DTU Fotonik

# Infrared Thermography

**34553 Applied Photovoltaics**

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**Abstract:** In this exercise, you will perform infrared thermography (IRT) on a PV panel for fault diagnostics in the lab. We cover several topics in the IEC standards that are under development. If the weather allows, we will expose the PV panels also to the sunlight and go to the Solar Park for a demonstration.

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**References and links**

- Slides from class (Block 4)
- Lecture slides from Course 34552 PV Systems, Lecture 11.

**Safety**

- Careful with the power supply connection and management: most of the experiment uses high current (~8A DC)
- Careful handling big PV modules. Two people should carry them carefully always.
- If in doubt, ask an instructor.

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## 1. Introduction

Infrared thermography (IRT) or infrared radiation imaging is a powerful diagnosis tool for PV devices, PV installations and electronics in general. This exercise covers the following practices:

1. Capture thermal images of photovoltaic modules by infrared thermography;
2. Process images to obtain quantitative metrics;
3. Provide guidance to qualitatively interpret the images for features that are observed.

This technique is applicable for PV modules measured indoors with a power supply that forward biases the cells in the modules, or outdoors where current in the module is generated by the module itself from sunlight. For this laboratory exercise, we will image the PV modules in open and short circuit for comparison. The outdoor part of the experiment will be performed only if the weather allows so.

## 2. Equipment

### 2.1 Camera description

Specialized thermal imaging cameras use sensors that respond to longer wavelengths (mid- and long-wavelength infrared). The most common sensor types are InSb, HgCdTe, VOx and quantum-well infrared photodetectors. The camera we use for this laboratory practice (Figure 1) is a rather special camera in two sensors. It has not only a thermal sensor, but also a normal optical sensor, which we will refer to as “visual” or “RGB” camera; and it is an airborne camera, as it has a lightweight construction and no visualization screen attached to it, as most of common cameras do. Have in mind that thermal imaging camera resolutions are considerably lower than visual cameras.

Table 1 shows the camera specifications in detail:


Figure 1 - FLIR Duo Pro R Camera

**Table 1 - FLIR Duo Pro R Specifications. Highlighted are the specific parameters of the camera available for this laboratory exercise**

### Specifications

| Overview | Duo Pro R 640 | Duo Pro R 336 |
|---|---|---|
| Thermal Imager | Uncooled VOx Microbolometer | |
| Spectral Band | 7.5 – 13.5 µm | |
| Thermal Sensitivity | < 50 mK | |
| Thermal Sensor Resolution Options | 640 x 512 | 336 x 256 |
| Thermal Lens Options | 13 mm: 45° x 37° | 9 mm: 35° x 27° |
| | 19 mm: 32° x 26° | 13 mm: 25° x 19° |
| | 25 mm: 25° x 20° | 19 mm: 17° x 13° |
| Thermal Frame Rate | 30 Hz | |
| Visible Sensor Resolution | 4000 x 3000 | |
| Visible Camera FOV's | 56° x 45° | 56° x 45° |
| **Radiometry** | | |
| Measurement Accuracy | +/- 5 C or 5% of readings in the -25°C to +135°C range<br>+/- 20 C or 20% of readings in the -40°C to +550°C range | |
| **Physical Attributes** | | |
| Size | 85 × 81.3 × 68.5 mm<br>85 × 86.5 × 68.5 mm (640/25 mm lens only) | |
| Weight | 325 g<br>375 g (640-25 mm only) | 325 g |
| **Image Processing & Display Controls** | | |
| Imaging Modes | IR-only, Vis-only, Picture-in-Picture (IR in Vis) | |
| MSX Image Enhancement? | Yes | |
| Multiple Color Palettes? | Yes – Adjustable in App and via PWM | |
| **IMU Sensor** | | |
| GPS? | Yes (GPS, GLONASS) | |
| Other Sensors | Accelerometer, Gyroscope, Magnetometer, Barometer | |
| **Interfaces** | | |
| USB 3.0 | Power in, USB Mass Storage | |
| 10-Pin Accessory Port | Power in, Analog Video Out, PWM, MAVLink | |
| Micro-HDMI | Digital Video Out | |
| Input Voltage | 5.5 - 26.0 VDC (10-pin JST Port) | |
| | 5.0 VDC (USB-C Port) | |
| Power Dissipation (avg) | 10 W | 10 W |
| Remote Control? | Yes - PWM (3 channels), MAVLink | |
| MAVLink interface? | Yes | |
| Digital Video Output | 1080p60, 1080p30, 720p60 | |
| Mounting Features | 1/4"-20 TPI Tripod Mounts (qty 2, bottom surface) | |
| **Environmental** | | |
| Operating Temperature Range | -20°C to +50°C | |
| Storage Temperature Range | -20°C to +60°C | |
| Operational Altitude | +38,000 feet | |

#### *2.1.1 Camera Configuration*

**Mount:** The camera should be mounted on a tripod in front of the device under test (DUT). The camera has to be connected to an HDMI screen or computer for image feedback. After this, you can properly adjust the distance to have the full PV module in the field of view (FOV) of the camera (for both RGB and IRT).

**Control:** To control the camera, you can use the laboratory tablet with the app "FLIR UAS". The camera is controlled via Bluetooth.

**Angle:** Angle of view relative to surface normal shall be maintained between 0° and 40° for the front glass and between 0° and 45° for polymer backsheets. When possible, angle of view is optimally made close to normal with respect to the module surface. However, when viewing close to 0° from module normal, it will be necessary to account for reflections from the camera and operator; when viewing far from normal outdoors, reflections of buildings, other modules, and landscape may become greater. Imaging with angles exceeding these specifications will lead to the module appearing colder than actual if no adjustments for the angular dependence of emissivity are applied.

