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The PocketLAI smartphone app: an alternative method for leaf area index estimation

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Abstract: The possibility of adopting the technology implemented in low-costs devices for the monitoring of biophysical processes is being increasingly explored by the scientific community. In the context of environmental studies, leaf area index (LAI) is one of the variables scientists and technicians are more interested in, since directly involved in radiation interception, and in crop response to water availability. An indirect method for leaf area index estimation was recently proposed and implemented in the smartphone app PocketLAI. The application uses the smartphone camera and the accelerometer to acquire images at 57.5° below the canopy while the user is rotating the device along its main axes. Images are automatically processed using a dedicated segmentation algorithm to derive the gap fraction. The PocketLAI was successfully evaluated for paddy rice canopies against data obtained with direct (planimetric) measurements, and results were compared with those provided by a number of commercial instruments. In a following study, PocketLAI was compared with AccuPAR ceptometer for canopies markedly deviating from the ideal assumption behind the simplified model for light transmittance into the canopy implemented in the app (i.e., random distribution of infinitely small leaves). Although a saturation effect was observed for dense canopies with big leaves (maize and giant reed) and a large number of measuring replicates was needed for markedly heterogeneous canopies (natural grassland), the overall positive results support the use of PocketLAI in context characterized by low portability or by limited economic resources. A step forward is here discussed by testing the performances of the app when installed on devices from different price categories and manufacturers, aiming at implementing automatic calibration facilities for entry-level smartphones.

Keywords: Leaf Area Index, Smartphone, AccuPAR, Calibration, PocketLAI

1. BACKGROUND

The competing pressure in the global smartphone market is leading manufacturers to provide this kind of devices with hardware able to guarantee nice user experiences when the device is used for recreational activities ranging from gaming to high level interaction with multimedia services. This – coupled with the production volumes typical of consumer products – is making available to the environmental scientists and technicians quality optics and sensors (Igoe et al., 2013), as well as relevant computational capabilities, at a cost of few hundred dollars (D'Elia and Paciello, 2012; Francone et al., 2014).

In this context, the PocketLAI© (patent pending) smartphone app for leaf area index (LAI, m^2 m^{-2}) estimates was recently proposed and evaluated for different types of canopies and compared with commercial tools (Confalonieri et al., 2013; Francone et al., 2014). The app is based on the implementation of a simplified model for light transmittance into the canopy, based on the estimation of the gap fraction (i.e., fraction of sky seen from below the canopy) at a view angle of 57.5°. This configuration allows acquiring information independently from leaf angle distribution and less affected by clumping effect in case of row crops (Weiss et al., 2004; Baret et al., 2010). The model adopted (Warren-Wilson, 1963) is shown in Eq. 1:

$$LAI = -\left[\frac{\cos(57.5°)}{0.5}\right]\log\left[P_0(57.5°)\right] \quad (1)$$

where $P_0(57.5°)$ is the gap fraction for a view angle of 57.5°.

Two prototypes were originally developed for the gap fraction estimation, one based on luminance measures above and below the canopy, and the other based on a dedicated segmentation algorithm, requiring just below canopy readings. The first method makes use of the EXIF information provided by the device camera – f-number (or focal ratio, *N*), exposure time (*t*, seconds), ISO sensitivity (*S*), and reflected-light meter calibration constant (*k*) – to derive the luminance (*L*, candela m^{-2}) according to Eq. 2:

$$L = \frac{N^2 \cdot k}{t \cdot S} \quad (2)$$

Gap fraction is then derived as the ratio of below to above canopy luminance multiplied by a parameter correcting the below canopy luminance for the amount of radiation scattered by the canopy. The second method is based on automatic processing of images acquired below the canopy using the smartphone camera in live-preview mode; sky pixels detection is performed in an HSB (Hue Saturation Brightness) color space for clear sky conditions, whereas it is just based on pixels intensity in case of cloudy sky. In any case, information is automatically acquired at 57.5° thanks to an inclinometer derived from the device accelerometer.

