OUC's All-In-One Photovoltaic Sensor: Phase II

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***Abstract* — As solar panels and arrays become more common as a dependable source of energy, it is useful to be able to monitor the performance and stability of the installed panels adequately and accurately. This paper provides a solution to a substantial issue that Orlando Utilities Commission (OUC) is facing; new research opportunities for solar panels and existing solar arrays are easiest to work with when accurate and timely data can be measured from the panels. The proposed device, The All-In-One Photovoltaic Sensor, can connect to any single solar panel to measure and record its generated voltage and current along with the panel's surface temperature and incident irradiance. The All-In-One PV Sensor will report the measured data to a locally owned database and simplify solar monitoring by providing clean and accurate data.**

***Index Terms* — Solar Monitoring, Photovoltaic Sensor, Real-Time Measurement**

I. Introduction

To monitor Solar Powered systems is to ensure that they are consistently generating power and doing so at a reasonable and reliable rate. To do this, many have created solar monitoring systems that can measure a solar panel's output voltage and current and translating those values into kilowatts delivered to the grid. The main purpose of these systems is to monitor other systems and collect data, and companies such as SolarEdge have created monitoring software and hardware that integrate directly into a solar network for easy data access. However, this data is subject to the company's discretion and therefore, customers of SolarEdge such as Orlando Utilities Commission (OUC) must use a 3rd party's software to access data generated by their own solar panels.

To remedy the disconnect between generated data and owned data, OUC set out to create the All-In-One Photovoltaic Sensor, a device that should be capable of measuring a solar panel's generated voltage and current. Funded and sponsored by OUC, our group set out to improve on a design created by a previous group which was unable to accurately represent a panel's generated current and surface temperature. The second phase of the All-In-One Photovoltaic Sensor is now able to measure a panel's generated voltage and current as well as its surface temperature and incident irradiance. In addition to this, the sensor will transmit its measured data wirelessly over a self-provided Wi-Fi Signal, allowing many All-In-One Sensors to be deployed in a single location for mass monitoring.

This paper will summarize relevant standards that affected our decision-making process in Section II, followed by a summary of each component that makes the All-In-One Photovoltaic Sensor truly 'All-In-One' in Section III. Section IV will explain the wireless capabilities of the All-In-One Photovoltaic Sensor, and the results of measurement and transmission will be presented in Section V and Section VI.

II. Customer Requirements

This project is sponsored and fully funded by OUC, so the product must be made to fulfill their standards and requests. OUC aims to further this product into one that is fully marketable, therefore they requested that the PCB's final design to be affordable. OUC also requested that the board use terminal connectors such that it can connect to existing solar panels that the company uses for research purposes along with NEMA rated packaging to protect from environmental conditions. In addition, OUC wants the product to be completely self-standing. This means that the board should be powered solely by the generation of the panel that it is attached to, and the data that it measures, and records should be hosted on its own database that can be scanned and read by OUC's engineers. Another key design choice was the ability to add or remove the temperature and irradiance sensing circuitry for a modular final design.

Table I summarizes OUC's requirements and highlights the sections of the final product that it impacts.

TABLE I
Summary of Customer Requirements

Customer Requirement	Subsystem Impacted
Final sensor to be ~$20	Entire System
Terminal connectors to interface with solar panels	PCB's connection points
Wireless Transmission	MCU, Storage Node
Self-Sufficient Operation	DC-DC Converter
Accurate to within 5% of true value	Voltage, Current, Temperature, Irradiance
40V, 10A DC rating	PCB's Connectors, DC-DC, Voltage, Current
Modular Design	Temperature, Irradiance

III. MEASUREMENT SYSTEM

Because our system was created as an All-In-One solution, it is best to split the board into sections for analysis as there are multiple individual sensors that culminate into one printed circuit board (PCB). Each section of our board will interface directly with the microcontroller unit (MCU) such that measured data can be transmitted with minimal interference between subsections. The proposed flow of the system can be seen in Figure 1.

