Mitwelten *(Co-Worlds)*

Media Ecological Infrastructures for Biodiversity

IoT Toolkit

This document describes the IoT Toolkit, sensors and actuators developed for the research project MITWELTEN (*Co-Worlds*, www.mitwelten.org), deployed in the Basel area, funded by the Swiss National Science Foundation (2020-2024).

Content

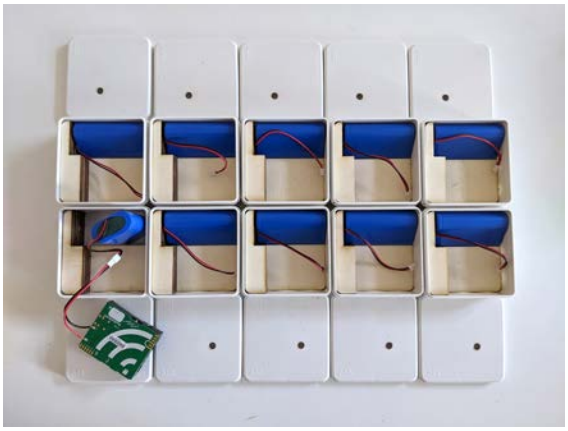
Design principles

DIY-friendly, modular and open design

The basic building blocks of the IoT Toolkit are microcontrollers with sensors and actuators, as well as single board computers with cameras, housed in off-the-shelf weatherproof, electrical junction boxes of the type AP9 and AP10. They come with rubber membranes for cables and a halogen-free plastic top that can be laser-cut.

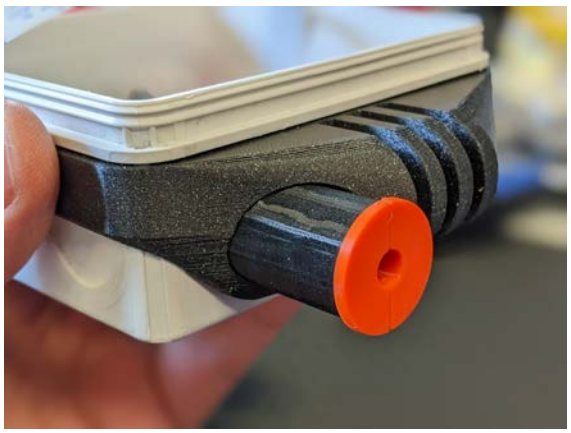
The box itself has ingress protection class IP65. Any added holes of course reduce water and dust protection and should either be covered or sealed with silicone, or at least placed to face downwards, away from the rain. If a device generates heat, an additional vent should be added to keep the inside humidity from condensing.

AP9 on AP10 box



AP9 based design

To allow customization of boxes, we designed use case specific, physical fixtures and adapters that can be produced by anyone with an FDM 3D-printer and a laser-cutter. For the PoE access point we used widely available building materials that can be cut with a CNC mill and assembled with wood working tools. Each design comes with a bill of materials (BOM) including links to buy all required components.

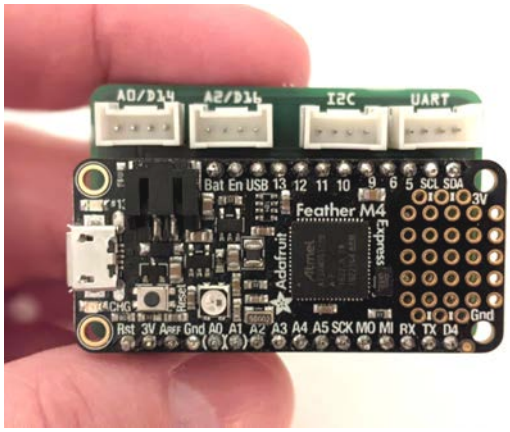


AP10 adapter (w/ printed PoE seal)

AP10 adapters in production

Commodity devices and open hardware

We used a range of microcontrollers conforming to the Feather board footprint and Grove wiring connectors to keep assembly simple. Connectivity options for sensor devices include Bluetooth, Wi-Fi and LoRaWAN, as well as Ethernet for cameras.



