Fast acquisition of UV-Fluorescence images and automated crack detection

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Introduction

Ultraviolet Fluorescence (UVF) is an emerging field inspection technique which enables the detection of cracks and other faults [1]. Köntges, Morlier, et al., have investigated the potential of UVF to detect cracks and hotspots, measure degradation in the encapsulant, and discriminate between new and old cracks [1]-[3]. They have developed and demonstrated a field system capable of imaging up to 200 modules/hour [1].

We present an updated design of a UVF field inspection system with a high-power UV source [4], capable of imaging 1000+ modules/hour, and an overview of an automatic processing utility capable of detecting cracks and accumulating plant-wide fault statistics.

Inspection System

The inspection system in shown in Fig. 1. A consumer camera with a large aperture and reasonable low-light performance was selected (Fuji X100F). The UV source is a standard external flash without UV-blocking coatings or lenses and a UV-pass/visible blocking filter. Long battery life, fast recycle times, and easy modification to remove UV-blocking elements are important. A monopod with a tilt head, handle, and a remote shutter release are used to position the camera above modules and take images.

The total cost is < $3500, weight is less than 4 kg, and the kit fits in carry-on luggage.

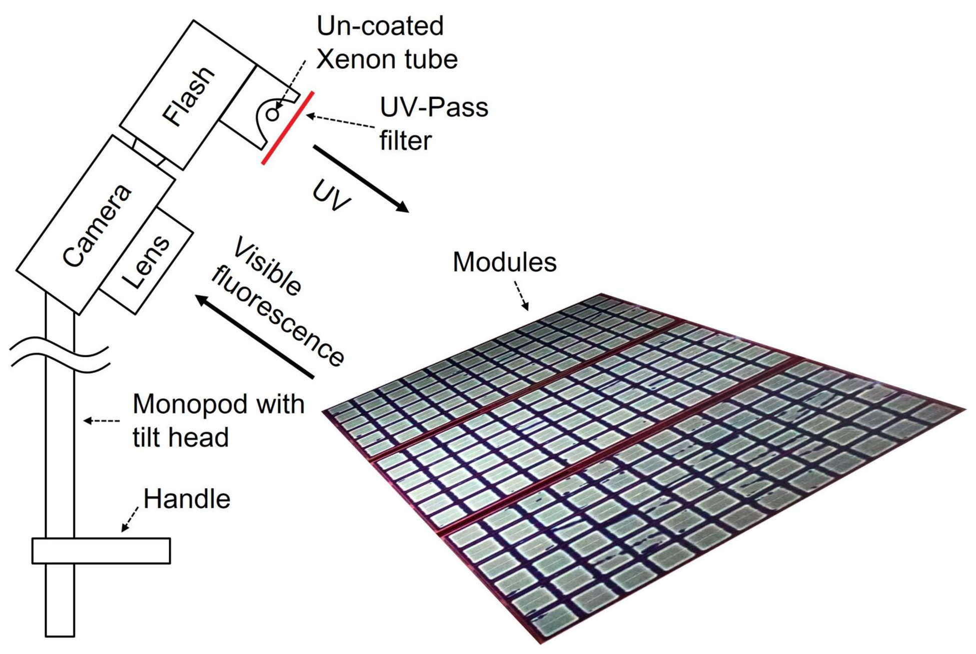

Fig. 1. Diagram of the UVF inspection system.

Automatic Processing Utility

Machine learning using TensorFlow's object detection API [5] was used to detect cracks. The processing workflow is illustrated in Fig. 2. Inputs to the machine learning model were simplified by segmenting images to individual cells. Cells were input into the detection model, which was built by retraining one of TensorFlow's Faster-RCNN models using a training set of cracked cells from a single site. This set contained 1,810 unique cracked cells, augmented 8 times to get a training set of 14,480 images.

The utility is planned to be made open source and was developed to be extensible to other PV sites. Check https://github.com/southern-company-r-d/OpenUVF in the coming weeks.