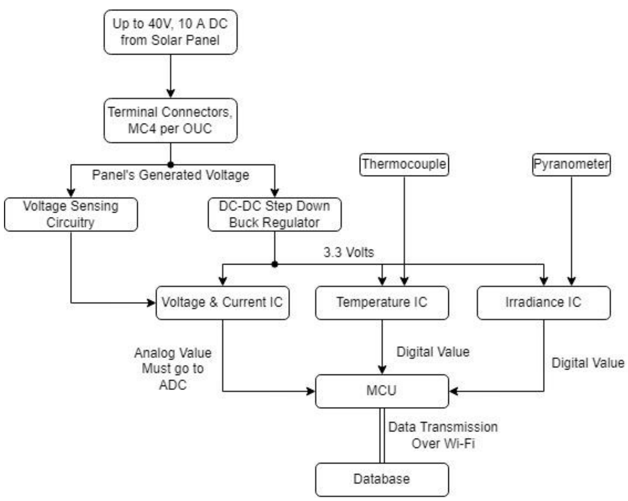

Fig. 1. Proposed flowchart of the All-In-One PV Sensor that shows necessary connections between on-board integrated chips and the power that should come from the solar panels.

Now with a vision of the system's layout created, the specifics of the components can be explored. This section will provide a technical overview for each section of the PCB.

A. Voltage regulator

For the sensors on the All-In-One PV sensor to operate, they would have to be energized by a source which produces a substantial voltage for the components to work on the PCB. The components that we are using would require a low operating voltage, so this factor will assist us in deciding the most efficient power supply for the sensors.

Given OUC's requirements, we were tasked to take the voltage directly from the Solar panel. This came with two challenges: the first was that the voltage and current that comes out form solar panel has more characteristics of an AC signal than DC, also the volage coming from the specific solar panel is the range of 32 – 39 V and the max current is 8.91 A, but the components have a significantly less max operating voltage and current. To counteract these issues, we decided to use a voltage regulator to minimize the voltage exposed to more sensitive Integrated Chips (ICs).

For a DC-DC Step-down converter, the team chose the LMR38010, a synchronous buck converter designed to regulate over a wide input voltage range. We designed the circuitry to accept from 4.2 to 60 V and output 3.3 V and 1 A.

B. Voltage Sensing

As required by OUC, we were to design a subsection that sensed the voltage of the solar panel. To accomplish this, we had decided to use an IC that sent a modified voltage reading to an MCU's analogue to digital converter (ADC). A challenge arose when attempting to find a cost-effective IC capable of handling 40 volts. To solve this, we decided to use a voltage divider which will reduce the voltage entering the IC. The IC will then send the voltage value to the ADC, and a simple calculation in the code would be used to determine the actual voltage, taking the offset and divider ratio into account.

The TLV342 was selected as our voltage sensing IC, a rail-to-rail operational amplifier with a low offset voltage. The panel a maximum of 40 Volts, but our IC's input can only handle between 0 to 5 Volts. To solve this issue, we used a 10 kΩ and 210 kΩ voltage divider. This allowed a maximum voltage of 1.77 V to be read by the ADC. The TLV342 was used as a unity gain buffer, minimizing current supply and providing a safe connection to the ADC.

C. Current Sensing

The current sensing was also an integral part of our design. The maximum current expected from the panel is about 10 A. First, we considered the method for current sensing. We decided to use a shunt resistor configuration since it was well suited for our application. Before picking the shunt value, we first had to consider the configuration we were going to follow, whether low-side or high-side. We first approached the design with the low-side configuration, using the TLV342 as a non-inverting differential amplifier. The approach was to put a shunt after the load, then the non-inverting amplifier's input will collect the current across the shunt, amplify it, and send the result to the ADC. After calibration and gain-adjustments, this configuration was able to operate within 5% error. To future-proof our design, we also opted to create a second current sensing configuration that used high-side current sensing and a new precision current sensing amplifier.

