Closed-Loop Feedback Control System for EXOhSPEC Development

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INTRODUCTION

- **EXOhSPEC,** the Exoplanet High-Resolution Spectrograph
- Focus on high-resolution spectrometry and precise radial velocity measurement
- Noteworthy features: bifurcated fiber for simultaneous telescope and Thorium Argon input
- Crucial for precise wavelength calibration
- IDS3010 Displacement Measuring Interferometer provides picometer-level displacement measurements. Integration of additional sensors: BME680 for pressure and humidity, PT104 for temperature
- Design prioritizes efficiency by minimizing optical components. Spectrograph achieves a resolution of ≥ 70,000
- Project targets environmental stability with a designed control system
- Utilizes off-the-shelf sensors in a feedback loop to calibrate the spectrograph
- Represents an innovative leap in stability optimization. Compact, low-cost, and efficient high-resolution spectrograph.

METHODOLOGY

The key steps in the closed-loop feedback control system:

1. **Initiation:**
   - Begin the process, using the web interface, which will send commands to the system to start.
2. **Data Acquisition:**
   - Source: Thorium Argon Lamp, Sun, or a Star.
   - Measure displacement and environmental parameters using the Interferometer and BME680, respectively using Python.
3. **Sensor Data Processing:**
   - Combine the Interferometer and BME680 data.
   - Send integrated data to the Control Unit.
4. **Spectrograph Calibration:**
   - Adjust Spectrograph settings based on integrated sensor data.
   - Transmit calibration commands.
5. **Spectral Data Reception:**
   - Obtain spectral data.
6. **Feedback Loop:**
   - The feedback loop runs faster than the spectrograph readout
   - Needs calibration.
   - Evaluate calibration success.
     - If successful, repeat data acquisition.
     - If not, adjust calibration and repeat the process.
7. **Conclusion:**
   - End the process after desired iterations.

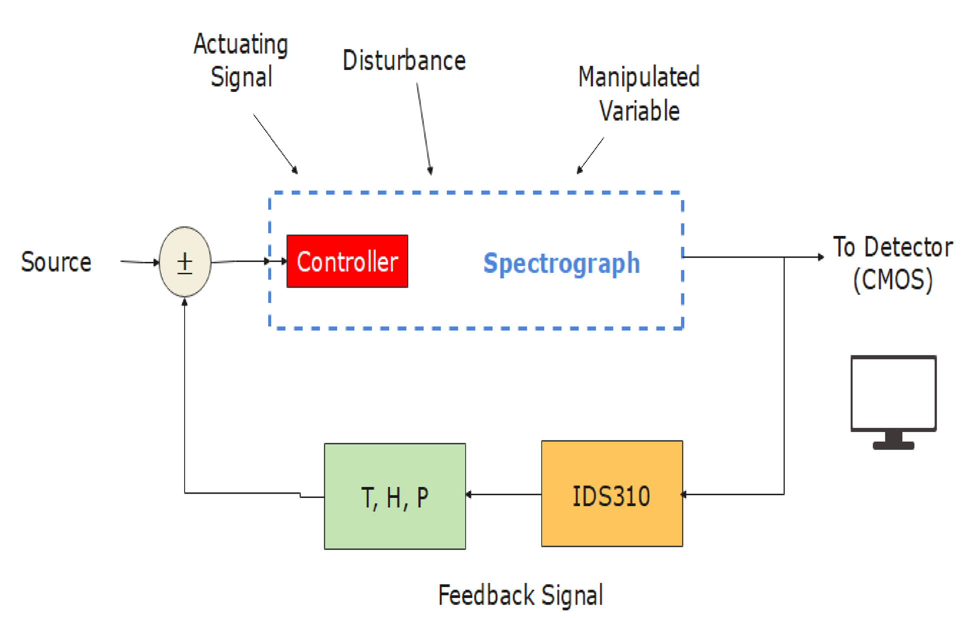


Fig. 1. Schematic Block Diagram of the Spectrograph Control Feedback System

KEY MILESTONES

PHASE 1: Equipment Orientation and System Introduction — Completed
- Familiarize with system components, and execute basic code for IDS using Python language

PHASE 2: Closed-Loop Feedback System Development — In Progress
- Establish the foundation for the closed-loop system using IDS, BME680, and Peltier 101
- Integrate BME680 with ESP8266, design a webpage interface, and implement refractive index correction.

