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Innovative resource efficient technologies, processes and services

ZEPHYR project – Deliverable D6.1

Report on the technical validation of the Zephyr System

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Summary**: This document describes the function and operational configuration of the different technical components designed and implemented as part of the Zephyr system a practical perspective, based on the set up of the growth cycle conditions for different (real) growth protocols tested during the project life.**

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1. Executive summary

This document explains the function of the different technical components in the new growth chamber, a step by step description of the set up procedure in manual and automatic mode is evaluated with specific operational tests. Different growth cycles (applying 2 different growth protocols) are described: following the approach defined in the task 3.1, seeds are placed under the controlled growth conditions in order to evaluate the performance of the subsystems operated under the integrated Zephyr system

Related documents

D3.3 Final report on growth test and biological validation
D5.1 New growth chamber assembled
D5.2 User’s manual

2. System control and configuration

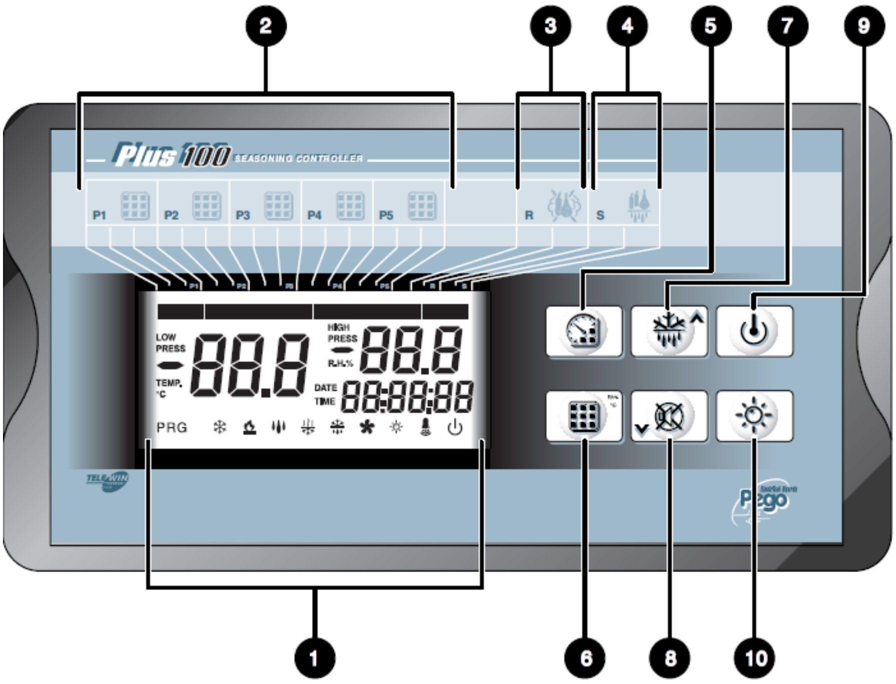
The system enables the use of the specific subsystems both in manual and automatic mode. Manual mode is particularly indicated whenever a certain protocol is being tested and the specific settings are not yet established or whenever a specific action is needed (such as an emergency stop). Automated mode on the hand is suited for those actions which settings are already well known and must be periodically repeated over time.

2.1. Configurable parameters - Manual mode

Manual mode is the default operating mode of the system. This allows direct control over the different devices to the lowest possible level, and is always available even during the automated processes, as it may be necessary to act directly during them.

2.1.1. HVAC system setup

The HVAC control console allows the user to control temperature and humidity in the growth chamber. The system consists of the 100 MASTER THR unit to which all electrical connections are made and the PLUS 100 THR control console, equipped with LCD display for fast, comprehensive monitoring of conditions. The system allows the user to control cold, heat, ventilation, humidification, air change, pauses, dehumidification, defrosting and alarms.



1. LCD display
2. Program phase (the bar on the LCD display indicates the progress of the automatic program);
3. Pause phase
4. Drip phase
5. Cycle START/STOP (press for a few seconds to start or stop an automatic cycle) / Timer (pressing once displays the remaining time for the phase in progress);
6. SET temperature / SET humidity (press the key to switch back and forth between temperature and humidity)
7. UP, pause/defrost forcing (activates both functions)
8. DOWN, air change forcing, alarm mute
9. Stand-by (stops system, does not interrupt cycle in progress)
10. Room light

For safety reasons and to simplify the operator's work, the console has two programming levels; the first level is used to modify SETPOINT parameters (i.e. those parameters that are changed frequently). The second level is for general parameter programming of the various board work modes.