For this a special current sense amplifier had to be chosen due to their high common mode voltage design. Since our maximum voltage is 39 V, we had to choose an IC that had a common mode voltage above that value. We found and looked for several IC's that met our specification, and we ended up going with the INA290. This IC has a common mode voltage range between 2.7 – 120 V, which is well within the rage of our design. It is also an ultra-precise current sensor. The model of the amplifier we chose provides an in-built gain of 200, using a differential amplifier configuration. We also chose a shunt value of 1 mΩ, this was picked after calculating the maximum value of the shunt resistor we could use is 1.5 mΩ. The voltage coming through the shunt would be exceptionally low approximately 0.009 V (9 A x 0.001 Ω), so we calculated a gain of 200 provided by the IC that would boost the voltage going to the ADC. This makes the final output voltage from the IC 1.8 V (9 A x 0.001 Ω x 200 = 1.8 V). Some calculations in the code, and ohms law would be used to find the actual current. a

Table 2 summarizes the INA290's key characteristics, with Figure 2 highlighting the percent error when testing values from 0 to 10 amps.

TABLE II
SUMMARY OF INA290 ELECTRICAL CHARACTERISTICS

Current Sense IC	**INA290**
Common mode Voltage(V)	2.7 - 120
Input offset (Max) (uV):	12
Supply voltage(V)	2.7 - 20

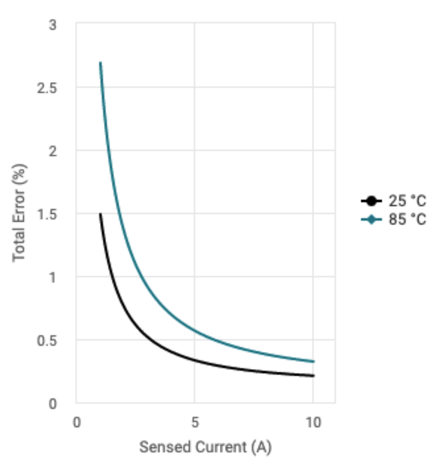

Fig. 2. INA290's Percent Error over sensing range

D. Surface Temperature Sensing

Another requirement set for us by OUC was to accurately monitor the temperature of the connected solar panel to monitor its temperature over time. The implementation of a surface contact temperature sensor was implemented to have the ability to monitor the temperature surface at the back side of the solar cell.

The implementation of a Type T thermocouple as a surface temperature sensor was strongly preferred by OUC but the team recommended the use of a Type K. While a Type K thermocouple needs Cold-Junction compensation for accurate readings, it has a wide temperature sensing range compared to a Type T thermocouple. Therefore, a consensus was made that the system will be available to work with both a Type T and a Type K thermocouple.

These types of thermocouples work with a simple concept that consists of two junctions of two different types of metal join at one end. By having two dissimilar metals as seen in Figure 3 heating up at different rates, a temperature difference between the cold junction and the hot junction creates a thermo-electric effect inducing a voltage via the Seebeck Effect. This gives a measurable voltage in the range of millivolts that can be as low as 0.039 millivolts at 0ºC for both Type T and Type K thermocouples. [2]

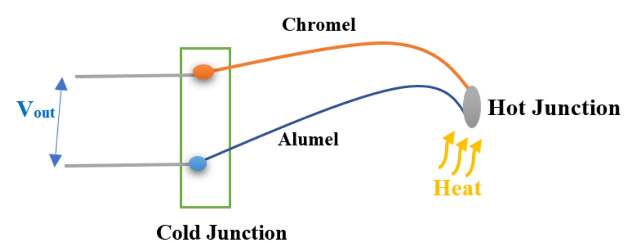

Fig. 3. Simplified view of a typical thermocouple's functionality

The thermocouple produces a very small voltage per temperature difference such that it cannot be interpreted accurately by the MCU's ADC. Typical 12-bit ADCs detect a lowest nominal input voltage with a 3.3V voltage source as 8mV/step. With such a small input voltage, a signal conditioning circuit is required to increase the output voltage of the thermocouple to match the ideal input voltage to maximize ADC resolution. We also take into consideration the introduction of noise in the system which increases the system noise floor, thereby decreasing the temperature sensing resolution.

To mitigate and correctly condition our low voltage signal coming from the thermocouple, the team decided to use the MAX6675 thermocouple digital converter. This IC has a 12-bit ADC with a unique 0.25ºC increment resolution with an accurate temperature sensing range of 0ºC to 1024ºC. Apart from this specification it also satisfies the more complex project features requested by OUC which entails the compatibility of Type T and Type K Thermocouples. The MAX6675 is Type T and Type K compatible according to our testing as it can convert readings from both thermocouples since they have a similar voltage output behavior.

