urbisphere

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I4C INTELLIGENCE FOR CITIES

A compact and customisable street-level sensor system for real-time weather monitoring and outreach in Freiburg, Germany

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X4.166

Reader Bar

Background

The Freiburg WSN is a subproject of the ERC project *urbisphere*. With a tight budget and plans for a spatially dense WSN that would allow near real-time data measurements and transmissions, the plan to develop a low-cost WSN ourself was born.

Task

Developing a cost-effective solution for collecting and transmitting sensor data from various sensors to the university data gateway with high measurement and data transmission rates.

Swift - Programming Language

Choosing the appropriate programming language for this project was not easy, as they all have their pros and cons. Eventually, we decided that C++ was best for bare bone programming and Swift was best for the logger software, data management, server and app development.

1st Challange: Power Supply

The plan to power the logger with solar energy failed during feasibility testing. Not only do solar panels require special energy management, but it was not possible to find sufficiently small panels for our power and price requirements. Even if were possible, installing them on public streetlights could lead to legal problems. Therefore, we used batteries and the mains voltage of the streetlights.

2nd Challange: Data Transmission

LoRa? WiFi? GSM? LoRa is widely used and offers low-power data transmission, but it is not very stable and the amount of data that can be transmitted is too small. Public WiFi is not available in Freiburg and Wifi is not suitable for rural areas. GSM was right for us, with shared SIM cards, it was still cheap enough.

Solution

Finally, the developed system:

A Raspberry Pi operated logger software (**uniLog**) combined with a self-developed multi-purpose-logger board (**uniSens**). Remote access, logging and data transfer is handled by a custom server based on *vapor* (**uniServer**). Outreach by the **uniWeather** app.

[1] Freiburg's Weather Sensor Network

Our two-tiered weather sensor network (WSN) aims to map, for example, localised thermal heat stress, heavy precipitation events or air quality spatially resolved across cities at high temporal resolution. Therefore 13 Tier-I and 29 Tier-II stations are installed across Freiburg (Fig. 1).

Installed within the canopy-layer height at ~3 m on city-owned street lights, the stations are capable of resolving intra-urban variabilities and microclimates at the level of people. To quantify the impact of different environments on heat stress, the stations are placed in urban and rural areas (Fig. 2.1, 2.2, 2.3).

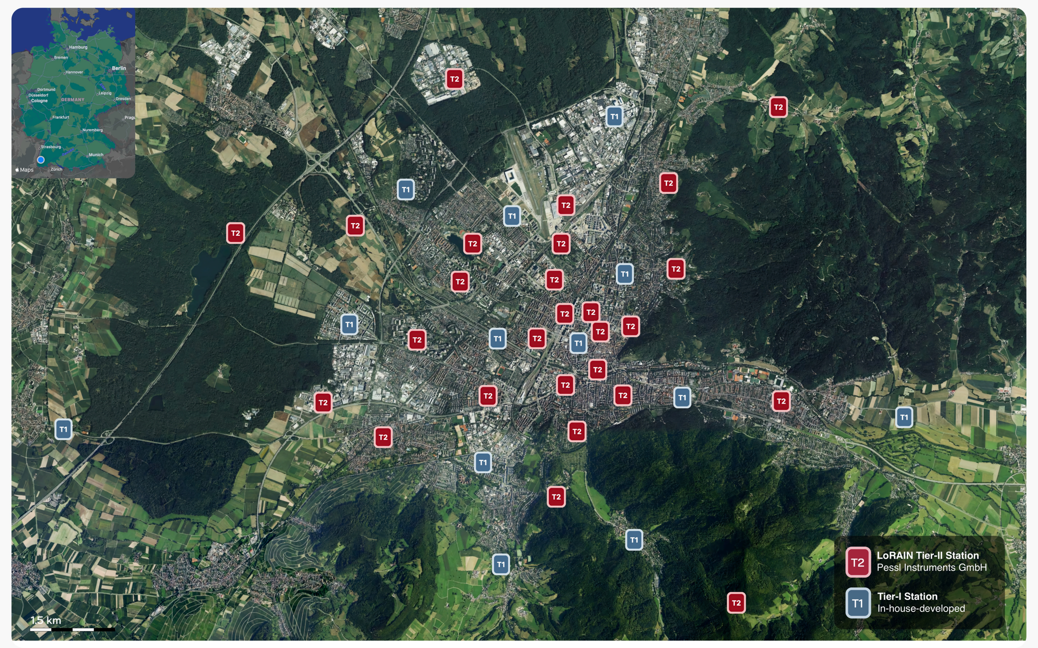


Fig. 1: WSN sites in Freiburg.