PHASE 3: System Integration and Optimization — Next Steps
- Assemble the integrated setup and conduct preliminary tests.
- Precisely calibrate optical components, implement Nano-HS3M, and conduct experiments for system validation.

PHASE 4: Advanced Integration and Testing
- Subject the system to environmental robustness testing.
- Enhance interferometer configuration, refine calibration, and conduct extensive testing with various light sources.

Fig. 2. XYZ precision piezo nano-positioning system with picometer positioning resolution, Nano HS3M

EXPERIMENTAL SETUP

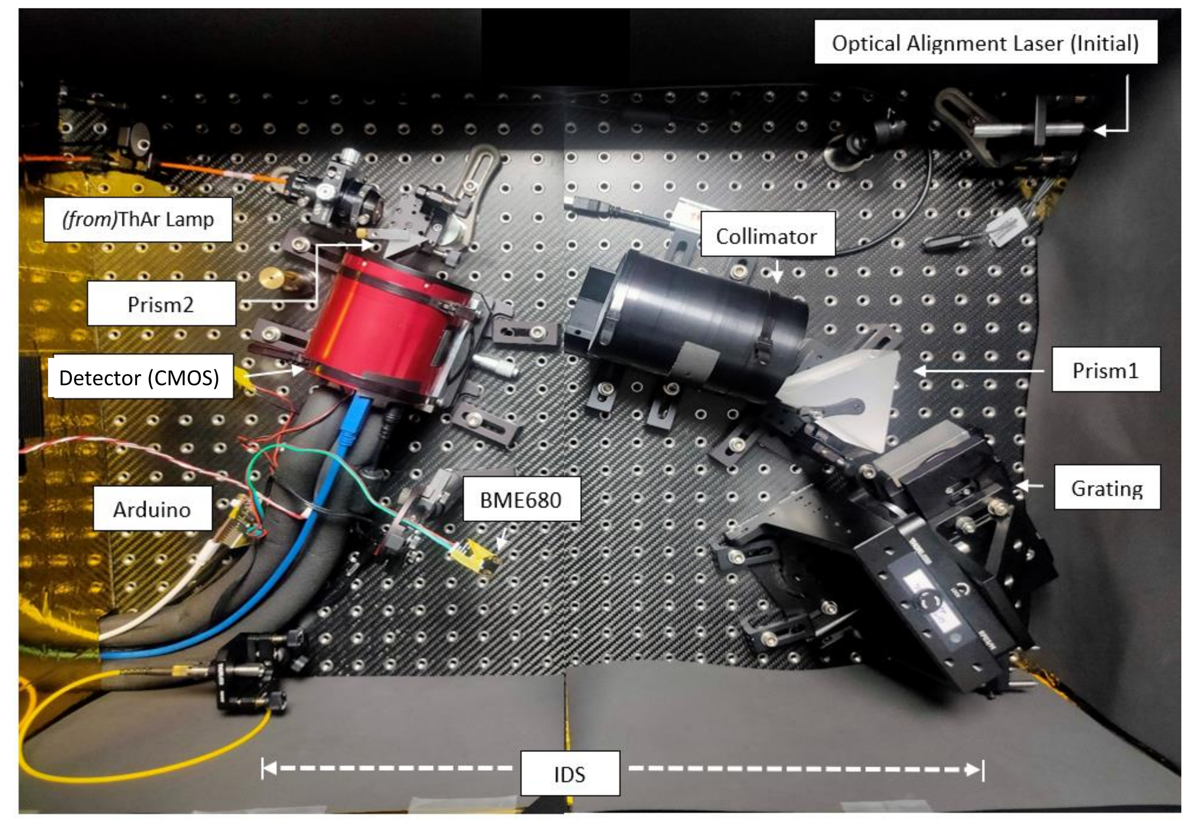


Fig. 3. Internal structure of the Modified EXOhSPEC along with IDS and BME680 integrated

Overview of Spectrograph Operation:

- **Light Source:** Utilizes a Thorium Argon lamp as the primary light source.
- **Multimode Fiber:** Channels emitted light through a multimode fiber.
- **Collimator:** Collimates incoming light, directing it to Prism 1.
- **Prism 1:** Disperses the light spectrum onto the grating for wavelength orders.
- **Grating:** Diffract light in many Spectral orders.
- **Collimator Lens:** Focuses the dispersed light.
- **Prism 2:** Focuses the spectrum onto the CMOS detector.
- **CMOS Detector:** Captures the spectral characteristics of the incoming light.