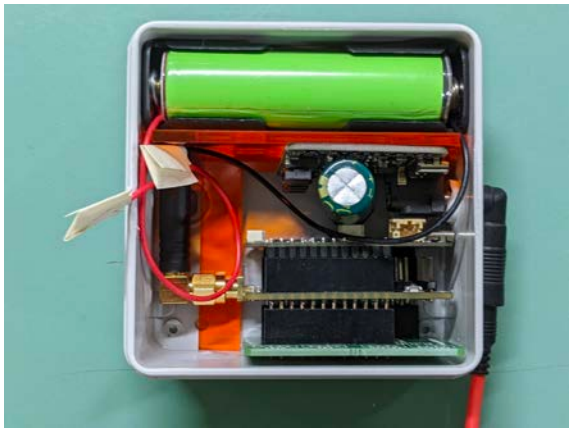
Microcontroller (w/ Grove adapter)

Modular electronics (w/ LoRaWAN)

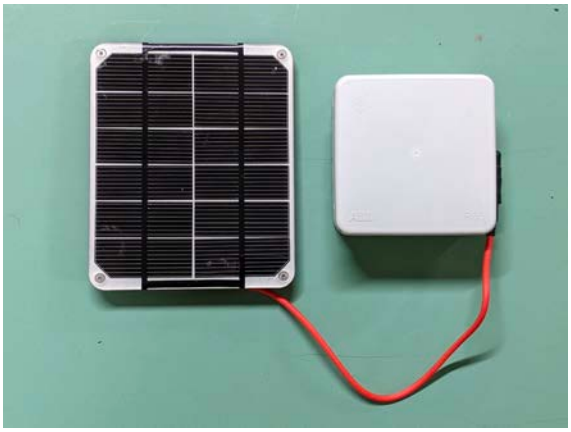
All physical design files and bills of material (BOM) are licensed under CC BY-SA 4.0. For third-party components, hardware with an open hardware license was chosen, if available. Exceptions are Raspberry Pi single board computers, as well as low-cost, commodity devices like network switches, harddisks and Wi-Fi routers with 4G. Our firmware and software is published as open source, usually under the MIT License, except if noted otherwise, see LICENSE in each repository (github.com/mitwelten).

PoE, battery power and solar panels

Depending on the use case, sensor and actuator devices get their energy from a Li-Ion battery, optionally with a 1 or 2W solar panel, or power over Ethernet (PoE). The latter works well for clusters of camera devices, see *PoE access point* below.



3000 mAh Li-Ion battery



Optional 2W solar panel

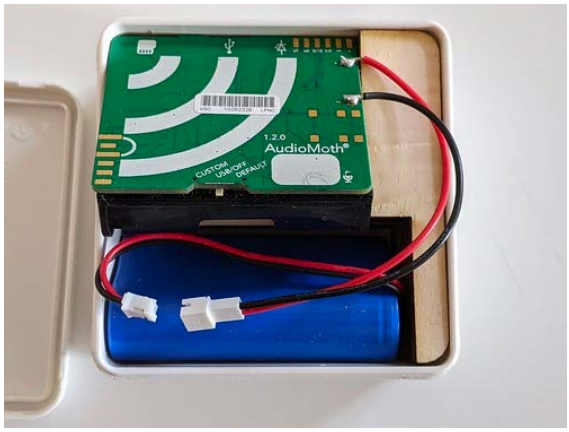
Cameras, sensors and actuators

The IoT kit covers a wide range of use cases. We built and used connected camera devices for insect monitoring, audio loggers with SD card storage for bird detection, LoRaWAN-connected environmental sensors for temperature, air humidity and soil moisture, people counters based on anonymised Bluetooth device addresses, as well as Wi-Fi-connected actuator devices for interactive installations. The collected data is available to authorized clients through the Web API (data.mitwelten.org/api/v3/docs), detailed documentation of the backend software and apps is available in *Appendix B*.