Fig. 2.1: Station Hochdorf (Tier-II).


Fig. 2.2: Station Rieselfeld (Tier-I).


Fig. 2.3: Station Dreisam (Tier-I).

[2] In-House Developed Data Logger

Modular? Scalable? Customisable? That's what our custom data logger offers, besides real-time data transmission and remote interaction capabilities. Build with easily obtainable components such as the Raspberry Pi Zero and Arduino; analog, digital and SDI-12 based sensors can be read. Data is stored in the onboard data storage system and transmitted via LTE to a server (Fig. 3).

Fig. 3: "uniSens-Light" logger parts, field-deployed logger, logger-box rendering, PCB-test.

[3] uniWeather App

The *uniWeather* app (iOS) allows for near-realtime data access and interpretation for stakeholders and public outreach. Different visualisation types and variables can be selected for the last 5 min and 24 h (Fig. 4.1, 4.2, 4.3). This system is open to be used by other groups for their data visualisation.

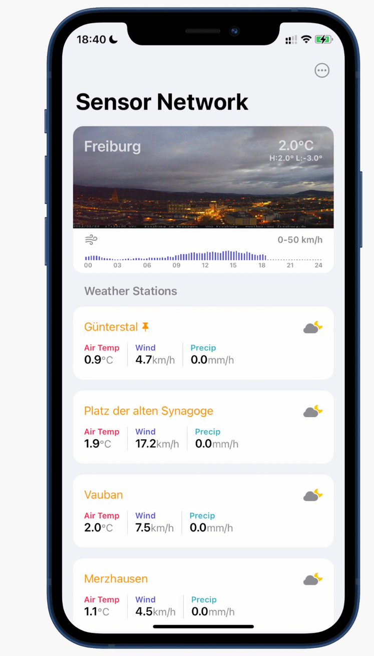


Fig. 4.1: Landing page.

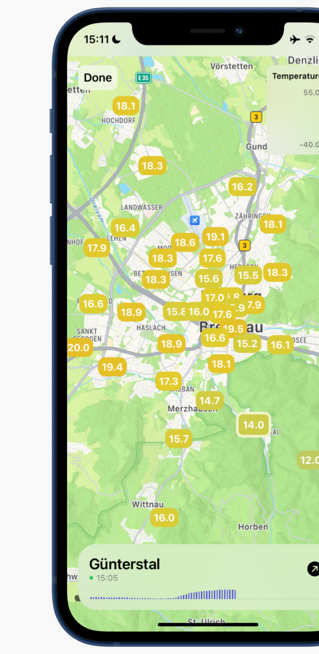


Fig. 4.2: Map view.

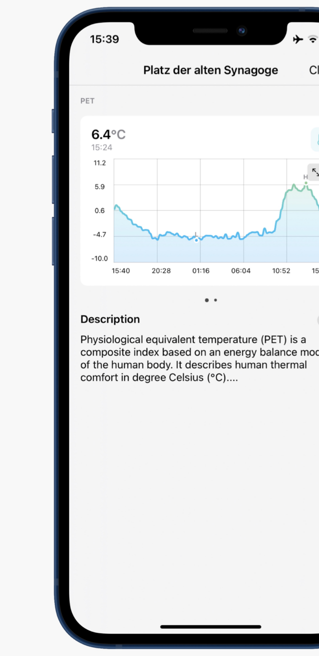


Fig. 4.3: Chart view.

[4] Network Development

The developments were based on experiences from the previous Berlin campaign, where a similar logger system was needed. While the hardware was developed quickly, software developments and logger-production (delayed due to global supply shortage) took most of the time (Fig. 5).

