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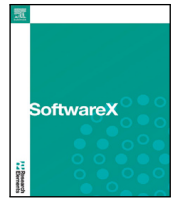
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Original software publication



Growth Data—An automatic solution for seedling growth analysis via RGB-Depth imaging sensors

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ABSTRACT

We describe Growth Data, a software for seedling growth analysis from time lapse acquired in top view via RGB-Depth low-cost sensors. The software is suited for the observation of young plants during their early developmental stages. Growth Data allows the discrete detection of the dicotyledon seedling stages and produces continuous growth curves of any type of seedlings. As a companion paper to recent articles providing the methodological innovation behind these algorithms, this article describes the use of the GUI interface provided for high-throughput analysis of general interest for the plant imaging community.

Code metadata

Current code version	v1.0
Permanent link to code/repository used for this code version	https://github.com/ElsevierSoftwareX/SOFTX-D-23-00495
Code Ocean compute capsule	None
Legal Code License	GNU GPL
Code versioning system used	None
Software code languages, tools, and services used	Docker, Python v3.7
Compilation requirements, operating environments & dependencies	Ubuntu x64, Windows 7, 10, 11 x64
If available Link to developer documentation/manual	github documentation
Support email for questions	geoffroy.couasnet@inrae.fr , david.rousseau@univ-angers.fr

Software metadata

Current software version	v1.0
Permanent link to executables of this version	github
Legal Software License	GNU GPL
Computing platforms/Operating Systems	Ubuntu x64, Windows 7, 10, 11 x64
Installation requirements & dependencies	Docker, Python 3.7 or higher. For use with Windows: CygwinX, VcXsrv Windows X Server.
If available, link to user manual — if formally published include a reference to the publication in the reference list	github documentation
Support email for questions	geoffroy.couasnet@inrae.fr , david.rousseau@univ-angers.fr

1. Motivation and significance

RGB-Depth is an imaging modality specially suited for plant phenotyping [1–5] as it includes both contrast in color provided by the RGB modality and in height provided by the Depth modality. Moreover,

this imaging modality is accessible at low-cost from the hardware perspective. Recently, RGB-Depth imaging has been shown of specific interest for the phenotyping seedling stages [5–7]. Detecting the growth stages of seedlings is a crucial issue in the field of plant science. This

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involves identifying key milestones such as the emergence of seedlings from the soil, the unfurling of cotyledons, and the appearance of the first leaves, which represent the initial phases of plant development. The successful completion or failure of these developmental stages, along with their rate of progression, significantly influence the future evolution of the plant.

Among the state-of-the-art for the phenotyping of seedling, deep learning approach presented in [6] has demonstrated the potential to automatically classify dicotyledon seedling development stages using RGB image sequences captured from a top-down perspective, achieving an accuracy of over 90%. This article is a companion paper of [6] providing a software with an ergonomic interface to allow anyone to reproduce the experiment of [6]. In addition to the classification of seedling developmental stages we include continuous analysis of growth curve via the use of depth images as published in [7]. It is important to note that these growth curves computed from the Depth can be applied to any types of seedling and are not limited to dicotyledon. The GUI interface allows in almost fully automatic way to analyze trays of seedlings. The user indicates the path to the folder containing the images to be processed, enters an “xlsx” file containing the different variables expected to be associated to the plants of the experiment, extracts the date and time of the data via a dedicated window and then selects manually or automatically via a “template matching” algorithm the trays and plants present on the images. From there, the user launches the measurements from the RGB images or from the Depth images. When the process is finished, one can compute the features described in [7] from the growth curves, export the cropped images of the plants, or start the predictions on the stages of evolution via inference of the convolution neural network trained in [6].

2. Software description

The Growth Data program takes as input images of plant observed from top view and organized periodically in trays. Images can be timelapse of RGB and or Depth sequences. It provides characteristic of agronomical interest concerning the growth of the seedling gazed in the images. This section describes the architecture and functionalities of the software.