Key Components of the Overall System:

- **Spectrograph:** Optical instrument for high-resolution spectral analysis.
- **IDS 3010 Displacement Sensor**: Precision interferometric sensor for picometer-level environmental compensation.
- **BME680** with **NODEMCU ESP8266:** Real-time monitoring of temperature, humidity, pressure, and altitude. ±1.0 ° C temperature accuracy, ±3% humidity accuracy, ±0.6 hPa pressure accuracy.
- **PT-104 Temperature Sensor:** Peltier-based sensor with 0.001°C resolution and 0.015°C accuracy for precise temperature measurements.

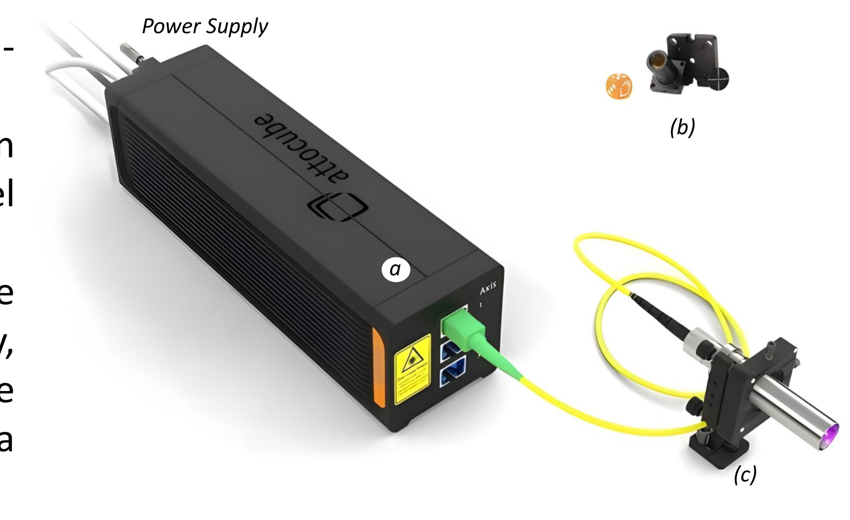


Fig. 4. (a) IDS including Accessories, (b) Sensor head selection and alignment simplified with advanced mounting kits, (c) Optical items: glass target, plane mirror, and retroreflector

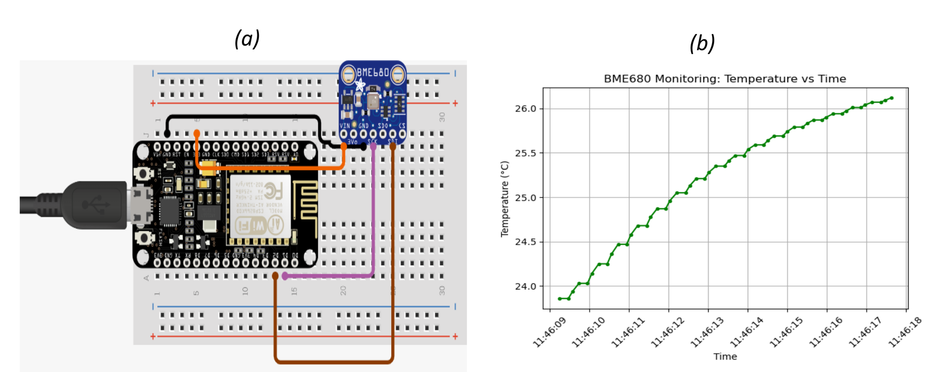


Fig. 5. (a) Circuit Design of Nodemcu ESP8266 along with BME680 sensor (b) Temperature (°C) vs Time