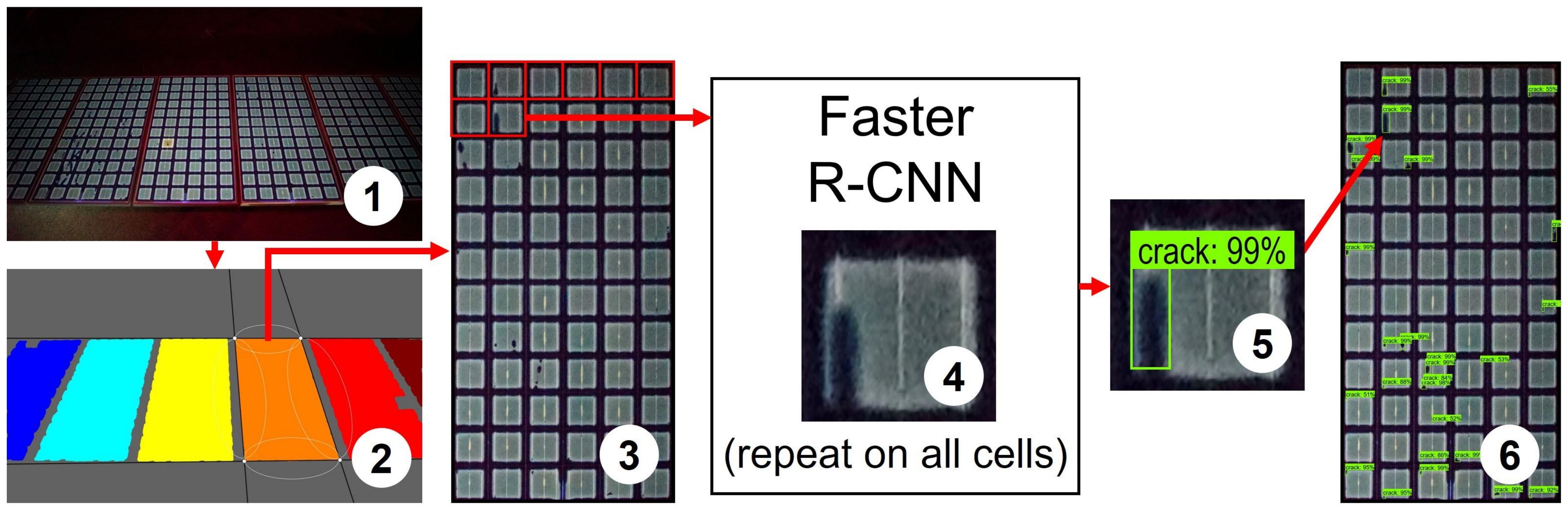

Fig. 2. Processing workflow steps, including 1) original image; 2) binarization, closing, and module segmentation; 3) perspective correction and cell segmentation; 4) TensorFlow F-RCNN crack detection; 5) detected cracks; and 6) module re-stitching.

Inspection Results

Multiple sites of various ages and manufacturers have been inspected. A subsample of results are shown in Fig. 3. Plants with older modules (1 and 2 in Fig. 3) exhibit a square UVF pattern, while most younger modules exhibit a ring (3, 5-6).

Throughput was measured at 4 sites and was consistently over 1000 modules/hr for single-module rows, and over 2000/hr for racking with modules mounted two-high.

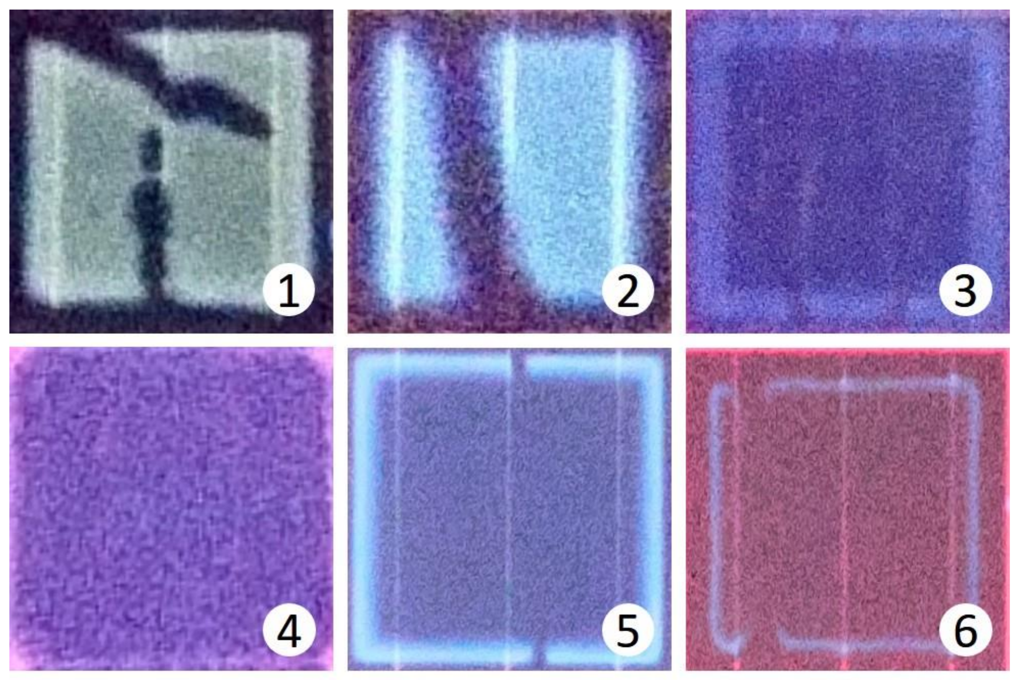

Fig. 3. Sample UVF profiles from 6 sites. Modules 1-2 manufactured 2011-2012, modules 3-6 2015-2017.