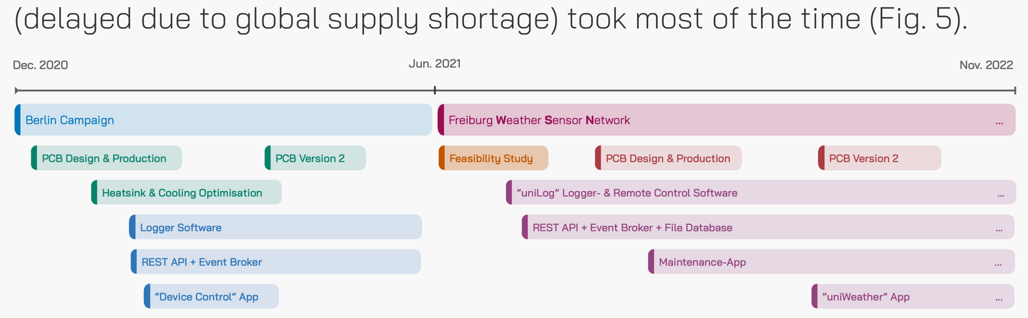
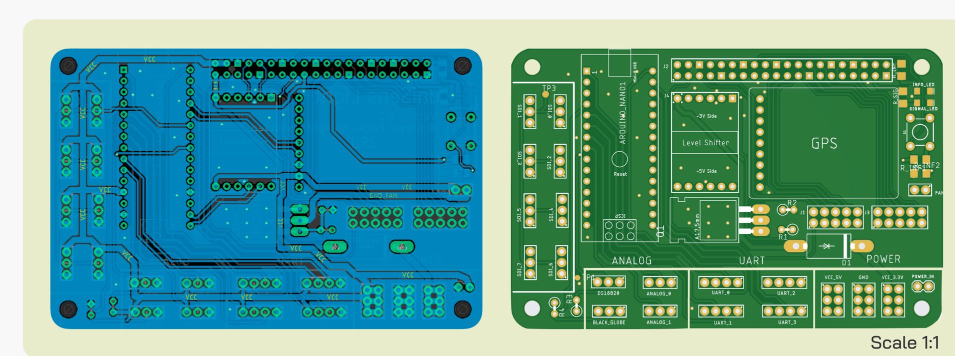


Fig. 5: Development timeline.

[5] The PCB

The heart of the Logger is the **P**rinted **C**ircuit **B**oard (PCB). Soldering the components on perfboard is not efficient and would take too long, but thanks to an Asian company that allows to produce PCBs cheaply and in small quantities, we were able to quickly manufacture professional logger boards. The PCB lay-out and Gerber view is shown in Fig. 6.



Design Rules

- Easy to obtain components
- Completely dismountable
- User friendly
- Cheap & Fast

Sensors

Supported Protocols:
- SDI-12
- UART/Analog
- SPI, I2C
- Voltage: 3.3V, 5V

Interaction

One LED for measurement cycle indication and one for light patterns. The button triggers events such as starting or ending a maintenance cycle.

Fig. 6: PCB overview.

[8] Thermal Comfort

Human thermal comfort can be expressed by indices such as **P**hysiological **E**quivalent **T**emperature (PET) or **U**niversal **C**limate **T**hermal **I**ndex (UTCI). The heatmap in Fig. 9 shows the hourly mean PET for Freiburg since August 2022, with extreme values ranging from -14°C to +41°C. The recorded values are also used to validate high-res deep learning models of urban thermal comfort; see the map showing the hours per year with an UTCI >= 32°C in 1x1 m resolution (Fig. 10).

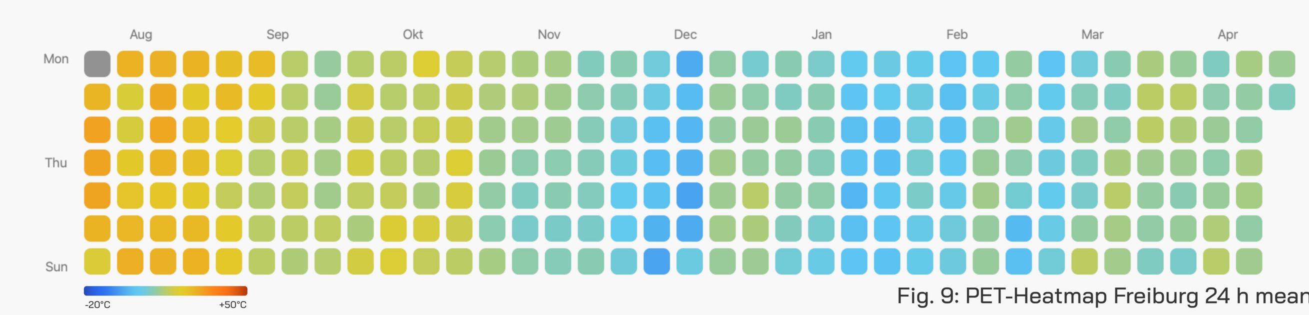


Fig. 9: PET-Heatmap Freiburg 24 h mean.

