# OnLine challenge on processing of lettuce images

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# Preface

The 3rd international challenge on autonomous greenhouses aims at having a fully automated control of growing lettuce. In modern greenhouses, the level of automation is already high, meaning that only planting and harvesting are done manually. Climate control and watering are automated and also spacing of the plants as they become larger is done by robots or some well-designed mechanical system.

The decisions however, on what climate to apply, when spacing at what plant distance is performed and whether the lettuce plants are ready for harvest, are made by human operators. Based on their knowledge and experience they decide to speed up or to slow down the growing process in order to allow for optimal resource use. Speeding up or slowing down are actions taken, based on the observed actual growing process. It means that the current crop growth has to be compared with an expected future growth in order to determine if the growing process is still on track.

In general, observations are done by an experienced human eye. In order to assist or replace the human eye by an automated decision process, images of a lettuce crop have to be translated to numbers. This automatic translation of images to numbers that reflect the growth of lettuce is the goal of this OnLine challenge on image analyses of lettuce.

This OnLine image processing challenge is the first part of a larger challenge, having the ultimate goal to deploy a fully autonomous controller for lettuce growing in the beginning of 2022. As autonomous growing means that there is no human eye to observe if the crop is still on track, image processing will be in the core of the controller.

In this OnLine event, teams are challenged to develop software that performs this conversion of images to numerical crop parameters. This software can be trained and developed on 340 images of lettuce provided together with ground truth data. The images have been taken from samples from a lettuce growing experiment at the facilities of WUR. In this experiment 4 lettuce cultivars were grown in a hydroponic growing system. The images were taken at 1 week intervals and cover the complete cycle from small plantlet to a harvestable lettuce head. Every week, about 70 plants were removed from the experiment and, after the picture has been taken, destructively measured to get the associated ground truth data of relevant crop parameters.

This document describes the dataset available and the procedure of sending an expanding amount of data from this dataset to the participating teams in a period of 6 weeks during the OnLine Challenge. During these 6 weeks intermediate results of the image recognition software can be explored by analysing each week a set of unseen images. Progress of the teams can be viewed on a public score board.

At the final date of the OnLine image recognition challenge a last set of 50 unseen images is sent to the participating teams. The team that returns the closest estimation of the parameters that were actually measured on these 50 images wins the challenge.

We tried to provide a concise but complete description of the contents of the dataset, the parameters to be estimated and the procedure of exchanging information between the challenge-organisers.

As there are many aspects and different readers will want to know different information, we hope that carefully chosen headers and the index below will provide a quick entry to the information of interest.

## Contents

## A sample series of the growth of the lettuce

The pictures below (examples) show the growth of four lettuce cultivars (all from RijkZwaan) from the day of planting (first row), till the harvesting day.