The MAX6675 is available to amplify, convert and cold junction compensate a Type K thermocouple by amplifying the output voltage and converting it to a digital value, sending it to the MCU via SPI communication. The IC can do all these tasks in by having 5 major components integrated, including a single stage differential amplifier, a low pass filter, a unity gain buffer, and a digital controller ADC.

The first major component is a differential amplifier that is available to amplify the differential input voltage of the thermocouple low and high side. After this is done, the second phase of the conversion completes through a low pass filter which can filter frequencies higher than 7955 Hz. This filters any unwanted noise caused by the first stage's amplification. The third phase of the conversion deals with the cold junction compensation as well as stabilizing the output voltage of the differential amplifier after it passes through the low pass filter. In this stage the voltage signal passes through the unity gain buffer and adds the voltage produced by the non-isometric block integrated temperature diode that measures the IC temperature, mimicking the cold junction voltage difference that needs to be added for a Type K thermocouple. The final stage of the conversion deals with the analog signal to digital conversion by using an ADC which converts the analog voltage to a digital value between 0 and 4,096. This digital value is sent from the serial output of the MAX6675 to an MCU via SPI. To allow proper digital value recognition by an MCU, both devices need to be synchronized. In this connection the Serial Clock pin of the MAX6675 will be supply 16 clock cycles where the digital value will be stored and activate where Chip Select pin is set to low allowing conversion. The first cycle or bit will be a dummy sign bit set at zero D15, followed by D14-D3 that contains the converted temperature in form of a digital value. The last bit D2 is naturally set to low which means that it allows open loop detections when it goes to high.

Next, the open loop detection ground needs to be connected to the low side of the input of the MAX6675 so it can display the open loop message assigned the by the user in the code. For our implementation, when the thermocouple is disconnected the MAX6675 will output NULL and send to the SQL data base until the thermocouple is connected. By having this feature active the modular requirement is met. This means that the thermocouple is not required to be implemented in every sensing node and the NULL data can be easily discarded when the data is been analyzed.

E. Incident Irradiance Sensing

The All-In-One Photovoltaic Sensor will be placed inside of protective casing, meaning that an on-board irradiance sensor is not a feasible option. Ideally, for the most accurate measurement of incident irradiance that is striking the panel, it would be best for an external irradiance sensor to be mounted onto or around the front-facing side of the solar panel and connect into the All-In-One sensor via a terminal connection.

This conclusion led the team to adopting Phase I's incorporated irradiance sensor, a pyranometer. More specifically, Apogee Instruments' SP-110-SS Pyranometer was selected to be implemented with select designs of the board as OUC requested the irradiance sensing circuitry be optional in comparison to the PCB's main functionalities, those being voltage and current sensing. The SP-110-SS is a silicon-cell pyranometer, a cost-effective alternative to a typical thermopile pyranometer. This type of pyranometer has an internal cast acrylic diffuser, photodiode, and signal processing circuitry that allow the sensor to output a differential analog voltage signal of up to 200 millivolts. [1] The incident irradiance is measured via the pyranometer's conversion factor of 0.2 millivolts per watt per meter squared, meaning a full output of 200 millivolts relates to 1000 watts per meter squared of sunlight striking the pyranometer's sensor.

The SP-110-SS is fully self-powered, meaning the PCB's modular design does not have to worry about providing power to an external sensor and saves on unnecessary traces. The pyranometer is also designed with a dome-shaped head that resists dirt and debris buildup that other sensors may face, allowing the pyranometer to run accurately for longer without human interference.

Because the SP-110-SS uses a differential voltage signal to model its output, the team was faced with a small challenge to implement the pyranometer into the circuit. The PCB was designed with a single positive supply voltage in mind of 3.3 volts, meaning an amplifier that required a negative supply voltage would need additional components to work. The solution to this problem was using a standalone differential ADC for the pyranometer to use on its own. This would remove the need of creating a negative voltage supply as the ADC would be completely capable of handling a differential signal and the converted values could be sent to an MCU over SPI communication. After deliberation, the team elected to move forward with a standalone ADC as it was more cost effective and space efficient compared to adding a negative rail to the All-In-One Photovoltaic Sensor.

