

# Engineering Tripos Part IIB, 4B25: Embedded Systems for the Internet of Things, 2017-18

## Module Leader

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## Lecturer

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## Timing and Structure

Michaelmas term. 100% coursework

## Prerequisites

3B2 useful

## Aims

The aims of the course are to:

- Introduce students to the principles and practice of computation and sensing systems that interact with the physical world.

## Objectives

As specific objectives, by the end of the course students should be able to:

- Define the role of uncertainty in measurements of physical signals and quantify measurement uncertainty for a given sensing system.
- Evaluate energy use in an embedded system using in-system current monitors.
- Define the role of noise in both measurements and displays and identify appropriate metrics to use in quantifying noise for a given design.
- Design communication subsystems and the required electrical circuit support between a collection of I2C- or SPI-interfaced sensor integrated circuits and an ARM Cortex-M0 microcontroller.
- Numerically quantify measurement uncertainty and noise in outputs given a system design.
- Recall and explain the interaction between displays and the human visual system.
- Design modifications to sensing, communication, and display systems to improve their energy efficiency.
- Design the logical organization and required firmware for new systems built around an ARM Cortex-M0 microcontroller, and sensors or displays connected via I2C and SPI communication interfaces.

## Content

measurement uncertainty and noise, common sensor communication interfaces and how they interact with modern Engineering Topics Part II, 4825: Embedded Systems for the Internet of Things, 2017-18. This exploration of output acquisition and OLED usage graduate a study of (https://teaching.122embedded.com). This exploration of output systems will be built on a study of the principles of operation of OLED displays and how the flexibility of the human visual system enables interesting circuit- and algorithm-level techniques to reduce display power dissipation.

## Preliminary Syllabus

**Lecture 1:** System overview of sensing, computation, I/O, and displays in embedded systems; interpreting device and system datasheets. At the end of this lecture, students should be able to: enumerate the important components in an embedded system design; read and interpret the datasheet for a component in a system or for an entire system; propose and design changes to a system to extend its uses.

**Lecture 2:** Precision, accuracy, reliability, and measurement uncertainty. Noise sources in analog and digital systems; role of signal gain and restoring logic. At the end of this lecture, students should be able to: define precision, accuracy, reliability, and measurement uncertainty; analyze a system design and quantify these properties for a design's components; enumerate the sources of noise and measurement uncertainty in analog and digital systems; propose design changes to improve the robustness of systems to noise.

**Lecture 3:** Embedded I/O interfaces: I2C, SPI, I2S, I3C, MIPI DSI, and MIPI CSI. At the end of this lecture, students should be able to: enumerate the differences between the common embedded wired communication interfaces; select and substantiate a choice for an interface for a given design problem.

**Lecture 4:** C and assembly programming for embedded systems. At the end of this lecture, students should be able to: implement firmware that runs in the absence of an operating system and which contains a mixture of C and ARM assembly code.

**Lecture 5:** Embedded library and OS support overview; ARM Mbed OS API and TI-RTOS. At the end of this lecture, students should be able to: design the firmware for an embedded sensing and computing problem using Mbed OS API calls for actions such as I/O.

**Lecture 6:** Case study.

**Lecture 7:** Field-programmable gate arrays in low-power embedded systems; Verilog overview. At the end of this lecture, students should be able to: describe and explain the basic architecture of FPGAs; use their understanding of the Verilog hardware description language and FPGA synthesis tools to modify an existing Verilog design.

**Lecture 8:** Human color vision perception and its interaction with OLED displays: Their structure, interfaces, and techniques for energy-efficiency. At the end of this lecture, students should be able to: enumerate the properties of OLED displays; propose changes to existing system designs that use OLED displays in order to improve their energy efficiency; enumerate the basic properties of human color vision that have a bearing on the design of displays for embedded systems.

**Lecture 9:** Physical invariants in embedded systems. At the end of this lecture, students should be able to: define physical invariants in the context of a sensor-driven system; apply concepts from Lagrangians, Hamiltonians, the Euler-Lagrange Equations, Noether's theorem, and recent research on inferring Lagrangians and Hamiltonians from sensor data to embedded systems designs.

**Lecture 10:** Wireless communications using Bluetooth, 802.15.4/Zigbee, and LoRa; Bluetooth HCI interface. At the end of this lecture, students should be able to: enumerate the differences between the major low-power radio interfaces available for embedded or Internet-of-Things systems; propose energy-efficient choices for a wireless sensing system design given the application's design constraints.

**Lecture 11:** Schematic capture and basic printed circuit board layout using Eagle. At the end of this lecture, students should be able to: create a design ready to be submitted for manufacturing (Gerber files) using the Eagle schematic capture and printed-circuit-board layout tools.

**Lecture 12:** Designing new embedded systems to solve a specified application need. At the end of this lecture, students should be able to: propose an architectural design comprising sensing, computation, communication, and display to address a given application need, with the design implementable within the limitations of schematic capture and printed-circuit-board layout tools such as Eagle.

