urbisphere

universität freiburg

European Research Council

I4C INTELLIGENCE FOR CITIES

One year data of a customisable real-time weather monitoring system at street level, with public outreach in Freiburg, Germany

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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

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.

Challange: 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).

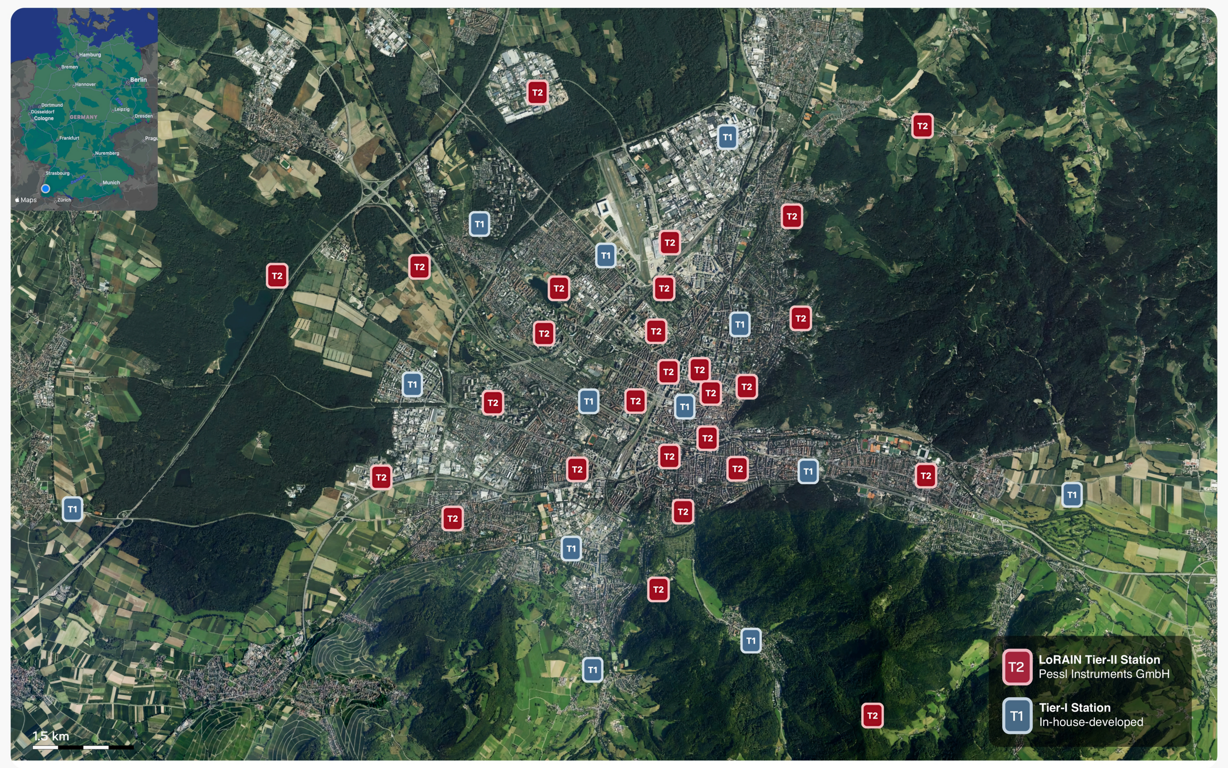

Fig. 1: WSN sites in Freiburg.

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).

