Internet of Things

Abstract

The aim of this project is to implement an Internet of Things (IoT) device. Such a device embeds a micro-controller which controls sensors and provides connectivity features.

Contents

Part 1: Microcontroller

An IoT device is an electronic device witch embeds sensors to collect measurements from its environment and/or actuors to remotly control systems. It is connected to Internet through a computer network interface that is often wireless. Such devices are often built around a micro-controller which controls sensors and/or actuators and which interacts with one or more chips to provide network connectivity.

The ESP32-S3 from Espressif is used as a micro-controller to control the components of an IoT device. More precisely, the ESP32-S3 is a System-on-Chip (SoC) based on a dual-core XTensa LX7 micro-controller but which also integrates 2.4 GHz, 802.11 b/g/n Wireless Fidelity (Wi-Fi) and Bluetooth Low Energy (BLE) connectivity.

Technical informations about the ESP32-S3 SoC can be found in the manual [2].

1.1 Development Board

To simplify the development of applications based on micro-controllers, development boards provide features like integrated programmer and external pins connected to the micro-controller pins. Such boards allow to interface with components without soldering and to program the micro-controller using a Universal Serial Bus (USB) cable which also supplies power to the board.

The WiFi LoRa 32 V3 from Heltec is used as a development board to implement an IoT device. In addition to Wi-Fi and BLE connectivity, the WiFi LoRa 32 V3 provides Long-Range (LoRa) connectivity thanks to the SX1262 LoRa chip.

The pin map is depicted in Figure 1 and lists the devices linked to the pins. For example, the 12^{th} pin on the left is linked to the 1^{st} General Purpose Input/Output (GPIO) and to the channel 0 of the 1^{st} Analog-to-Digital Converter (ADC) component.

WARNING: USB-C Connection

The WiFi LoRa 32 V3 development board cannot be connected to the USB-C port of your computer (using your own USB-C to USB-C cable). You must use the USB-C to USB cable otherwise the board is not attached to your computer as a serial port (and you cannot program it).

1.2 Development Environment

An Integrated Development Environment (IDE) is a software application that provides in a same place the tools needed to write, build and run the program we develop.

In this tutorial, we need at least :

- a source code editor to integrate the codes for the micro-controller and the sensors,
- a cross-compiler that compiles source code for the ESP32 architecture from your host which probably is x86_64 architecture (or AMD64 if you have a recent Mac),
- a programmer that writes the resulting program into the memory of the micro-controller,
- a serial console that displays data sent by the micro-controller to its serial port (bridged to the USB port of the development port).