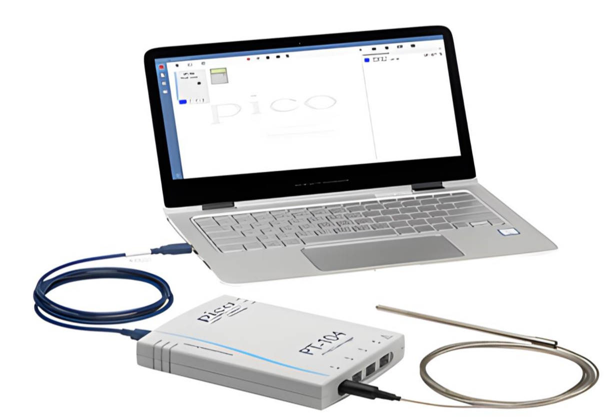


Fig. 6. Peltier-104 Temperature Sensor connected with a probe to computer

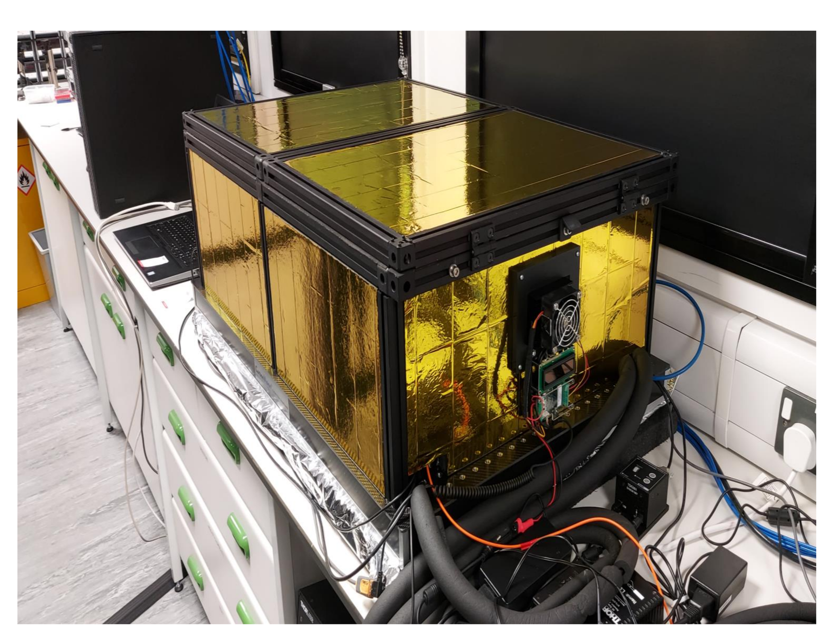
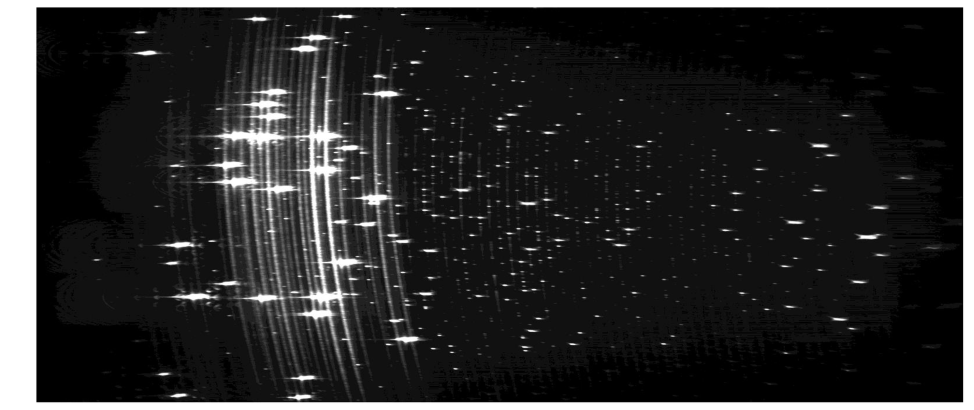


Fig. 7: The system's outer box is positioned on a carbon fibre breadboard.

Fig. 8. Modified protective box designed to shield the system from environmental factors, primarily focusing on temperature control.

PRELIMINARY RESULTS



Spectrum of Thorium Argon Lamp (Image on left) **:**

- Captured Spectral Data: Bright Lines indicate the Argon Emission Lines in the near-infrared.
- Exposure Time: The spectrum is acquired with a 1-minute exposure, enabling a detailed and comprehensive analysis of the lamp's emission characteristics.

