Physical Computing And Internet of Things (CM3040)

Course Notes

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Contents

Week 1

Key Concepts

- Should be able to explain what IoT is, IoT stack and IoT architecture
- Should understand what microcontrollers are, how they are used and why
- Should be able to install and set up Arduino IDE with drivers and relevant libraries

1.001 Introduction to the course

Course learning objectives:

1. Demonstrate understanding of electricity, electronics, and transducers
2. Program microcontrollers and understand how they receive, interpret and send data from/to transducers
3. Develop practical skills of building circuits
4. Use communication protocols for inter-computer and inter-device communication
5. Understand the principles of physical interaction design, including:
   a) monitoring bodily movement
   b) making mechanical movement
   c) design of tactile physical interfaces
   d) control of sound and light
6. Design and build complete physical computing systems

Course Topics:

1. Microcontrollers
2. Electricity and circuits
3. Sensors
4. Physical Interaction Design
5. Physical Computing Projects

6. Motors and actuators
7. Communications protocols
8. Networked Devices
9. Bodily Monitoring
10. Robots

1.101 Introduction to physical computing and IoT

Physical Computing refers to the creation and use of devices that sense, reason, and react to the world around them. Internet-of-Things (IoT) describes the network of physical objects.

1.103 Background to IoT, IoT stack and IoT architecture

As shown in Iot Building Block figure 1 below, the communication networks play a central role allowing all other nodes to communicate with each other.

A Typical IoT node is composed with several modules which are shown in figure 2 below.

Figure 3 describes how a set of IoT nodes form an ecosystem:

1.105 IoT stack and IoT architecture

- Cheruvu, S, A. Kumar, N. Smith and D.M. Wheeler Demystifying Internet of Things security: Successful IoT device/edge and platform security deployment. (New York, NY: Apress, 2019) Chapter 2.
- Tamboli, A. Build your own IoT platform: Develop a fully flexible and scalable Internet of Things platform in 24 hours. (New York, NY: Apress, 2019) Chapters 1, 2 and 3.
- Faiza, A., 'Evolution of the web: web 1.0, web 2.0, web 3.0, web 4.0, web 5.0 and beyond' ahmadfaiza.blog.