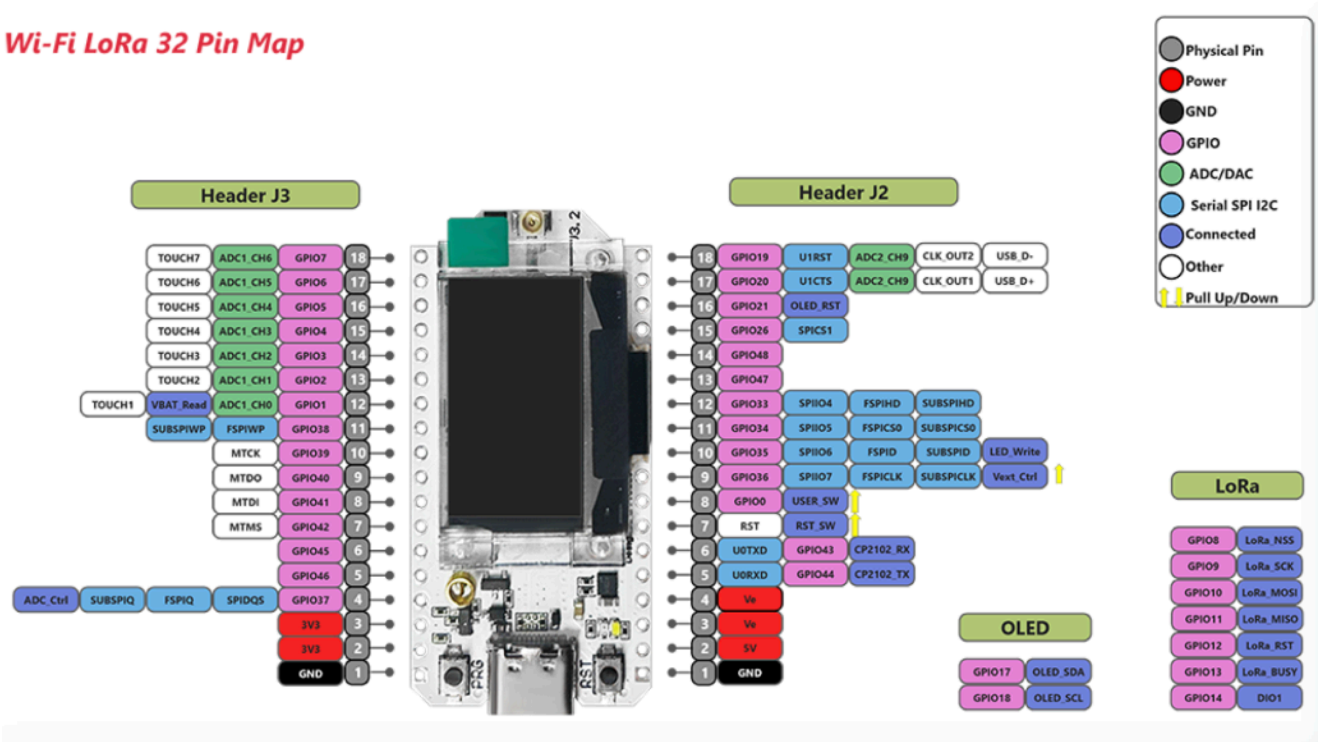


Figure 1: Heltec WiFi LoRa 32 (v3) Pinout.

1.2.1 Arduino IDE

Arduino IDE is a part of the Arduino project which aims at simplifying the development of embedded applications by abstracting the complexity of both hardware and software.

The last release of Arduino IDE can be downloaded from the dedicated page of the Arduino website [7].

The WiFi LoRa 32 board can be configured for the Arduino IDE by following the dedicated quick start guide [3]. A library manager (see left sidebar in Figure 2) allows to easily install additional libraries for an application.

A program can be compiled and written in the memory of the connected development board by pressing the right arrow button (see top left toolbar in Figure 2).

A serial monitor can be opened to observe data sent by the program running on the development board by pressing the magnifying glass button (see top right toolbar in Figure 2).

TODO: IDE installation

- Install Arduino IDE,
- Test to build a simple program which writes a message on the serial port of the development board and to program it in the development board memory,
- Observe the message which is received by your computer on the serial console of the IDE.

