedded software.

3. [*8 points*] The quadcopter mentioned in the previous problem is able to fly autonomously by automatically adjusting its altitude with respect to the ground using a distance sensor. The nominal altitude a is a parameter provided by the pilot, and remains constant during flight. When the quadcopter is flying, it constantly measures the difference between its actual altitude (measured by the sensor) and a. If the absolute value of this difference exceeds 20 cm, then the aircraft adjusts its altitude at a speed between 0.9 and 1.1 m/s on the vertical axis, in the appropriate direction. When the measured altitude is 20 cm or less from a, the quadcopter keeps its vertical speed between -0.1 and 0.1 m/s.

The quadcopter is equipped with a 2400 mAh battery. During flight, its motors and embedded electronics drain a current between 2 and 10 A. As soon as the charge level of the battery drops below 600 mAh, the quadcopter immediately enters an automatic landing procedure, during which it decreases its altitude at a constant rate of 2 m/s until it touches the ground. It then automatically shuts off. The aircraft also shuts off if its battery becomes totally depleted, which corresponds to an abnormal situation that should be avoided.

Initially, we assume the quadcopter to be on the ground with its motors turned on and a fully charged battery.

(a) Model the behavior of this quadcopter with a hybrid system. (The additional details given in the statement of Problem 2 do not have to be taken into account.)

(b) Explain how this hybrid system can be used for checking whether an abnormal situation can be reached for a given value of the parameter a. Illustrate your answer by carrying out in detail the first three steps of the procedure.