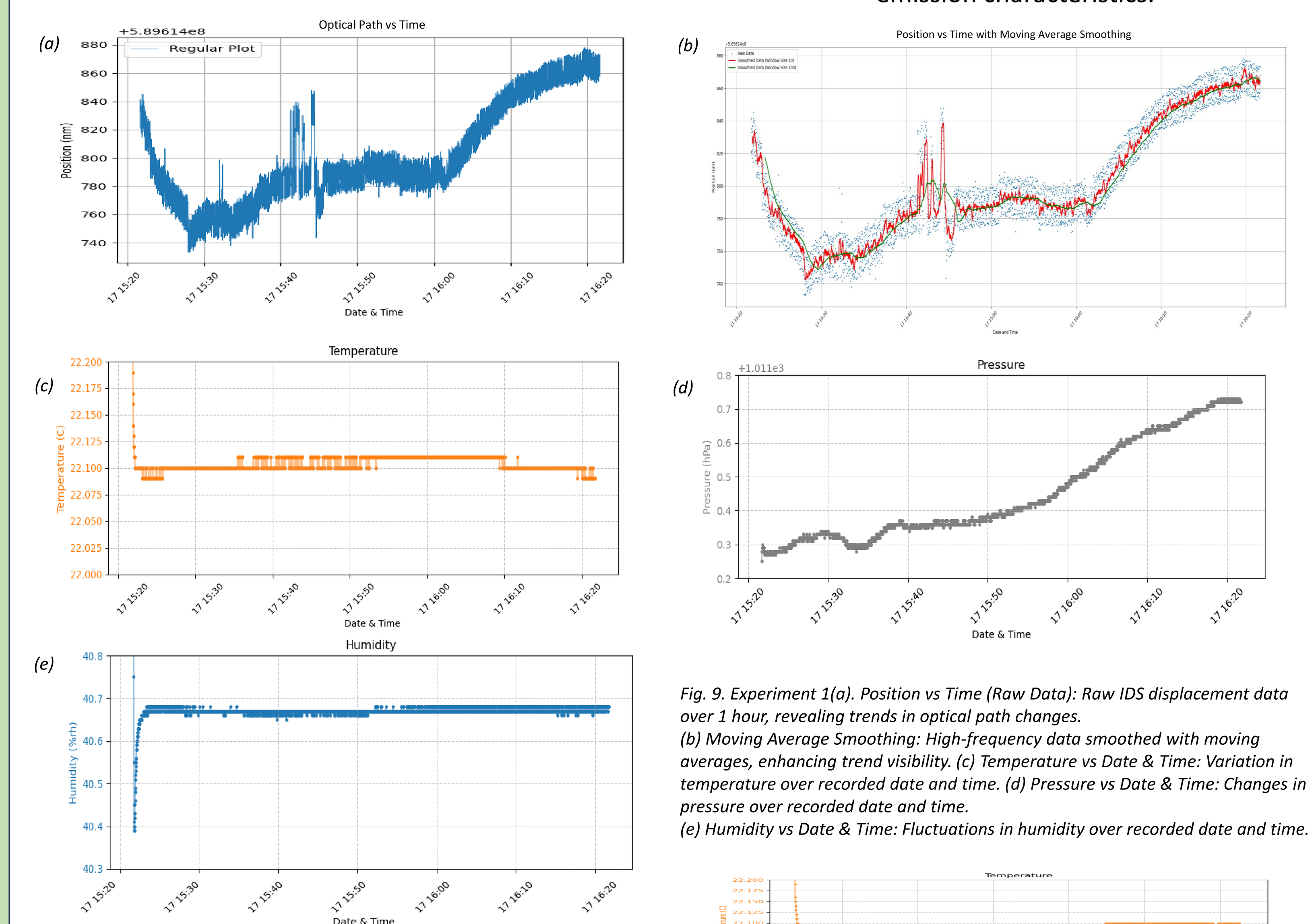


Fig. 9. Experiment 1(a). Position vs Time (Raw Data): Raw IDS displacement data over 1 hour, revealing trends in optical path changes. (b) Moving Average Smoothing: High-frequency data smoothed with moving averages, enhancing trend visibility. (c) Temperature vs Date & Time: Variation in temperature over recorded date and time. (d) Pressure vs Date & Time: Changes in pressure over recorded date and time. (e) Humidity vs Date & Time: Fluctuations in humidity over recorded date and time.

