







### 3.3. Data collection and analysis

The integrated sensor circuit will be connected to the 60 W PV electricity generation system. The current sensors will be connected in series with the PV system while the voltage sensor will be connected parallelly. The temperature sensor is installed on the PV panels and the radiation sensor is positioned near the photovoltaic panels. Just like how it was executed during the manual measurement, the integrated sensor circuit will collect data for 2 days. The first day is just to measure the PR throughout the day while the second day the PV panel will be randomly shaded to emulate external interference on PV performance. The system collects data for 11 hours, which is between 8 am till 7pm and data will be recorded down hourly for the two days. The data will then be tabulated and analyzed based on the results collected via manual measurement.



Fig. 1. The prototype collecting data

## 4. Results and Discussion

### 4.1. Manually collected the data of the output of a PV system.

Figure 2 contains the graph of the PR collected on Day 1 and Day 2 of manual measurement. On the first day of data collection, the magnitude of PR had minimum fluctuations. It stayed consistent throughout the day despite the output power varying. The lowest PR value was 0.7419 at 8.00 am and the highest was 0.8351 at 1.00 pm, with the overall average PR being 0.80335. The slight fluctuations in PR can be attributed to various factors including human error during measurement, random error present in the measuring equipment and power loss due to voltage drop across the wires. However, it should be noted that these fluctuations are within acceptable bounds as the lowest PR magnitude and highest PR magnitude vary approximately 7.649% and 3.952% from the average. Hence it can be inferred that during ideal conditions, PR can provide an accurate assessment of the performance of PV panels.

On the second day of data collection, the PV panels experience partial shading at random intervals. From the graph, it can be observed that whenever the panels are covered there is a notable decrease in the magnitude of the PR. The magnitude of PR can drop as low 0.3128 as when the output of the PV panel is affected due to shading. However, in the most efficient state of operation where no shading occurs, the PR is close to the average that was obtained during ideal conditions.

From the data collected on both days, it proves that PR can provide an accurate reading of the PV panel performance and it has a potential to be integrated into an automated system where it will be capable of providing an accurate analysis of the performance of the PV system.

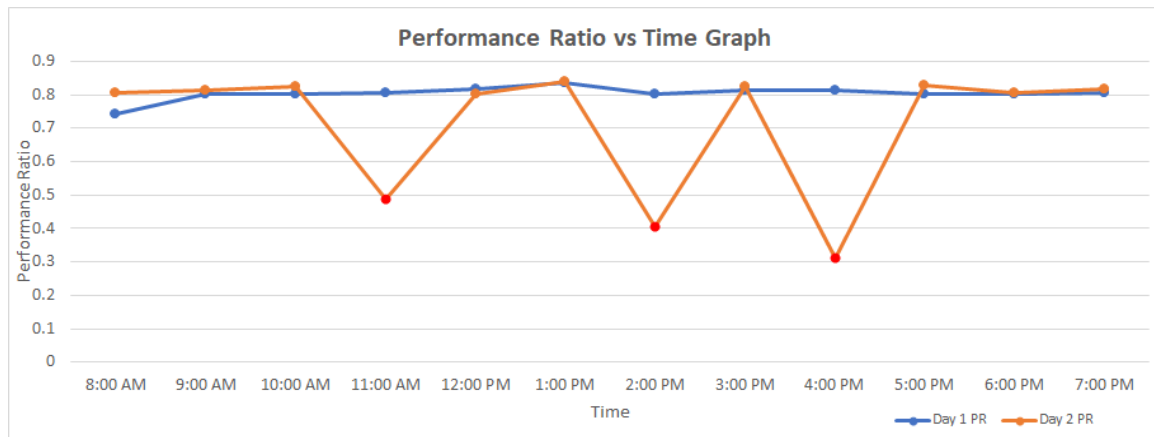


Fig. 2. The graph comparing the PR magnitude when the PV system during ideal conditions (Day 1) and during partial shading (Day 2)

#### 4.2. Data collected using the microcontroller-based integrated sensor circuit.

The collected data is visualized in Figure 3. The data collected by the prototype is visualized in the figure below. The data is similar to the manual measurement. When the PV system experiences no interruption in electricity generation, its PR is relatively stable and has minimum fluctuations. While the average PR magnitude, which is 0.79923 is slightly lower than the manual measurement, the data overall is consistent. This proves that a microcontroller integrated sensor circuit with can be used measure the performance of a PV system accurately, despite some minor differences in the data collected. Even on the second day of data collection where performance issue was emulated, the microcontroller-based system was able to pick up the dips in PV system performance. Hence, it can be inferred that the system is capable of measuring PV performance accurately.