PocketLAI was first evaluated for scatter-seeded rice canopies, presenting small deviations from the assumption behind the light transmittance model used, and compared with the widespread commercial instruments LAI-2000 (Li-Cor, Lincoln, NE, USA) and AccuPAR (Decagon, Pullman, WA, USA) by using the evaluation protocol for in vivo field methods proposed by Confalonieri et al. (2014), and assuming direct (planimetric) measures performed in different moments during the season as reference values. PocketLAI achieved – with the segmentation method – overall performances similar to those obtained by LAI-2000 and AccuPAR in terms of both trueness and precision. The luminance method – instead – provided the best trueness metrics but the poorest repeatability and reproducibility. This – together with the need for performing two measures (above and below the canopy) and with the incompatibility with the most widespread mobile platform (i.e., Android) – led to the momentary stop of the development of the luminance-based version (Eq. 2). A second test – comparing PocketLAI and AccuPAR estimations – was performed on canopies markedly deviating from the assumptions behind the simple light transmittance model implemented in the app, characterized by big leaves and/or by high heterogeneity in terms of leaves shape and size (i.e., maize, giant reed, and grassland). In this test, a marked saturation effect was observed for LAI values higher than 5 m^2 m^{-2} in case of maize and giant reed, mainly because of the leaf size and the clumped canopy structures (both crops were row-seeded). Moreover, the heterogeneity of the natural grassland required a larger number of measuring replicates compared to the AccuPAR, because of the ceptometer capability to capture the small-scale variability thanks to its 80 cm 180°-field-of-view probe. However, PocketLAI provided, in general, estimates very close to those obtained with the AccuPAR ceptometer, with R^2 equal to 0.86, 0.92 and 0.88 for grassland, maize and giant reed, respectively.

Unpublished data collected during both the tests led to identify a device-effect in case of low-cost smartphones, that suggested the development of calibration facilities for PocketLAI, to allow its use regardless of the producer and model.

The aims of this paper are:

- to present the first official release of PocketLAI focusing on the software aspects and on the user experience;
- to present the first version of the calibration utility.

2. PocketLAI: GUI DESCRIPTION AND USER EXPERIENCE

PocketLAI v. 1.6.0.7 uses the smartphone camera and accelerometer to automatically acquire real-time images from below the canopy while the user is rotating the smartphone along its main axis. When the view angle (i.e., the angle between the vertical and the normal to the screen) reaches 57.5°, frames are automatically processed to detect sky pixels via two dedicated segmentation strategies, one for clear sky and the other for cloudy sky (Confalonieri et al., 2013). The images are acquired in live-preview mode, thus reducing possible discrepancies – in case the device is rotated quickly – between the target angle and the actual acquisition angle due to the time-lag needed to invoke a full-frame image capture; deviations from the target angle could indeed generate relevant errors in LAI estimates (Baret et al., 2010).
Figures 1 and 2 show the PocketLAI Graphical User Interface (GUI). The home screen (Fig. 1.a) allows the user to access main functionalities: consulting the integrated user guide, accessing data stored and specify options. The settings menu (Fig. 1.b) allows the user to specify preferences (i) for the number of measuring replicates to average, (ii) for storing or not images that have been processed, and (iii) for the sky conditions (clear or cloudy). When the main icon on the home screen is selected, the user can specify a name for the measure (Fig. 1.c) and enter the measuring mode (Fig. 1.d). The option for sky conditions is available via a dedicated icon (Fig. 1.d) in the measuring mode.

