An affordable system to phenotype the root system architecture of the chickpea

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Abstract

Plant phenotyping studies the growth dynamics of plants, relating genetic information with different (a)biotic conditions. Recently, the lack of reliable software has been identified as the new bottleneck hindering high-throughput plant phenotyping [8]. Previously, In [6], the authors argued that the bottleneck was the availability of the relatively affordable hardware. With the recent introduction of affordable solutions to image plant shoots [3, 7], hardware has become ubiquitous. However, the imaging of root system architectures is not easy due to soil opacity and requires specific growing system to optimize its visualization. Artificial ones, such as semi-hydropony [2] or transparent synthetic soil [5] help the root system visualization but do not reflect real soil growing conditions. Otherwise, high-throughput automated equipment developed for root phenotyping [9] are expensive solutions that only a few research groups can afford them.

The root system architecture (ensemble of root system in space) evolves along time to allow resource foraging [4]. Thus, root phenotyping is important to improve resource acquisition in agricultural systems, especially in a context of climate change that would limit crop yields. In Ethiopia, chickpea (*Cicer arietinum L.*) is one of the major crop and faces environmental constraints such as arid and infertile soil conditions. The development of affordable tools that could be used on the spot by breeders to identify chickpea root system architecture(s) adapted to local soil is then relevant.

Due to the importance of the analysis of root dynamics, we were inspired to develop affordable chickpea growing (the mesocosm) and imaging (the imaging station) systems that allowed us to acquire high-resolution images of roots. The mesocosm, depicted in Figure 1(A), holds a thin layer of soil between a polyvinylchloride sheet back and a glass sheet front of same size (rectangular 150cm $\times$ 45cm $\times$ 0.6cm thick) separated by silicon strips as spacers and closed to the side by metal U-profile, as shown in Figure 1(B). Pre-germinated chickpea seeds were transferred in mesocosm inclined at 45° against a

slotted angle support to force the roots growth against the glass and maximize root system visualization.

The imaging station (c.f. Figure 1(C)) was designed to support a mesocosm and built using slotted angle, as shown in Figure 2(A). It allowed to acquire, through the glass sheet of the mesocosm, time series pictures of the roots growing inside. An illumination device composed of a cheap LED strip ($5000^{\circ}K$, $4.8W/m$) lighting the mesocosm from each side was installed in the imaging station, as shown in Figure 2(B). We installed and configured five Phenotiki Sensors [7] (c.f., Figure 2(C)), in which we added project-specific requirements. As an example, a master camera (e.g., the top camera) can trigger the other devices to acquire images simultaneously. The station was covered with black felt to avoid external ambient light to come inside the field of view and prevent severe reflection on the mesocosm glass.

When images are acquired, we remove the optical distortion caused by the lenses, using the camera calibration parameters. Then, images of the same plant are stitched together. To correctly perform the stitching of two consecutive images, we use the information coming from the Aruco fiducial markers and we also extract SIFT robust keypoints [1], as shown in Figure 3(A1). Using these two sources of points, we stitch two consecutive images (Figure 3(A2)). In Figure 3(B), we show the final result of the stitching, after trimming the lateral side of the picture to remove the imaging station frame.

We developed an algorithm to segment the root system architecture to isolate it from the background. We extract local patches in the image and we determine an optimal threshold value, using the Otsu's method [10]. However, this is not enough to get a good RSA segmentation, as this way may cause oversegmentation. To solve, this, only threshold values within a specific range are accepted. In this way, we obtain a coarse segmentation. We further improve the segmentation by extract local patches only from the detected pixels from the step before. An example of the result of this procedure is shown in Figure 3(C). From the segmented images, we can extract phenotyping data and detect the primary and second roots.

Our affordable plant growing and imaging system allows to study the chickpea root system architecture and would be useful for breeders in Ethiopia. In future prospects, those tools would be tested in (a)biotic interaction conditions and could be transposed to other crops.