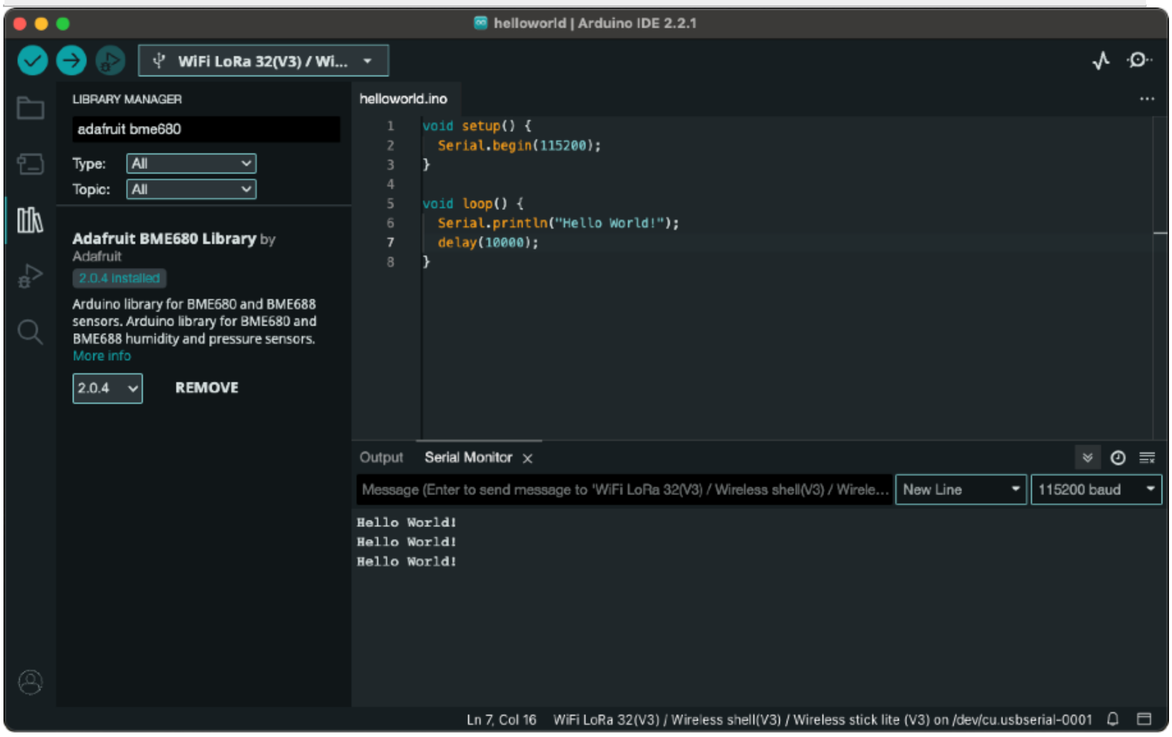


Figure 2: Arduino IDE interface.

Part 2: Sensors

2.1 Temperature, air pressure, humidity and air quality sensor

The Joy-IT SEN-BME680, depicted in Figure 5, is a digital temperature, air pressure, humidity and air quality sensor. It embeds the Bosch gas sensor BME680 and provides both Inter-Integrated Circuit (I²C) and Serial Peripheral Interface (SPI) digital interfaces.

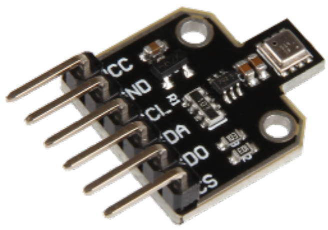
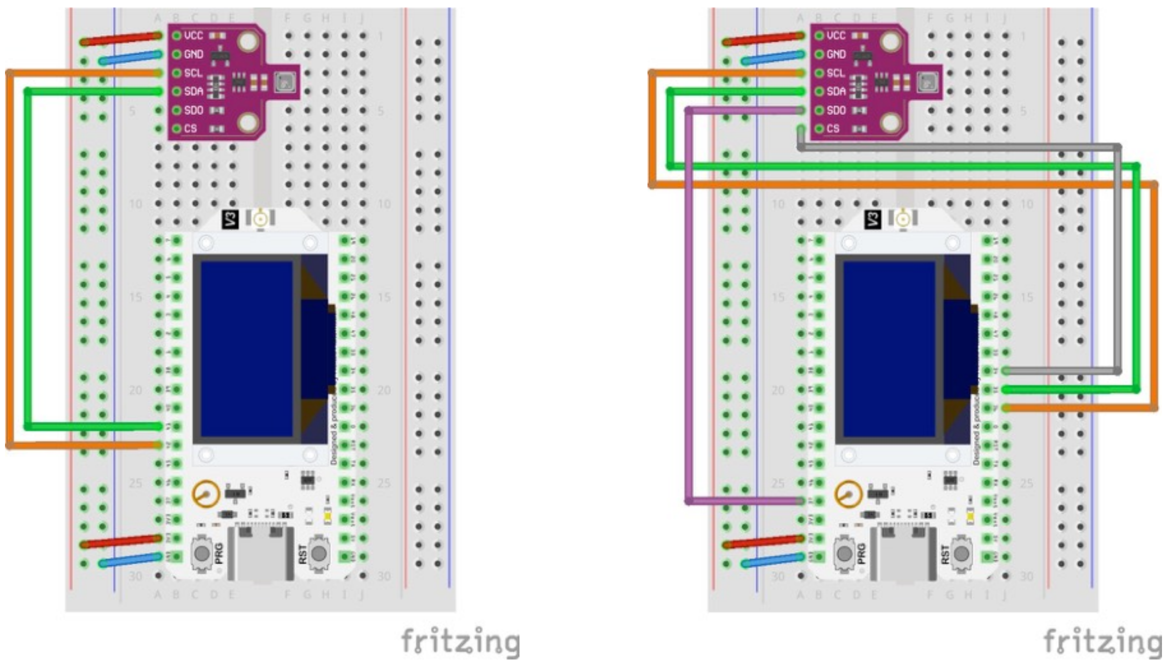


