Assignment 2

Dew Point Generator Controller and Sensor Data Logger

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Intro

This report documents the design and implementation of an embedded system developed to serve as both a scientific data logger and a smart interface with an analogue dew point generator. The system utilizes the RP2040 microcontroller and various sensors, including SDI-12 environmental sensors and a load cell, to collect and process data for use in climate modelling applications. The project aims to provide a reliable and efficient solution for monitoring and controlling environmental parameters, particularly in the context of research on tropical plant behaviour under varying climate conditions.

The LI-610 Dew Point Generator is a precision instrument designed to produce a stable stream of gas with a precisely controlled dew point. It uses Peltier thermoelectric coolers to regulate the temperature of water reservoirs, ensuring the air stream is fully saturated with water vapor. This precise control of dew point is critical in environmental research, as it helps prevent condensation inside climate-controlled chambers, which could disrupt experimental conditions and data accuracy.

Accurate and continuous monitoring of environmental parameters is essential for tropical plant research, but traditional data collection methods are labor-intensive and prone to error. Moreover, physical presence in climate-controlled rooms can disturb experimental conditions. Commercial solutions like those from Campbell Scientific are often expensive and use closed-source technology, limiting accessibility and customization options for researchers. This project addresses these limitations by providing an open-source, cost-effective alternative that enables remote monitoring and control of environmental parameters. By integrating various sensors and offering a smart control interface for the dew point generator, the system allows researchers to simulate different climate conditions and monitor plant responses without entering the controlled environment, ensuring data integrity while maintaining flexibility and affordability.

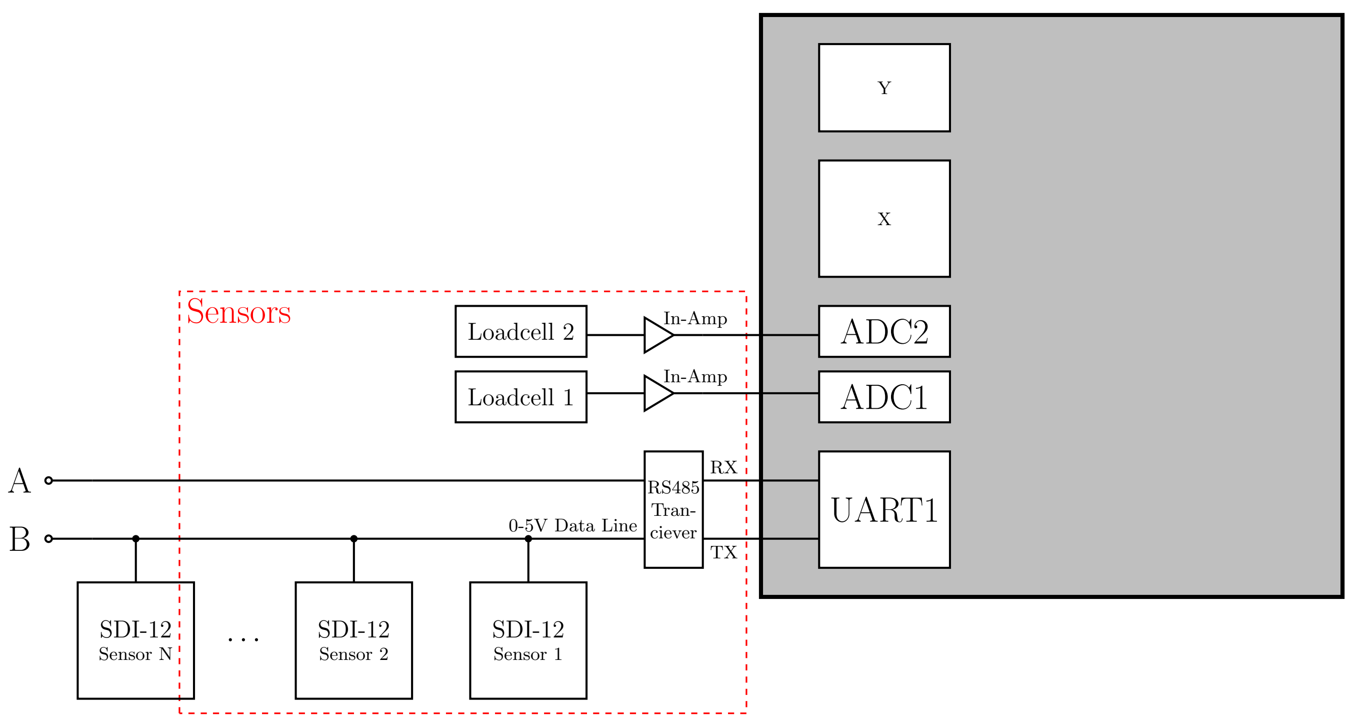

Fig. 1. Block diagram of the system

System Design Overview

The system was designed around the RP2040 microcontroller, acting as the central processing unit for interfacing with a variety of sensors and control devices. The design incorporates the SF-5M sap flow sensor, LT-1T leaf temperature sensor, and MT-603 load cell to measure various environmental parameters. Each of these sensors uses different communication protocols, requiring careful consideration of power requirements, signal integrity, and communication compatibility.