2.1. Software architecture

The software is an exe file programmed in Python. The visual appearance of the GUI and architecture of Growth Data are depicted in Fig. 1. The software includes three main steps. First step concerns the import of the RGB-Depth images. Then, in step 2, the user performs the pots selection, which can be done either automatically via a template matching algorithm or after manual selection by the user. As final step 3, the data are processed and output features are produced together with the export image stacks in tiff format of each individual seedling.

2.2. Software functionalities

The software has been designed to process 2 types of images: RGB images and/or Depth images (16 bit grayscale images). Each of these 2 types of images is associated with one or more software functions. RGB images enable the use of an inference model capable of giving a prediction of the stage of evolution of the plants at each acquisition. Depth images enable the calculation of the growth curves of each plant and the extraction of different features. In cases where the user imports both types of images in parallel, a specific inference model taking both types of images as input can be chosen, giving better results in terms of predictions. The choice of image type to process will largely depend on the type of data the user has, although the simultaneous use of RGB and depth images will unlock the full functionality of the program

and improve the performance of the prediction model. The user should also provide an experimental design file under ‘xlsx’ format which is imported into the software. This file enables the traceability of the plant under the nomenclature provided by the user in the ‘xlsx’ file. An example of this ‘xlsx’ is provided with associated images. In the example provided for illustration a camera follows the development of the plants present on 2 trays of germination containing 6 lines and 10 columns. We produce 2 distinct files ‘xlsx’, one for each tray, of which each sheet corresponds to a variable to be associated with the experiment. Each sheet contains thus 6 lines and 10 columns, the name of the sheet corresponds to the name of the variable to be associated, and each cell corresponds to the value of the corresponding plant of the tray.

Once these ‘xlsx’ files are created the analysis with Growth Data can start. The user imports the images and the files ‘xlsx’ to be associated with the trays of germination (see button 1 in Fig. 1). Then Growth Data extracts the date and time of each image. It is possible to specify this timeline of the experiment as detailed in the video demo [8]. The next step is to select the trays present in the image. If we assume that there are 2 trays in the image, one on the right and one on the left, and that the user has previously imported the metadata (‘xlsx’ files) for the left and right trays. In this case, the trays must be selected in the same order so that the program can associate the metadata with the correct tray. For the selection of the plants, as for the selection of the trays, the user can make the selection manually or automatically via a “template matching” algorithm. If the automatic selection is not appropriate, the user can create new templates by selecting the desired areas and via 2 buttons “Add plant templates” and “Add tray templates” (see button 2 in Fig. 1).

Once the selection of plants and trays is completed, if Depth images have been imported, the user can start the measurements (see button 3 (Depth) in Fig. 1). A window of options will then appear allowing us to choose whether or not to apply an “inpainting” algorithm in case of missing pixels, and to choose the maximum ratio of missing pixels for the execution of the algorithm. It can then choose the duration of the day (photoperiod), and finally the minimum and maximum depth values to take into account during the measurements. When the measurements are done, the user can extract features from the obtained growth curves, such as: daily growth, final plant height, amplitude of the circadian cycle and harmonic distortion rate (HDR) as detailed in [7]. In short, to obtain the daily growth rate, we perform a daily linear regression and record a daily slope. For the amplitude, we use Fourier series decomposition which allows us to describe the frequency spectrum of a signal. We then compute the amplitude of the fundamental frequency of the daily detrended signal. This quantifies the amplitude of the circadian cycles oscillating at the daily period around the daily growing trend. Lastly, the harmonic distortion rate, noted *HDR*, is computed. *HDR* corresponds to the energy of the detrended signal not included in the circadian cycles and which occur when new leaves appear.