Temperature/Humidity setpoint programming

1. Push the **SET key** to display the current **SETPOINT** (temperature and humidity).
2. Push the **SET key** and press one of the ( ) or ( ) keys to modify the **SETPOINT**.
3. Release the **SET key** to return to cold room temperature display; modifications are saved automatically.

Figure 1 HVAC control unit

2.1.2. Lighting system setup

The three lamps of the chamber are controlled simultaneously. Control of the lighting system is done through the ***Zephyr Scheduler App,*** and it is possible to switch them completely on or off, or to attenuate the light intensity by changing the dimmer value.

Figure 2 Lighting System Manual Controls

Figure 3 Different Light Levels

The amount of light received by the plants is measured by a PAR sensor installed below the lights. This is particularly handy to ensure that the plants are receiving the adequate amount of light.

Figure 4 Light Sensor Position

2.1.3. Rotation system setup

The rotation system makes sure each of the trays receive the same amount of light during the growth period. With the manual controls it is possible to set the rotation direction (clockwise or anticlockwise) and the speed.

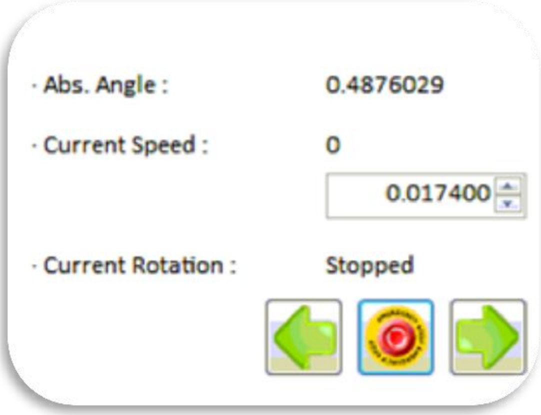


Figure 5 Chamber Rotation Controls - Speed and Direction

During a normal irrigation cycle, the system rotates anticlockwise as this has been considered the best solution to avoid dripping with water unwanted parts of the chamber. The maximum speed has been fixed at 0.0174 rad/s as this minimizes the dripping of water whilst maintaining the correct lighting conditions of the plants.

Additionally it is also possible to move a specific tray to a certain position or custom angle. Among the fixed positions are the irrigation and image capturing positions, which are pre-established at set angles.

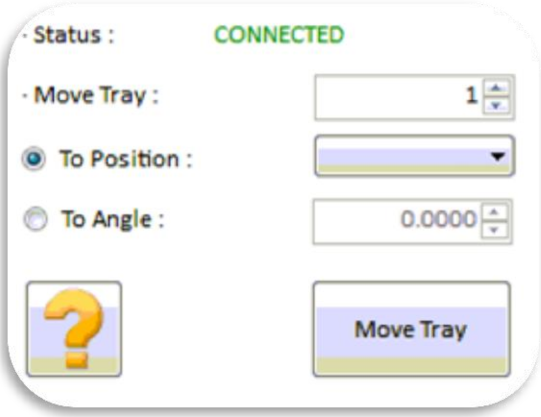


Figure 6Chamber Rotation Controls - Specific Positions

Figure 7 Chamber Rotation

2.1.4. Irrigation system setup

The irrigation manual controls manage the status of both the filling pump and the draining valve. This allows the user to manually fill the irrigation tub with water to start the watering of the plants. Once the tub is filled each of the trays advance to the irrigation position and remain submerged for a certain time.

Figure 8 Irrigation System Manual Controls

An ***Auto Fill*** option is also available for those occasions in which we want to maintain the watering tub filled with water whilst we are doing other things, such as moving different trays to the watering position. Without that control we would be forced to manually switch on and off the pump and the valve to maintain the level.

To keep the tub water level constant the application makes use of several sensors that indicate the water level of the irrigation tub as well as the remaining water in the tank.This is useful not only for the automated processes but also for the user who is manually controlling the irrigation.

Figure 9 Irrigation system sensor and actuator status

Filling the irrigation tub completely takes approximately 5 minutes and draining it again around 4. This must be taken into account whenever setting up automated irrigation procedures as we will see later on.