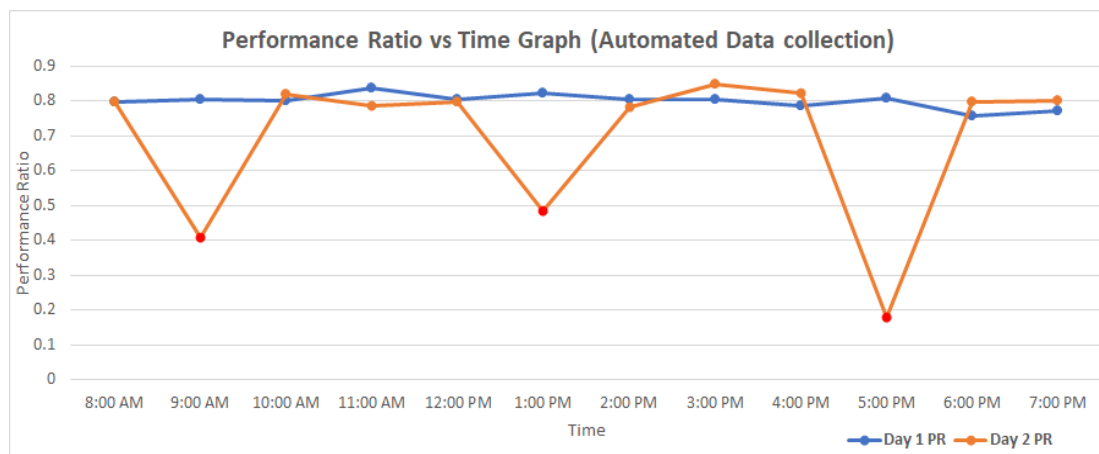


Fig. 3. The graph compares the PR magnitude when the PV system during ideal conditions (Day 1) and during partial shading (Day 2) via automated data collection.

#### 4.3. Discussion and future

Based on the results of the experiment, it is evident that PR mathematical model can be used measure the performance of the PV system and it can also be used to detect if there are any issues with the PV panels such as the panels experiencing shading or soiling. However, there is a flaw with this method of measuring PV panel performance. The mathematical model cannot be used to detect faults if they occur. The model can only be used to alert the consumer whenever their PV panels are not performing at its optimal point, but not provide a diagnosis of the issue or faults. Despite that, it is possible to integrate the mathematical model with other methods of fault detection which can provide a more accurate diagnosis. Another weakness of this method of performance evaluation is that it is not suitable large scale PV performance monitoring due to the complexities that come with large scale PV systems. Instead, it has to be limited to systems within the kilowatt (kW) range. That being said, further investigation must be conducted by upscaling the microcontroller system so that it can be tested PV systems of kilowatt scale. Additionally, a software can be developed to act as the user interface for consumer when the want to access the data. Finally, it is recommended that the Arduino prototype board be switched to the more standard PIC (Programmable Interface Controllers) microcontrollers as they are much more suitable for real

life applications, especially when considering to upscale the data collection system into the kilowatt range of PV electricity generation systems.

## 5. Conclusion

To conclude, as the utilization of PV systems is becoming more common, it is essential that each system is equipped with a performance monitoring system. In the system, the performance monitoring method will determine architecture of the device. The performance ratio mathematical model was used to monitor and evaluate the performance of PV panels. The data collected from the experiments indicate that PR can be used to monitor the performance of the PV panels as it provides an accurate evaluation of the performance and is able to detect when the PV panels performance is affected by shading. However, the PR equation does not provide an indication of the type of faults that causes the performance issue. The next step of this research is to develop a more robust prototype that can be used for PV systems that range in kilowatts and to integrate the PR mathematical model with other methods of fault detection.

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## Conflicts of interest

The authors have no conflicts of interest to declare.

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