If RGB images have been imported (alone or with Depth images), after having performed the selection of the pots, the user can use a Deep Learning algorithm to obtain predictions on the stages of evolution of the plants for each of the images (see Fig. 2 and the neural network used is the one presented in [6] for dicotyledon seedlings. The interface implements 2 different models depending on the type of input data: a model taking RGB image stacks and a model taking RGB image stacks as input to which we add a layer composed of the corresponding Depth image. In summary, the input data must be in the form of a stack of images in tiff format, $XX \times YY \times 3$ in size for RGB images alone or $XX \times YY \times 4$ for RGB and Depth images. For each image stack, the algorithm will associate to each image of the stack a label corresponding to one of the 4 possible stages of evolution:

0. Soil
1. First appearance of the cotyledon (FA)
2. Opening of the cotyledon (OC)
3. Appearance of the first leaf (FL)

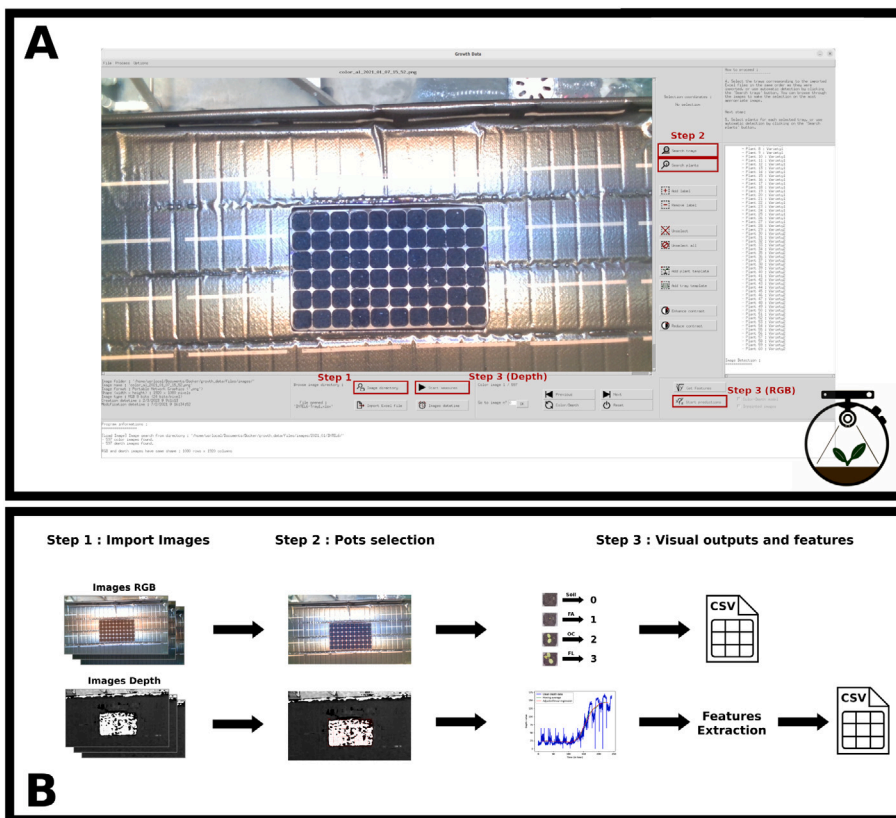


Fig. 1. Appearance of the GUI (Panel A) and architecture of the main functionalities (Panel B) of the software. The three main steps identified in Panel B correspond to the button in Panel A.

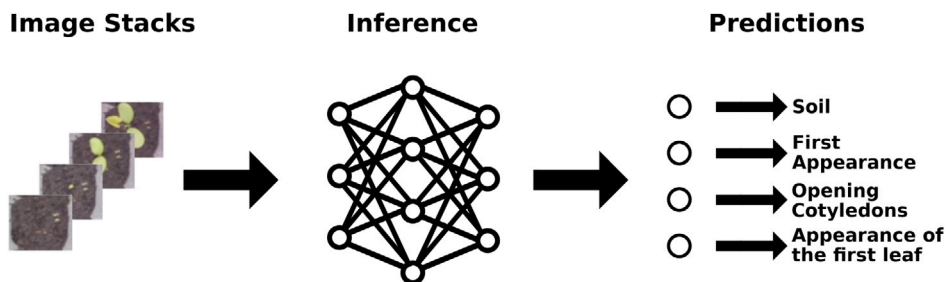


Fig. 2. Illustration of the different stages of plant evolution and associated labels associated with the RGB analysis for growth stage recognition.

3. Illustrative examples

In this section, we provide an example of the application of the Growth Data program on a set of 653 RGB and Depth images obtained in real conditions via an Intel Realsense D435 camera that recorded the growth of plants for about a week [9]. A video demo associated with this data set is provided at [8].