Sensor Devices

Audio Logger with Large Battery

An audio logging microphone based on AudioMoth hardware, fitted with a large Li-Ion battery, to record a broad range of frequencies, triggered by time of day or loudness.



Hardware (AudioMoth, Li-Ion battery)

Enclosure (w/ membrane)

A detailed BOM and links to open source software are online at github.com/mitwelten/mitwelten-iot-hardware-poc/blob/main/README.md#audio-logger-with-large-battery

Our charging solution

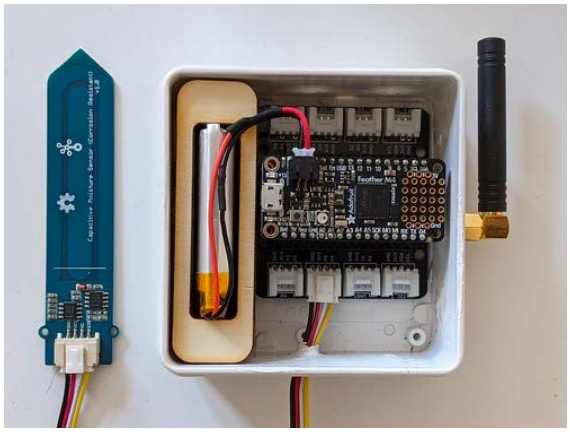
Deployed device (w/ fix)

Humidity damage

We deployed this type of device from April to September, recording multiple hours a day. Batteries had to be recharged and SD-card data collected about once a week. Note that charging Li-Ion batteries can be a safety hazard and take precautions.

LoRaWAN Env Sensor with Solar Power

This LoRaWAN environment sensor device can send small amounts (< 52 bytes) of data with a low frequency (once every 15+ min) over long distances (1+ km).



Hardware (w/o solar charger, DHT11)

Enclosure (w/ 1W solar panel)

A detailed BOM and links to open source firmware are online at github.com/mitwelten/mitwelten-iot-hardware-poc#lorawan-env-sensor-node-with-solar-power

Deployed device

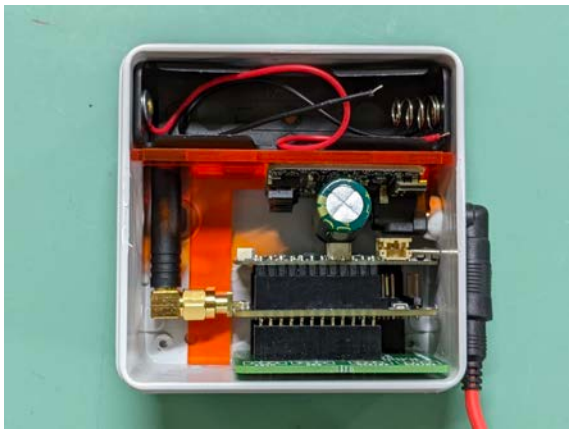
Adapters for 2cm tube

Fixed issue w/ zip tie

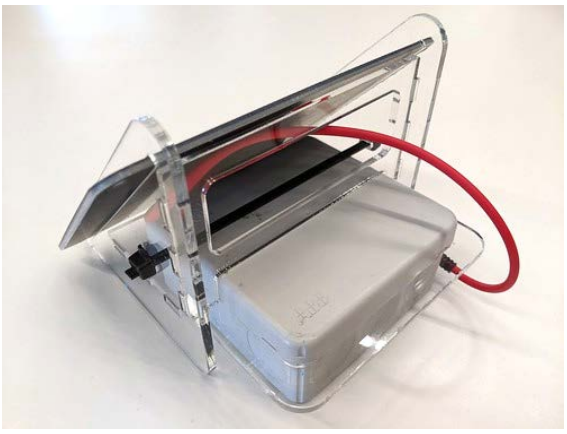
We deployed this type of device from April to September, without any maintenance. Note that LoRaWAN network coverage is required to operate this, see *Gateways*.

LoRaWAN Pax Sensor with Solar Power

This LoRaWAN "people counting" sensor delivers an anonymous count of Bluetooth addresses, and thus roughly the number of smartphones, in the range of ~10 m.



