Application Note 29. Outdoor Multi-Channel Phytosensor System

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***Abstract*—This Application Note describes the outdoor version of the multi-channel phytosensing system for environmental monitoring and plant physiological tracking. The hardware uses IP65-rated enclosures and sensor assemblies and supports wired (Ethernet with Power over Ethernet) and wireless (2.4/5 GHz Wi-Fi via Silex modules) data transmission, with LoRaWAN support planned. The system uses 2 m sensor cables and power lines up to 23 m in length, consisting of two segments. The system consolidates multi-node data streams with up to 49 physical and 43 synthetic channels on a single workstation with AI computing infrastructure, supporting digital twin architectures and local deep learning training. This document covers deployment procedures, system configuration, and operational requirements. 3D-printed plastic components, including the 7DoF positioning arm, can be obtained from designs available on printables.com.**

firmware version: > 1189.65; client version: > 1.4.8

I. Introduction

This platform represents a ruggedized adaptation of indoor phytosensor systems, such as the 'AI Biolab', see the Application Note 28 [1] and publication [2], [3], [4], [5], [6] re-engineered within an IP65-rated sealed enclosure alongside weather-resistant sensor assemblies. Despite its IP rating, shield the system from direct sunlight (e.g., install in shaded areas) to prevent overheating. An implementation example of the outdoor system is shown in Fig. 1.

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The system supports wired (Ethernet incl. Power over Ethernet solutions) and wireless communication, currently with 2.4GHz/5GHz WiFi with Silex modules (potentially with long-range LoRaWAN transceivers) for remote data transmission. Power input requirements operate at 5 V or 12 V DC supply voltages, depending on the specific communication variant deployed. Firmware version 1189.65 or higher is required for Silex module communication.

II. Initial setup

1. Set up USB device server Silex DS700AC. Follow the setup guide from www.silextechnology.com.

- Web interface: ip address of the device;
- Password on web interface: *admin*;
- Latest firmware 2.1.0 is typically installed, if not, please install the latest firmware;

Fig. 1. Example of outdoor phytosensor system for ecological monitoring with WiFi connectivity (Silex DS500AN module).

Fig. 2. Example of reliability tests: seven remote phytosensing systems connected to one PC with 'SX Virtual Link' and client software via combination of DS700AC and DS500AN modules. The system processes 644 channels (343 physical and 301 virtual) across the seven sensor systems with 1 sps sampling rate.

- Use USB 3.0 port on Silex device to connect the pythosensor (it provides less latency for WiFi communication).

The device server typically delivers to the end user configured for the router environment used during tests. To reinitialize the device, restore the factory default settings: 1) Press and hold the Reset button; 2) Cycle the input power (turn off, then turn on). Upon reset, the device server resumes Ethernet communication and can be configured through its web interface.

Known issues. The device server has undergone extensive testing and exhibits stable operation. Over wired Ethernet connections, performance remains reliable with operation equivalent to local connections. However, wireless Wi-Fi connections introduce inherent physical constraints, specifically increased latency and potential packet loss. Consequently, operating over Wi-Fi can result in several typical issues:

- *'COM Port not available/ in use'* (or any other similar messages). This reflects typical interaction between the device server and Windows during USB device identification, which temporarily locks system access. Reseating the device in 'SX Virtual Link' (disconnecting and reconnecting) resolves the issue.
- *'Time limit for semaphores is archived'*. This error occurs when the client application sends an initialization request to a remote device, but no response is received within the timeout period. This issue typically arises in high-device-density networks experiencing bi-directional communication bottlenecks. To resolve this issue, re-attempt the connection through the client software two to three times.
- *Connection established, but the client program failed to initialize.* Occurs when the client application connects to the remote device but fails to receive the initialization sequence. Caused by network latency or connection timeouts. Resolution: Retry the connection from the client program.

The aforementioned errors occur only during initial device connection to the network or client application. Once the connection is established, these issues do not recur.

During operation, the Silex device may reinitialize the COM port connection due to high traffic or latency in the Wi-Fi network. In this case, the remote phytosensor still continues sampling and automatically resumes data transmission once the connection is restored (enable the auto-connection option in the client program).

III. Software

The Silex system emulates a remote USB connection locally on a PC, facilitating centralized data collection from multiple distributed devices. To configure the setup, download, install and launch the latest version of 'SX Virtual Link' www.silextechnology.com and connect the devices. Step-by-step sequentially connecting each device in 'SX Virtual Link' and with the client software minimizes connection issues for multiple devices.