UFV was demonstrated to be able to detect what appear to be cracks along busbars, which are hidden under tabbing wires and not visible in electroluminescence (EL). An example is illustrated in Fig. 4, where busbar cracks are prevalent and bleaching occurs over some cells with no visible defect in EL. Additional destructive and non-destructive testing is planned to confirm the presence of these cracks.

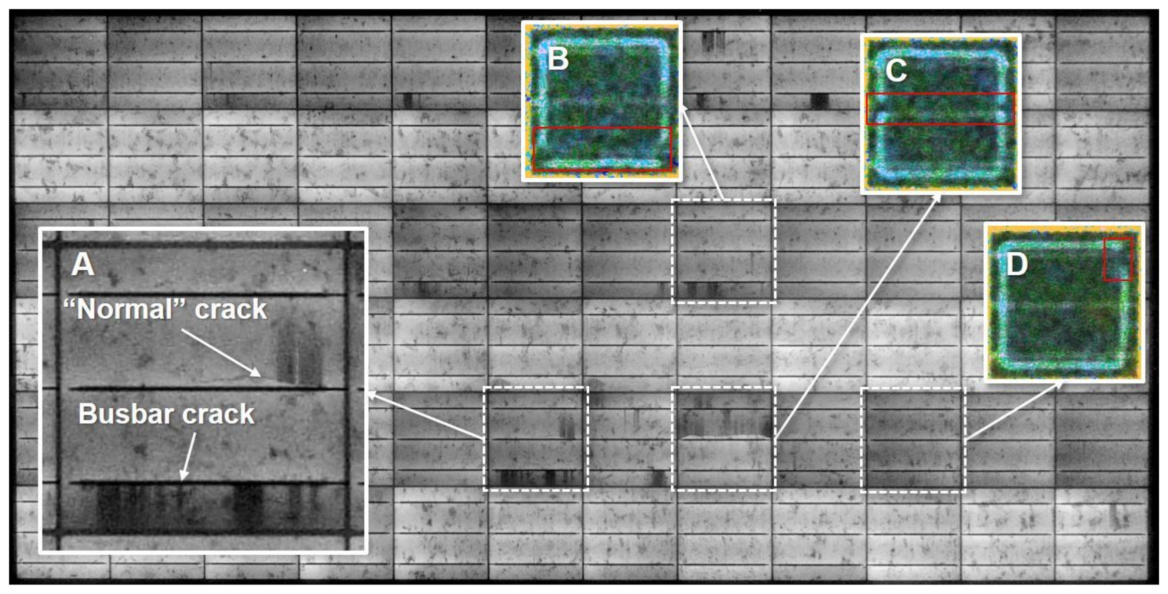

Fig. 4. EL of a module with UVF details. Highlighted cells show EL-visible cracks along busbars (A, B), normal cracks (A, C), and EL-hidden cracks (D).

Crack Age Estimation

A plant that was subjected to high winds was imaged using EL and UVF approximately 3 weeks after the storm (Fig. 5). Differences in UVF may be able to differentiate between cracks that existed before the storm and cracks caused by the storm. More testing is planned to explore this.