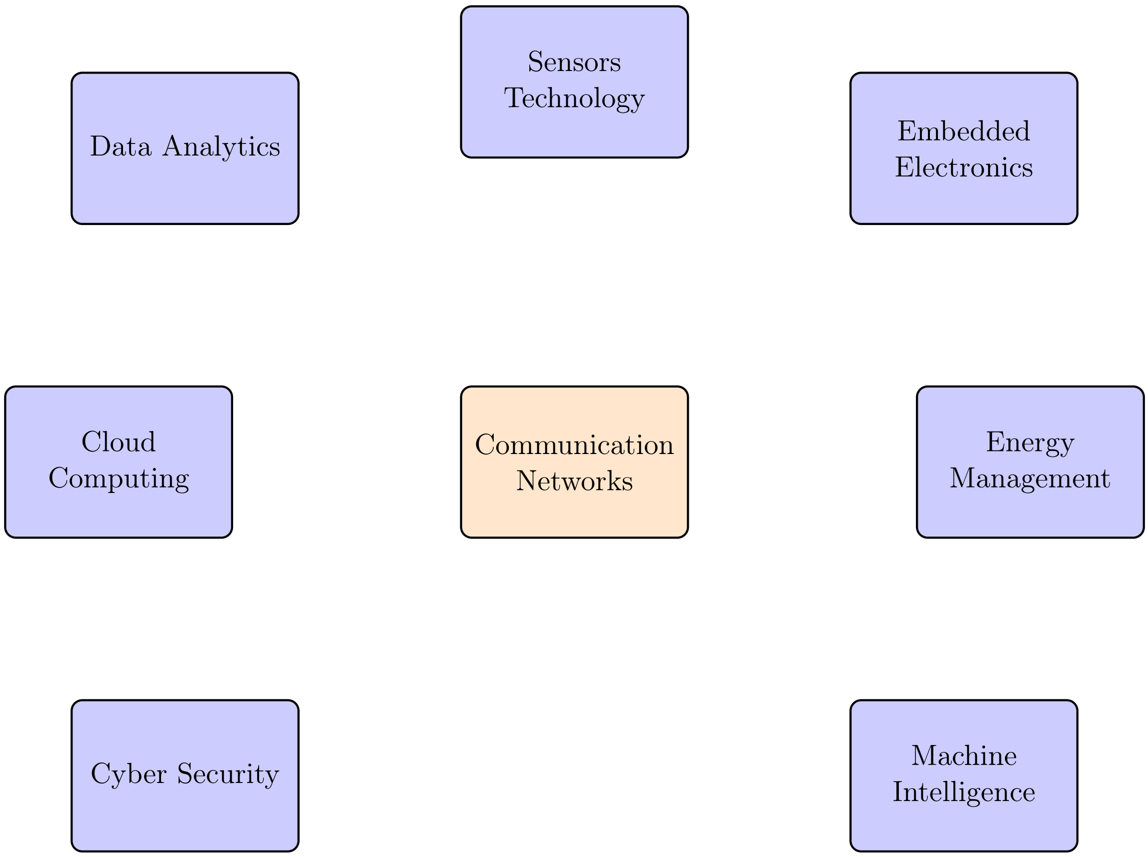

Figure 1: IoT Building Block

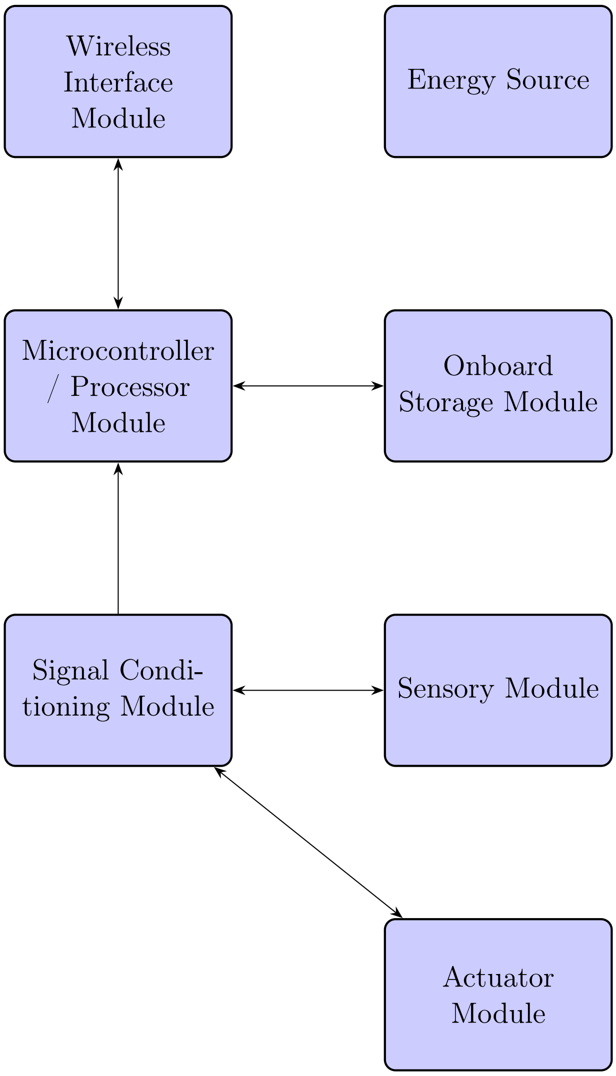

Figure 2: Typical IoT Node

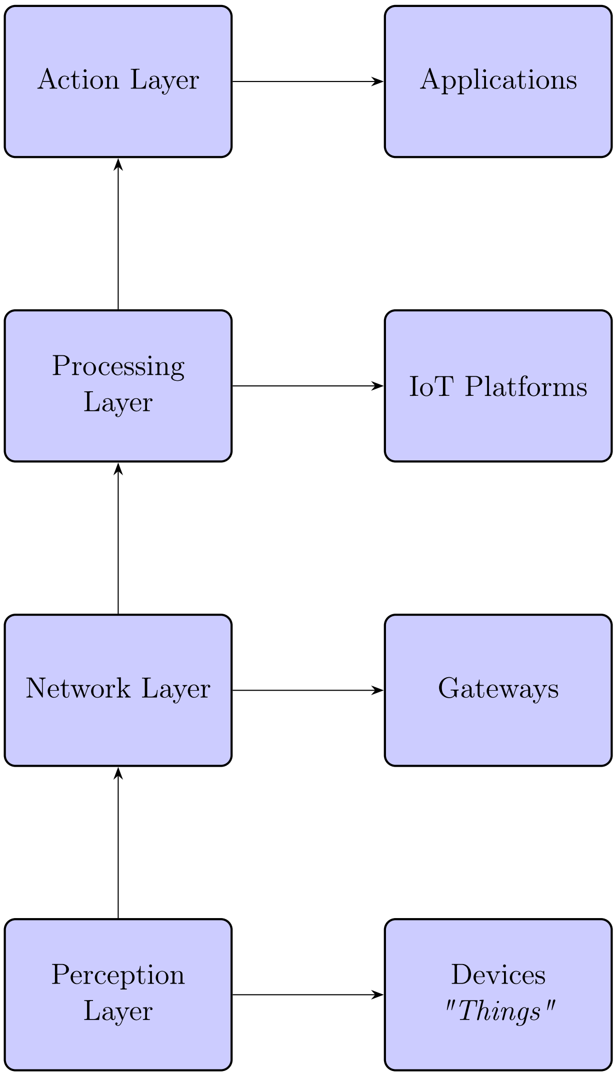

Figure 3: IoT Ecosystem

Week 2

Key Concepts

- Should be able to explain what IoT is, IoT stack and IoT architecture
- Should understand what microcontrollers are, how they are used and why
- Should be able to install and set up Arduino IDE with drivers and relevant libraries

1.301 Introduction to microcontrollers, their types and capabilities

A microcontroller is a small *System-on-Chip* comprising of a small CPU, Memory (volatile and non-volatile), and I/O peripherals (I^2C, SPI, GPIO, etc).

Some popular microcontroller platforms are:

1. Arduino Uno
2. Intel Galileo
3. ESP8266 and ESP32
4. STM32L/F
5. Raspberry Pi
6. Beaglebone
7. Pocketbeagle

1.501 Basics on breadboards, extension shields, wiring/pins and transistors

Breadboard a prototyping place where components can be inserted without any soldering requirements

Extension Shields a ready-made *extension* for a platform containing e.g. sensors, wireless connectivity modules (LoRa, ZigBee, etc), passive components, voltage regulators required for the sensors

(Dupont) Wires make it easier to wire things together in a breadboard

Transistors essentially, a voltage-controlled switch

Week 3

Key Concepts

- Understand the role of electricity, electronics and Transducers.
- Understand how electricity flow in the microcontroller circuit & breadboard
- Explain the difference between Arduino and PLC and how to read schema drawings

2.001 - Introduction to electricity flows in sensors and transducers

Current flow of electrons moving through a circuit. Measured in Amperes or Amps (A).

