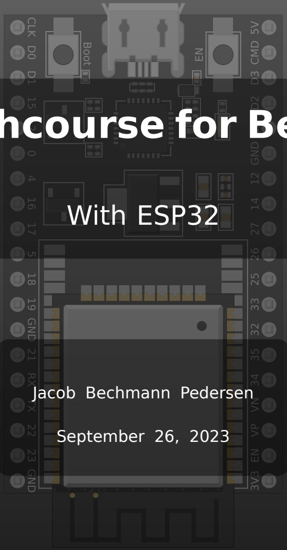

IoT Crashcourse for Beginners

With ESP32

Jacob Bechmann Pedersen

September 26, 2023

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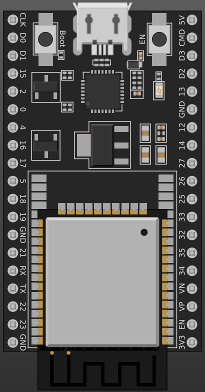
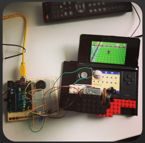


Figure 1: ESP32 DevkitC v4, the board we're working with

Who am I?



Jacob Bechmann Pedersen

- Speaker/Facilitator on Embedded Electronics programming and Arduino workshops
- Embedded electronics engineer at DTU Electro, Automation and Control
  - Robots, embedded Linux, autonomous systems
- Embedded software developer at Oticon
  - Applications for hearing aid OS, unit- and device testing
- Teacher at MakerCamp
  - "Inventors" team - 12-16 y/o
- Volunteer in Coding Pirates 2016-2018
- Electronic Design Engineer (AU, 2019)
- Started with Arduino in 2014

Purpose

- To understand the basic principles of IoT
  - Topologies
  - Protocols i. e.:
    - HTTP
    - Websockets
    - MQTT
- To program simple implementations
  - On ESP32
  - With the Arduino platform
  - In VSCode

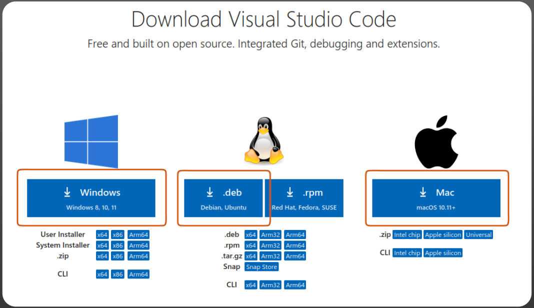
Resources

Useful links:

- `https://github.com/iakop/IoT-Crashcourse`
  - Presentation and code for this workshop
- `https://code.visualstudio.com/`
  - Download for Visual Studio Code
- `https://platformio.org/`
  - Download for PlatformIO
- `https://www.arduino.cc/en/reference`
  - Reference on keywords in Arduino
- `http://mqtt-explorer.com/`
  - MQTT client to explore topics on a broker
- `https://nodered.org/`
  - Editor based tool for flowbased IoT programming

Setup of VSCode and PlatformIO

Setup VSCode



Download Visual Studio Code

Free and built on open source. Integrated Git, debugging and extensions.

User Installer x64 x86 Arm64
System Installer x64 x86 Arm64
.zip x64 x86 Arm64
CLI x64 x86 Arm64

.deb x64 Arm32 Arm64
.rpm x64 Arm32 Arm64
.tar.gz x64 Arm32 Arm64
Snap Snap Store
CLI x64 Arm32 Arm64

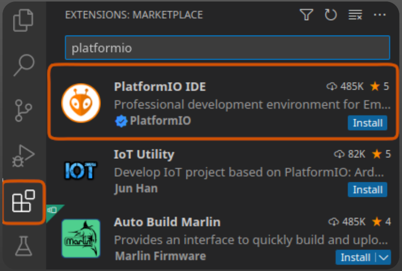
.zip Intel chip Apple silicon Universal
CLI Intel chip Apple silicon

Figure 2: The `Visual Studio Code` download page has versions for many different architectures, typically the default button will download the right installer