System stability was verified through long-term testing with seven parallel sensor systems, see Fig. 2, each logging 49 physical channels and calculating 43 virtual channels with 1 sps sampling rate (totally 644 data channels across the seven sensor systems each second, see [2], [6]).

Data sampling does not require the native client software. Serial stream data from the virtual COM ports can be read by third-party applications, such as a Python script. The script receives ASCII streams from multiple COM ports (representing different remote phytosensor systems) and logs them into a single unified file for downstream processing.

Fig. 3. Cable and sensor storage position during transportation. Removable mounting brackets can be configured with forward or backward slope.

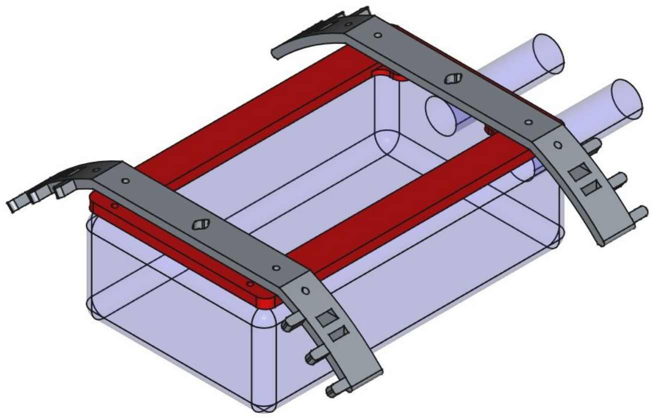


Fig. 4. Two angled brackets sloped forward.

When implementing a custom software, Wi-Fi network propagation delay must be taken into account. Setting a 100-microsecond confirmation timeout in the USB stack with a maximum retry limit of 500 yielded positive results. Note that setting the 'auto connection' option should be implemented if the COM port is closed, and re-opened via SX Virtual Link within a short timeframe.

IV. Power Supply

System power requirements depend directly on the specific communication hardware selected: the DS700AC module operates at a nominal input of 12 V DC, whereas the DS500AN and LoRaWAN configurations require 5 V DC. To ensure uninterrupted operation, a sufficiently stable power supply network must be provided. System power consumption is estimated at approximately 6 W for Wi-Fi-enabled configurations and 0.9 W for LoRaWAN deployments.

Field trials were conducted using solar-powered setups incorporating a 20 W photovoltaic panel paired with a 20 Ah battery storage unit. Under conditions of restricted daily photoperiods and continuous overnight operation, this power budget proved insufficient to sustain continuous operation of the Wi-Fi-equipped variant.

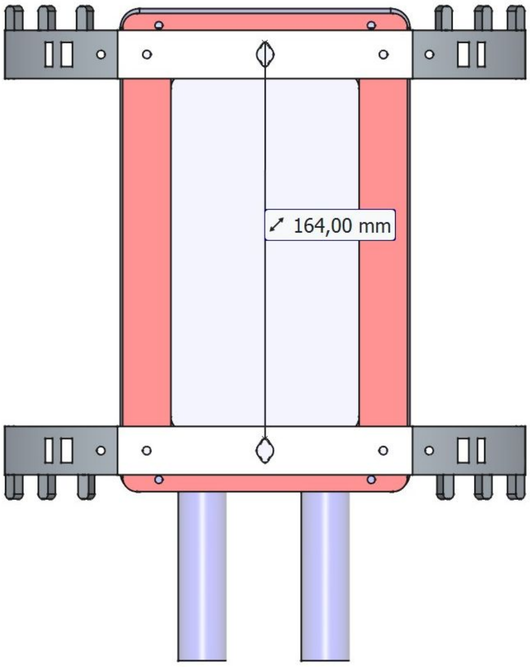
When using 220 V AC grid-tied power supplies, adequate environmental protection – primarily against ambient humidity – must be implemented alongside careful consideration of cable run lengths. Using standard commercially available outdoor lighting cables (e.g., LED landscape wiring), the system was successfully validated over a maximum tested cable length of 23 meters at a 12 V DC operating voltage (3-meter embedded cable combined with two 10-meter extension segments).