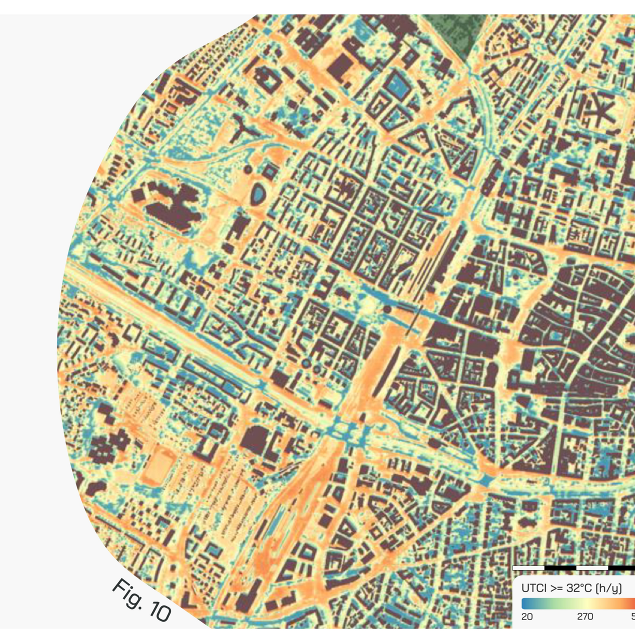


Fig. 10

[6] The Backend

Real-time data transfer and interaction have very different backend requirements that a non-event-driven data server cannot meet. So we developed an event-driven backend unit that uses custom TCP and WebSocket APIs for communication (left box). Since we already have a data management system (under active development), we have developed a server-to-server communication interface and linked the two systems. The custom backend was built using vapor, a powerful and easy-to-use open source Swift framework. Both systems run behind an Nginx reverse proxy (Fig. 7). Right box described in poster X5.113.

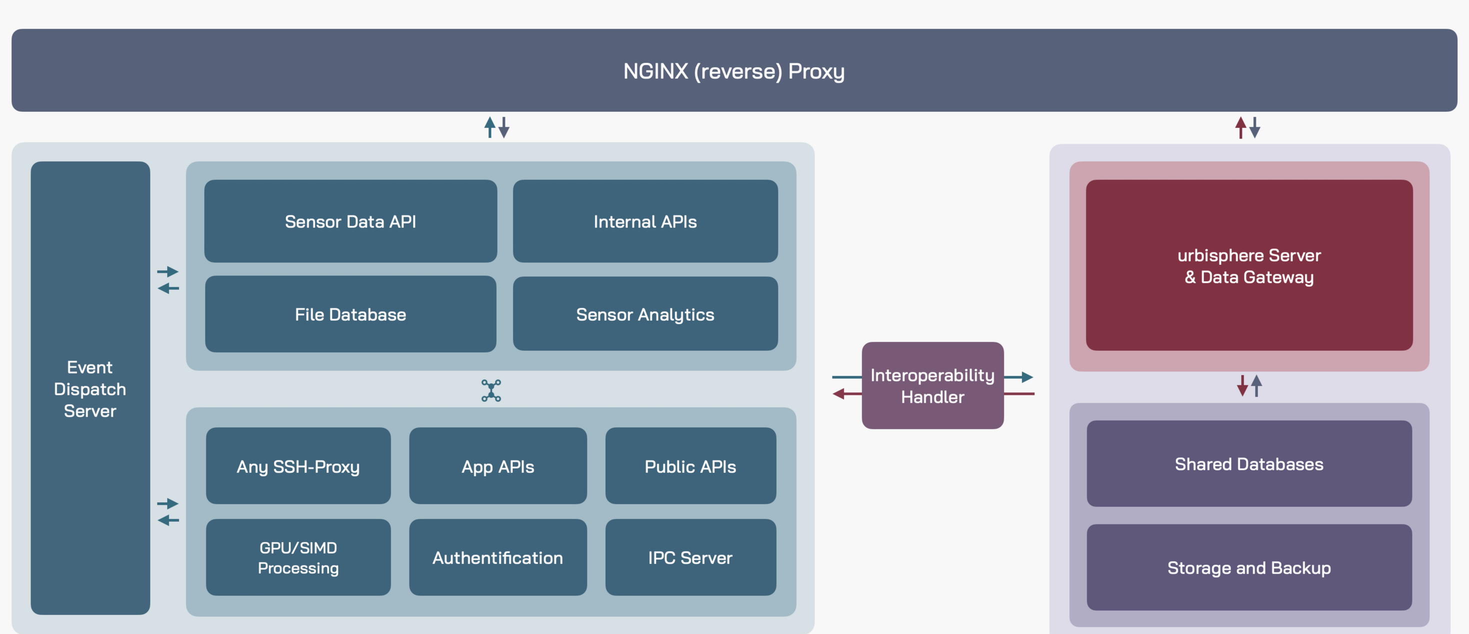


Fig. 7: The two data backends.