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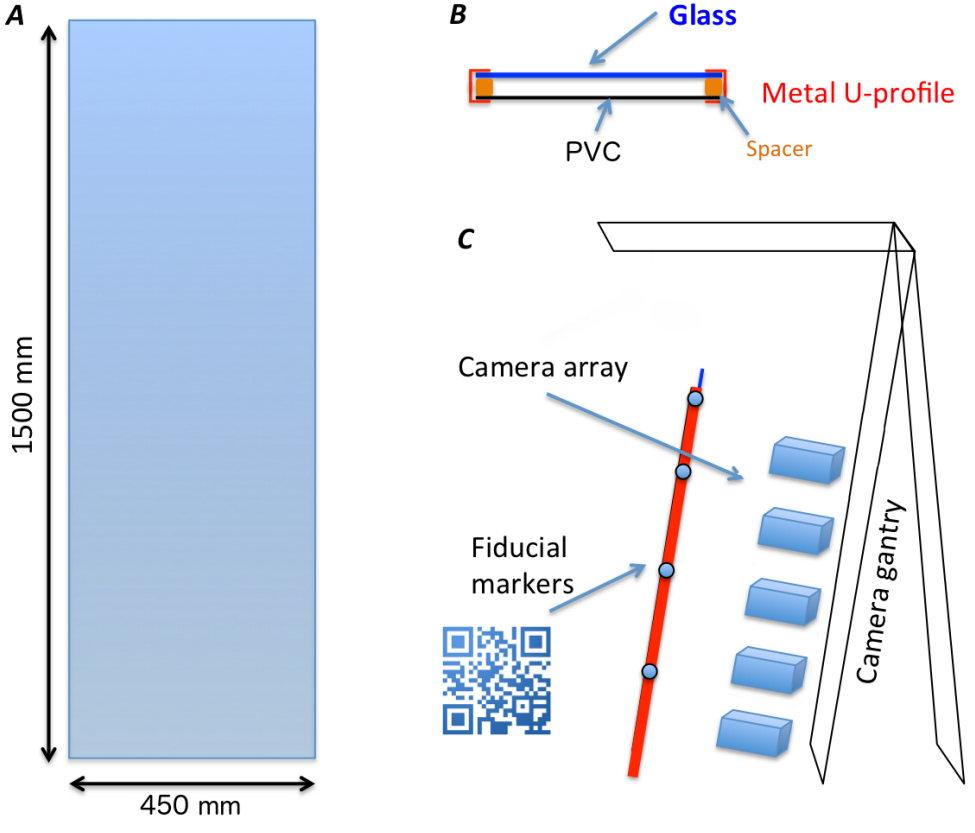

Figure 1: Mesocosm and imaging station design. (A) Height and width of the mesocosm (front view). (B) Mesocosm top view. (C) Imaging station and camera arrangement.

Figure 2: Imaging station. (A) Overview with of the imaging station with a mesocosm. (B) Close-up image of the LED strip. (C) Close-up of the Phenotiki sensors [7].

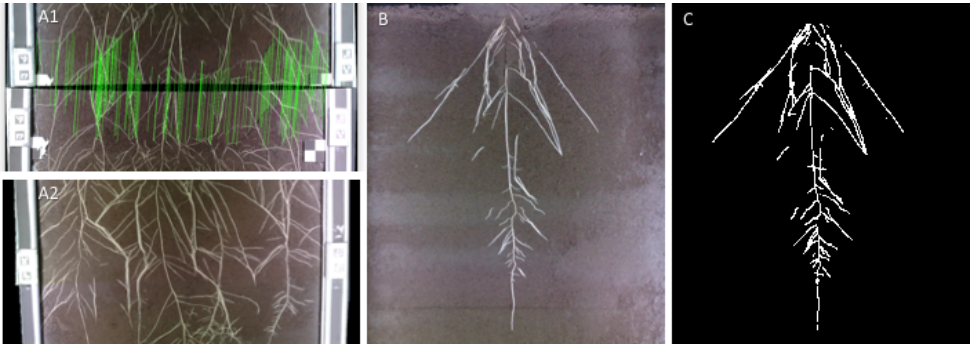

Figure 3: Image stitching and root segmentation. (A1) SIFT keypoints are matched between two consecutive images. (A2) Images stitched. (B) Final result of root system architecture stitched. (C) Root segmentation.

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