V. Mounting the Outdoor Module

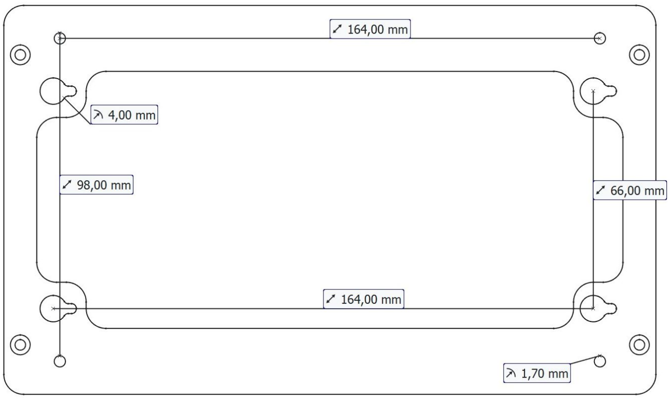
The modules feature two angled brackets sloped forward, see Fig. 4, which can be reconfigured to slope backward. The forward inclination secures cabling, see Fig. 3, whereas the backward inclination allows mounting to objects such as trees, trunks, or large-diameter cylindrical structures, see Fig. 1. These brackets are removable. For mounting the phytosensor module on a vertical surface, use either the two holes on the brackets or the four holes on the main board, as shown in the Figs. 5.

VI. Sensors

The general architecture of all sensors matches previous versions of the phytosensor system. However, specific features apply to outdoor deployment. For instance, electrochemical (impedance) sensors for hardwoods can be mounted directly



(a)



(b)

Fig. 5. Dimension of mounting holes on the brackets **(a)** or on the main board **(b)**. Use M3 screws to mount the brackets.

(a)

(b)

Fig. 6. Installing electrochemical (impedance) sensors in the tree trunk with **(a)** upper and **(b)** lower sensors.

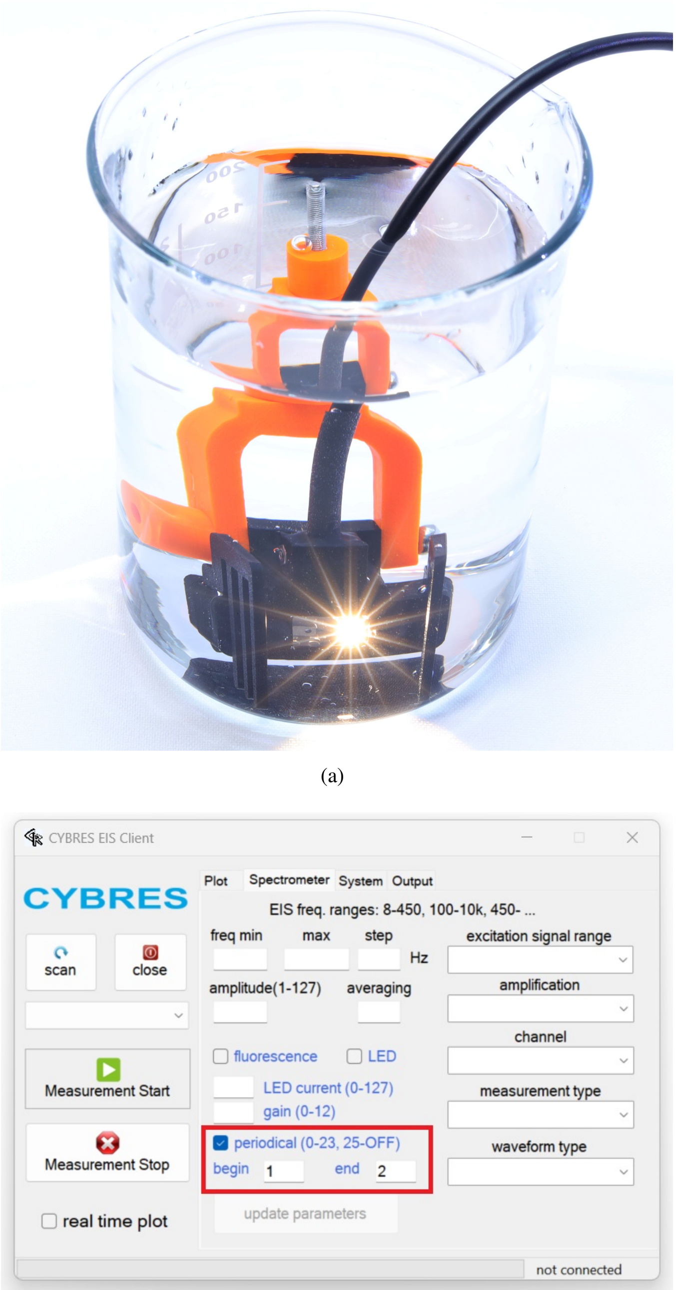
onto the tree trunk, see Fig. 6. To do so, remove the locking bolts and press the pins into the wood. Follow the standard distribution of upper (black mark) and lower (red mark) hydrodynamic sensors established in other application notes and publications.