- Download Visual Studio Code from the link:
  - `https://code.visualstudio.com/Download`
- Click the big button for you OS
- Run the installer, this should go without a hitch
- IF that doesn't work, you can try:
  - Windows:
    - If you don't have admin rights, you can download the `User Installer` (typically x64-version)
  - Linux:
    - If you don't use Ubuntu try checking your package managers repositories, or try the `CLI` installer
  - Mac OS X:
    - Try the `Universal .zip`, or maybe the App Store? 🤷

Setup PlatformIO

- When VSCode is installed and started, go to the `Extensions` tab
  - Search for PlatformIO
  - Pick the extension pictured, and click `install`
  - VSCode will automatically install and configure PlatformIO



EXTENSIONS: MARKETPLACE

platformio

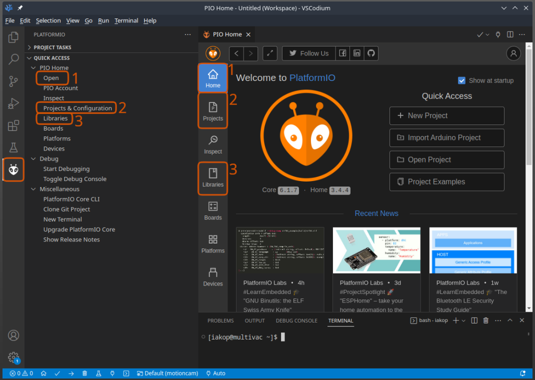
PlatformIO IDE 485K ★ 5
Professional development environment for Em...
PlatformIO Install

IoT Utility 82K ★ 5
Develop IoT project based on PlatformIO: Ard...
Jun Han Install

Auto Build Marlin 485K ★ 4
Provides an interface to quickly build and uplo...
Marlin Firmware Install

Figure 3: Installing `PlatformIO` in VSCode

Setup PlatformIO



```
[iakop@multivac ~]$ 
```

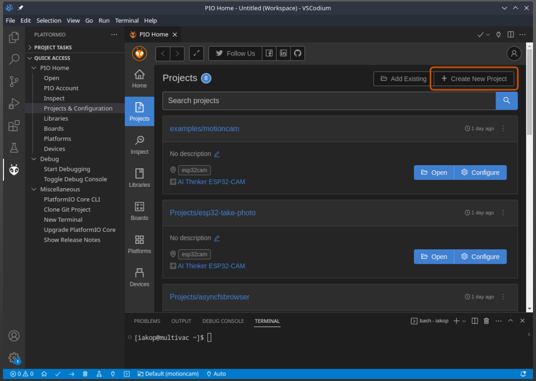
Figure 4: PlatformIO standard view, featuring `Home` , `Projects` , `Libraries` , and Quick Access

- The PlatformIO extension is opened by clicking the PlatformIO tab
- The most important menu items of the extension:
  1. Open / Home
     - Main page of PlatformIO, featuring quick access and tabs for most functions
  2. Projects & Configuration / Projects
     - Project management page, for creating and managing projects
  3. Libraries
     - For searching and adding Libraries to PlatformIO projects

Setup of ESP32 project in PlatformIO

Setup of ESP32 project in PlatformIO

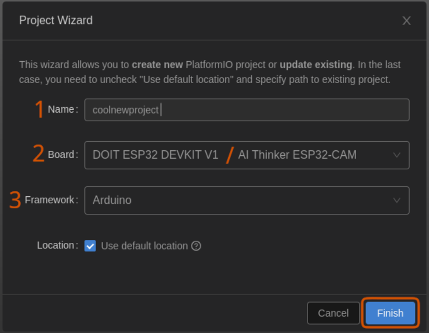
- Click the tab `Projects` to enter the projects view
- To create a new project, click the button `Create New Project`



```
[iakop@multivac ~]$
```

Figure 5: `Projects` tab in PlatformIO. For creating and managing projects within the GUI

Setup of ESP32 project in PlatformIO



Project Wizard

This wizard allows you to **create new** PlatformIO project or **update existing**. In the last case, you need to uncheck "Use default location" and specify path to existing project.