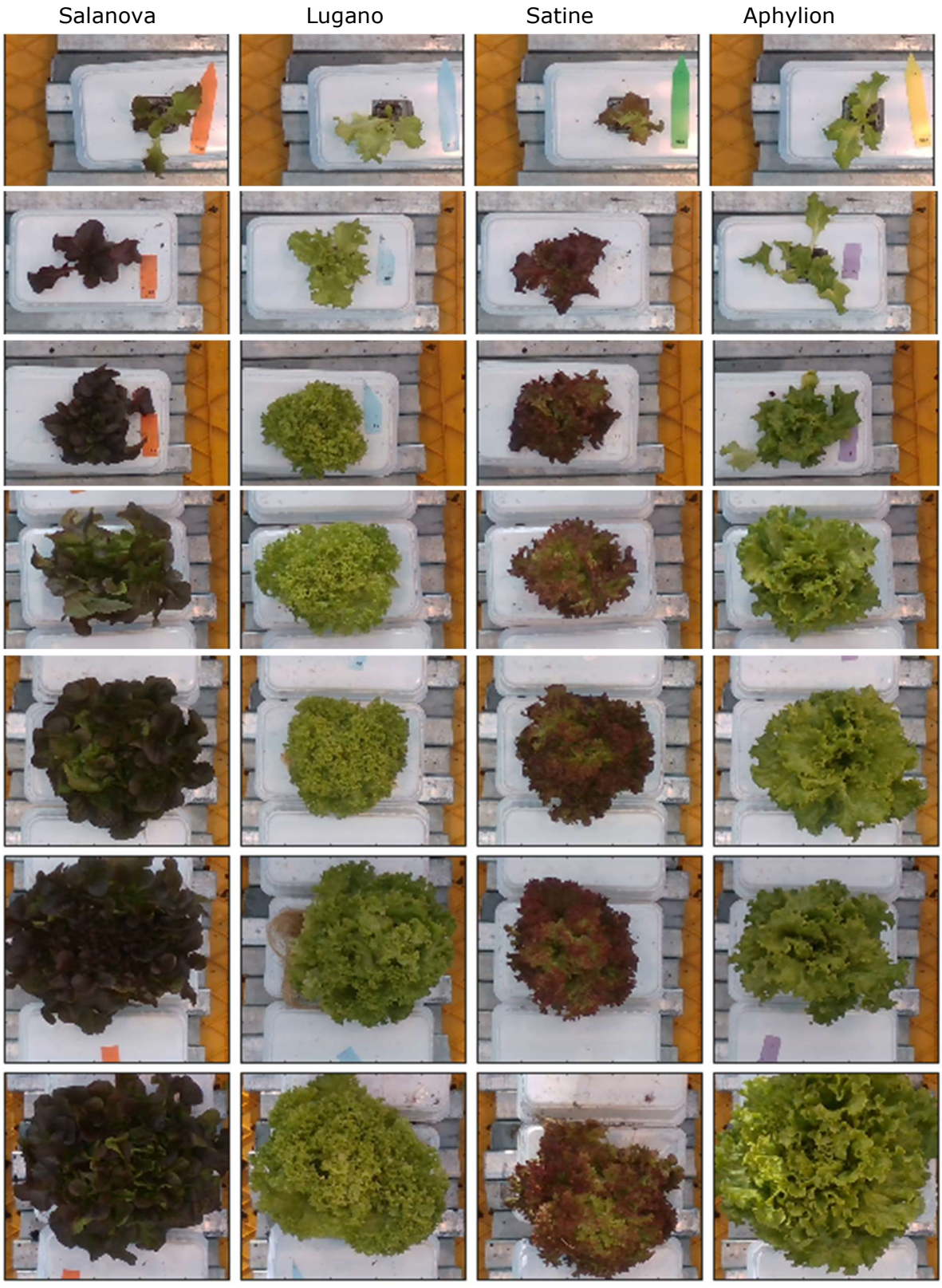
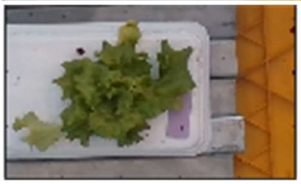
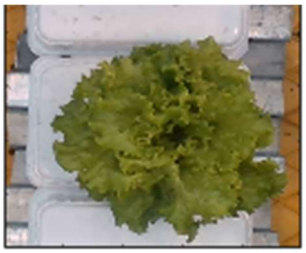



*Figure 1. 4 Cultivars of lettuce growing from plantlet to (almost) harvestable plants.*

The pictures come from a large set with annotated data. When we look at the data available on the pictures in the last column (cv. Aphylion) we get the list below:

*Table 1. Examples of images and the accompanying ground truth parameters.*

| RGB-image | Fresh weight [gram] | Height [cm] | Diameter [cm] | Leaf area [cm²] | Dry weight [gram] |
|---|---|---|---|---|---|
|  | 3.2 | 5.1 | 16.1 | 88 | 0.2 |
|  | 6.5 | 5.3 | 19.5 | 144 | 0.7 |
|  | 23.2 | 7.1 | 20.0 | 475 | 1.2 |
|  | 94.0 | 13.4 | 21.9 | 1670 | 4.5 |
|  | 149.0 | 15.0 | 23.0 | 2256 | 6.9 |
|  | 164.8 | 17.5 | 30.6 | 2525 | 9.2 |
|  | 406.0 | 25.0 | 30.0 | 5380 | 16.0 |

The attribute 'Diameter' is the maximum distance between two leaf tips. So, for the young plant in the top example picture, it is the distance along the (almost) vertical axis. For older plant the same definition holds, but as the older plants are almost round, the orientation of the measurement is less critical.
The Height attribute can be estimated from the images as each RGB-image is accompanied with a file containing the corresponding depth-information. This depth information provided by a RealSense-camera and defines the xyz-coordinates of the object in each pixel. These xyz-coordinates also provide the scale-information.