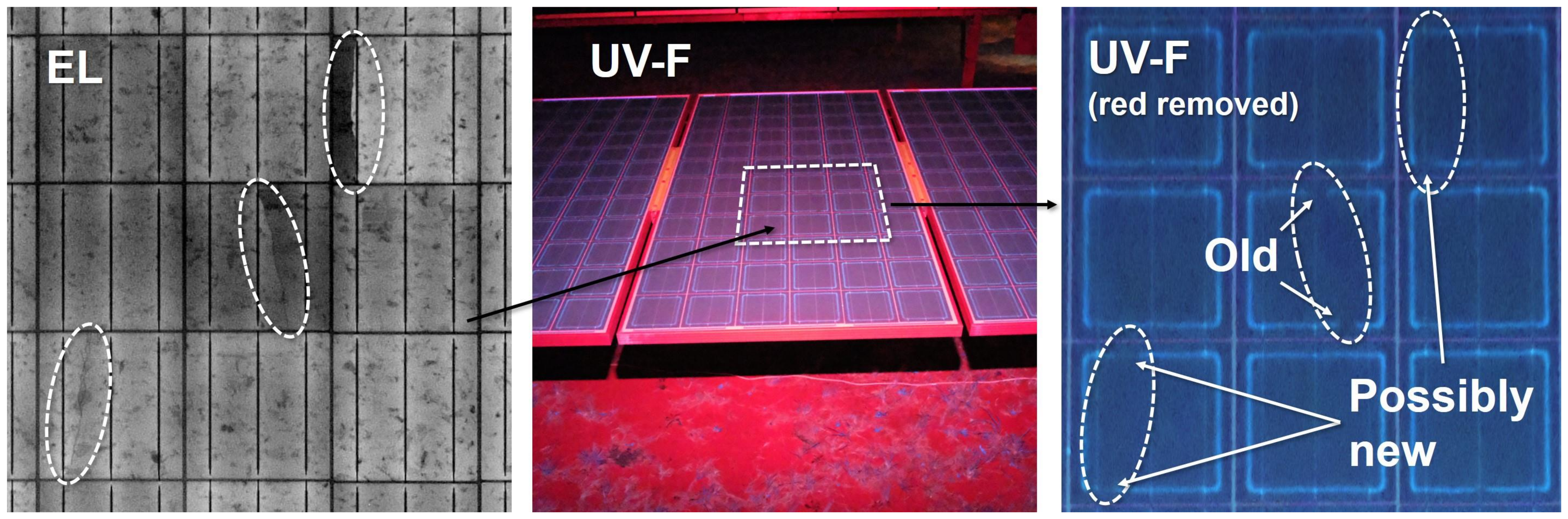

Fig. 5. Sample module with suspected storm damage. EL (left) highlights three cell cracks. UVF taken about 3 weeks after the storm (original image, center; processed, right) shows variation in bleaching of fluorescence that may differentiate old cracks from new ones.

Automatic Processing Results

Crack detection accuracy was 97.4% with a unique set of 3172 (augmented) cells, including a diverse set of image qualities and crack geometries. Module segmentation steps did not perform as consistently, only segmenting 60% of modules. Improvements to field protocols (i.e., camera alignment) could reduce most of this error, however improved segmentation may be needed. An example output of the entire utility is shown in Fig. 6, along with an EL image of the same module.

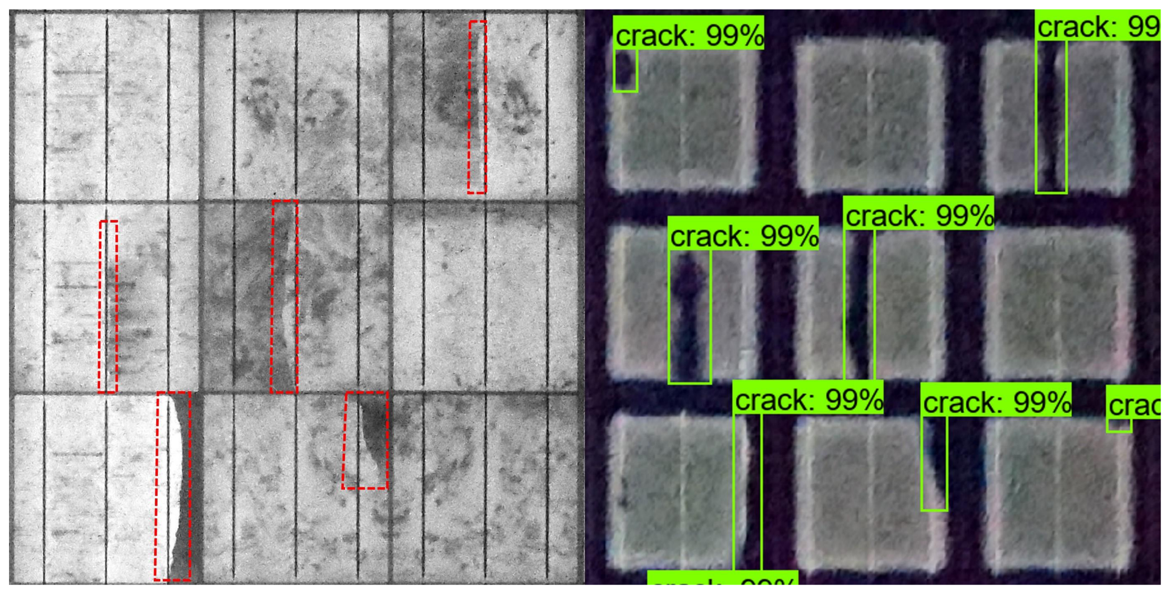

Fig. 6. Portion of a module in EL (left) and UVF (right). Cracks detected manually in EL are highlighted in red and cracks detected automatically in UVF are shown in green.

Conclusions & Next Steps

At over 1000 modules/hr and with automated processing, these systems could greatly improve PV inspections. Being a nearly 20X increase over to EL [6], UVF could be combined with IR and used to identify modules for EL, providing a more representative sample of a plant. While UVF has been demonstrated from drones [7], we believe our systems will improve drone applications, and use of a drone may improve our image segmentation reliability. More testing to understand crack age is planned and will greatly aide in insurance claims.

References

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