Fast In-Field Imaging of PV Modules for Crack Detection: Methods, Results, and Modeling Implications

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Fast In-Field Crack Imaging

Ultraviolet fluorescence (UV-F) has been shown to be an effective method for easily detecting cracks in PV modules [1]. We have developed a system for fast nighttime UV-F imaging (<3 seconds per module) as well as un-shaded daytime UV-F imaging.

Ultraviolet (UV) imaging is a new, even faster method for crack detection. It requires only sunlight and a modified consumer camera with a low cost lens and filters. Tradeoffs with UV imaging are that it does not appear to work on all modules, and defects have lower contrast than in UV-F.

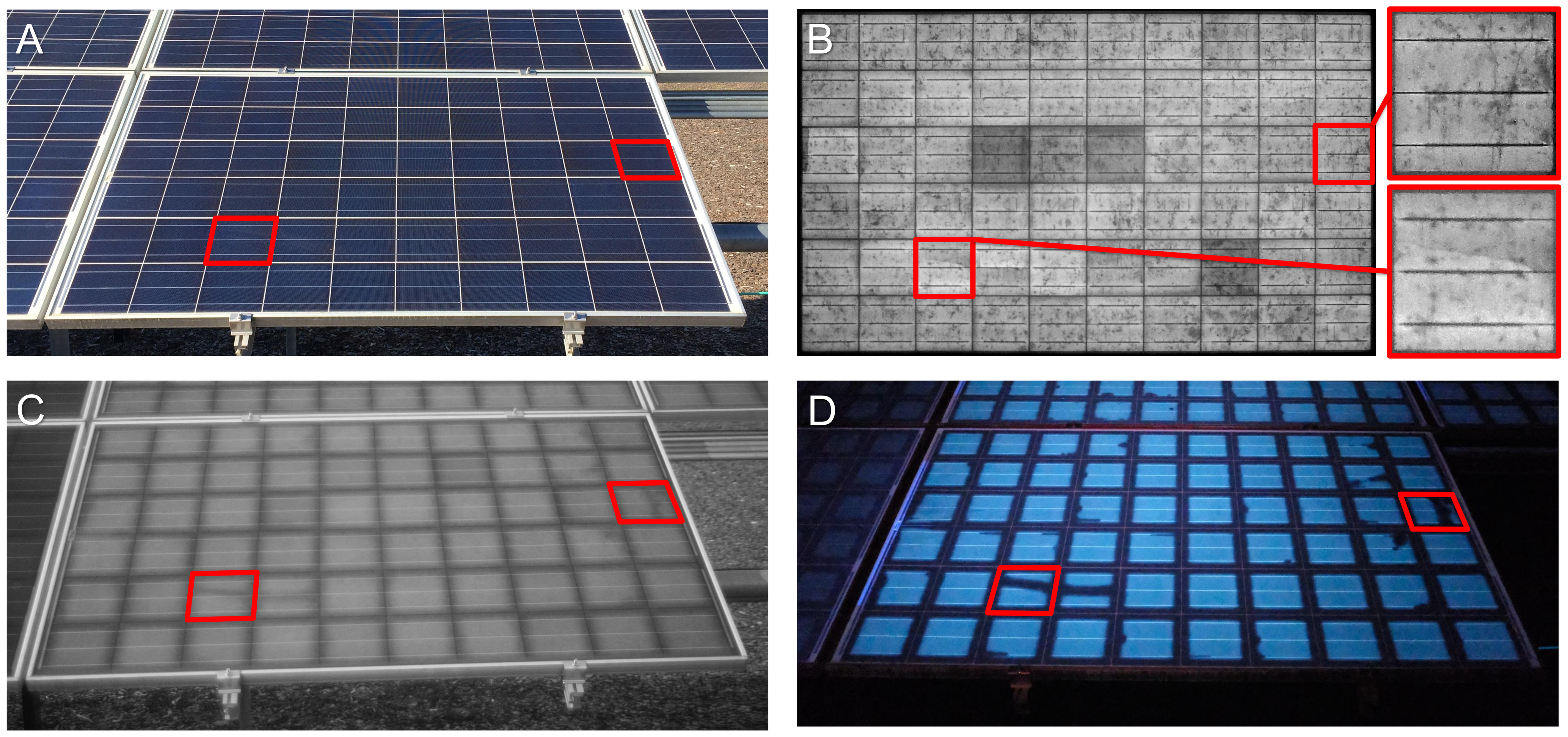


Figure 1. Test module images with different methods: Visible (A), electroluminescence (B), UV (C), UV-F (D)

Methods: UV-F Imaging

A standard camera and modified flash unit are used for UV-F. Flash tubes without UV-blocking coatings are required, so specific flash units or aftermarket tubes are needed. A UV-pass filter is used to block most or all visible light from the flash.