Given this decision, the team elected to use the MCP3008 Pseudo-Differential Analog-to-Differential Converter for initial designs of the board. This Integrated Chip is cost effective and can function correctly even with an empty input, allowing the IC to work well with the pyranometer's proposed modular design. This ADC features a 10-bit resolution and full support of differential signals, allowing 3.22mV of change to be detected between datapoints. Given the resolution of the pyranometer, this means that the current irradiance sensing circuitry will be able to reflect irradiance changes of 16 Watts per meter squared. Our sponsor OUC stated that the trend of the pyranometer is more important that the raw data, so the current comparatively low resolution is acceptable. Future versions of the board would benefit from a smaller, higher resolution differential ADC, given the market would allow it.

F. Microcontroller Unit

When choosing an MCU to be the brain of our device, we knew we needed to select a product that was generally purposed, is Wi-Fi-capable, has an analog to digital converter (ADC), and has sufficient ports. At the heart of our PCB is an ESP32 MCU that processes the data being collected by each measurement device, or sensor, onboard our All-In-One PV Sensor.

There are many variants of the ESP32 microprocessor, like the ESP32-D0WD-V3, ESP32-U4WDH, ESP32-S0WD, and more. The variant we will be implementing in our design is the ESP32-WROOM-32, which features many functions that will help satisfy our design requirements such as multi-channel ADCs, multiple general-purpose input/output (GPIO) pins, universal asynchronous receiver-transmitter (UART) technology, and variable input power voltage.

At the heart of the ESP32-WROOM-32 is a ESP32-D0WDQ6. Within the WROOM is a series of connections, such as an antenna, Crystal, capacitors, and other connections which turn the ESP32 to an easy-to-use platform. ESP32-D0WDQ6 is designed for mobile, wearable electronics, and Internet-of-Things (IoT) applications. It features all the state-of-the-art characteristics of low-power chips, including fine-grained clock gating, multiple power modes, and dynamic power scaling. For instance, in a low-power IoT sensor hub application scenario, ESP32 is woken up periodically only when a specified condition is detected. Low-duty cycle is used to minimize the amount of energy that the chip expends. The output of the power amplifier is also adjustable, thus contributing to an optimal trade-off between communication range, data rate and power consumption.

ESP32 is a highly integrated solution for Wi-Fi and Bluetooth IoT applications, with around 20 external components. ESP32 integrates an antenna switch, RF balun, power amplifier, low noise receives amplifier, filters, and power management modules. As such, the entire solution occupies minimal Printed Circuit Board (PCB) area.

Once each sensor on our device collects its respective data, their data is transmitted to the onboard ESP32. Next, the ESP32 will make any necessary calculations and conversions and then wirelessly transmit the collected values as a string to its receiving node, a Raspberry Pi, which we will discuss section IV.

Upon startup of the ESP32, it is instructed to connect its local Wi-Fi access point (WAP) and then continuously collect data from each sensing device on the PCB and make any necessary calculations and conversions and then wirelessly transmit the collected values as a string to its receiving node, a Raspberry Pi, via an HTTP POST request. Upon verification of a valid HTTP POST response, the ESP32 will return a valid response code and repeat the process from the start.

IV. WIRELESS NETWORK

A. Wireless Access Point

For our PCB's Wi-Fi-capable MCU to interface with a remote web server, we needed to select a device that will act as low-cost, low power-consuming WAP. Since we had already become familiar with the ESP32 and its vast applications, we decided to utilize an additional ESP32-WROOM-32 device in our product to stand as the system's Wi-Fi network that will bridge the All-In-One PV Sensor to the standalone web server device, a Raspberry Pi. Like the PCB's MCU, it is given a series of instructions via a C-language code that will set up its Wi-Fi network credentials, broadcast a wireless signal, and then continuously look for clients to be connected to and read data from them.