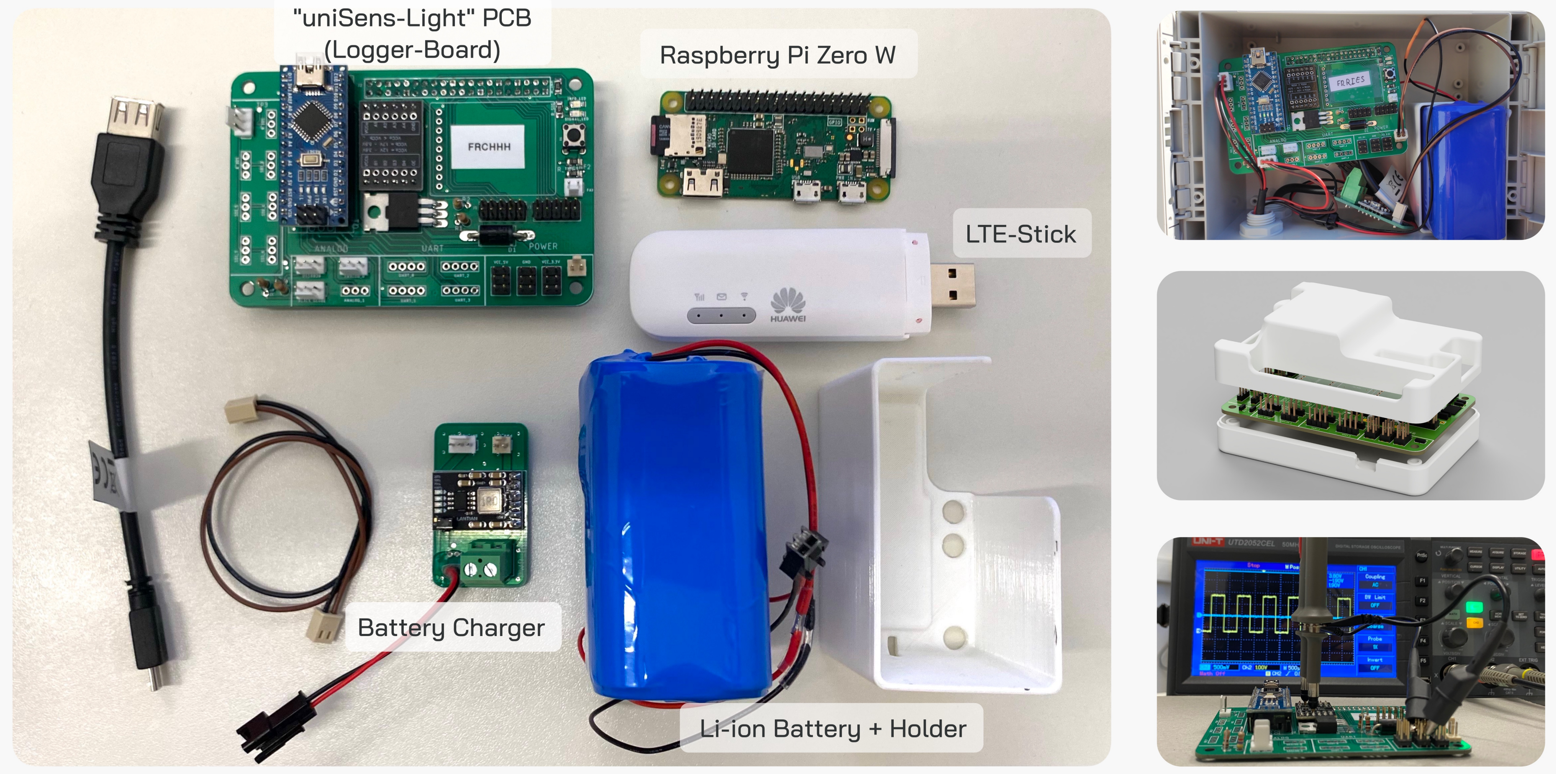

Fig. 3: "uniSens-Light" logger parts, field-deployed logger, logger-box rendering, PCB-test.

[3] First Data

Human thermal comfort can be expressed by indices such as Physiological Equivalent Temperature (PET). The time series heat-map in Fig. 4 shows the 10 min avg. mean PET for Freiburg since August 2022, with extreme values ranging from -14°C to +45°C and local extremes of -16°C and 48°C, both recorded outer-city. While cold-stress is mainly experienced during DJF, heat stress with values persistently exceeding 30°C is experienced during MJJA. In addition, the data is used to validate high-res deep learning models of urban thermal comfort.