**Coursework**

Coursework	Format	Due date & marks
<p><b>Coursework activity #1:</b> OLED display control over SPI exercise</p> <p>Obtain hands-on experience writing a device driver in C for an SPI peripheral, using the FRDMKL03 ARM board and the OLED display from the course hardware kit.</p> <p><u>Learning objective:</u></p> <p>After successfully completing this exercise, students should be able to:</p> <ul style="list-style-type: none"> <li>• Read a datasheet for an unfamiliar embedded hardware component such as an SPI peripheral and write a device driver in C to interface with the peripheral.</li> </ul>	<p>Individual</p> <p>Git repository with working code</p> <p>non-anonymously marked</p>	<p>Friday, week</p> <p>[10/100]</p>
<p><b>Coursework activity #2:</b> Project proposal one-page report</p> <p>Identify an interesting engineering problem that can be addressed using an embedded system developed using the concepts, theory, techniques, and tools covered in this course.</p> <p><u>Learning objectives:</u></p> <p>After successfully completing this exercise, students should be able to:</p> <ul style="list-style-type: none"> <li>• Identify an interesting and important engineering challenge that can be solved using a combination of embedded sensing, embedded computation, and possibly displays and communication.</li> <li>• Present a clear list of design objectives for solving the engineering challenge using an embedded system.</li> </ul>	<p>Individual Report</p> <p>non-anonymously marked</p>	<p>Friday, week</p> <p>[4/100]</p>
<p><b>Coursework activity #3:</b> Power measurement using TI INA219 I2C device exercise</p> <p>Obtain hands-on experience writing a device driver in C for an I2C peripheral, using the FRDMKL05 ARM board and the TI INA219 daughterboard from the course hardware kit.</p> <p><u>Learning objective:</u></p> <p>After successfully completing this exercise, students should be able to:</p> <ul style="list-style-type: none"> <li>• Read a datasheet for an unfamiliar embedded hardware component such as an I2C peripheral and write a device driver in C to interface with the peripheral.</li> </ul>	<p>Individual Report</p> <p>non-anonymously marked</p>	<p>Friday, week</p> <p>[10/100]</p>
<p><b>Coursework activity #4:</b> Sensor interfacing from Lattice iCE40 FPGA exercise</p> <p>Obtain hands-on experience implementing a design in the Verilog hardware description language.</p> <p><u>Learning objectives:</u></p>	<p>Individual Report</p> <p>non-anonymously marked</p>	<p>Friday, week</p> <p>[10/100]</p>

Coursework	Format	Due date & marks
<p>After successfully completing this exercise, students should be able to:</p> <ul style="list-style-type: none"> <li>• Use the supplied FPGA tools to map an existing Verilog hardware design to the iCE40 FPGA.</li> <li>• Modify an existing Verilog hardware design that harnesses hard-macros on the iCE40 FPGA and map/evaluate the design on the FPGA evaluation board.</li> </ul>		
<p><b>Coursework activity #5:</b> Project interim report</p> <p>Present progress made towards final project goals, evaluate lessons learned so far, and obtain feedback and guidance on necessary plan adaptation.</p> <p><u>Learning objectives:</u></p> <p>After successfully completing the interim project report, students should be able to:</p> <ul style="list-style-type: none"> <li>• Identify and present progress made towards final project.</li> <li>• Identify and present potential challenges and propose necessary changes to project plan.</li> </ul>	<p>Individual Report</p> <p>non-anonymously marked</p>	<p>Friday, week 6</p> <p>[6/100]</p>
<p><b>Coursework activity #6:</b> Project concept, design, implementation, and final report</p> <p>Present the problem addressed, approach employed, system implemented, and system evaluation.</p> <p><u>Learning objectives:</u></p> <p>After successfully completing the final project, students should be able to:</p> <ul style="list-style-type: none"> <li>• Identify an interesting and important engineering challenge that can be solved using a combination of embedded sensing, embedded computation, and possibly displays and communication.</li> <li>• Design an embedded computing system that address the engineering challenge.</li> <li>• Prototype an embedded system design using a combination of sensors, microcontrollers, communication, displays, or FPGAs using the tools provided in the course kit, and potentially design a custom PCB implementing the design.</li> <li>• Quantitatively evaluate an embedded sensing and computation system in terms of its time efficiency (performance), energy efficiency (battery life), and measurement and data processing accuracy.</li> </ul>	<p>Individual Report</p> <p>non-anonymously marked</p>	<p>Easter Term</p> <p>[60/100]</p>

## Booklists

The following books are relevant to the material in the course and will all be available from the Engineering Library.

1. *Introduction to Embedded Systems, A Cyber-Physical Systems Approach*, ISBN: 978-0262533812
2. *An Introduction to Uncertainty in Measurement*, ISBN: 978-0521605793
3. *Linkers and Loaders*, ISBN: 978-1558604964
4. *The Circuit Designer's Companion*, 3rd Edition, ISBN: 978-0080971384
5. *The Practice of Programming*, ISBN: 978-0201615869
6. *Expert C Programming*, ISBN: 978-0131774292
7. *C: A Reference Manual* (5th Edition), ISBN: 978-0130895929
8. *Bluetooth Low Energy: The Developer's Handbook*, ISBN: 978-0132888363
9. *Programming Embedded Systems: With C and GNU Development Tools*, 2nd Edition, ISBN: 978-0596009830
10. *Embedded Systems Dictionary*, ISBN: 978-1578201204
11. *The Art of Designing Embedded Systems*, Second Edition, ISBN: 978-0750686440
12. *The Art of Electronics*, ISBN: 978-0521809269
13. *Color Science: Concepts and Methods, Quantitative Data and Formulae*, ISBN: 978-0471399186

## Examination Guidelines

Please refer to [Form & conduct of the examinations](#) [2].

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**Source URL (modified on 17-10-17):** <https://teaching21-22.eng.cam.ac.uk/content/engineering-tripos-part-iib-4b25-embedded-systems-internet-things-2017-18>

## Links

[1] <mailto:ps751@cam.ac.uk>

[2] <https://teaching21-22.eng.cam.ac.uk/content/form-conduct-examinations>