B. Web Server

The final piece of our system is a web server that will store and serve the data collected from the All-In-One PV Sensor to the user. When designing our web server, we sought to develop a LAMP, or Linux, Apache, MySQL, PHP, server. The LAMP server includes a simple HTML webpage, which interfaces with two main components: a MySQL database to store the collected data and a simple, yet logical PHP backend to feed data to the HTML webpage that will neatly display the collected data in a table with their respective units, timestamp, and unique identifier. We decided to have the HTML webpage to be hosted on an Apache web server, being controlled by a Linux operating system.

The last component we had to choose was a system-on-a-chip (SOC) that would run the software mentioned in the previous section. We chose the Raspberry Pi 4 Model B+ as it can process large amounts of data at a time, can interface with large storage devices that will be necessary to store collected data over large period, and is Wi-Fi capable.

V. System Tests

In this section, subsections of the board will undergo testing to ensure that a fully cooperating system is able to function properly. The methodology and results of individual tests will be discussed in this section, and the results of an overall test will be seen in Section VI.

A. Voltage Receiving-End Preliminary Testing

The voltage receiving-end of our PCB consists of the DC-DC converter & regulator, Voltage Sensing IC, and Current Sensing IC.

To test the DC-DC Converter & Regulator, we added the resistors, capacitors, and inductor needed to reduce the voltage entering the LMR38010. Using a DC Power Supply, we found the DC-DC Converter able to accept voltages over 4 Volts up to the maximum voltage that we provided, which was 40 Volts.

For the voltage sensor, the same solar array simulator was used. The voltage from the power supply would travel over a voltage divider circuit before entering the op-amp, and a unity gain buffer will repeat the input voltage through the output and toward the ESP32's ADC. Using 210 kiloohm and 10 kiloohm resistors, the voltage is divided by a factor of 22 which will be compensated by the ADC's conversion code. Figure 5 shows the behavior of the voltage sensing circuit.

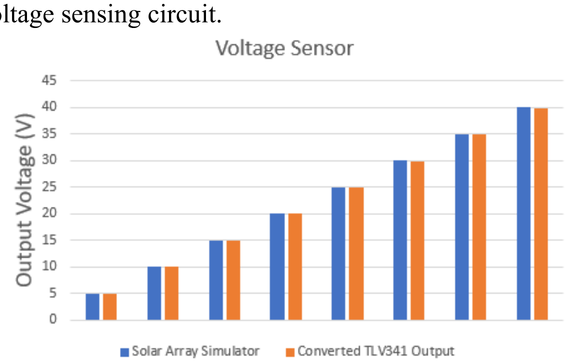

Fig. 5. Voltage Sensing Input vs. Converted Output

B. Current Receiving-End Preliminary Testing

To test the current sensor, the PCB was connected to a resistive load and a DC Power Supply or Solar Array Simulator was used to act as a supply voltage. Initial tests showed output saturation at 7 Amps supplied to the system. To combat this, we removed the 300 kiloohm gain resistor and replaced it with a 105 kiloohm resistor reducing the overall gain of the system to 139 kiloohm. This saturation could have been caused by the offset voltage of the TLV342 ranging from 0.3 – 4 mV, given our input voltage is also in the millivolt range. We supplied current to the system ranging from 0.5 to 8.2 amps. For each reading, we noted the value that was transmitted by the ESP32, and we were able to develop a formula that would convert the digital value of the ADC to the equivalent amperage supplied. Once the offset was applied, the measured current value was within a 5% error margin. These results can be seen in Figure 6.