For daytime UV-F, two images are taken in quick succession – one with the flash and one without. The images are subtracted to highlight additional light from the module caused by fluorescence.

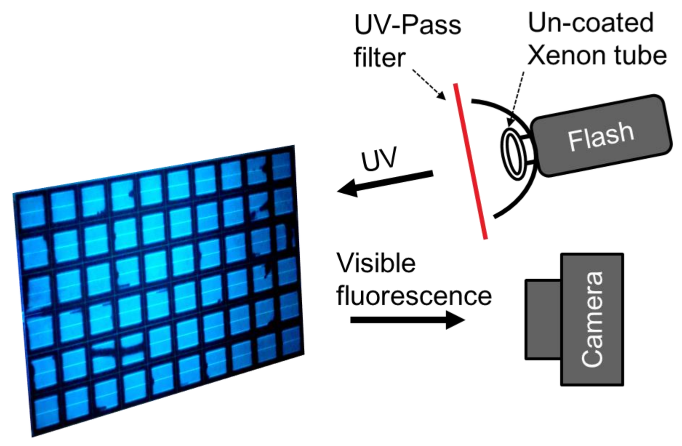


Figure 2. UV-F setup diagram

Equipment used:

- Camera: Fuji X100F (chosen for high flash sync speed to reduce background light)
- Flash A: Canon 199A with UV-blocking lens/cover replaced with 2mm Hoya U-340 UV-pass filter [2]
- Flash B: Godox/Flashpoint AD200 with uncoated flash tube [3] and Hoya U-340 2.5mm UV-pass filter [4] with custom mounting bracket and wireless flash trigger or hot shoe adapter and PC-sync cable.
- Wired or wireless remote shutter release
- Tripod (for daytime) and/or monopod (for nighttime)

Figure 3. UV-F equipment

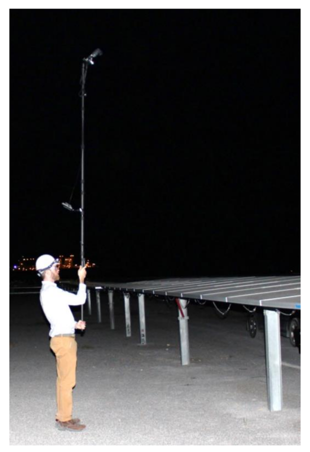


Figure 4. UV-F night use

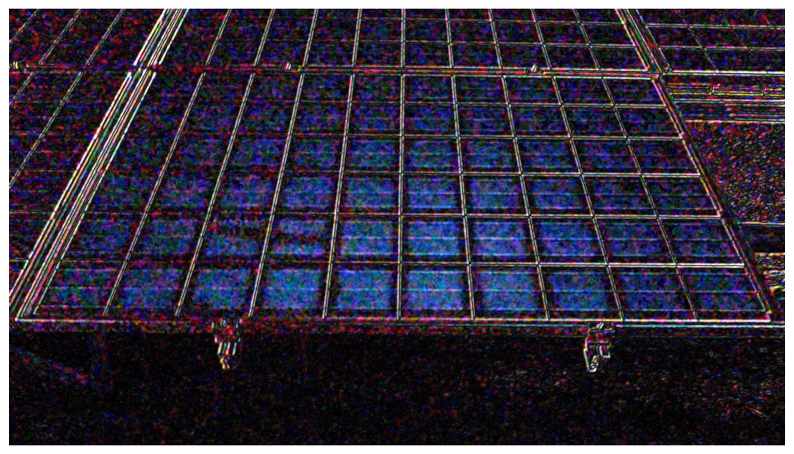


Figure 5. Daytime UV-F image of test module from Fig. 1

Methods: UV Imaging

UV imaging requires a lens that transmits UV, a camera sensitive to UV, and appropriate filter(s) to pass only UV. Images are typically taken in daylight, but a UV flash can be used for nighttime imaging. We used:

- Sony a7s with hot mirror replaced by broad-spectrum glass [5]
- Kyoei Kuribayashi 35mm f/3.5 lens [6] with UV-pass and IR blocking filters [7]