Resistance measure of a material's ability to oppose electrical flow. Measure in Ohms (Ω).

Voltage difference in charge between two different points. Measured in Volts (V).

Capacitor stores a certain amount of electricity as potential energy. Capacitance is measured in Farads (F).

Inductor stores a certain amount of electricity as a magnetic field. Inductance is measured in Henries (H).

Transistors a voltage-controlled switch. Can work as an amplifier.

Ohm's Law gives a relationship between voltage, resistance, and current:

$$V = I \times R$$

Resistors come in 4, 5, or 6 color bands, we start reading from the side with higher concentration of color bands[1].

[1] Y'all can Google for a color band table :-p

2.003 - Understanding Digital & Analog input&output signals

Analog continuous value between 0 and e.g. 3.3V.

Digital discrete value. Either 0 or 1.

Voltage divider is a simple technique to reduce the voltage with a linear transformation. Figure 4 shows a depiction of how it's implemented.

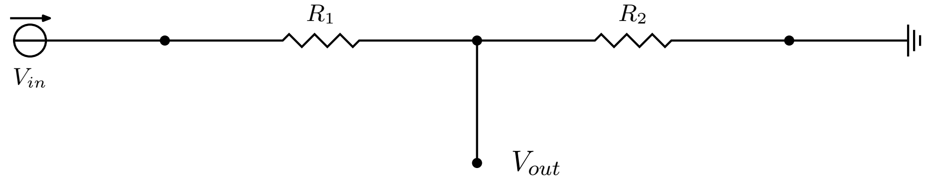

Figure 4: Voltage Divider

We can derive the voltage divider equation rather easily. Let's first redraw this circuit to make it easier to asee what's happening:

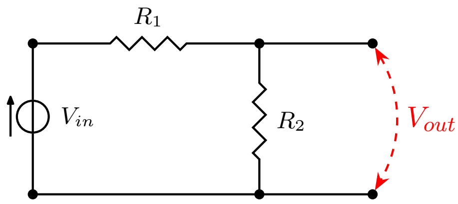

Figure 5: Voltage Divider: Redraw

The derivation is as follows:

$$\begin{aligned}
V_{in} &= (R_1 + R_2) \times I \\
I &= \frac{V_{in}}{R_1 + R_2} \\
V_{R_1} &= V_{in} - V_{out} = I \times R_1 \\
V_{R_2} &= V_{out} - 0 = I \times R_2 \\
V_{out} &= V_{R_2} \\
V_{out} &= I \times R_2 \\
V_{out} &= \frac{V_{in}}{R_1 + R_2} \times R_2 \\
V_{out} &= \frac{R_2}{R_1 + R_2} \times V_i n
\end{aligned}$$

Pulse Width Modulation is used for controlling voltage at each duty cycle.