Hardware (w/o Li-Ion battery, wiring)



Enclosure (w/ 2W solar panel)

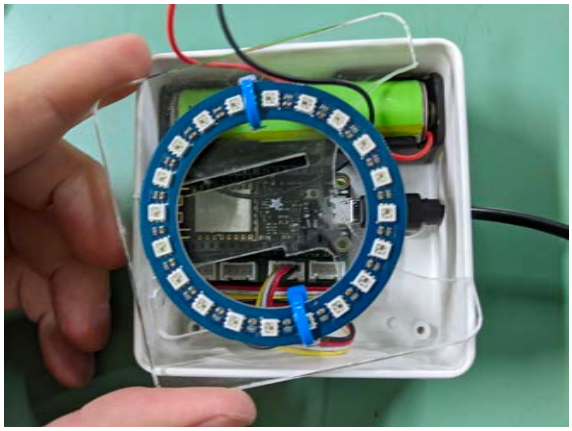
A detailed BOM and links to open source firmware are online at github.com/mitwelten/mitwelten-iot-hardware-poc/blob/main/README.md#lorawan-pax-sensor-node-with-solar-power

We deployed this type of device from April to September, without any maintenance. Note that LoRaWAN network coverage is required to operate this, see *Gateways*.

Actuator Devices

Color LED Pixel

This device uses a LED ring to light up a half-sphere, the black seal is printed in TPU.



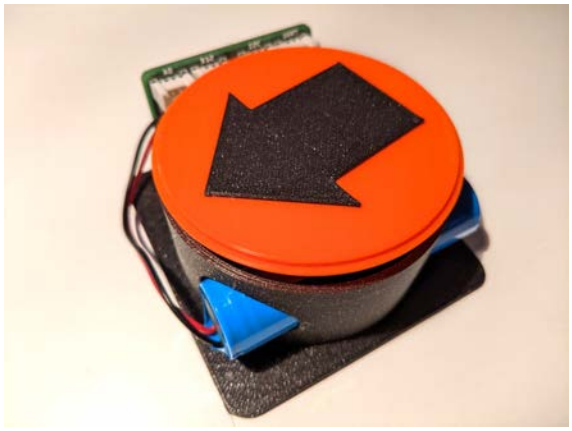
Hardware (work in progress)

Enclosure (work in progress)

A detailed BOM and links to open source firmware are online at github.com/mitwelten/mitwelten-iot-hardware-poc/blob/main/README.md#color-led-pixel

Direction Indicator

This device uses a servo motor to rotate an arrow direction indicator. Not waterproof.



Hardware (work in progress)

Enclosure (w/ fence adapter)

A detailed BOM and links to open source firmware are online at github.com/mitwelten/mitwelten-iot-hardware-poc/blob/main/README.md#direction-indicator

Bluetooth Speaker

This device is a standard portable Bluetooth speaker encased in an AP10 enclosure.

Fixture

Enclosure (w/ Bluetooth speaker)

A detailed BOM is online at github.com/mitwelten/mitwelten-iot-hardware-poc/blob/main/README.md#bluetooth-speaker

Camera Devices

Raspberry Pi 3B+ Streaming Pi Cam v2 with PoE

A Raspberry Pi-based streaming camera with power over Ethernet (PoE).

Hardware (w/ 2cm tube adapter)

Enclosure (w/ lens cover, valve, PoE)

A detailed BOM and links to open source software are online at github.com/mitwelten/mitwelten-iot-hardware-poc/blob/main/README.md#raspberry-pi-streaming-camera-with-poe (Consider the ArduCam-based design below, this design is deprecated.)

Deployed device w/ flower pot to attract pollinators

Applying silicone to PoE plug to stop moisture

Sun damage due to PLA instead of UV-proof ASA

We deployed this type of device from April to September, with lots of maintenance to water plants and adapting the camera focus from time to time due to growing plants. Note that a *PoE Access Point* is required to operate this camera, see *Gateways*.