Figure 5: Joy-IT SEN-BME680.

An example showing how to connect the sensor to the development board through the I²C bus is given in Figure 6a and an example showing how to connect it to the board through the SPI bus is given in Figure 6b.



(a) Connection to I²C bus.

(b) Connection to SPI bus.

Figure 6: Example of connection of BME680 sensor to WiFI LoRa 32 V3 board.

How to connect this sensor to the development board and how to program it to collect measurements is described in the manual [4].

TODO: BME680

- Choose the bus to connect this sensor to the development board (I²C or SPI),
- Connect it to this bus,
- Program it to get measurements for:
  - Temperature,
  - Pressure,
  - Humidity,
  - Gas,
  - Altitude.

2.2 Light, gesture, color and proximity sensor

The SeeedStudio TMG39931, depicted in Figure 7, is a digital light, gesture, color and proximity sensor.

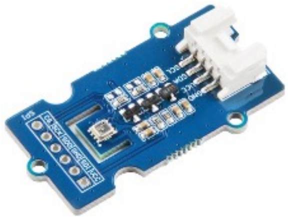


Figure 7: SeeedStudio TMG39931.

An example showing how to connect the sensor to the development board through the I²C bus is given in Figure 8[1].

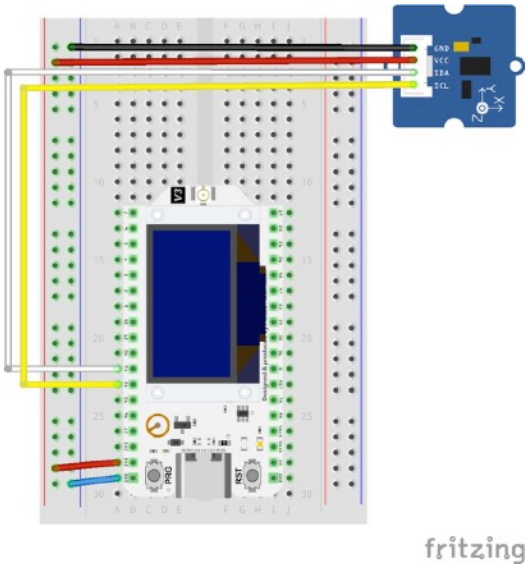


Figure 8: Example of connection of BME680 sensor to WiFI LoRa 32 V3 to I²C bus.

How to program this sensor to collect measurements is described in the manual [6]. This manual provides code examples and installation process for Arduino library.

Listing 3: Dependency to the Github library repository of TMG39931 when using PlatformIO.

TODO: TMP39931

- Connect this sensor to the development board using the I²C bus,
- Program it to get measurements for:
  - Proximity,
  - Red, Green, Blue and Clear,
  - Liminous flux,
  - Confocal Chromatic Triangulation.