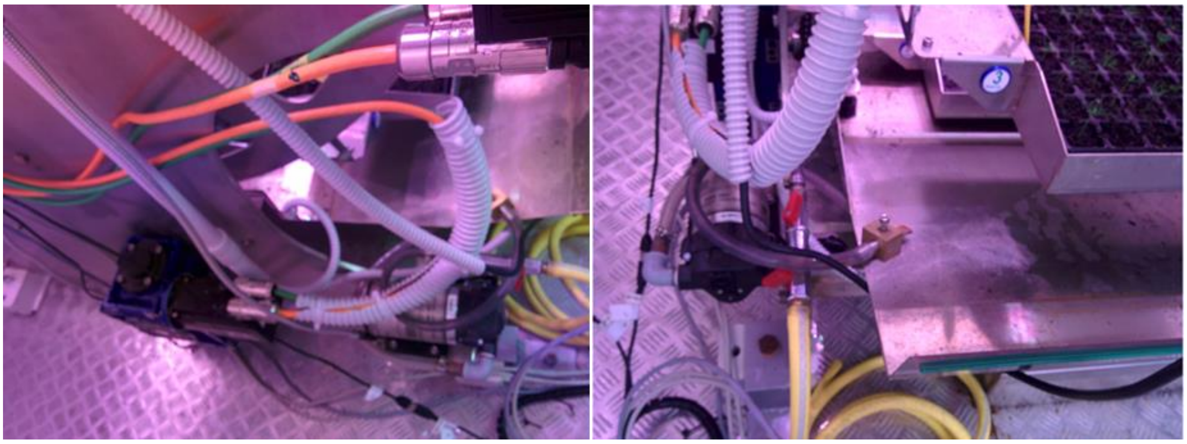


Figure 10 Cable and tubes connecting the pumps to the tub

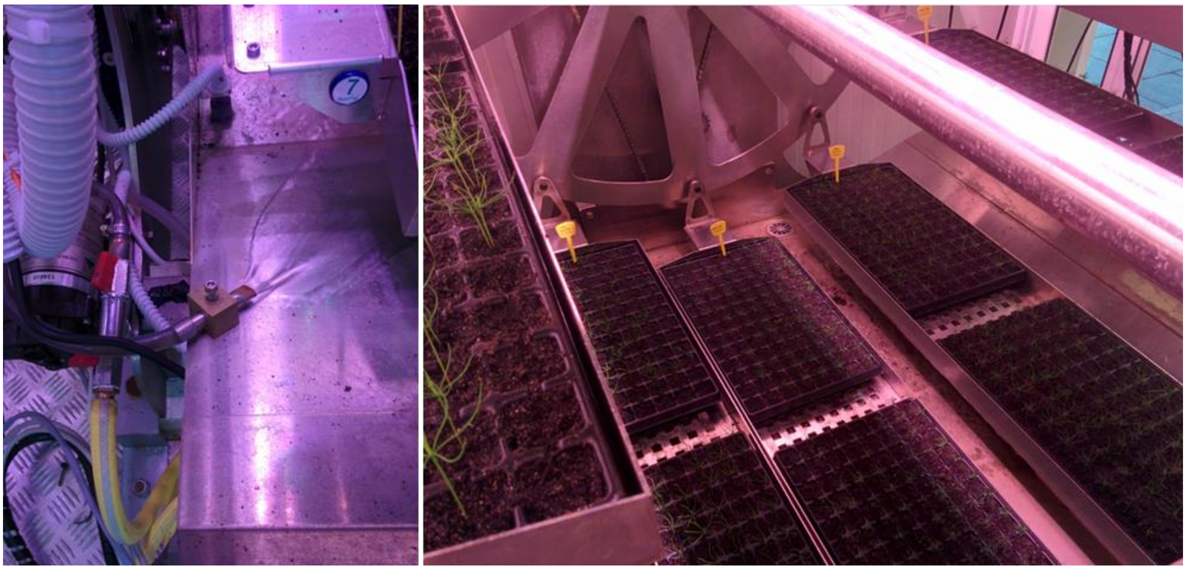


Figure 11From left to right, watering tub being filled and plants submerged

Figure 12 Draining valve opened

2.1.5. Image capturing system setup

Several subsystems intervene in the image capturing process. To begin with, the tray with the plants that are to be analysed is move to the image capturing position. As explained before, to do so we make use of the chamber rotation subsystem's ability of sending a specific tray to a certain angle. The image position is already a stored position within the software, so it is only needed to select the tray we want and send it to that position:

