240AR031 - Embedded & Real Time Systems

Coordinating unit: 240 - ETSEIB - Barcelona School of Industrial Engineering
Teaching unit: 707 - ESAII - Department of Automatic Control
Academic year: 2019
Degree: MASTER'S DEGREE IN AUTOMATIC CONTROL AND ROBOTICS (Syllabus 2012). (Teaching unit Compulsory)
ECTS credits: 4.5 Teaching languages: English

Teaching staff

Coordinator: SEBASTIAN TORNIL SIN
Others: Perera Lluna, Alexandre

Prior skills

Basic background on digital electronics and computer programming.

Degree competences to which the subject contributes

Specific:
2. The student know about microcontrollers implement handlers that respond to real-time requirements identified in a system

General:
1. Have adequate mathematical skills, analytical, scientific, instrumental, technological, and management information.

Transversal:
3. EFFECTIVE USE OF INFORMATION RESOURCES: Managing the acquisition, structuring, analysis and display of data and information in the chosen area of specialisation and critically assessing the results obtained.

Teaching methodology

The course will combine lectures with labs (50%-50%).

Learning objectives of the subject

Introduce the students to the development of Embedded Real Time Systems based on microcontrollers, with focus on software development and control applications.

The students will learn how to:
- Program and verify the temporal correctness (schedulability analysis) of an Embedded Real Time application.
- Program an Embedded Real Time system by directly programming its microcontroller (low level programming: ports, timers, interrupts, ADCs, PWM,?).
- Program an Embedded Real Time system with the aid of a Real Time Operating System (RTOS).
- Program an Embedded Real Time system with the aid of graphical environments.
# Study load

<table>
<thead>
<tr>
<th><strong>Total learning time:</strong> 112h 30m</th>
<th>Hours large group:</th>
<th>20h 15m</th>
<th>18.00%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hours small group:</td>
<td>20h 15m</td>
<td>18.00%</td>
</tr>
<tr>
<td></td>
<td>Self study:</td>
<td>72h</td>
<td>64.00%</td>
</tr>
</tbody>
</table>
### Content

<table>
<thead>
<tr>
<th>Basic concepts on embedded and real-time computing. Review of C programming. Introduction to Arduino.</th>
<th>Learning time: 9h</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Theory classes: 6h</td>
</tr>
<tr>
<td></td>
<td>Laboratory classes: 3h</td>
</tr>
</tbody>
</table>

**Description:**
Fundamental concepts of embedded systems will be given, with an important focus on those providing service to time critical applications. The C programming language will be reviewed. The Arduino platform will be presented.

**Related activities:**
- Lecture T1.
- Lecture T2.
- Lecture T3.
- Lab L1.

<table>
<thead>
<tr>
<th>Low level programming.</th>
<th>Learning time: 12h</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Theory classes: 6h</td>
</tr>
<tr>
<td></td>
<td>Laboratory classes: 6h</td>
</tr>
</tbody>
</table>

**Description:**
The low level programming of microcontrollers will be presented. The hardware architecture and resources and the low level programming of the microcontroller ATmega328P (the one integrated in Arduino UNO) will be detailed. The programming of periodic tasks and control tasks will be presented. The table-driven scheduling method for multiple periodic tasks will be presented.

**Related activities:**
- Lecture T4.
- Lecture T5.
- Lecture T6.
- Lecture T7.
- Lab L2.
# Development using Real Time Operating systems (RTOS)

**Description:**
The development of embedded real time systems with Real Time Operating Systems (RTOSs) will be introduced. The operating system FreeRTOS will be presented. The real time schedulability analysis for priority-based systems will be presented.

**Related activities:**
- Lecture T8.
- Lecture T9.
- Lecture T10.
- Lab L3.

**Learning time:** 7h 30m  
Theory classes: 4h 30m  
Laboratory classes: 3h

---

# Development using graphical programming environments

**Description:**
Arduino programming using MATLAB/SIMULINK.

**Related activities:**
- Lecture T11.
- Lab L4.

**Learning time:** 4h 30m  
Theory classes: 1h 30m  
Laboratory classes: 3h

---

# Programming a control application

**Description:**
Programming the control for the "Ball in tube" experiment.

**Related activities:**
- Lab L5.

**Learning time:** 6h  
Laboratory classes: 6h
# Planning of activities

<table>
<thead>
<tr>
<th>Lecture T1.</th>
<th>Description:</th>
<th>Hours: 2h</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Introduction to Embedded Real Time Systems.</td>
<td>Theory classes: 2h</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lecture T2.</th>
<th>Description:</th>
<th>Hours: 2h</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Review of the C programming language.</td>
<td>Theory classes: 2h</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lecture T3.</th>
<th>Description:</th>
<th>Hours: 2h</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basics of embedded hardware.</td>
<td>Theory classes: 2h</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lab L1.</th>
<th>Description:</th>
<th>Hours: 3h</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Programming Arduino with the Arduino IDE.</td>
<td>Laboratory classes: 3h</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lecture T4.</th>
<th>Description:</th>
<th>Hours: 1h</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basics of embedded hardware.</td>
<td>Theory classes: 1h</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lecture T5.</th>
<th>Description:</th>
<th>Hours: 2h</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AVR microcontrollers: hardware and programming.</td>
<td>Theory classes: 2h</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lab L2.</th>
<th>Description:</th>
<th>Hours: 6h</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Programming Arduino in C with Eclipse.</td>
<td>Laboratory classes: 6h</td>
</tr>
</tbody>
</table>
### Lecture T6.

**Hours:** 1h 30m  
Theory classes: 1h 30m  
**Description:**  
Programming periodic tasks: programming the control loop.

### Lecture T7.

**Hours:** 1h 30m  
Theory classes: 1h 30m  
**Description:**  
Table-driven scheduling.

### Lecture T8.

**Hours:** 1h 30m  
Theory classes: 1h 30m  
**Description:**  
Principles of concurrent programming.

### Lecture T9.

**Hours:** 1h 30m  
Theory classes: 1h 30m  
**Description:**  
The FreeRTOS operating system.

### Lab L3.

**Hours:** 3h  
Laboratory classes: 3h  
**Description:**  
Programming Arduino with FreeRTOS.

### Lecture T10.

**Hours:** 1h 30m  
Theory classes: 1h 30m  
**Description:**  
Real-time scheduling.

### Lecture T11.

**Hours:** 1h 30m  
Theory classes: 1h 30m
240AR031 - Embedded & Real Time Systems

**Description:**
Arduino programming with MATLAB/SIMULINK.

<table>
<thead>
<tr>
<th>Lab L4.</th>
<th>Hours: 3h</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Laboratory classes: 3h</td>
</tr>
</tbody>
</table>

**Description:**
Arduino programming with MATLAB/SIMULINK.

<table>
<thead>
<tr>
<th>Lab L5.</th>
<th>Hours: 6h</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Laboratory classes: 6h</td>
</tr>
</tbody>
</table>

**Description:**
Programming a real control application: the "Ball in tube" experiment.

<table>
<thead>
<tr>
<th>Midterm exam.</th>
<th>Hours: 3h</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Theory classes: 3h</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Final exam.</th>
<th>Hours: 3h</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Theory classes: 3h</td>
</tr>
</tbody>
</table>

**Qualification system**

The course grade will depend on:
a) the midterm exam - 25%
b) the final exam - 25%
c) the achievements during the labs - 50%

There will be a re-evaluation exam for a) and b).

**Regulations for carrying out activities**

The rules will be announced whenever required
Bibliography

Basic:
