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SCALING UP LASER LINE PHOTOLUMINESCENCE IMAGING FOR OUTDOOR INSPECTIONS

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ABSTRACT – As outdoor electroluminescence is implemented in the field, with several developments for automated inspection, an increasing concern rises upon the limitation that the electrical connections will bring to the inspection speed. In the effort to avoid both electrical contact and time limitations for PV inspections, here we present the progress in scaling up the well-known cell level photoluminescence imaging to a module level. The final goal is to build up a system that can perform PL excitation and image acquisition from the distance on PV modules and brought easily to the field by unmanned aerial vehicles (UAV).
Keywords: Photoluminescence imaging, PV inspections, Fault detection, Laser line.

1 INTRODUCTION

In order to ensure the expected return on investment (ROI) of both small and large-scale PV installations, regular fault detection is highly desirable. At the same time, frequency and level of detail in large power plant inspections is often limited by manpower and cost. Luminescence based imaging can be used to rapidly and accurately detect a large range of major and minor faults in PV modules such as cell cracks, broken interconnections, potential induced degradation (PID), among others differently from current field inspection methods such as infrared thermography and electrical characterization [1]–[3]. As outdoor electroluminescence is implemented in the field, with several developments for automated inspection, an increasing concern rises upon the time limitation that that the appropriate electrical connections to the PV system will bring to the inspection speed.

Luminescence can be induced not only by electricity as performed in electroluminescence (EL), but can also be driven by light therefore called photoluminescence (PL). The sun would be the straightforward way to induce PL, however, as the sunlight is orders of magnitude more intense than the luminescence signal, the need for modulation between V_{OC} and I_{SC} to obtain the PL image require again electrical connections. Another possibility would be to acquire images while the PV panels are at different temperatures (i.e. times of the day), what maximize the time demand of the inspection. There are valuable strategies in the literature to avoid electrical contracting, such as contactless EL and outdoor contactless PL [4], [5]. However, these strategies require the images to be acquired at a very short distance or masks touching the surface of the panels, what represent a speed limitation to a fast UAV-based inspection scenario.

In order to avoid both electrical contact and time limitations for PV inspections, the development of a line shaped laser light source for inducing PL on a module level is the most promising technical solution and it is under development. The final goal of the setup is to be able to induce PL with a single laser light source in a homogeneous line shape over a PV module, where the light source can be switched on and off synchronized with the camera acquisition for the purpose of ambient light subtraction.

Here we describe the prototype and perform a laser line PL image of a 36 cells module with luminescence inducing light source and camera at one meter distance from the PV sample, corresponding to fully contactless PL scanning tool, developed until the moment for low natural light ambient condition. A fast scan concept is presented, taking 2 seconds to scan 2 cells and the final module PL montage is compared with an EL image of the same module. The results from the PL laser line scan demonstrate the possibility of a fast mirrored scanning to be constructed in the future.

2 EXPERIMENTAL

In the following described experiment, an InGaAs camera from Raptor Photonics, a 25 mm sapphire lens and a long-pass filter to cut out the laser emission were used. The sample is a module with 36 multi-crystalline silicon 15.6 cm cells arranged in a 6 x 6 matrix, mechanically stressed showing several cracked cells.

PL images under low natural light were acquired using as PL excitation source an 800 nm laser diode at two different optical power intensities at open circuit (Fig. 1). The camera