Multispectral sensor. The optical multispectral sensor is enclosed in a protective housing featuring an acrylic glass window. Water-resistance testing was conducted underwater, see Fig. 7. Deploying the multispectral sensor in outdoor environments presents several operational considerations:

- First, acrylic glass was selected over other transparent plastics (such as polycarbonate) for its better optical properties; however, it is highly susceptible to scratching and mechanical damage. Handle with care, as surface degradation alters the sensor's reflectance parameters.
- **Always keep the protective cap** installed when the sensor is not in use to shield the optical glass from dust, dirt, and physical damage.
- Operating multispectral sensors in outdoor environments under direct sunlight introduces measurement variability due to fluctuating solar irradiance. To mitigate this effect, two data acquisition strategies can be implemented: acquiring data exclusively during nighttime hours under total darkness, or collecting data continuously and automatically filtering out unrepresentative daytime records during post-processing. To establish periodic sampling, apply the configuration parameters shown in Fig. 7(b), which defines an automated operating window to capture data strictly within the specified timeframe.

Measurements with the multispectral sensor require prior calibration using a white reference surface. Subsequently, raw values across all spectral channels must be divided by the corresponding channel values obtained from the reference surface. This calibration step is mandatory.

Because the acrylic window and protective enclosure alter the optical and reflective characteristics of the assembly, standard calibration data measured on an unhoused sensor from other phytosensing system cannot be used; recalibration is required. Calibration must be performed prior to data acquisition using the exact gain and LED current settings selected



(a)

(b)

Fig. 7. **(a)** Multispectral sensor underwater operation test (several hours duration); **(b)** Periodic sampling configuration: using these settings, the multispectral sensor samples once per day between 01:00 and 02:00 in total darkness at night to eliminate solar irradiance variability.

for your measurement. Refer to Application Note 28 for the detailed calibration procedure. Although reference calibration data for this sensor configuration are provided, calibration must be executed under the specific operational parameters of your experiment.

Mounting sensors. To mount sensors directly on the plant – such as on a stem near the leaves – a positioning arm with seven degrees of freedom is used, see Fig. 8. Two arm segments have a combined length of approximately 20 cm and feature multiple adjustment holes to extend or shorten the arm length, effectively providing an additional degree of freedom. This rigid holder maintains the sensors in their set position even under strong wind conditions without damaging the plant. The minimum recommended stem diameter is 2-3 mm; mounting on thinner stems is discouraged due to the risk of breakage, though rubber inserts can be added to the base platform for small stems. The standard platform accommodates stems up to approximately 20 mm in diameter, while a replacement base platform can be used for thicker stems and branches. When 3D printing this positioning arm, UV-resistant filament must be used. PETG was primarily used during testing, demonstrating adequate stability across two years of outdoor field deployment. However, switching to ABS or ASA filament is recommended for production, despite their higher printing complexity.

VII. Data access

This system simplifies data access because all connected COM ports are located on a single computer. There are three independent methods:

1) the client program writes data to files for further processing;
2) the custom program receives data *using named pipe mechanisms* from the client. The client continues to write and process the data;
3) the custom program *opens COM ports directly* and processes the data stream without a client running. In this case, the custom program must handle file and data management.

More details can be found in Application Note 28 [1]. In the last two cases, data access requires independent handlers to process incoming streams and store the data in data structures. We recommend the first method for post-processing, using recorded data files. For real-time processing, use method 2). This method keeps phytosensor configuration, data reception, and local plotting under the control of the client, while the custom program processes the data for digital twins, machine learning, and other functions.

To activate the data exchange via named pipe enable in

```
usePythonOutputPipe=X;
```

```
usePythonInputPipe=Y;
```

in *init.ini* file (X and Y are the number of input and output pipes). Data are provided to the pipe at the same time and in the same structure as they are stored in files – line by line with all data columns (see [7]). If the parameter

```
saveAfterNSamples=x;
```

is set to x, the pipe will provide x lines of data after x measurement cycles.

VIII. 3D Printable Accessories

Typical auxiliary components – such as cable management brackets, mounting screws, leaf positioning guides, and other accessories – are available as 3D-printable models. These files can be downloaded from the Printables platform and produced

(a) (b) (c) (d)

Fig. 8. 7DoF positioning arm for mounting sensors directly on the plant. **(a)** 3D drawing; **(b-c)** Different application cases.

locally by end users using standard 3D printers with 0.4 or 0.25 nose diameter. Search for "Cybres" or "Cybres Phytosensor" on Printables.com to access the stl files.

References

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