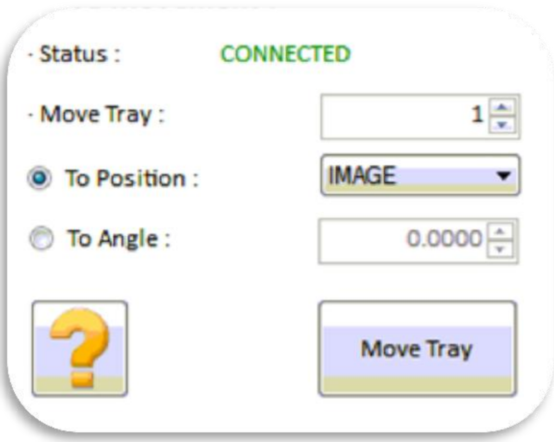


Figure 13 Example, moving tray 01 to Image Position

The chamber always chooses the shortest route to the destination to minimize movement time. Eventually the tray arrives to the set position:

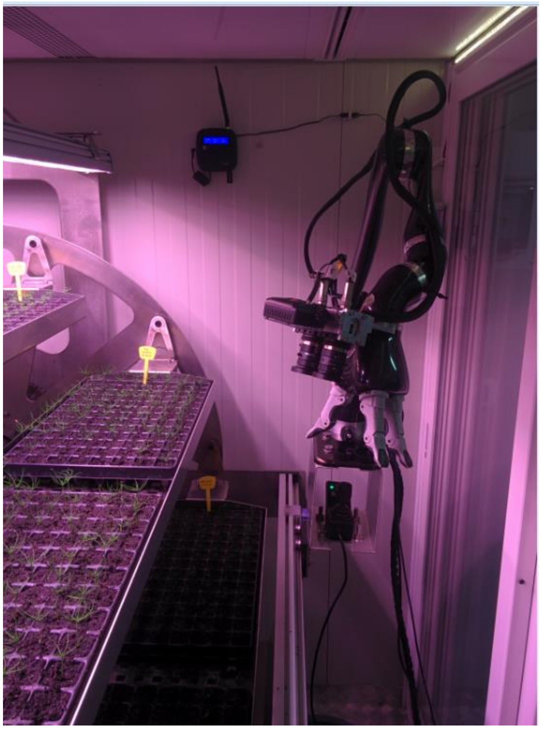


Figure 14 Tray01 at Image Position

Once the tray is positioned, it is time to start the robotic arm. The robotic arm moves through a predefined route to the image gathering position to avoid hitting any of the elements of the chamber. The idea is to position the camera on top of the plants to give a top-down view of them. As the robot's positioning system is extremely accurate, it is guaranteed that all pictures are taken with the same distance conditions. This way a correct greenness and height calculation can be done.

Figure 15 Robot moving, intermediate position

Eventually the robot gets to image capturing position. In the picture below we can see that the robot is positioned above the first pot of plants in the tray (this is the default starting position):

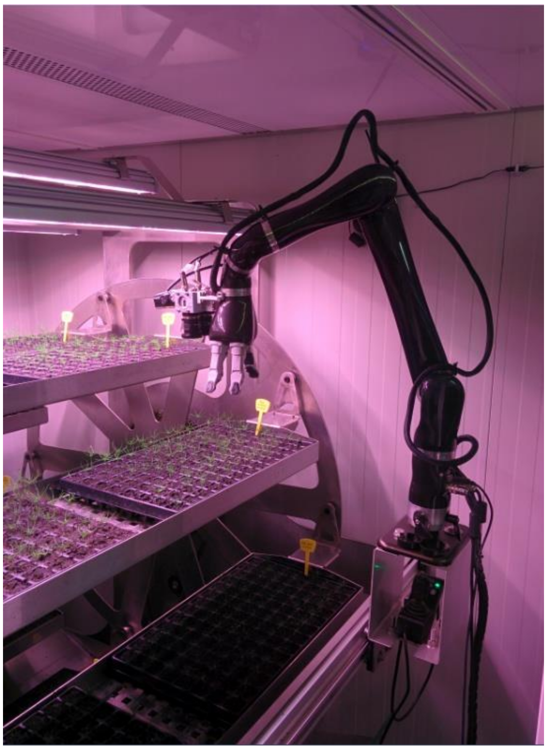


Figure 16 Robot positioned and ready to take picture

As everything is ready it is now time to use the optical sensor to take the picture and analyse it. From the optical sensor manual controls it is possible to switch on and off the auxiliary led light incorporated. This light is useful as the inside of the chamber is somewhat dark and the light not only illuminates the area but also helps achieving the most homogenous conditions to take the picture.