3.1. Selection of areas of interest

After loading the images, importing the associated ‘xlsx’ file and extracting the date and time information, we manually selected the tray present on the image. We then used the automatic selection of the pots, made with a template matching algorithm. We can see the result in the image below (Fig. 3). This part of the application, although of generic interest in plant imaging, is currently nowhere to be found while it is

obviously very useful to select individual pots even if a user was not interested in our specific data analysis. Therefore, even if it is a side product of our software we believe it is interesting to stress the interest of this functionality.

3.2. Growth curves

Once the selection of the plants has been made, we can start the process of extracting the measurements from the Depth and RGB images. Fig. 4 shows in mm the height of 4 individual seedlings. The circadian cycles are clearly visible as expected and the growth observed from the opening of the cotyledon is also observable from the adjusted linear regression. Fig. 5 provides for the same seedling the output of the Deep learning algorithm classifying the stages of development of the seedling from RGB images.

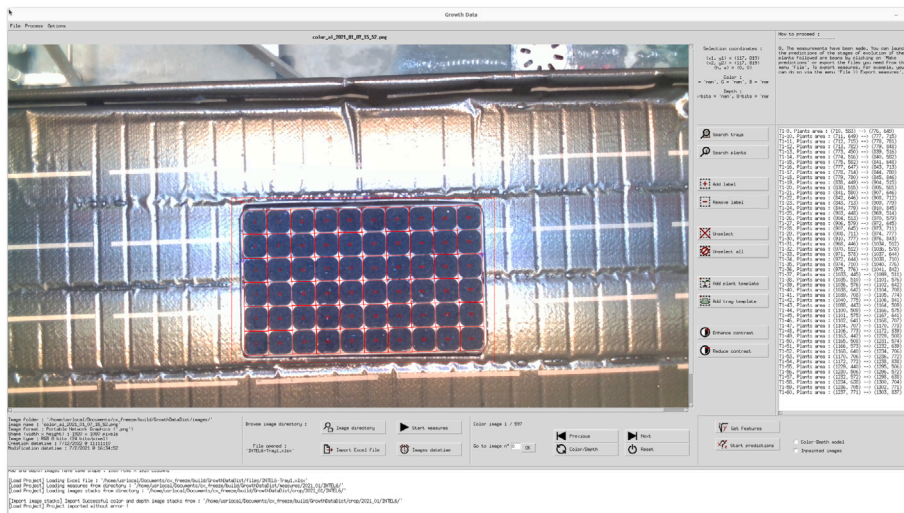


Fig. 3. Automatic selection of pots with template matching algorithm.

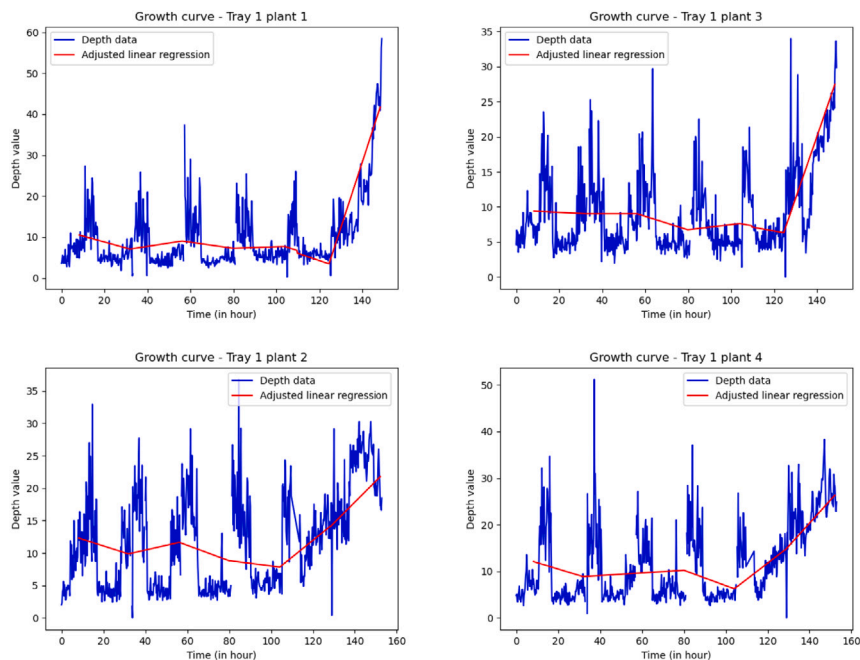


Fig. 4. Four growth curves obtained on the data set proposed with the software, extracted from depth images.