.... As seen in fig. 1, the system consists of

Hardware Design

Load Cell and ADC Integration: The MT-603 load cell required an ADC (Analog-to-Digital Converter) for signal conversion, as its output is an analog signal representing weight measurements. One of the RP2040's ADC pins was utilized to convert the load cell's voltage output into a digital signal that the microcontroller could process. This ADC integration allowed for precise scaling and calibration of the load cell to achieve accurate data representation.

SDI-12 Sensors and Communication Interface: The SDI-12 protocol was used because it is the standard communication protocol for the environmental sensors (Sap Flow Sensor and Leaf thermistor) integrated into this system. However, SDI-12 differs from typical UART communication in that its bit values are inverted. To address this, the project leveraged the RP2040's UART capabilities in conjunction with an RS485 transceiver, using only the B line of the differential pair to handle the inverted logic levels. By setting the voltage reference at 2.5V, the design effectively mapped the inverted SDI-12 signals to conventional UART high and low values, allowing reliable sensor communication.

Power Supply and Voltage Regulation: Due to the diversity of communication protocols and components used in the system—such as ADC for the load cell, SDI-12 for sensors, and I2C for the DAC—multiple voltage levels were required on the PCB: 12V, 5V, and 3.3V. Each voltage level was supplied through dedicated regulators to ensure stable power delivery to each module. The careful placement of decoupling capacitors was critical to minimize voltage ripple and noise, ensuring stable operation of the entire system.

Data Logging and Storage: An SD card module was added to the schematic, utilizing the SPI interface as defined in the RP2040 datasheet. This module enabled reliable data storage and allowed easy access to logged data for further analysis.

DAC Integration: The MCP4716 DAC was integrated to provide fine-grained control of the dew point generator. Proper bypass capacitors were placed near the Vdd pin to minimize induced noise and ensure stable operation.

An initial approach to converting a digital signal to an analogue signal was Pulse Width Modulation (PWM). However, this method proved unreliable and inaccurate when tested with a Raspberry Pi Pico. As a result, a digital to analogue converter (DAC) was selected instead.

Software Design

Sensor Data Acquisition: Custom drivers were developed for each sensor, adhering to the SDI-12 protocol. Specific issues with the byte framing of the SDI-12 protocol were addressed by using the `uart_set_format()`