Focusing a camera using the access point Wi-Fi

Plugging in PoE requires opening this (bad) design

Helper object to prevent broken SD-cards

To fix various issues with this design, we made the adapter more sturdy and changed the PoE plug as well as the fixture. We also upgraded to ArduCam camera modules.

Raspberry Pi Zero Streaming Pi Cam v2 with PoE

Derived from the Pi 3B+ version, using a Pi Zero W with Wi-Fi, no Ethernet, but PoE. This version was designed out of necessity, due to the shortage of Raspberry Pi 3B+. Its hardware turned out to be error prone, probably due to the squeezed PoE adapter and bad Wi-Fi. But the redesigned AP10 adapter worked well and was later reused.

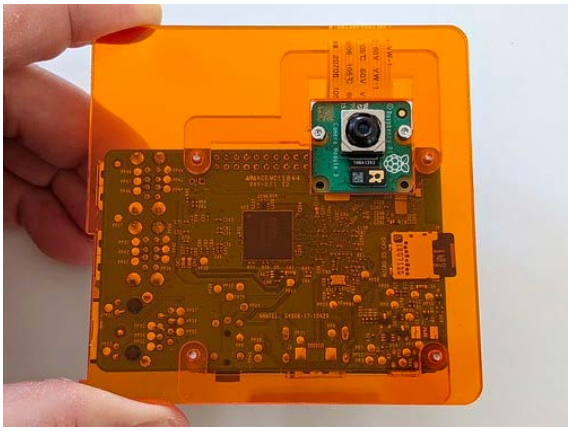
Hardware (w/ Pi Zero, Pi Cam v2, PoE)

Enclosure (w/ adapter, fixture, etc.)

A detailed BOM and links to open source software are online at github.com/mitwelten/mitwelten-iot-hardware-poc/blob/main/README.md#raspberry-pi-zero-streaming-camera-with-poe (Consider the ArduCam-based design below, this design is flawed.)

Raspberry Pi 3B+ Streaming ArduCam with PoE

This design combines the Raspberry Pi 3B+ and PoE shield with the redesigned AP10 adapter, and upgrades the camera to a 16 MP ArduCam with auto focus. A printed TPU rubber seal allows PoE to be plugged in without opening the device.



Hardware (w/ Pi 3B+, fixture, ArduCam)

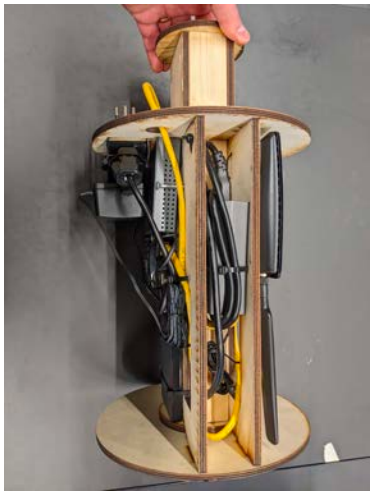
Enclosure (w/ PoE shield, adapter, plug)

A detailed BOM and links to open source software are online at github.com/mitwelten/mitwelten-iot-hardware-poc/blob/main/README.md#raspberry-pi-arducam-streaming-camera-with-poe (This is the recommended design, works with Pi cam v3 as well.)

Gateways

PoE Access Point with 4G Uplink

This Access Point with 4G uplink provides Internet-connectivity via Wi-Fi and PoE. It also houses a Pi 4 with a 2 TB disk to cache photos collected from camera devices.



Fixture with hardware

Workshop result

Cable adapter

A detailed BOM and links to open source software are online at github.com/mitwelten/mitwelten-iot-hardware-poc/blob/main/README.md#wi-fi-and-poe-access-point-with-4g-uplink and there is a #poe-access-point-port-upgrade to add 4 extra PoE ports.

Deployed access point

QR-code for information

Heat management

We deployed multiple gateways from April to September, with very little maintenance. The setup and teardown takes some work, especially digging ditches for cables. We recommend starting at the access point, then work towards the power source. Make sure to mount a plug on each side of the power cable, before plugging anything in. A feature we did not plan for,

but used a lot, is the fact that if the blue cover is removed, the electronics are easily serviceable in the field. Also, the foot is a table for tools.