## Organisation of the data set

Crop measurements, RGB-file name and depth-information is all organized in a json-file which is sent to the challenge participants, together with the actual images. Below, a sample of this file is shown.

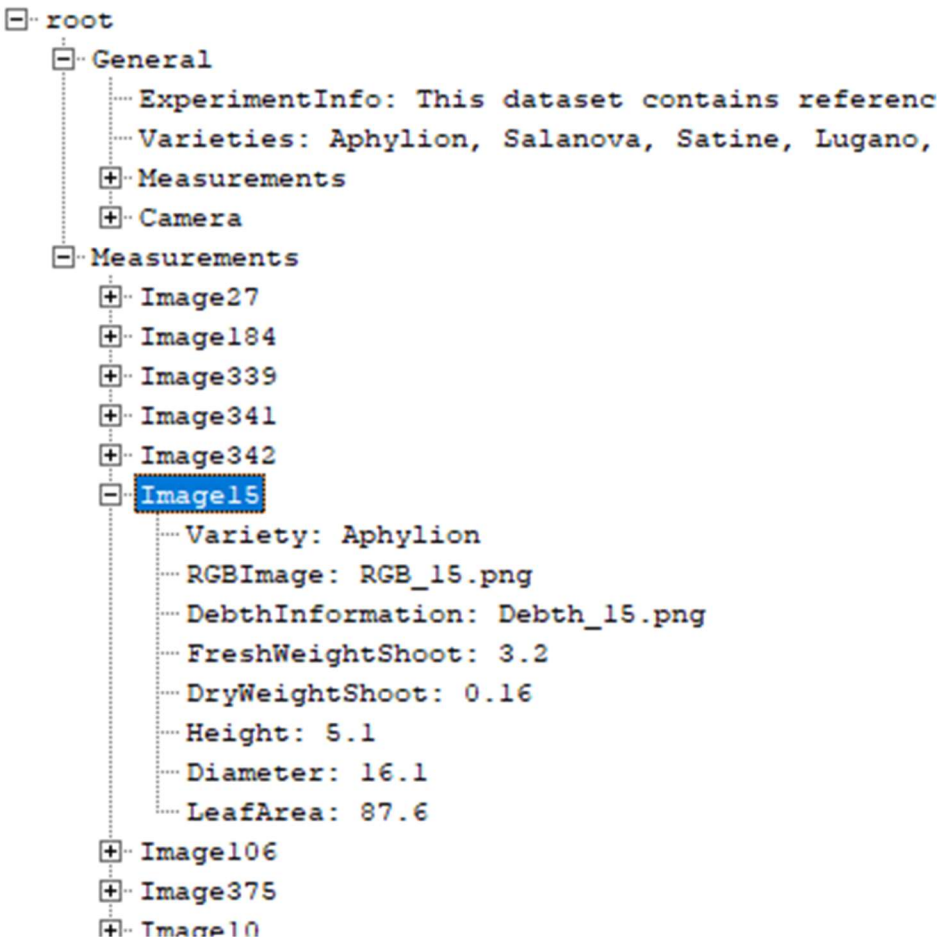



*Figure 2. Example of the organisation of the json-file linking the image numbers to the ground truth data.*

In this sample Image15 is highlighted and expanded. It is the information of a picture of the Aphylion cultivar in its youngest stage. You easily recognize the Fresh Weight, Height, Diameter, Leaf area and Dry weight figures that are shown in the first line in Table 1. These measured data hold for the RGB-image stored as RGB_15.png.