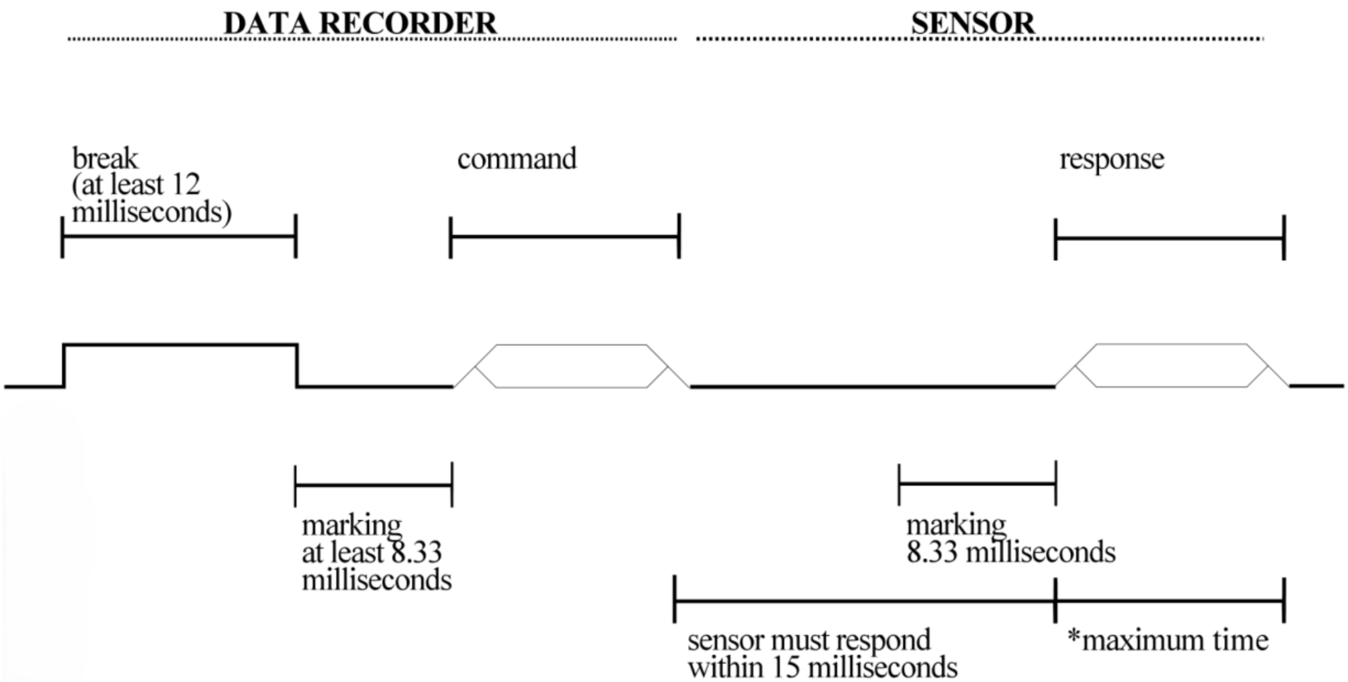

Fig. 2. SDI-12 timing from SDI-12 Support Group (2019)

function to configure the communication format correctly, allowing the RP2040 to receive the inverted data without additional circuitry. We used the `uart_break()` function to send the break signal, and then used the `uart_read_stuff()` function to read the response from the sensor. The response was then parsed to get the data. The timing of the SDI-12 protocol is shown in fig. 2.

Data Storage: The FatFs API was integrated to enable read/write operations on the SD card, using the SPI protocol. This allowed for structured data logging and easy retrieval of information.

Control Interface: A software interface for controlling the dew point generator was implemented using the I2C protocol to communicate with the DAC. This interface allowed precise voltage adjustments to the generator, with preliminary tests confirming accurate output predictions based on command inputs.

The careful selection of communication interfaces and voltage levels, along with robust software integration, allowed the system to operate seamlessly and efficiently, providing a reliable solution for monitoring and controlling environmental parameters.

Components

Section can be completely renamed/utilized

Technical Challenges and Solutions

SDI-12 Sensor Communication Issues

During the testing of the SDI-12 sensors, initial attempts to communicate using RS485 transceivers failed due to improper framing of byte streams. The strict timing requirements of the SDI-12 protocol made it difficult to achieve reliable communication using standard UART settings. This issue was addressed by applying the `uart_set_format()` function, which allowed the RP2040 to handle the SDI-12 protocol's timing more accurately. Additionally, a `custom is_timed_out()` function was created to automate character reception without using traditional sleep methods, ensuring precise byte timing and avoiding data loss during transmission.

Load Cell Signal Scaling and Stability

The MT-603 load cell exhibited a significant dead zone and provided inconsistent readings due to mechanical vibrations in the experimental setup. Software-based noise reduction techniques, such as averaging past data points, were implemented to mitigate the effect of oscillations. This software solution was preferred over hardware filtering due to the constraints of the existing apparatus.

I2C Bus and DAC Communication Issues

During the process of getting the DAC functioning, software implementations from GitHub were tested, but scanning the I2C bus showed no devices detected. This pointed to a hardware issue. Upon further inspection, it was discovered that the SDA and SCL pins were swapped on the RP2040, and the pullup resistors for the DAC were incorrectly sized. To address this, the traces were manually cut and resoldered to correct the pin connections. Smaller pullup resistors (initally through-hole but eventually surface-mount) were also added to compensate for the track capacitance, which had caused the rising edges of the clock signal to appear more triangular than square. After these modifications, the I2C bus functioned correctly, and basic software confirmed the DAC's operation. This highlighted the importance of thoroughly reviewing the final PCB layout before submission, as the initial errors could have been avoided.

Discussion

We discuss.

Conclusion

We conclude.

Appendix

References

SDI-12 Support Group, *SDI-12: A Serial-Digital Interface Standard for Microprocessor-Based Sensors*, SDI-12 Support Group, River Heights, Utah, Jan. 2019, version 1.4. [Online]. Available: http://www.sdi-12.org