1 Name: coolnewproject

2 Board: DOIT ESP32 DEVKIT V1 / AI Thinker ESP32-CAM

3 Framework: Arduino

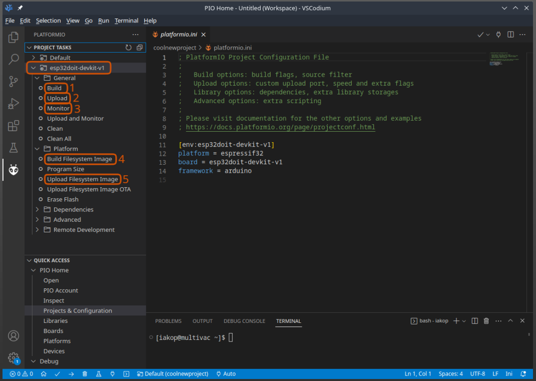
Location: ☑ Use default location

Figure 6: The `Project Wizard` dialog in PlatformIO, with settings for name, board and framework

- A `Project Wizard` dialog will be opened
- It contains 3 fields, to be filled as follows:
  - Name
    - A fitting name for the project, e.g. "`coolnewproject`"
  - Board
    - `DOIT ESP32 DEVKIT V1`
  - Framework
    - `Arduino`
- Finish by clicking `Finish`

Setup of ESP32 project in PlatformIO

- PlatformIO will generate the project and set up the toolchain
  - This requires an internet connection
- When done, load `platformio.ini`
  - This file contains the project settings, and can be edited by hand
- On the side of the window there are `Project Tasks` :
  1. Build
     - Build an image for the device to be flashed
  2. Upload
     - Uploads the image through an automatically detected USB/UART connection
  3. Monitor
     - Monitors the UART connection to the hardware (Baud rate can be set in `platformio.ini`)
  4. Build Filesystem Image
     - Builds file system image for the hardware (based on the contents of the `data` folder of the project)
     - `data` folder needs to be created manually
     - File system can be specified in `platformio.ini`
  5. Upload Filesystem Image
     - Uploads the built image to the hardware
     - IMPORTANT : Monitor can not be active during upload



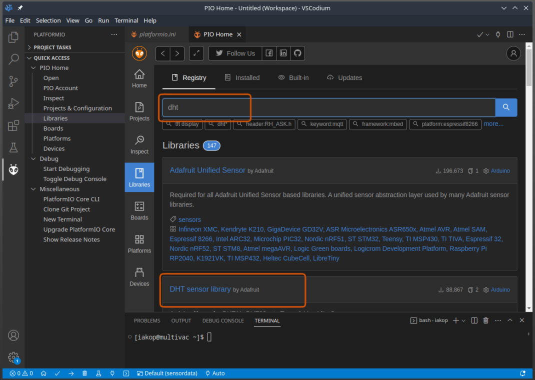
```ini
; PlatformIO Project Configuration File
;
;   Build options: build flags, source filter
;   Upload options: custom upload port, speed and extra flags
;   Library options: dependencies, extra library storages
;   Advanced options: extra scripting
;
; Please visit documentation for the other options and examples
; https://docs.platformio.org/page/projectconf.html

[env:esp32doit-devkit-v1]
platform = espressif32
board = esp32doit-devkit-v1
framework = arduino
```

```
[iakop@multivac ~]$
```

Figure 7: Opened project in PlatformIO, shows `platformio.ini` and the `Project Tasks` for the project

Add libraries to an ESP32 project



Required for all Adafruit Unified Sensor based libraries. A unified sensor abstraction layer used by many Adafruit sensor libraries.

sensors

Infineon XMC, Kendryte K210, GigaDevice GD32V, ASR Microelectronics ASR650x, Atmel AVR, Atmel SAM, Espressif 8266, Intel ARC32, Microchip PIC32, Nordic nRF51, ST STM32, Teensy, TI MSP430, TI TIVA, Espressif 32, Nordic nRF52, ST STM8, Atmel megaAVR, Logic Green boards, Logicrom Development Platform, Raspberry Pi RP2040, K1921VK, TI MSP432, Heltec CubeCell, LibreTiny