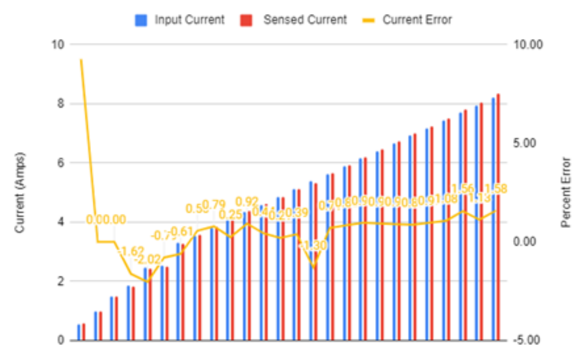

Fig. 6. Output Current vs Sensed Current & Percentage Error

C. Temperature Sensor Preliminary Testing

To properly test the capabilities of the MAX6675 with both Type T and Type K thermocouples, three tests were created. The first will test for accuracy and percent difference between an accurate temperature meter and the MAX6675 using the same thermocouple type. The second test will attach a Type T and a Type K thermocouple to the back of a solar cell during one day with no overcast weather. The final test will explore the open loop detection capability of the MAX6775 by disconnecting the thermocouple during conversion and reconnecting it to demonstrated if NULL only appears when the thermocouple is disconnected and if conversion resumes when reconnected.

The first test will deal with the accuracy of the MAX6675 using a Type K Thermocouple. We use the M400 temperature meter as an external benchmark. The results of this test can be seen in Figure 6, and we can conclude that the overall percentage error of the MAX6675 is 0.6117 %. This result falls within the 5% temperature error requirement set by OUC.

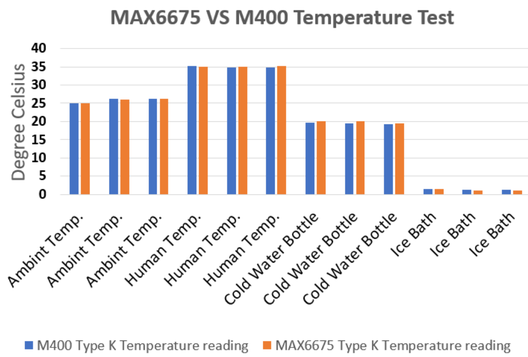

Fig. 7. MAX6675 VS M400 temperature test.

For the second test, the results of which are seen in Figure 8, a Type T and Type K thermocouple measure a single panel and report the temperature over a day's time. There is minimal difference between the Type T and Type K results, therefore allowing us to use either type of thermocouple for the All-In-One Photovoltaic Sensor.

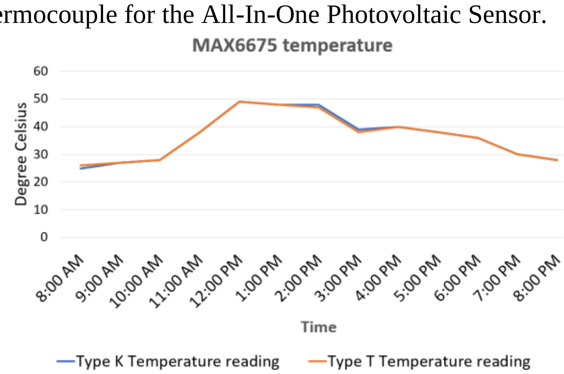

Fig. 8. Type T & Type K Temperature over a single day.

For the final test, the MAX6675's capability to output NULL when no thermocouple is connected will be examined. During testing, a thermocouple is disconnected. Once done, the database began showing NULL values being recorded and stored. Following this, the thermocouple is reconnected. Once reconnected, the database shows the proper temperature conversion instead of the NULL message. This test demonstrated the open loop detection is fully functional, proving that the database can react reasonably to a modular designed thermocouple connection.

D. Irradiance Sensor Preliminary Testing

On the All-In-One Photovoltaic Sensor, the pyranometer will connect to its own ADC and send digital values over SPI to the ESP32 for data storage. To ensure that the pyranometer is working correctly, its raw millivolt output will be compared with the Campbell Scientific CR310 Datalogger to ensure that it accurately changes to the sun's exposure. Figure 9 shows the millivolt output of the SP-110-SS and the recorded value by the CR310 datalogger.