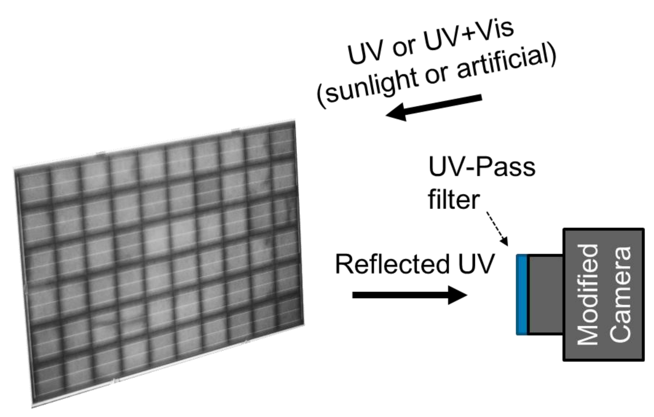


Figure 6. UV setup diagram

Image Processing

UV-F images in particular can benefit from image processing to aid in crack detection, which could be fully automated with existing methods. Procedures include:

- Correction of non-uniform flash illumination using reference images of flash directed at a uniform surface
- Lens and perspective distortion correction with module isolation (optional)
- Contrast/levels adjustment
- Grayscale conversion
- Binary thresholding

These procedures could be mostly or fully automated, followed by image region analysis to either flag modules with cracks for manual review, or to fully characterize cracks.

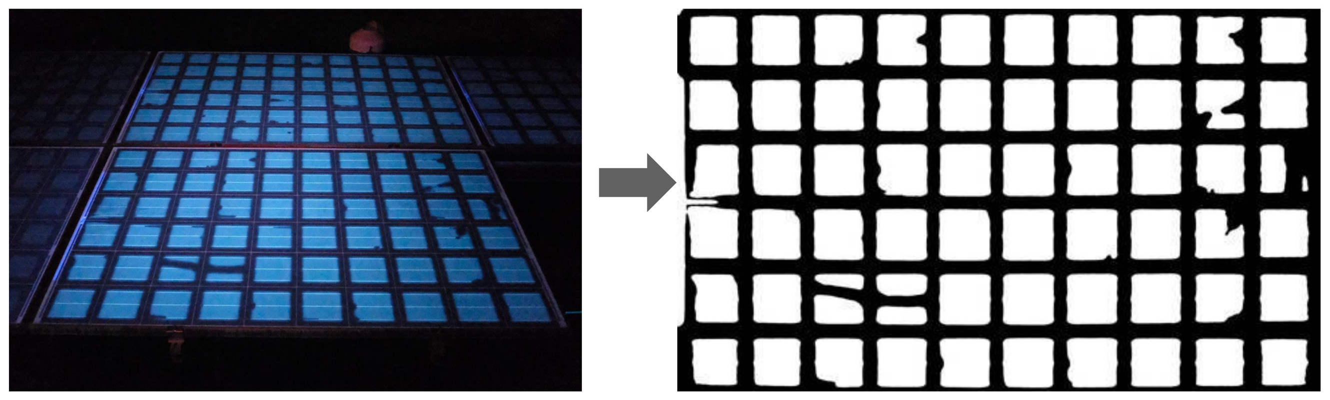
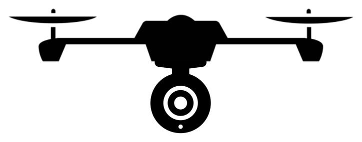


Figure 7. Test module images before (left) and after (right) image processing

Additional Images and Future Work

Both UV and UV-F images can have different characteristics with different modules. Compared with the test module in Fig. 1, the module highlighted in Fig. 8 shows lightening rather than darkening over cracks in UV and a different color fluorescence in UV-F.



Planned future work to improve image acquisition includes use of aircraft for UV and UV-F as well as experimentation with different flash units and filters.