**Calibration:** The thermal camera should be calibrated according to any procedures specified by the manufacturer. A manufacture-specified standard calibration of the camera shall be performed within the prior two years of the use date. In our case, we validate the temperature reported by the camera with another thermometer as well.

**Emissivity:** Typical emissivity values that should be set into the camera in the absence of specific data measured or provided by the material manufacturer are 0.85 for the glass and 0.95 for the polymer backsheet. These values can be entered in the FLIR UAS app.

**Temperature range:** Cameras may have fixed or adjustable temperature ranges. Temperature ranges for thermal cameras are usually wide enough for practical purposes so that it does not have to be changed; however, once selected, it should be kept consistent. Note: The camera temperature range is distinguished as different from the temperature level and span, which are readily adjustable in software during the course of imaging.

**Reflections:** Reflections from heat sources including the sun, electronic equipment, people (including the photographer) and other reflected sources should be minimized. In the case of measurements on fielded systems, care should be taken to not shadow the sun on the module before or during image capture, either by the photographer, clouds, or other buildings. Instances where reflections and effects of shadowing are inevitable, notation of such circumstances and conditions shall accompany the recorded thermal image along with indication of the resulting artifact on the image.

### 2.2 Power supply

For indoor IRT, a DC power supply capable of applying the correspondent $I_{Pmax}$ or $I_{SC}$ of the DUT is required. Be aware that this current level can be dangerous. You should know beforehand the $I_{SC}$ and $V_{OC}$ of your module (at least roughly) to be able to drive a forward bias current safely.

Figure 2 - BK Precision DC Power Supply

### 2.3 Image processing

To process the IRT images, verify temperature ranges, etc., you will use the "FLIR Tools" software. You can download it by this link (https://support.flir.com/SwDownload/app/RssSWDownload.aspx?ID=120) or get the file in a flash drive with the instructor.

## *Task 1 – Indoors IRT: Power applied to the module by the DC power supply*

**Indoor measurements:** For consistency, they shall be made in an isothermal environment, void of localized effects of air conditioning and ventilation. The imaging laboratory temperature shall be between 18 °C and 25 °C.

These measurements will be performed on **your working module**.

Follow the steps:

1) Preparation
   a. Place the DUT securely in position for imaging. In this task, we will only image the module from the front.
   b. Electrical connection: Connect the (+) and (-) electrical leads from the DC power supply to the sample, matching the (+) lead of the power supply with the (+) of the sample. Set the current to $I_{Pmax}$ or $I_{SC}$ and the voltage to few volts above $V_{OC}$ to allow forward bias. Turn it on quickly, just to verify if there is forward bias running and turn it off.
   c. Have in mind: Heat transfer through the front glass will generally follow a longer, slower, and less precise route than through thin polymeric backsheet.
2) Image acquisition
   a. Take an image at time zero, before biasing the module.
   b. Turn on the DC power supply and take an image soon after application of electrical bias.
   c. Take an image at 20 seconds of bias.
      i. Record the actual current and voltage applied to the module.
   d. Capture an image at 2 minutes of bias from time zero.
   e. Capture an image at 5 minutes of bias from time zero.

## *Task 2 – Outdoors IRT: Power applied to the module by solar irradiation*

**Outdoor measurements:** The images shall be taken with the irradiance equal to or greater than 700 W/m$^2$ in the plane of the array (POA) and with wind speed not higher than 20 km/h or 5 m/s.

These measurements will be performed on **your working module**.

Follow the steps:

1) Preparation
   a. The POA measurement should be made using a reference cell connected to a multimeter.
   b. Place the DUT in a rack securely in position. The module should be covered with a blanket until the measurements start.
   c. In this task, we will image the module from the front and from the back by the end of the sun exposure. Remember to set the correct emissivities.

   d. The POA global irradiance at the time of the image shall be recorded either manually or electronically such that the irradiance at the time of each image can be later assigned.

2) Image acquisition – At Open Circuit
   a. Record POA, remove the blanket from the module and take an image from the front of the module at time zero.
   b. Record POA and take an image from the front of the module at 2 minutes of bias from time zero.
   c. Record POA and take an image from the front and the back of the module at 5 minutes of bias from time zero.
   d. Cover the module again and wait 5 minutes.

3) Image acquisition – At Short Circuit
   a. Connect the modules connectors to each other, record POA, remove the blanket from the module and take an image from the front of the module at time zero.
   b. Record POA and take an image from the front of the module at 2 minutes of bias from time zero.
   c. Record POA and take an image from the front and the back of the module at 5 minutes of bias from time zero.

4) Image acquisition – String connected
   a. We will go to our Tracker Facility and take a few images from the PV modules installed normally functioning series strings connected to the grid via an inverter.
   b. Make sure you take EVERYTHING you will need.
   c. Connect the camera to the battery and position it in front of a PV panel following the angle requirements. The strings have POA measurements, so there no need to acquire them. However, register the time to acquire the correct POA later.
   d. Take an image from a Bifacial module - front (glass)
   e. Take an image from a Bifacial module - back (glass)
   f. Take an image from a Standard module - front (glass)
   g. Take an image from a Standard module - back (polymer backsheet)

## 3. Results Presentation

The slides containing this exercise results should include:

- Short theory about IRT. } 1 slide
- Presentation of the IRT+RGB images acquired, in an organized way, including:
  - Test type (indoor, outdoor, string connected)
  - Location (find coordinates when outdoors)
  - Time
  - Ambient Temperature
  - Wind speed and direction (outdoors)
  - Current and voltage (indoors)
  - Irradiance (POA - outdoors)

} 1 slide for indoor results
1 for outdoor results (if any)

During the presentation, discuss about:

- Interpretation of the IRT images, spotting warmest and coolest points.