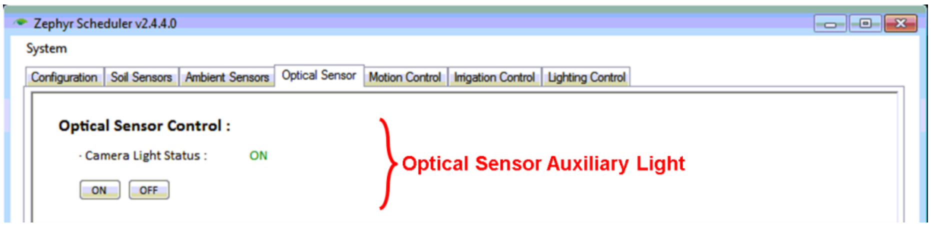


Figure 17 Optical sensor auxiliary light control

Before starting the analysis it is necessary to select the adequate tray and pot we are analysing. This is necessary for two reasons:

- To select the adequate optical sensor configuration for the pot plants
- To store the output results in the correct tray and pot folder

From the beginning this approach was judged necessary as it is not always the case that all the trays and pots contain the same species. Therefore each of the pots of each tray has its own specific configuration files.

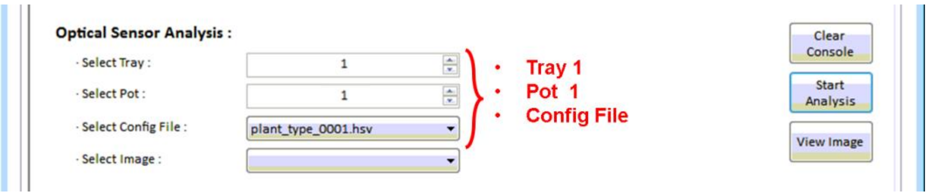


Figure 18 Optical sensor configuration setup

When all the settings are ready the image process can start. This is done by pressing the Start Analysis button, and the results are shown in the console below.

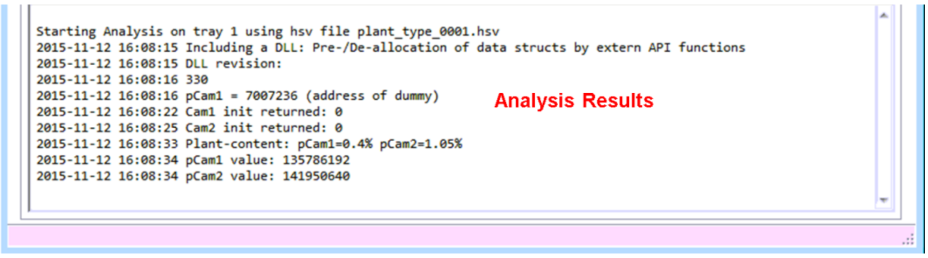


Figure 19 Optical sensor analysis results

This process generates two images (as it is a dual cam) and a greenness analysis of them, which is stored in the respective folder with a timestamp indicating when it was taken. With these images and in a separate process it is possible to generate a height report using the ***HeightMap*** tool.