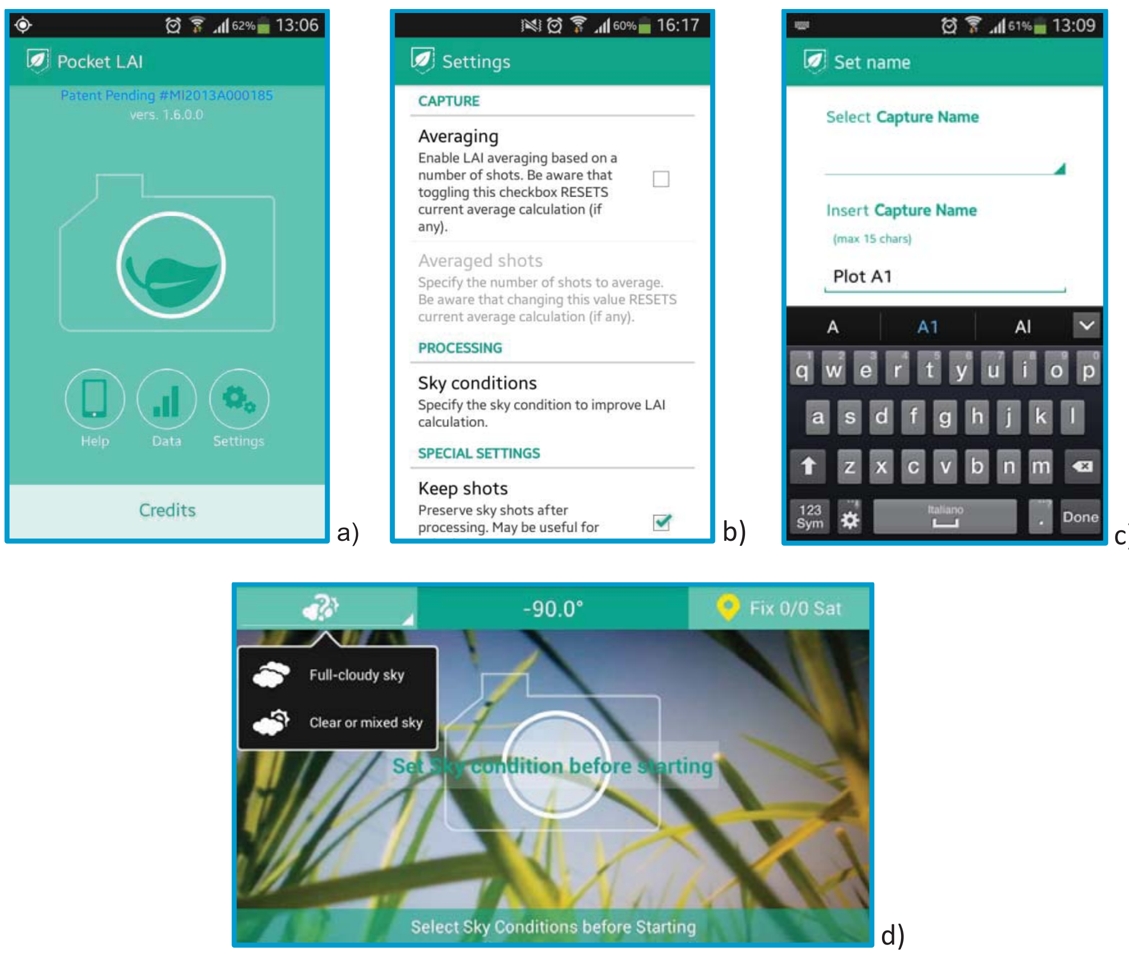

Figure 1. PocketLAI graphical user interface: home screen (a), setting options (b), specifying the name of the measure (c), measuring mode (d).

After entering the measuring mode (Fig. 1.d), it is possible to click on the camera icon, that (i) launches a 5-second countdown to allow the user to put the device below the canopy and (ii) activates the app inclinometer. When the countdown is completed, a vibration informs the user that it is possible to start rotating the device along its main axes. When the target angle (57.5°) is reached, the image is automatically acquired and processed; three short vibrations inform the user that the LAI estimate is complete, and the value just measured is displayed. Once acquired, LAI values are stored in a table with information on date, time, and GPS coordinates/accuracy (Fig. 2.a). Tables with LAI estimates and related metadata can be exported/imported via a dedicated menu (Fig. 2.b) as comma-separated text files (.CSV) and/or as geospatial vector data (.SHP) that allows to directly load data in a GIS application. An integrated user's guide is available to provide users with full support while using the app (Fig. 2.c).