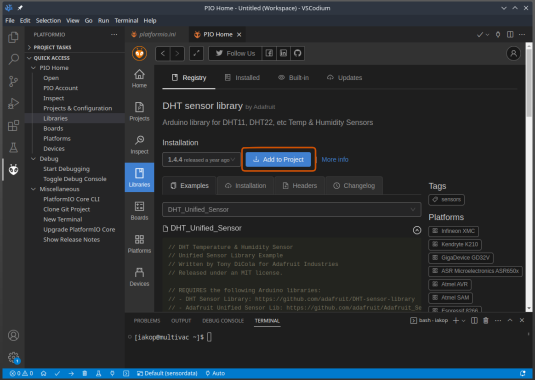
```
[iakop@multivac ~]$
```

Figure 8: The `Libraries` tab in PlatformIO. For searching and adding libraries to projects

- To add external libraries to a project, use the `Libraries` tab for finding contributed libraries
  - Can be found under `Registry`
  - Installed libraries can be viewed underr `Installed`
- Click a relevant library

Add libraries to an ESP32 project

- The following can be found within the library:
  - Examples
  - Headers
  - etc.
- Click `Add to Project` to add the library to a project



DHT sensor library by Adafruit

Arduino library for DHT11, DHT22, etc Temp & Humidity Sensors

DHT_Unified_Sensor

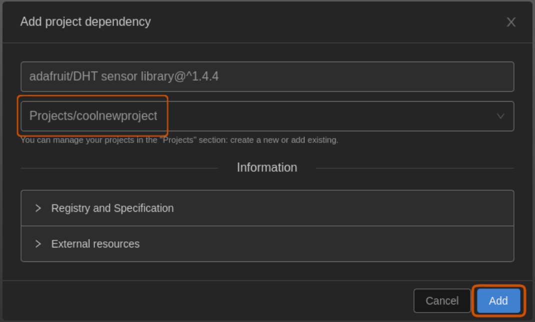
```
// DHT Temperature & Humidity Sensor
// Unified Sensor Library Example
// Written by Tony DiCola for Adafruit Industries
// Released under an MIT license.

// REQUIRES the following Arduino libraries:
// - DHT Sensor Library: https://github.com/adafruit/DHT-sensor-library
// - Adafruit Unified Sensor Lib: https://github.com/adafruit/Adafruit_Se
```

```
[iakop@multivac ~]$
```

Figure 9: `DHT sensor library` in PlatformIO. Can be added to projects that support the Arduino framework

Add libraries to an ESP32 project



Add project dependency

adafruit/DHT sensor library@^1.4.4

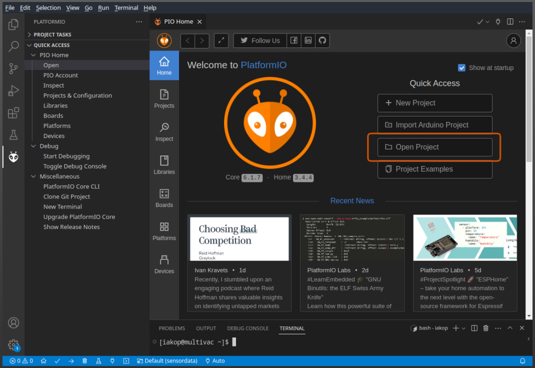
Projects/coolnewproject

You can manage your projects in the "Projects" section: create a new or add existing.

Figure 10: The `Add project dependency` dialog in PlatformIO. To pick which library to add the library to

- The `Add project dependency` dialog will open
- Under `Select a project`, pick the project to add the library to
- Click `Add`
- PlatformIO will automatically add a `lib_deps` dependency within `platformio.ini`, and set up the library

Opening external ESP32 Projekt in PlatformIO



Choosing Bad Competition
Reid Hoffman
Greylock

Ivan Kravets • 1d
Recently, I stumbled upon an engaging podcast where Reid Hoffman shares valuable insights on identifying untapped markets

PlatformIO Labs • 2d
#LearnEmbedded 🎓 "GNU Binutils: the ELF Swiss Army Knife"
Learn how this powerful suite of

PlatformIO Labs • 5d
#ProjectSpotlight 🚀 "ESPHome" – take your home automation to the next level with the open-source framework for Espressif