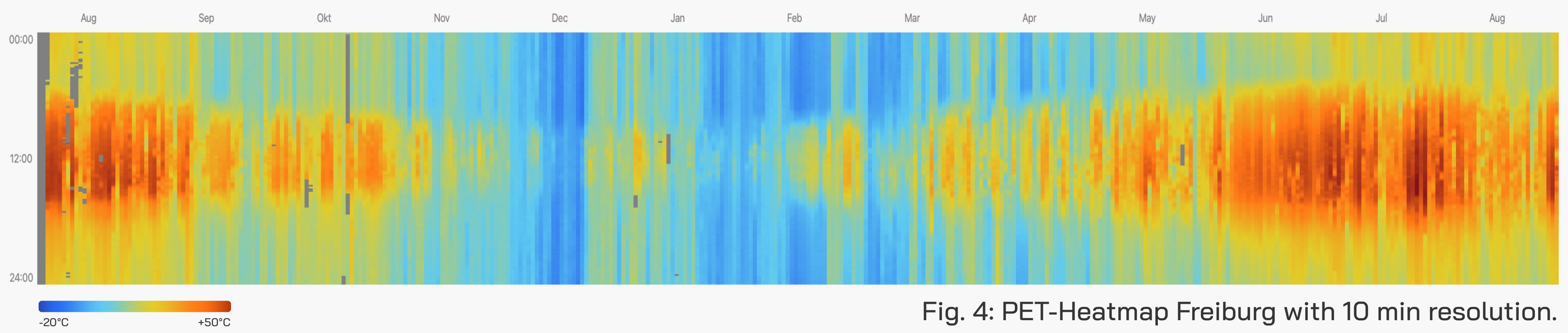

Fig. 4: PET-Heatmap Freiburg with 10 min resolution.

[4] Spatial Coherence

Visualised in Fig. 5, the one year data averaged to 10 min confirms that all stations follow the same seasonal trend despite local deviations. Strongly urbanised sites like FRPDAS show generally higher average temperatures but lower variance than outer-city or rural ones, suggesting city infra-structure to mitigate temp-erature and moisture fluctuations. Consistently, PET variability is higher than Ta and tends to vary most in JJA and least in DJF.

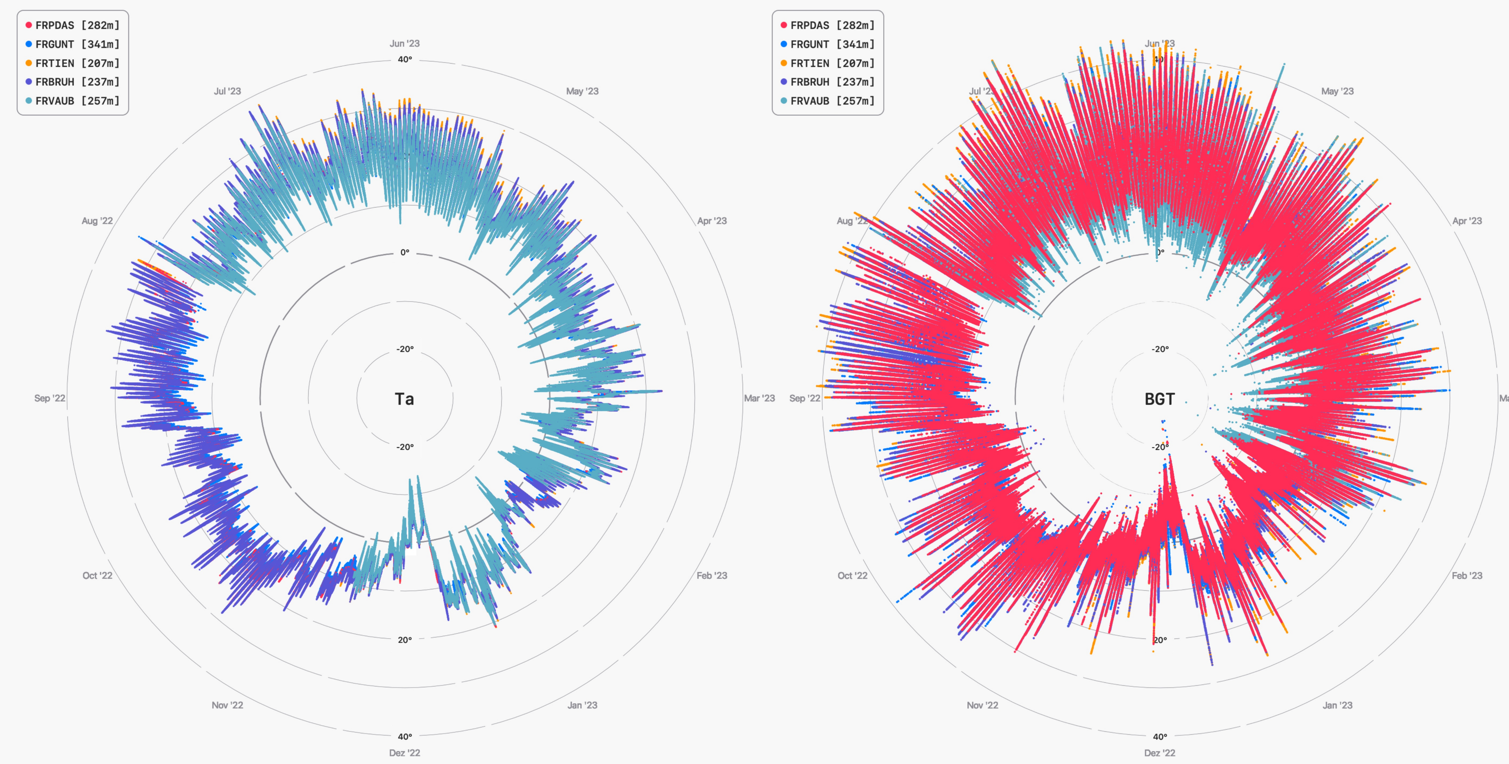

Fig. 5: Radial plots of Ta (left) and PET (right) showing one year 10 min res data of five stations.