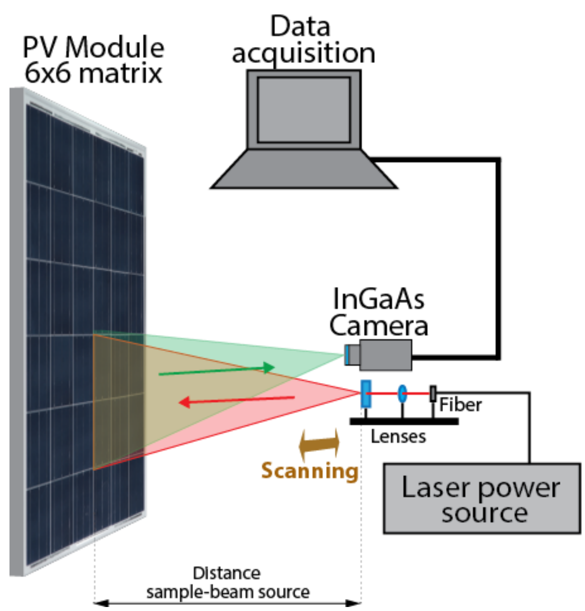

Figure 1: PL laser line scan setup.

was kept fixed in its position at 1.2 meter from the sample, comprising 4 cells in its field view. The laser beam coming from a fiber was shaped into a line using lenses with <5% of optical power loss. The laser fiber was placed at 1 m from the sample, with the line presenting 10 mm width and 360 mm length, with intensity of ~ 4 suns and covering 2 cells each scan. The line beam was mechanically scanned over the region of interest with the use of a hand crank, allowing linear scanning speeds. The scan over the field of view of the camera was performed in 4 seconds, and the images were acquired with a 28 ms exposure time. The image processing was performed using the software ImageJ 1.47t. The setup was built as a freely movable setup, since the goal is to have a line scan not attached to the installation structure, but mounted in movable source, as an UAV.

3 RESULTS

The main challenge towards the field application of PL generated by a line shaped light source without enclosures is the low signal to noise ratio in relation to ambient light, even lower than an regular EL signal. This challenge needs to be carefully considered, since the amount of information presented by PL images change with the excitation light source intensity [6]. The PL signal induced by low light intensities (in the order of few suns) presents higher PL signal in isolated or enhanced series resistance regions. In parallel, at such (relatively) low inducing light intensities, not only PL is observed by also contactless EL [4], [6], due to the solar cell's very efficient lateral current spreading. Consequently, PL imaging has the ability of not only provide data concerning cracks and crystallographic defects, but also broken contact fingers and enhanced resistance areas. These results have been shown previously both experimentally and by simulations [7], [8]. Good quality PL images reported are performed under 2.5 suns [8], [9].

The resulting module PL image shown in Fig. 2 and the corresponding EL image shown in Fig. 3. The inset in Fig. 2 shows a section acquired in a single scan, and the histogram of the PL and EL insets is also shown. The PL and EL are comparable in their level of detail in detecting mode A (micro-cracks), B and C cracks. Some artifacts in the PL image can be observed without a clearly correspondence with the EL image, possibly are due the scanning procedure still to be fully optimized.

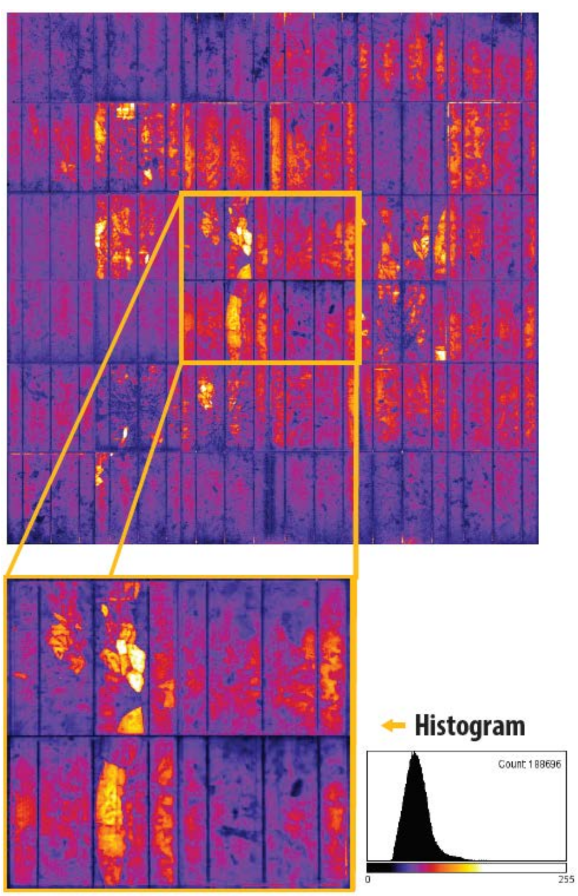

Figure 2: Laser line PL image. Inset shows zoomed in an area obtained with a single laser scan and its correspondent histogram.