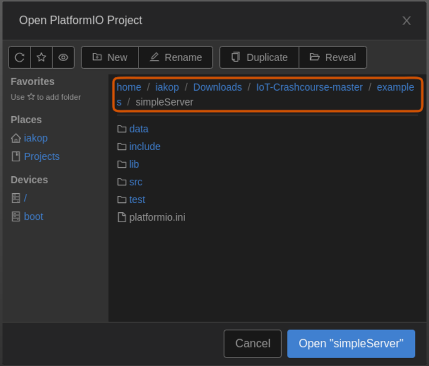
```
[iakop@multivac ~]$ 
```

Figure 11: `Home` tab in PlatformIO, button to load project from disk is highlighted

- The projects for this workshop use specific libraries and settings
- To get them quickly set up, the projects can be downloadet and imported from the Github repo
- Download the entire workshops materials here:
  - `https://github.com/iakop/IoT-Crashcourse/archive/refs/heads/master.zip`
- Extract them somewhere easy to locate
- Under the `Home` tab, click `Open Project`

Opening external ESP32 Projekt in PlatformIO

- In the `Open PlatformIO Project` dialog, open the examples folder for the workshop
- If the `Open` button, for example, shows `Open "simpleServer"` the dialog is in the correct folder
- Click the `Open` button

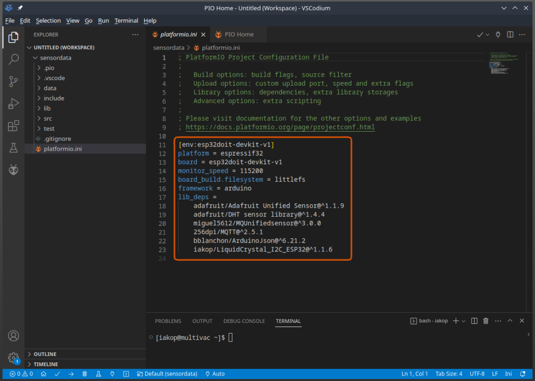


home / iakop / Downloads / IoT-Crashcourse-master / examples / simpleServer

data
include
lib
src
test
platformio.ini

Figure 12: `Open PlatformIO Project` dialog in PlatformIO. To open a project the folder needs to be extracted and located on the disk, for example, in: `Downloads/IoT-Crashcourse-master/examples/simpleServer`

Opening external ESP32 Projekt in PlatformIO


PIO Home - Untitled (Workspace) - VSCodium
File Edit Selection View Go Run Terminal Help
EXPLORER
UNTITLED (WORKSPACE)
sensordata
.pio
.vscode
data
include
lib
src
test
.gitignore
platformio.ini
platformio.ini
PIO Home
sensordata > platformio.ini
PROBLEMS OUTPUT DEBUG CONSOLE TERMINAL
bash - iakop
OUTLINE
TIMELINE
Default (sensordata)
Auto
Ln 1, Col 1 Tab Size: 4 UTF-8 LF Ini

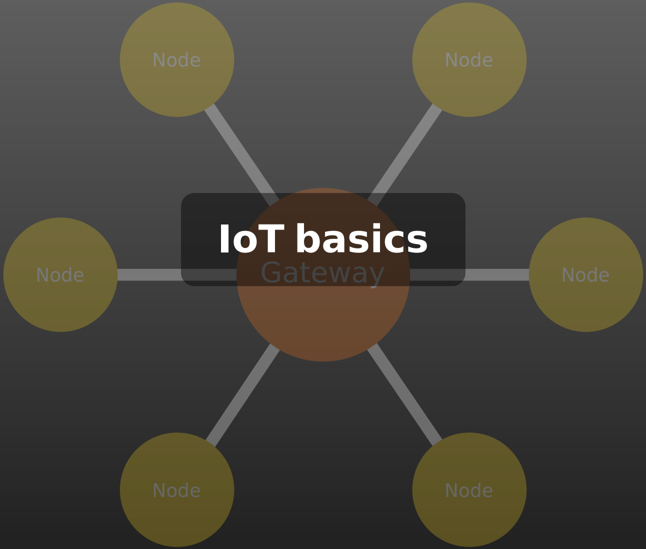
```ini
; PlatformIO Project Configuration File
;
;   Build options: build flags, source filter
;   Upload options: custom upload port, speed and extra flags
;   Library options: dependencies, extra library storages
;   Advanced options: extra scripting
;
; Please visit documentation for the other options and examples
; https://docs.platformio.org/page/projectconf.html

[env:esp32doit-devkit-v1]
platform = espressif32
board = esp32doit-devkit-v1
monitor_speed = 115200
board_build.filesystem = littlefs
framework = arduino
lib_deps =
    adafruit/Adafruit Unified Sensor@^1.1.9
    adafruit/DHT sensor library@^1.4.4
    miguel5612/MQUnifiedsensor@^3.0.0
    256dpi/MQTT@^2.5.1
    bblanchon/ArduinoJson@^6.21.2
    iakop/LiquidCrystal_I2C_ESP32@^1.1.6
```

```
[iakop@multivac ~]$
```