[7] Logger Software

"uniLog 32-Bit" is the logger, remote interaction and data management software running on the Pi Zero. It's modularity allows to add sensors on the fly. Software updates can be provided remotely. Accessing local resources like UART remotely or requesting data for a certain day from the local data storage system can be done via the bidirectional task distribution system.

The software is designed to run as a deamon but also features a rich user interface for command-line use (Fig. 8).

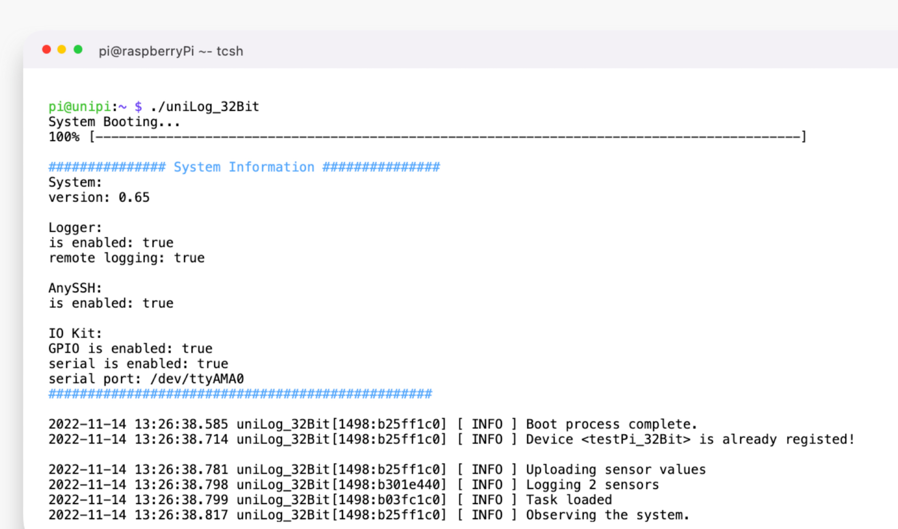


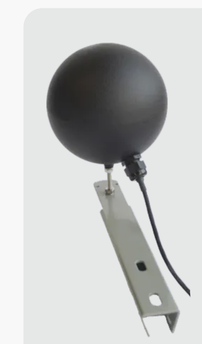
Fig. 8: *uniLog 32-Bit* Terminal.

[9] Measured Variables

In addition to **air temperature**, **humidity** and **precipitation**, measured by the Tier II stations, the Tier-I stations provide data on **wind**, **pressure**, **lightning**, **solar radiation** and **black globe temperature**. From these, other meteorological and biometeorological variables are calculated. Measuring thermal radiation is necessary to calculate thermal indicators such as the PET from above.

ClimaVUE 50

Small mid-cost all-in-one weather station developed by Campbell Scientific Inc., offering wide range of variables. Data transfer via SDI-12. (Fig. 11)



Black Globe

15 cm large black painted hollow copper sphere, developed by Campbell Scientific Inc. Measures thermal radiation analog. (Fig. 12)

[10] Take Home Message

Our in-house developed Tier-I Weather Sensor Network (WSN) is a cost efficient and modular system, which is easily scalable to gather realtime data of, e.g. thermal heat stress, for cutting edge science and early warning systems.

The system deployed consists of 4 parts (see Fig.3-8): uniLog, uniSense-Light, uniServer, and uniWeather app (see barcode).

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[11] Acknowledgement

This work was funded by the European Research Grant (ERC) and the German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection.

References

[1] Fig. 11 -> https://campbellsci-res.cloudinary.com/image/upload/c_limit,f_auto,w_500,h_500/10866.png

[2] Fig. 12 -> https://campbellsci-res.cloudinary.com/image/upload/c_limit,f_auto,w_500,h_500/2837.png

Available on the App Store