Week 4

Key Concepts

- Understand the role of electricity, electronics and Transducers.
- Understand how electricity flow in the microcontroller circuit & breadboard
- Explain the difference between Arduino and PLC and how to read schema drawings

2.301 - Introduction to creating and reading own circuits diagrams

Figure 6 shows and example schematic diagram of a very simple circuit.

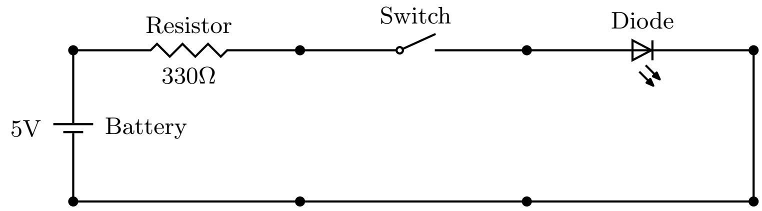

Figure 6: Simple schematic diagram

KiCAD EDA is a good quality Schematic Capture and PCB Layout toolchain.

2.303 - Understanding the types of nodes (Gateway, Router, Hub, Actuators)

Nodes are any devices capable of sensing, reacting, or communicating. Within *IoT*, these devices have some sort of connectivity (WiFi, Ethernet, LoRaWAN, etc).

Hub Broadcasts messages to all other nodes connected to it. Messages which are not addressed, are silently ignored. Limited to half-duplex operation.

Bridge Resolve addressing problems. Reviews and record MAC addresses. Fewer ports. Considered to be deprecated

Switches Maintain MAC and port address tables. Support full-duplex operation. Increase network security.

Gateway Edge node. Less traffic control. Support different protocols (ZigBee, Zwave, GSM, ...). Generally also support onboard programming and I/O.

Router Connects to internet via an ISP. Uses (and usually assigns) IP addresses. Configurable with increased security features.

Actuators Reacts to the environment and perform actions (opening doors, starting sprinklers, opening/closing binds, ...).

Week 5

Key Concepts

- Explain and critically evaluate types of sensors available, their capabilities and potential applications
- Able to control and monitor sensor states from HTML page using HTTP protocol
- Understand power sources requirements of different by sensors and actuators

3.001 - Introduction to multimodal sensors approaches (Ambient, Dense, Wearables)

A Smart Environment is created using various sensing devices. These devices can, in general, be separated in two main categories:

Vision involve some method of image processing to detect and track objects of interest. Common process for vision-based sensing is as follows:

1. Sequential image processing
2. Pre-processing
3. Fragmenting images
4. Feature extraction
5. Movement tracking

Popular algorithms for image processing are:

1. Scale Invariant Feature Transformation *SIFT*
2. Speed-Up Robust Features *SURF*
3. Features from Accelerated Segment Test *FAST*
4. Histogram of Oriented Gradients *HOG*
5. Histogram of optical Flow
6. Gaussian filter
7. Motion boundaries

Sensor involve sensing physical characteristics of the environment such as walls, windows, and large funitures. In general, data from such sensors are used for Time-series Analysis. Some of these sensors can be worn or even implanted in our body. This category can be further broken down into three main subcategories.

Ambient Distributed around the environment

Dense Embedded within objects. Common sensors are:

1. Capacitive touch
2. Tilt sensor
3. Accelerometer
4. Gyroscope
5. Force
6. Pressure
7. Liquid level (FDC1004)
8. Weight scale (Load cell)
9. Temperature / Humidity (DHT11/DHT22)
10. RFID tags

Wearable Worn sensors, such as:

1. Smart Watches
2. Smart Glasses
3. Smart Garments
4. Chest and angle belts

Or implants, such as:

1. RFID chips
2. Lens
3. Diabetes pumps
4. Pacemakers

3.101 - Common physical sensors - Ambient and Dense

Temperature Sensors:

1. Thermocouple
2. Thermistor
3. Resistor Temperature Detector

4. Semiconductor Sensor
5. Infrared Temperature Sensor
6. Thermometer

Distance Sensors

1. Infrared Distance Sensor
2. Ultrasonic Distance Sensor
3. LiDAR

Inertial Measurement Units

1. 6 Degrees of Freedom (6DoF)
2. 9 Degrees of freedom (9DoF)