4. Impact

As a all-in-one tool, Growth Data has the potential to save huge time to biologists interested in monitoring seedling growth without requiring any specific knowledge in the field of image processing. The software has been presented in various occasions including the North American Plant Phenotyping Network annual conference [10] and during the annual meeting of the European project INVITE on variety testing [11]. Initiated on a plant phenotyping platform, the imaging system which provides images to Growth Data has started to disseminate in seed company such as ENZA ZADEN and Vilmorin-Mikado. The software is expected to allow new experiments on seedling to unravel the impact of the environment on these early stages of plant’s life. This includes for instance the impact of temperature, CO₂ concentration, salt or water stress in relation with climate change but also investigation on the

microbiota of the seed. These are ongoing experiments on our facility but are now accessible to any use with the delivery of Growth Data.

5. Conclusions

Growth Data was introduced and demonstrated as a stand alone application capable of monitoring seedling via RGB and Depth images in order to quantify growth trajectory and detect stages of development. Some further works could extend the capabilities of the software. Currently it is processing RGB images of dicotyledon seedling. In principle, the overall GUI in architecture of the software would be compatible to any other characteristics extracted from RGB sequences. We are currently extending the deep learning model to operate also on monocotyledon crops [12,13] in greenhouse environment and field conditions. These improvements could constitute updates of the Growth

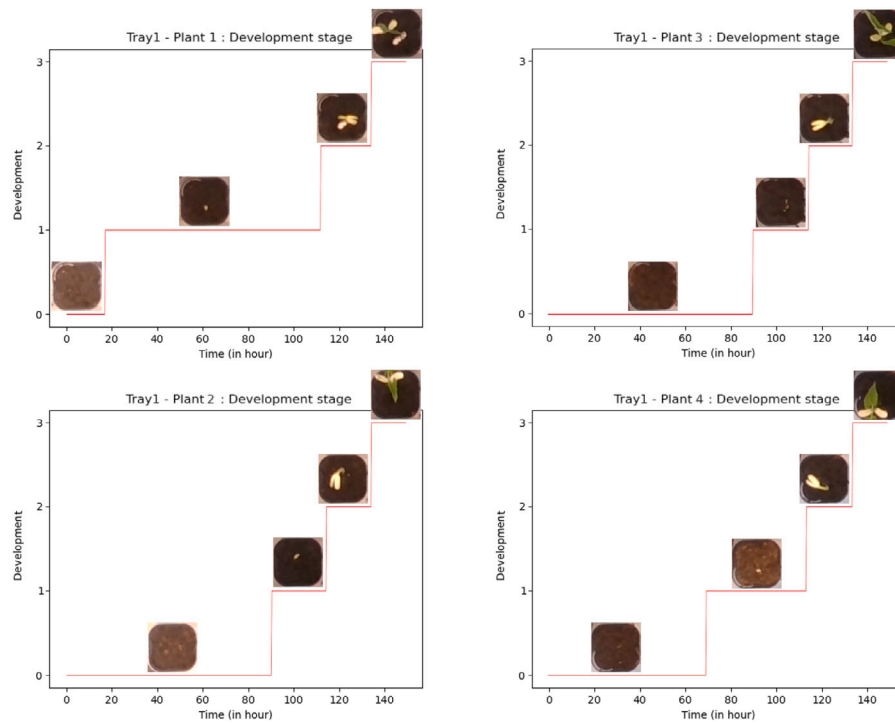


Fig. 5. Graphs of development stage corresponding to the four growth curves of Fig. 4.

Data software as provided here in its initial version of companion paper of [7,14].

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgments

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