When opening 'RGB_15.png' the picture shown below is obtained.

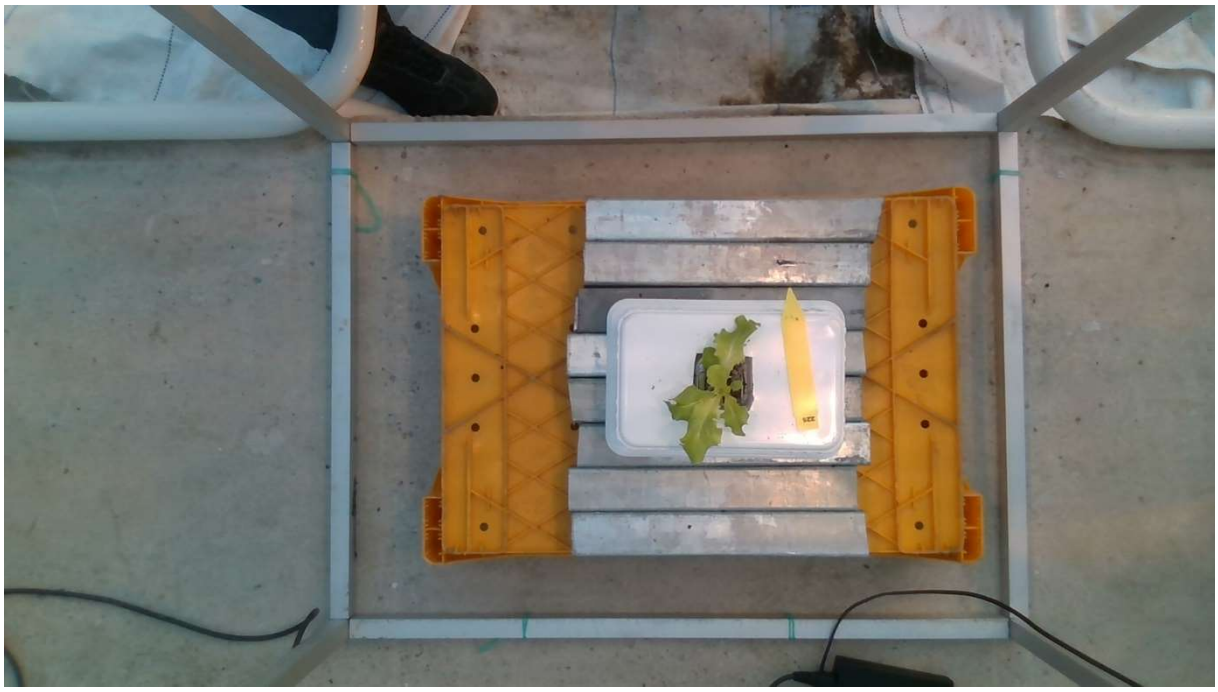


*Figure 3. The full content of image RGB_15.png.*

One might be surprised that the actual area of interest is only about 5% of the total image. This is not a mistake as the camera was deliberately placed at the height at which the camera will be hung during the real growing challenge in 2022. The resolution of the image is therefore comparable to the resolution that one can expect later on the real growing challenge in the greenhouse. In this real experiment, the camera will observe about 1 m² of growing area.

The json-structure shown in figure 2 shows that next to the RGB-image there is also a depth-information file. This depth-information file has the extension '.png', but is actually a 16bit file that has to be converted to a point cloud data file with the appropriate conversion software (see later on).

In the 'General'-section of the json-file, some information is provided on the experiment from which the data are collected. The 'Measurements' sub-branch of 'General' gives a description the parameters that are determined for all images (units and ways of measuring).
The 'Camera' sub-branch provides the information that is needed for the interpretation of the RGB-data and for the conversion of the depth-information to xyz-coordinates of the pixels.