[1] The sensor depicted in Figure 8 is not a TMG39931 but it provides the same grove connector for I²C interface.

2.3 Heartbeat sensor

The Iduino heartbeat sensor depicted in Figure 9 is an analog sensor.

Figure 9: Iduino heartbeat.

An example showing how to connect the sensor to an ADC channel of the development board is given in Figure 10[2].

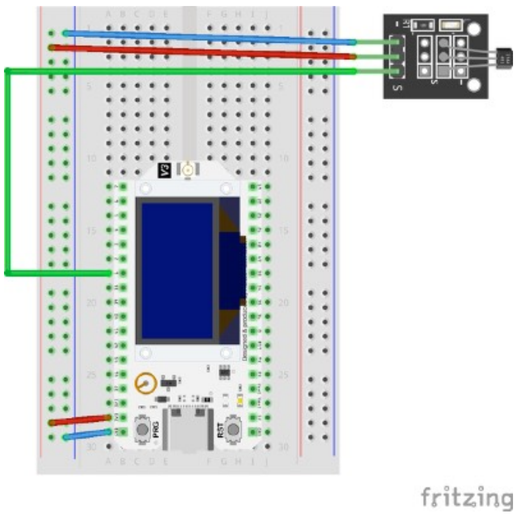


Figure 10: Example of connection of heartbeat sensor to WiFI LoRa 32 V3 to an ADC channel.

Actually, this sensor is just a Light-Dependent Resistor (LDR) that can measure the light emitted by the Light- Emitting Diode (LED) on top of the sensor board. If we put a finger between the LDR and the LED, the blood pulsing in our veins slightly varies the light intensity. By processing the signal measured by the LDR, one get a set of peaks, each peak corresponding to a heart beat.

The heart rate measurement can be implemented by counting the number of peaks per minute [8].

As an analog device, the heartbeat sensor must be connected to an ADC channel of the development board. Values processed by the ADC can be easily read as written in the Listing 4 where <X> is the number of the GPIO pin on which the data wire (green in Figure 10) is linked to the development board (see Figure 1 for pin numbers).

```
#define HB_PIN <X>

void loop() {
        int adcValue = analogReadMilliVolts(HB_PIN); Serial.println(adcValue);
        delay(100);
}

```

Listing 4: Example of code reading analog signal on pin <X> every 100 ms.

TODO: Heartbeat sensor

- Connect the sensor to an ADC channel,
- Program it to get measurements for heart rate.

[2] The sensor depicted in Figure 10 is not a heartbeat sensor but it provides the same pin interface.

Part 3: OLED Display

Onboard 0.96-inch 128*64 dot matrix OLED display can be used to display debugging information, battery power, and other informations. In this part, you will use the OLED display available on the development board to display in the first time a text and in the second time the measurement results.

TODO: OLED

- Program the development board Heltec LoRa WiFI to display a text (i.e "Hello World") on the OLED display.
- Program it to display the measurements for each sensor that we have tested in previous parts: (i.e Temperature, Humidity, Proximity, Herat beat..etc)

Figure 11: OLED displaying a text

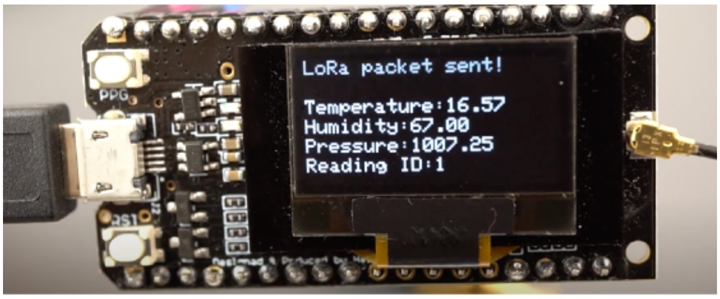


Figure 12: OLED displaying a sensor results

Part 4: IoT device (sensor monitoring with web server)

In this part, you'll build a sensor monitoring system using a heltec Lora WiFi 32 board that sends sensor results (exple: temperature, humidity and pressure) readings via LoRa radio to an ESP32 LoRa receiver. The receiver displays the latest sensor readings on a web server.