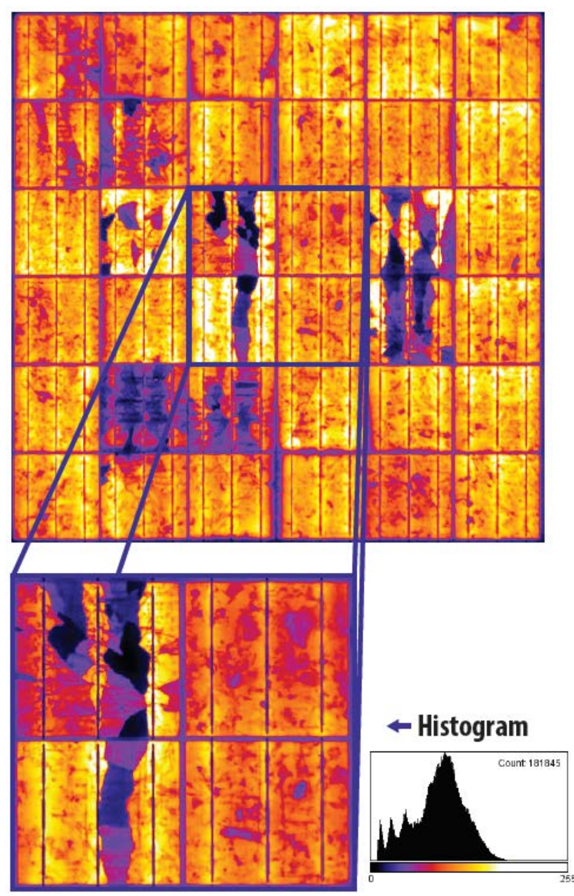

Figure 3: EL image. Inset shows zoomed in of the correspondent EL image from the laser line scan PL obtained with a single laser scan and its correspondent histogram.

The combination of the laser beam shape and the scanning speed provided good quality of images in relation to the laser intensity and exposure time of the image acquisition, showing cracks clearly identifiable and isolated regions appear highlighted. Compared with previous works [10], we have improved the scanning uniformity with a mechanic tool moved by a hand crank and defined the focal distance for the given line shape determined by the optics.

When the histograms of the inset luminescence images are compared, the higher intensity of the EL image allow us to observe the high contrast of the dark areas, evidenced in the high counts of low pixel numbers (see the 3 small peaks to the left of the EL histogram – inset Fig.3). Even though the highlighted isolated regions (cracks B and C) are clearly visible in the PL image, the low PL intensity does not provide enough contrast for efficient histogram analysis. Still, these results suggest important guidelines for the next steps of the development of this technology.

4 CONCLUSIONS AND OUTLOOK

In this work, laser beam shape and scanning uniformity (relative to the scanning speed) were defined to obtain good qualitative comparison of the PL image of a PV module in relation to its EL image. We presented PL images with laser line scan of a 6x6 matrix multi-crystalline PV module with the laser beam at a distance of 1 meter from the PV sample. Acquisition of PL images was feasible at such distance presenting well defined cracks and highlighted enhanced series resistance isolated regions (B and C cracks).

The lower luminescence intensity of the PL signal compared with EL still represents a challenge for outdoor applications. The continuation of this work consists of further development of the light source to overcome the low PL intensity.

At the same time, engineering efforts for a compact automatic scanning tool also need to be addressed for the final outdoor PL scan application for a full contactless luminescence imaging independent of sun irradiance conditions.

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