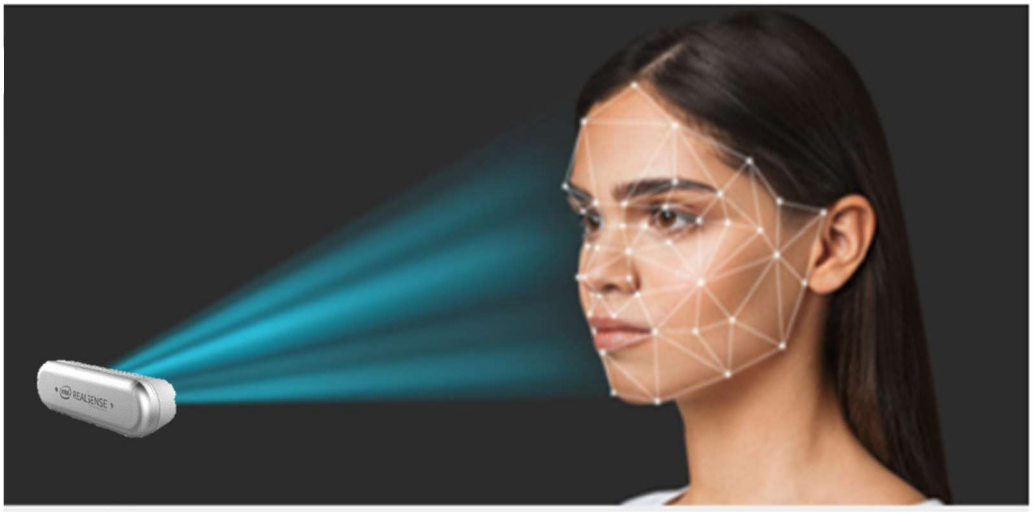
The largest part of the json-file is formed by list of image numbers and the attributes associated. At the start of the preparation period for the challenge, June 1st, 221 images are made available and the json file contains therefore 221 entries for image-data.
Then, each following week, 20 unseen pictures are sent. First without disclosing the ground truth data, but after the participating team has sent their estimates of the attributes of these unseen pictures to the challenge organizers, a new, expanded json-file is made available. This expanded json-file contains the earlier disclosed information, extended with the ground truth information of the last 20 sent images.

As the preparation period spans 6 weeks, there will be 6 batches of these additional 20 images, which means that by July 12th, the set of annotated images has grown to 341. This is the ultimate amount of images on which the image processing algorithm can be trained.

On July 13th 12:00 CET, for the OnLine image processing challenge, a set of 50 unseen images is made available for download and the teams are assumed to respond with their estimation on the 5 missing attributes in a 10-minutes time period (until 12:10 CET). The team with a reply that is closest to the ground truth data wins this part of the challenge.

## Converting the depth-information to a point cloud

The images are made with a RealSense D415, hanging about 0.90 meter above the growing crop. The camera allows for stereo vision and stores a depth image along with the RGB-image (and even an IR-image, which is not used in our application).



All camera parameters can be found in the json file under 'camera'. Both the intrinsics and extrinsics are given. The intrinsics for the color and depth image are the same because the depth images are aligned with the color images. This means that the extrinsic information can be neglected. The depth images can be converted to point clouds by using these intrinsics and the depth scale.

## Receiving images and ground truth data

For the challenge, the organizers have prepared the following set of files:

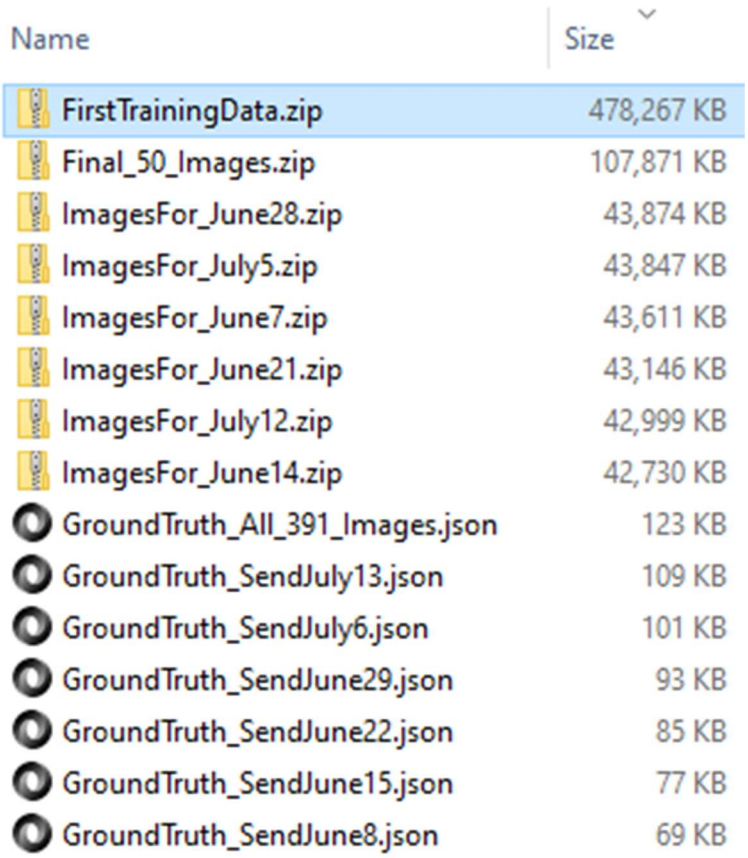



*Figure 4. Screenshot of the files prepared to be passed to the teams during the OnLine challenge.*

The first file that will be made downladable from the Atonomous greenhouse website will be 'FirstTrainingData.zip'. This is the package of 221 images and accompanying information with which the teams can start their development and training image analyses software. It contains the 'RGB_xxx.png' files, the 'Depth_xxx.png' files and a json-file 'GroundTruth.json' showing the information needed to link images to the numbers of interest.

One week after the start of the challenge, on June 7$^{th}$, the file 'ImagesFor_June7.zip' will be disclosed. The link will become available at the teams page on the web site, which allow for the download of additional images. Thus, after unpacking, 20 additional images will become available and a small json-file called 'Images.json', having the following content

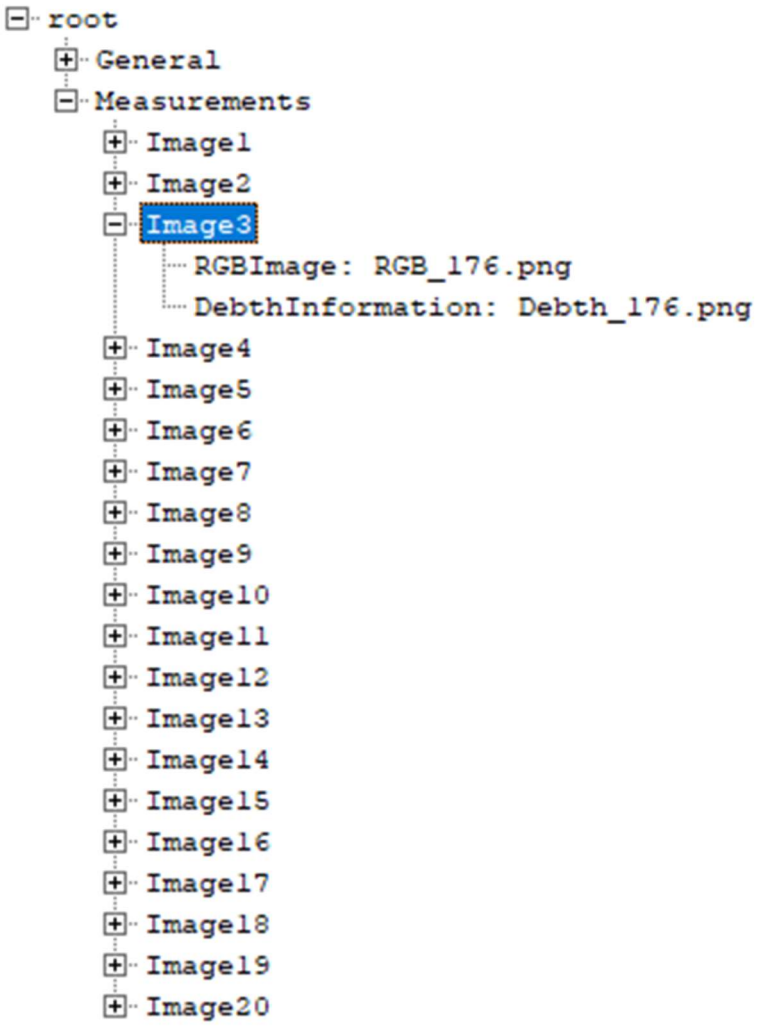



*Figure 5. Content of the json-file referencing to the 20 image- and depth-files send after the first preparation week.*