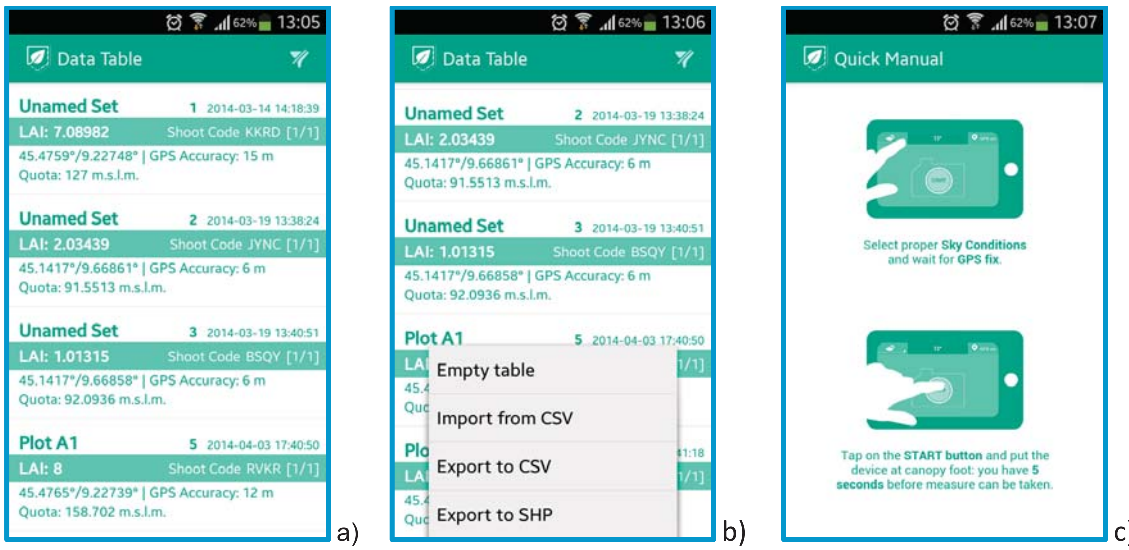

Figure 2. PocketLAI graphical user interface: displaying acquired information (a), data table with LAI readings and related metadata (b), import/export options (c), integrated user's guide (d).

3. CALIBRATION UTILITY FOR LOW COST DEVICES

During the testing activities, a device effect was noticed, with some low-cost devices presenting an underestimating behavior for LAI values higher than 3 m^2 m^{-2}. This underestimation appears as an over-saturation compared to the one normally observed for indirect LAI estimates using optical methods (Facchi et al., 2010) (Fig. 3). This effect was not observed when medium- and high-cost products from different manufacturers were used (e.g., Samsung GT-i9105 Galaxy S II Plus, HTC Desire Z) (Fig. 3).

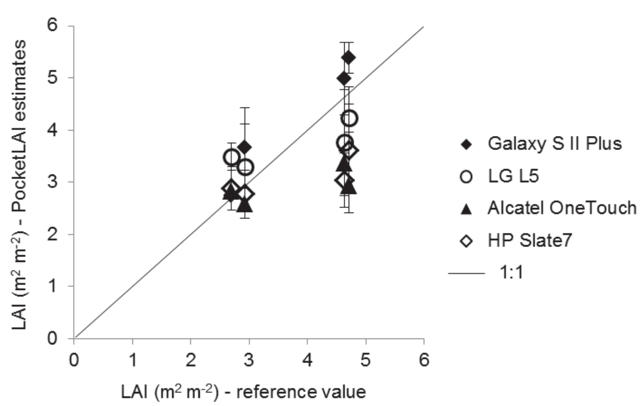

Figure 3. Comparison between data collected with destructive (planimetric) method and with different devices.