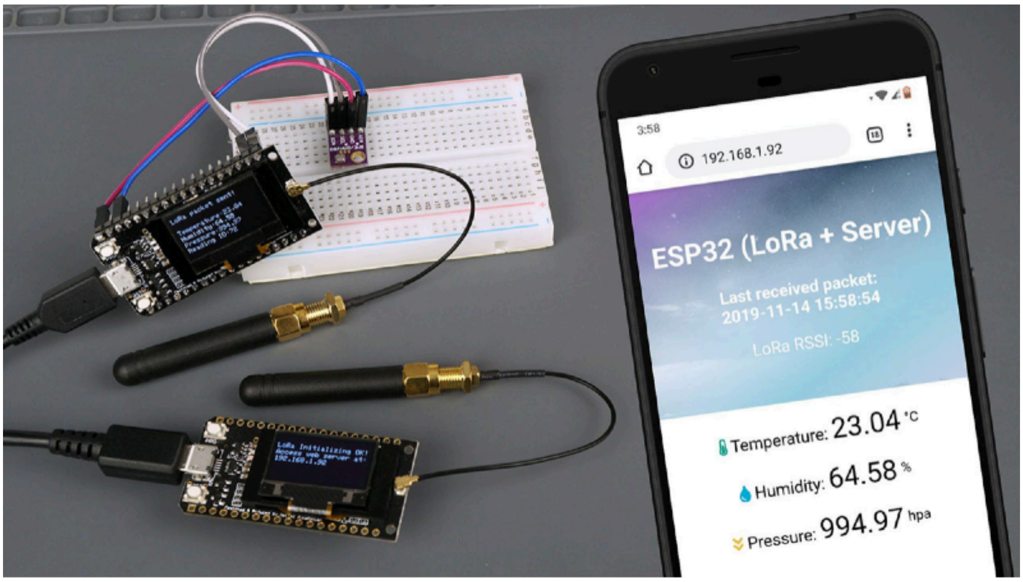


Figure 13: Sensor Monitoring with web server

Part 5: Optimizations

Power consumption

The loop() function of an Arduino program corresponds to an infinite loop that could be written white (1) {}. The delay() function at the end of loop() delays the next call of the loop. But this delay is active in the sense that the microprocessor consumes energy for running no operation.

Instead of using delay() function to delay measurements (which could be made every 5, 15 or even 30 minutes in a real application), we have to use the *deep sleep* feature of the ESP32 as presented in [1].

TODO: Deep Sleep Mode

Program the micro-controller to sleep between each measurement by using the deep sleep feature of ESP32.

Acronyms

ADC Analog-to-Digital Converter. 2, 8

API Application Programming Interface. 5

BLE Bluetooth Low Energy. 2

ESP-IDF Espressif IoT Development Framework. 5

GPIO General Purpose Input/Output. 2, 8

IDE Integrated Development Environment. 2, 3

IoT Internet of Things. 1, 2

I²C Inter-Integrated Circuit. 6, 7

LDR Light-Dependent Resistor. 8

LED Light-Emitting Diode. 8

LoRa Long-Range. 2

SoC System-on-Chip. 2

SPI Serial Peripheral Interface. 6

USB Universal Serial Bus. 2

Wi-Fi Wireless Fidelity. 2

Glossary

Analog-to-Digital Converter In electronics, an analog-to-digital converter is a system that converts an analog signal, such as a sound picked up by a microphone or light entering a digital camera, into a digital signal. ***Source*** https://en.wikipedia.org/wiki/Analog-to-digital_converter. 2, 8