As an example, Image3 is unfolded, saying that in this week, Image3 refers to camera image 176, which, as always, has a RGB-file and a depth-information file.
The 'General' section of this json-file contains the same information as provided in 'GroundTruth.json' in the first batch of files.

These 20 unseen images can be used to test to what extent the image processing analyses is capable to estimate Fresh weight, Height, Diameter, Leaf area and Dry weight of the head of lettuce in the picture. If the image processing algorithm sends these estimations to the challenge organizers by a file named 'Response_TeamName.json', these intermediate achievements of the team will be processed and posted on a public score board. In this file name, 'TeamName' of course refers to your team.

The content of 'Response_TeamName.json' may look like below:

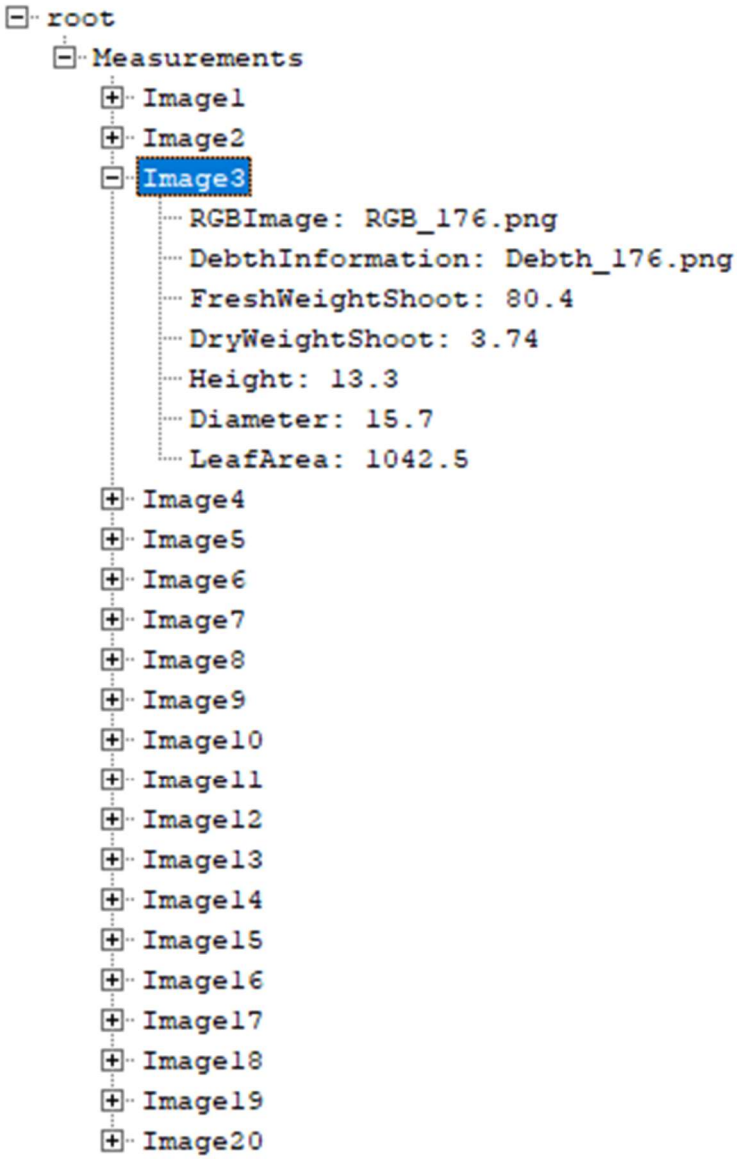



*Figure 6. Sample content of the json-file sent to the organisers as a response on the 20 unseen images that have been provided at June 7th.*

As you see in the expanded data on Image3, the data of RGBImage _176 is now completed with the team's estimation for Fresh weight, Height, Diameter, Leaf area and Dry weight of the head of lettuce in the picture number 176.