[5] uniWeather App

The *uniWeather* app (iOS) allows for near-realtime data access and interpretation for stake-holders and public outreach. Different visualisation types and variables can be selected for the last 5 min and 24 h (Fig. 6.1, 6.2, 6.3). This system is open to be used by other groups for their data visualisation.

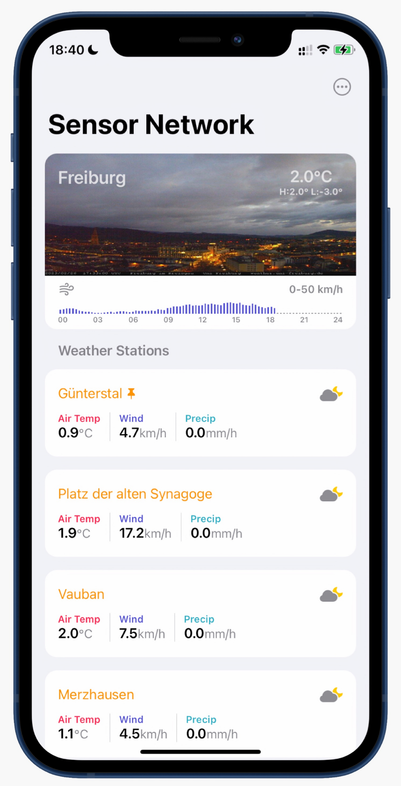

Fig. 6.1: Landing page.

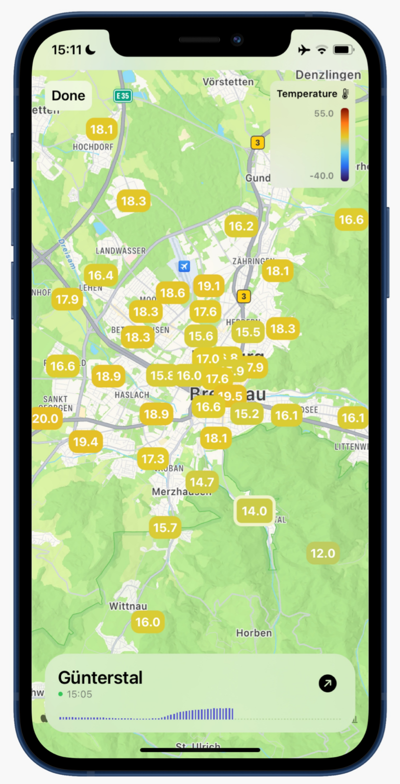

Fig. 6.2: Map view.

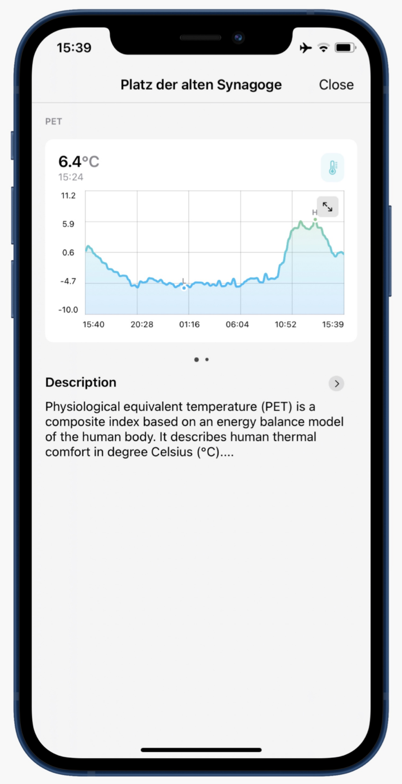

Fig. 6.3: Chart view.

[6] 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.

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. 7)

Black Globe

15 cm large black painted hollow copper sphere, developed by Campbell Scientific Inc. Measures thermal radiation analog. (Fig. 8)

[7] 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 with minimal data loss (<1%), of e.g. thermal heat stress, for cutting edge science and early warning systems.

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[8] Acknowledgement

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