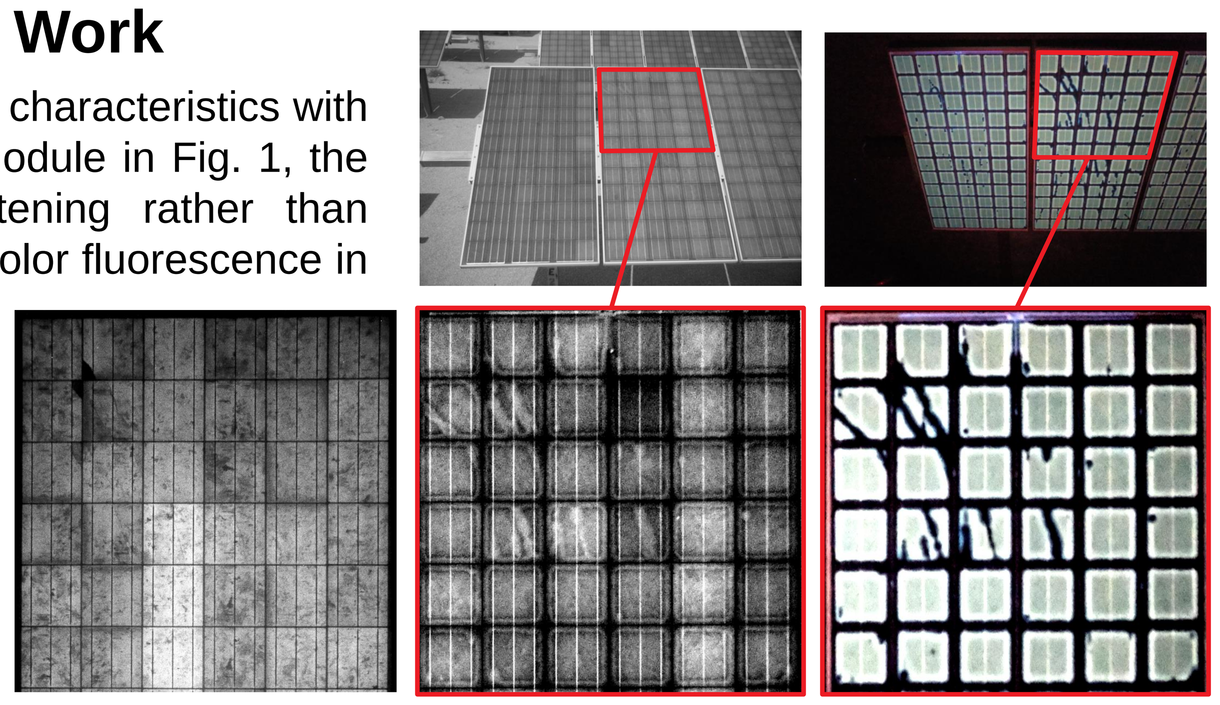


Figure 8. Additional module EL (left) UV (center) and UV-F (right) images

Proposed Modeling Work and Acceptance Testing Application

Modules can be damaged during shipping and installation or weather events. Some damage may cause immediate power losses, but other damage may be "latent". **<u>How much latent damage is acceptable</u>?**

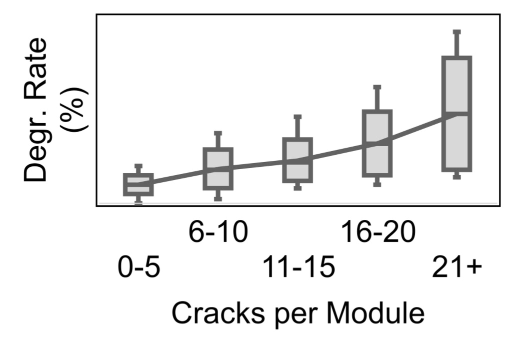
- Modules with cell cracks → increased degradation rates [8]
- Increased degradation → increasing lost power *and* increasing mismatch losses
- Magnitude of mismatch losses will depend on:
  - Number and location of damaged modules
  - Variation in degradation rates
  - Plant design

To determine acceptance criteria for cell cracks in a plant, the following is needed:

1. Correlations between number of cracks and degradation rate
2. Modeling capabilities to explore degradation rate distributions, mismatch losses, and lifetime energy impacts

To address 1 above, we could select plants that are approximately 5+ years old and have factory flash test data, and:

- use UV or UV-F to count cracks in a large number of modules
- group modules into bins by number of cracks
- randomly sample from those bins and measure module P_{MPP}
- quantify degradation distributions for each bin using factory flash test data



To address 2 above, new modeling capabilities will need to be developed.

References and Acknowledgements

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[1] A. Morlier, et al. *UV fluorescence imaging as fast inspection method for PV modules in the field*. 14th IEA PVPS Task 13 Meeting. 2016. http://www.eurac.edu/en/research/technologies/renewableenergy/conferences/Documents/1_160406_UV%20fluorescence%20in%20field_Morlier.pdf

[2] Hoya U-340 UV Flash Filter for Canon Speedlite 199A smooth polish or sandblasted, http://stores.ebay.com/uviroptics

[3] FT-50R Round Flash Tube Lamp 200ws, https://www.xenonflashtubes.com, with 4mm bullet connectors soldered on.

[4] Hoya U-340, 165mm sq X 2.5mm, http://www.hoyaoptics.com/color_filter/uv_transmitting.htm

[5] Kolari Vision, https://kolarivision.com

[6] Kyoei Kuribayashi (T-Mount Variant) 35mm F3.5 Lens & Filter Set! UV Photography!, https://www.ebay.com/usr/igoriginal

[7] 2mm ZWB1 and 2.5mm Schott BG39, included with [6]

[8] S. Chattopadhyay et al., *All-India Survey of Photovoltaic Module Reliability: 2016.* Indian Institute of Technology Bombay. 2016.