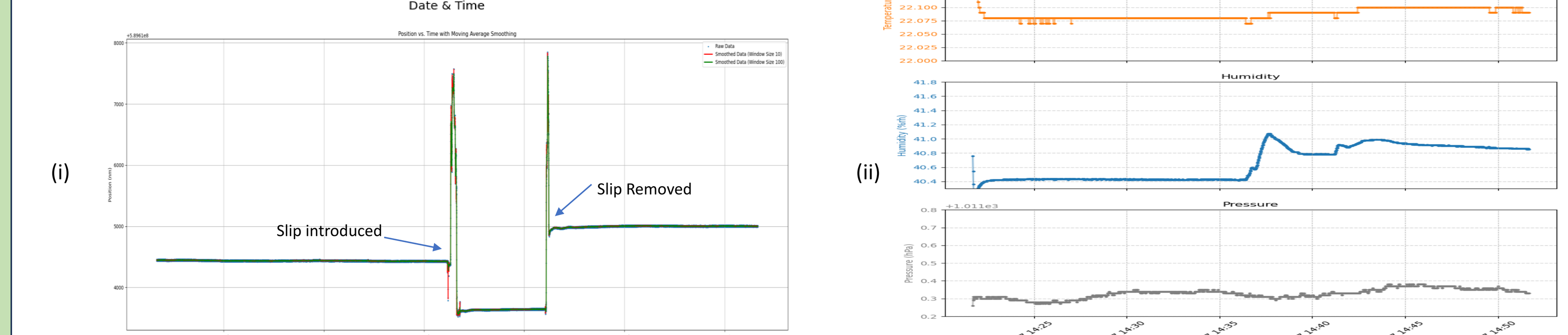


Fig 10. Experiment 2(i). Slip Width Variation: Introduces a glass slip of thickness 0.12-0.16mm, highlighting its impact on the experimental setup. (ii) Along with, Environmental parameters variations over time

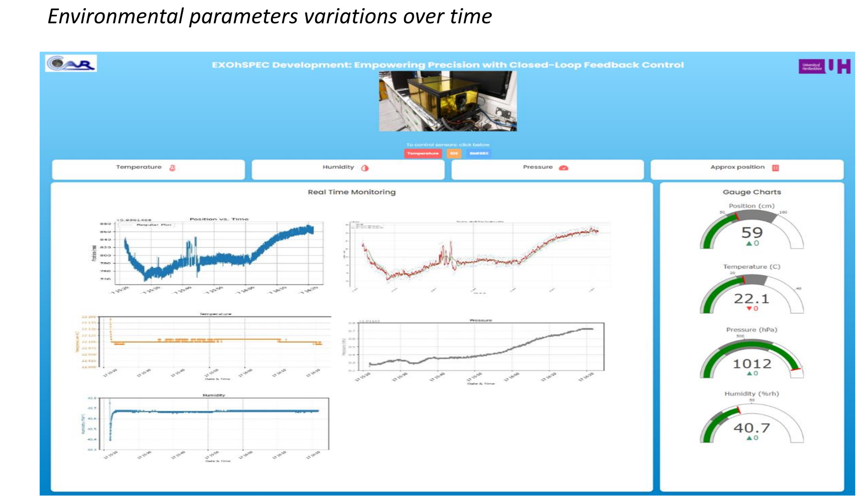


Fig. 11: Real-time Monitoring Web Interface for Spectrograph Functionality and Sensor Control.

- **Remote Access:** Efficient, Monitor spectrograph and control sensors from anywhere.
- **Instant Control:** Optimize system performance in real-time.
- **Enhanced Robustness:** Strengthen system resilience with quick, web-based adjustments.
- Preliminary results illuminate the Thorium Argon Lamp's spectral characteristics, while Experiments reveal trends in IDS displacement, temperature, pressure, and humidity.

REFERENCES

- Jones et al., 2021, "A small actively controlled high-resolution spectrograph based on off-the-shelf components". Publications of the Astronomical Society of the Pacific, 133(1020).
- https://www.picotech.com/data-logger/pt-104/high-accuracy-temperature-daq
- https://www.attocube.com/application/files/7115/5360/4707/IDS3010_brochure.pdf
- https://www.bosch-sensortec.com/products/environmental-sensors/gas-sensors/bme680/
- https://components101.com/sites/default/files/component_datasheet/ESP8266-NodeMCU-Datasheet.pdf