One day later, the team's estimation and placement of the intermediate achievements on the public score board, will be 'rewarded' by a json file with the ground truth data of these last 20 previously unseen images.
As you may have seen in Figure 4, the files with additional ground truth data are already prepared, so 'GroundTruth_SendJune8.json' is to be expected.
'GroundTruth_SendJune8.json' has all entries that were in 'GroundTruth.json' before, but on top of that the 20 newly added. Probably, after receiving 'GroundTruth_SendJune8.json' you will rename it to 'GroundTruth.json' for further processing on your now expanded set of images.

The next paragraph will dig deeper into the procedure of sending of files, ranking of teams on the public score board and expansion of the amount of images.

## Analysing unseen images during the 6 weeks preparation period

On every Monday after the start of the OnLine image analyses challenge, each team will get a zipfile with 20 new images available. In Figure 4 you can see the names of the files to be expected.
After unpacking the file, the image processing software may be tested on these 20 unseen image data sets and may produce a file with estimations like shown in Figure 6. Upon sending this file to the TenCent server http://www.autonomousgreenhouses.com/online_challenge/public_board, the quality of the parameter estimation will be scored by computing the average Normalised Mean Square Error over the 5 plant traits as described below.

The result of this scoring will be posted on a public score board, which can be viewed on

http://www.autonomousgreenhouses.com/online_challenge/public_board

**Note** that the file will only be processed if it contains the estimation of the exact 20 images as defined in 'Images.json'.

As said in the previous section, sending in intermediate estimations on a weekly base is rewarded by receiving the ground truth data on these 20 images. This 'reward' will be made available for the teams on the next day.

By sending intermediate results each week, your dataset on which an image recognition algorithm can be trained will grow with about 50% during the preparation phase of the OnLine Image Processing challenge.

## Scoring the quality of the image analyses

The public score is calculated by the average of the normalized mean squared error (NMSE) for the plant traits. This normalization is needed to calculate a total error from all plant traits. In formula:

$$\text{Total error} = \sum_{i=0}^{m} \frac{\sum_{j=0}^{n} \left(y_{ij} - \widehat{y_{ij}}\right)^2}{\sum_{j=0}^{n} \left(y_{ij}\right)^2}$$

with m the number of plants traits {FreshweightShoot, DryweightShoot, Height, Diameter, LeafArea} and n the number of predictions.

## The Final Image analyses

On **July 13th 2021 12:00 CET** a download link to the final set of 50 unseen images will be sent to the teams. 10 Minutes later, the teams are supposed to have returned their estimations of the 5 traits (FreshweightShoot, DryweightShoot, Height, Diameter and LeafArea), thus not later than 12:10 CET. As sufficient processing speed is one of the qualities of the images processing algorithm, these maximum 10 minutes time window is mandatory to be eligible for the final ranking. You have to be sure to have posted your estimation before 12:10 CET.

The whole procedure of obtaining the images, processing and sending of the result will be equal to the procedure applied in the 6 intermediate applications of the image processing algorithm in the preceding Mondays, except for the fact that in this final, 50 images will be processed instead of 20. Another difference is that on the final day the posting have to be before 12:10 CET, where on the former Mondays you will have time till midnight.

Yet another difference is that the score of the obtained result will not immediately be processed on the score board. The update of the score board and therefore the announcement of the winner of the Image processing part of the OnLine challenge will be shown in the final event ceremony on July 14th.

After the submission time for the estimations on the final 50 images has passed, the last file 'GroundTruth_All_391_Images.json' will become available.

## … and finally

Tencent and Wageningen University and Research organized this challenge with care and dedication, but cannot completely rule out technical disruptions (e.g. malfunctioning mail servers or download link servers). In case teams' contributions clearly suffers from such issues a suitable solution will be found.