Application Programming Interface An Application Programming Interface (API) is a way for two or more com- puter programs to communicate with each other. ***Source*** https://en.wikipedia.org/wiki/API. 5

Bluetooth Low Energy Bluetooth Low Energy is a wireless personal area network technology designed and mar- keted by the Bluetooth Special Interest Group aimed at novel applications in the healthcare, fitness, beacons, security, and home entertainment industries. ***Source*** https://en.wikipedia.org/wiki/Bluetooth_Low_Energy. 2

Espressif IoT Development Framework ESP-IDF is the official development framework for the ESP32, ESP32- S, ESP32-C, ESP32-H and ESP32-P Series SoCs. ***Source*** https://docs.espressif.com/projects/esp-idf/en/latest/ esp32/. 5

General Purpose Input/Output A general-purpose input/output (GPIO) is an uncommitted digital signal pin on an integrated circuit or electronic circuit (e.g. MCUs/MPUs) board which may be used as an input or output, or both, and is controllable by software. ***Source*** https://en.wikipedia.org/wiki/General-purpose_input/output. 2, 8

Inter-Integrated Circuit I2C (Inter-Integrated Circuit; pronounced as "eye-squared-C"), alternatively known as I2C or IIC, is a synchronous, multi-master/multi-slave (controller/target), single-ended, serial communication bus. It is widely used for attaching lower-speed peripheral ICs to processors and microcontrollers in short- distance, intra-board communication. ***Source*** https://en.wikipedia.org/wiki/I%C2%B2C. 6, 7

Integrated Development Environment An integrated development environment (IDE) is a software application that provides comprehensive facilities for software development. An IDE normally consists of at least a source-code editor, build automation tools, and a debugger. ***Source*** https://en.wikipedia.org/wiki/Integrated_ development_environment. 2, 3

Internet of Things The Internet of things (IoT) describes devices with sensors, processing ability, software and other technologies that connect and exchange data with other devices and systems over the Internet or other communications networks. ***Source*** https://en.wikipedia.org/wiki/Internet_of_things. 1, 2

Light-Dependent Resistor A photoresistor (also known as a photocell, or light-dependent resistor, LDR, or photo- conductive cell) is a passive component that decreases resistance with respect to receiving luminosity (light) on the component's sensitive surface. ***Source*** https://en.wikipedia.org/wiki/Photoresistor. 8

Light-Emitting Diode A Light-Emitting Diode (LED) is a semiconductor light source that emits light when current flows through it. Electrons in the semiconductor recombine with electron holes, releasing energy in the form of photons (Energy packets). ***Source*** https://en.wikipedia.org/wiki/Light-emitting_diode. 8

Long-Range LoRa (from "long range") is a physical proprietary radio communication technique. It is based on spread spectrum modulation techniques derived from chirp spread spectrum (CSS) technology. srcurl- https://en.wikipedia.org/wiki/LoRa. 2

System-on-Chip A system on a chip or system-on-chip is an integrated circuit that integrates most or all com- ponents of a computer or other electronic system. ***Source*** https://en.wikipedia.org/wiki/System_on_a_chip. 2

Serial Peripheral Interface Serial Peripheral Interface (SPI) is a de facto standard (with many variants) for syn- chronous serial communication, used primarily in embedded systems for short-distance wired communi- cation between integrated circuits. ***Source*** https://en.wikipedia.org/wiki/Serial_Peripheral_Interface. 6

Universal Serial Bus Universal Serial Bus (USB) is an industry standard that allows data exchange and delivery of power between many various types of electronics. ***Source*** https://en.wikipedia.org/wiki/USB. 2

Wireless Fidelity Wi-Fi is a family of wireless network protocols based on the IEEE 802.11 family of standards, which are commonly used for local area networking of devices and Internet access, allowing nearby digital devices to exchange data by radio waves. ***Source*** https://en.wikipedia.org/wiki/Wi-Fi. 2

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