Figure 13: Example of a `platformio.ini` for a project. Pay attention to `monitor-speed`, `filesystem` and `lib_deps` that are pre-defined

- When the project is loaded, open the `platformio.ini`
- Specifies libraries and components that the project depends on
- Tools and settings will be set up autimatically by PlatformIO



IoT basics

IoT basics

- IoT (Internet of Things), is a common name for networked devices
- These devices typically consist of:
  - A microprocessor or -computer
  - Sensors
  - Actuators
  - Wired or wireless connectivity

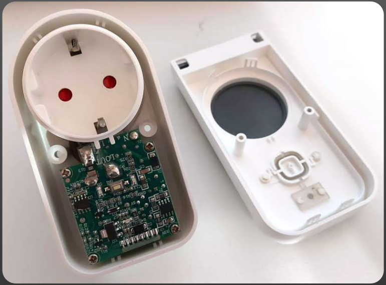


Figure 14: Nedis SmartLife torn down to show the insides. Contains a TYWE3S WiFi module and an HLW8012 power sensor
Kilde: `https://callaa.github.io/2021/01/26/liberating-nedis-smartplug.html`

IoT basics

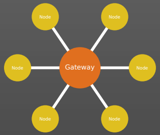


Figure 15: Star-topology, where every device communicates through a central gateway to the rest of the internet

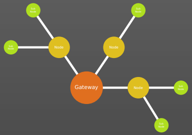


Figure 16: Tree-topology, Where the devices are connected in branches, where they heirarchically relay information to the gateway

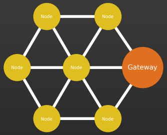


Figure 17: Mesh-topology, where devices communicate internally, relaying information through eachother to the gateway

- Communication between devices can be done in several ways
- Some typical IoT toplogies:
  - Star
  - Tree
  - Mesh

IoT basics

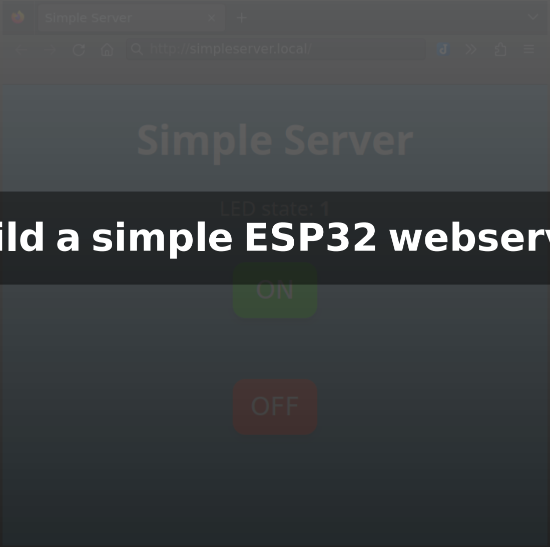
- There are also several protocols for devices to communicate
- In this workshop we focus on:
  - HTTP
    - The ubiquitous Hypertext Transfer Protocol, for transferring web content, e.g. between servers and browsers
  - WebSocket
    - A full duplex (two-way communication) protocol for quick, simultaneous communication between client and server - low overhead
  - MQTT
    - (Originally acronym for MQ (Message Queue) Telemetry Transport) Publish-subscribe based protocol between devices and a central broker - low overhead

Figure 18: HTTP logo
Kilde: https://en.wikipedia.org/wiki/File:HTTP_logo.svg
Licens: Public Domain

Figure 19: WebSocket logo
Kilde: https://logodix.com/logos/1825947
Licens: Non-Commercial

Figure 20: MQTT logo
Kilde: https://en.wikipedia.org/wiki/File:Mqtt-hor.svg
Licens: Public Domain