A calibration utility was thus developed, based on a quadratic adjustment of LAI estimates obtained from two LAI values measured on the same canopy: the first should be obtained using the destructive (planimetric) method for a canopy with LAI between 4 m^2 m^{-2} and 5 m^2 m^{-2}, the second provided on the same canopy by PocketLAI. Data to test the calibration algorithm were collected in Northern Italy during summer 2013 on rice (*Oryza sativa* L., cv Volano, Japonica type) and giant reed (*Arundo donax* L.) plots; detailes on the field experiments are provided by Confalonieri et al. (2013) for rice and Francone et al. (2014) for giant reed. The app was installed on three low cost devices (two smartphones and one tablet): LG OPTIMUM L5 E610 (800 MHz processor and 512 MB RAM), Alcatel OneTouch Idol 6030A (dual core 1 GHz processor and 512 MB), and the tablet HP Slate 7 (dual core 1.6 GHz processor and 1 GB RAM), respectively. Each PocketLAI estimates included five below canopy readings. Figure 4 shows the comparison between (i) PocketLAI estimates provided by different devices before (black squares) and after (white squares) the calibration and (ii) reference values (planimetric method). Despite its simplicity and the few information needed (just one pair of PocketLAI – planimetric readings) the calibration algorithm allowed to decidedly improve the accuracy of PocketLAI estimates even in case of low-cost devices.

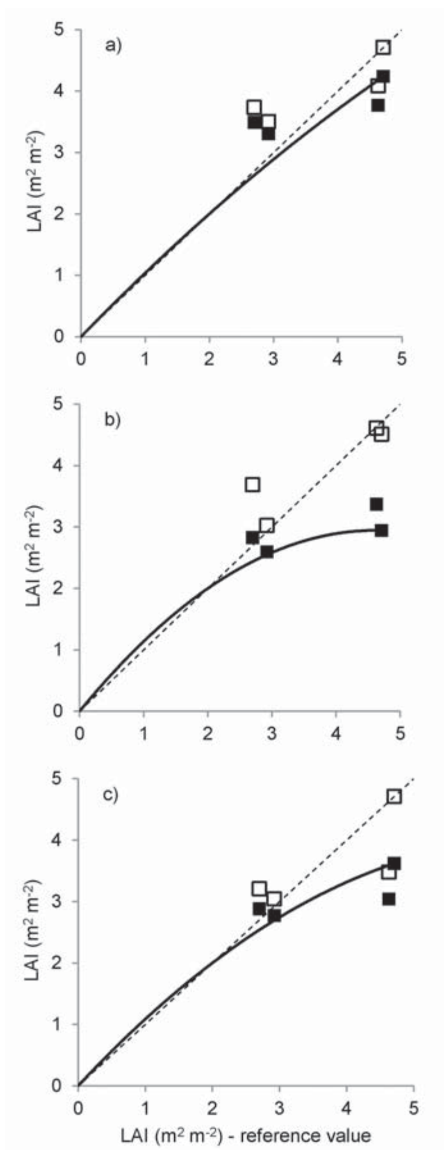

Figure 3. Comparison between data measured with the planimetric method and estimated with PocketLAI using different devices before (black squares) and after (white squares) the calibration. (a) LG L5, (b) Alcatel OneTouch, (c) HP Slate7.

4. SUMMARY AND DISCUSSION

PocketLAI was tested in previous studies (Confalonieri et al., 2013; Francone et al., 2014) for canopies characterized by different structures, providing satisfactory results when compared with other commercial instruments for indirect LAI estimates, like LAI-2000 and AccuPAR ceptometer. Now, a detailed work on the user experience and on the graphical user interface allowed to refine the application and to get to the first official release (PocketLAI v. 1.6.0.7).

The calibration utility for low-cost devices developed and tested in this study is the starting point of a wider analysis aimed at investigating the effect of different manufacturers and prize categories on the accuracy of PocketLAI estimates. This study – that will be carried on during 2014 – targets the improvement of the simple and automatic calibration utility to assure the best PocketLAI performances regardless of the specific device used.

6. ACKNOWLEDGMENTS

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