Up to 8 PoE cameras

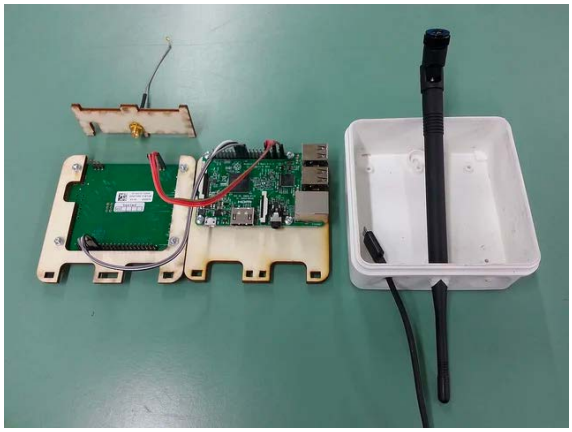
Up to 60 m power cord

One 230V power plug

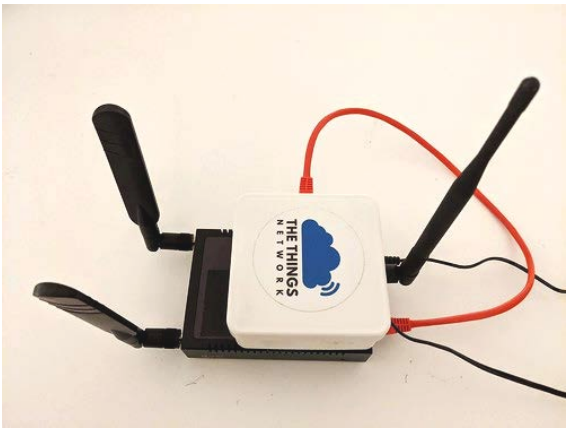
For planning deployments we used the Swiss government's open data map tool (map.geo.admin.ch/) drawing functionality and the *Deploy* app, see *Appendix B*.

LoRaWAN Gateway with 3G Uplink

This LoRaWAN gateway provides Internet-connectivity to LoRaWAN sensor nodes.



Hardware with LoRa concentrator

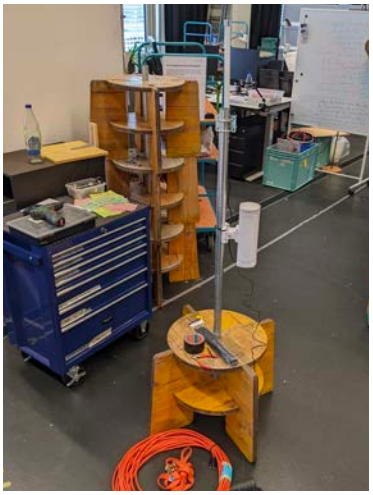
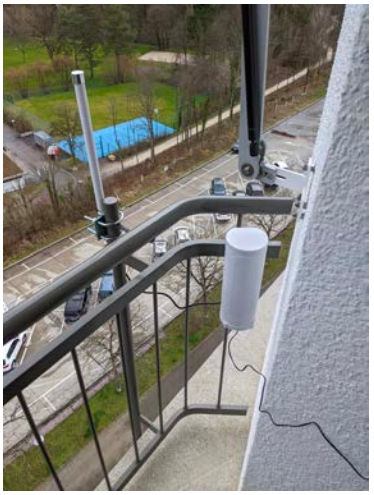


Enclosure connected to 3G modem

A detailed BOM and links to open source software are online at github.com/mitwelten/mitwelten-iot-hardware-poc/blob/main/README.md#lorawan-gateway-with-3g-uplink

LoRaWAN Gateway with 4G Uplink

This LoRaWAN gateway provides Internet-connectivity to LoRaWAN sensor nodes.

		
Hardware (off-the-shelf)	*Mounting option*	*Deployed gateway*

Buy: www.bastelgarage.ch/dlos8n-4g-version-outdoor-multichannel-lorawan-gateway

Schweizerischer Nationalfonds

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