Build a simple ESP32 webserver



Simple Server

LED state: 1

Simple Server

- For this example we need a breadboard setup
  - An ESP32 board
  - An LED
  - A 220Ω resistor
- HTML and the Arduino program will be presented and explained on the board
- Source code can be found on:
  - https://github.com/iakop/IoT-Crashcourse/tree/master/examples/simpleServer

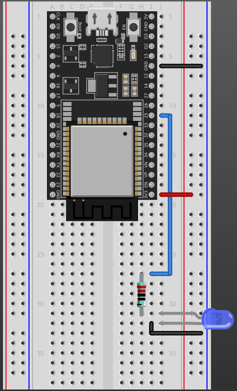


Figure 21: Breadboard setup with ESP32 and LED

WebSockets on ESP32

Websocket Server

websocketserver.local

Websocket Server

LED

DHT

Temperature: 21.4°C

Humidity: 49%

WebSocket Server

- This example adds a sensor to the setup
  - An ESP32 board
  - An LED
  - A 220Ω resistor
  - A DHT11 temperature/humidity sensor module
- We'll add Javascript and a WebSocket connection, which we'll also cover on the board
- Source code can be found on:
  - https://github.com/iakop/IoT-Crashcourse/tree/master/examples/websocketServer

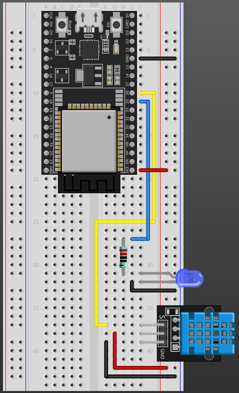


Figure 22: Breadboard setup with ESP32, LED and DHT11 sensor

MQTT on ESP32

MQTT Client

- Same setup
  - An ESP32 board
  - An LED
  - A 220Ω resistor
  - A DHT11 temperature/humidity sensor module
- All server code is exchanged for client code, connecting through SSL to an MQTT broker
- Source code can be found on:
  - `https://github.com/iakop/IoT-Crashcourse/tree/master/examples/mqttClient`

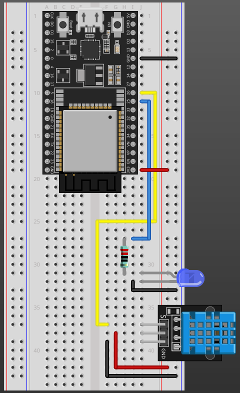
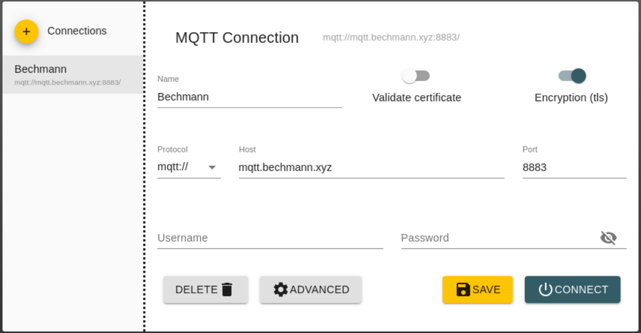


Figure 23: Breadboard setup with ESP32, LED and DHT11 sensor

MQTT Client



Bechmann
mqtt://mqtt.bechmann.xyz:8883/

MQTT Connection mqtt://mqtt.bechmann.xyz:8883/

Name: Bechmann

Validate certificate

Encryption (tls)

Protocol: mqtt://

Host: mqtt.bechmann.xyz

Port: 8883

Username

Password

Figure 24: MQTT Explorer Connection dialog window, with the settings for connecting to `mqtt.bechmann.xyz`

- MQTT Explorer can be used to check and explore topics on a broker:
  - `http://mqtt-explorer.com/`
- Settings for `public` server for this workshop:
  - Name: `Bechmann` (optional)
  - Validate certificate: `off`
    - `Bug in MQTT Explorers cert storage prevents validating Let's Encrypt RootCA`
  - Encryption (tls): `on`
  - Protocol: `mqtt://`
  - Host: `mqtt.bechmann.xyz`
  - Port: `8883`
  - Username: `blank`
  - Password: `blank`