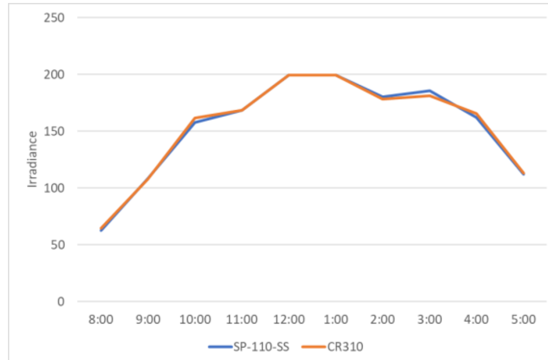

Fig. 9. SP-110-SS & CR310 Datalogger Irradiance over a day

VI. Results

The All-In-One PV Sensor was tested both in a lab setting and in a real-world setting at OUC's Research Array at their Pershing Facility. In the lab, a Solar Array simulator was used as a power supply for the All-In-One Sensor, and the Raspberry Pi and Access Point were placed away from the sensing node to account for distance. In the field, a real solar panel connected to OUC's on-site load was used as a power source, and the Pi and Access Point were located near a data collection area that OUC uses for their own research.

After calibration, we conducted a benchmark test that spanned over all operating voltage and current values that the Solar Array was able to output using different loads. The solar array simulator can output a maximum of 8 amps, and the voltage was determined by the load. In this test, a 1-ohm power resistor was used. Table 3 summarizes the lab's testing results and displaying the largest, or most significant (M.S.) error, between recorded voltage and current.

TABLE III
Lab Testing Results

Input Voltage	Input Current	ESP32 Voltage	ESP32 Current	M.S. Error
3.89	3.30	3.86	3.28	0.77%
4.19	3.56	4.07	3.58	2.86%
5.14	4.34	5.00	4.38	2.72%
6.06	5.12	5.89	5.14	2.81%
6.98	5.89	6.96	5.94	0.85%
7.59	6.41	7.36	6.47	3.03%
8.21	6.93	8.01	6.99	2.07%
8.83	7.44	8.41	7.52	4.76%
9.14	7.7	9.08	7.82	1.56%
9.75	8.21	9.55	8.34	2.05%

During testing, the error for both the voltage and current does not surpass 5% which is within OUC's requested accuracy.

The next test was conducted at OUC's Research Array, and the results can be seen in Table 4.

TABLE IV
FIELD TESTING RESULTS

Panel Voltage	Panel Current	Temp. in Degree F	Irrad. In W/m²	Time-stamp
25.75	7.14	94.10	982.9	33:12
27.85	7.04	94.55	982.9	33:11
28.44	7.02	94.10	950.7	33:10
26.64	7.08	93.20	982.9	33:09
28.13	7.15	94.10	982.9	33:08
27.71	7.07	94.55	950.7	33:07
25.93	7.01	94.55	999.02	33:06

This test showed a consistent voltage and current measurement, along with consistent temperature and irradiance measurements being reported to the database at 1 second intervals. The panel voltage sways in value, and this is likely due to the sporadic nature of solar generation. An averaging algorithm to sample the ADC multiple times per second would likely increase the accuracy of the sensor.

In addition, we found that the system works at up to roughly 150 meters between each pair of nodes and did not falter in ambient temperatures of as much as 38º C, or 100º F. In possible future revisions of this design, it would be beneficial to equip the WAP with an upgraded antenna to support increased distances between node pairs.

VII. CONCLUSION

Over two semesters of researching and prototyping, the All-In-One Photovoltaic Sensor is complete. As prototyping ends, the team is left with a sensor that can accurately measure a solar panel's generated voltage and current alongside its temperature and irradiance.

With these systems working in tandem, the final version of the sensor complies with each requirement that OUC has set out before us and will serve as a great blueprint for OUC's future developments as we move on.

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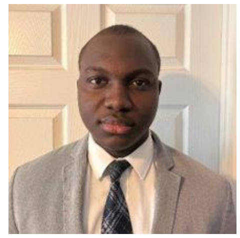
GROUP 6



Timothy Ajao will be graduating from the University of Central Florida with a bachelor's degree in the field of Electrical Engineering following the signal processing and communications path. Post-graduation, he would begin working as an entry level electrical engineer at Jacobs Engineering's energy and power division.

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Andrew Hollands is a graduating senior at the University of Central Florida, obtaining his Bachelor of Science degree in Computer Engineering in August of 2022. He is currently working as a Software Quality Engineer at Apple in Cupertino, CA, and is planning to further develop his skills in software development.

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