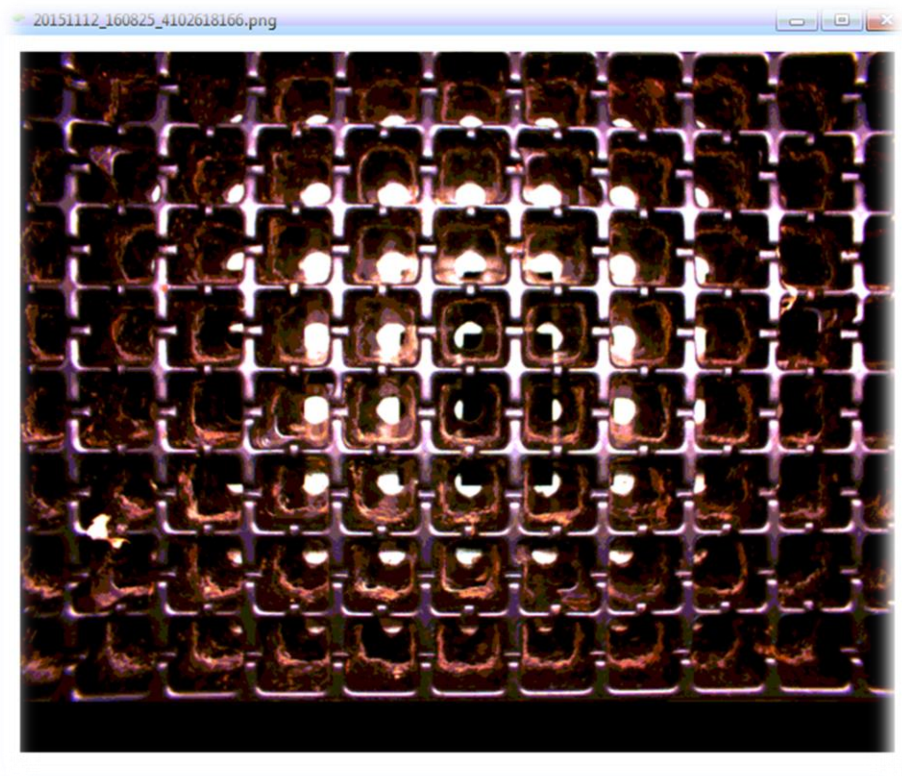


Figure 20 Example of optical sensor output

Once finished with that pot it is possible to move the robot to the next using the robot translation control. This control allows the user to move the robotic arm, and the optical sensor attached to it, to a custom position or to the predefined stored positions of the pots.

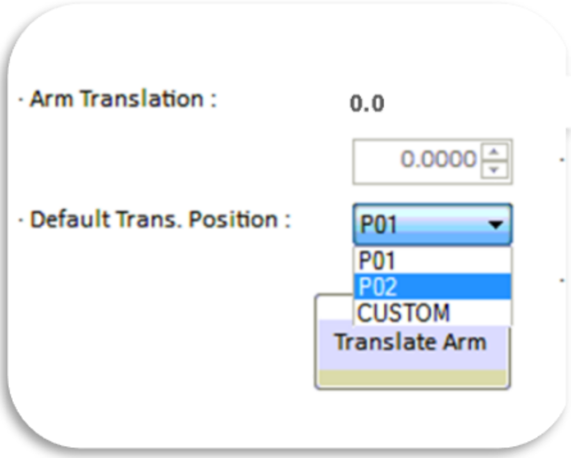


Figure 21 Translation of robotic arm to specific position

The robot starts moving and eventually reaches the second pot position.

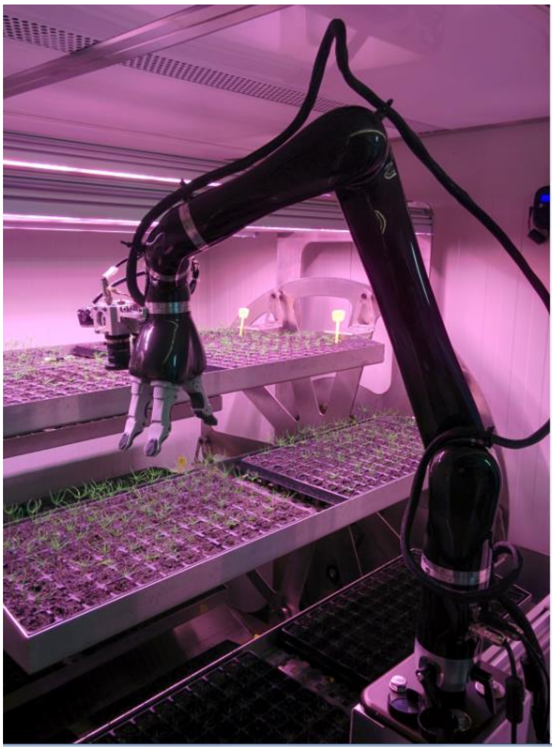


Figure 22 Robot positioned on top of the second pot

The image capturing process starts once more only this time we select the second pot to store the output and load the configuration.

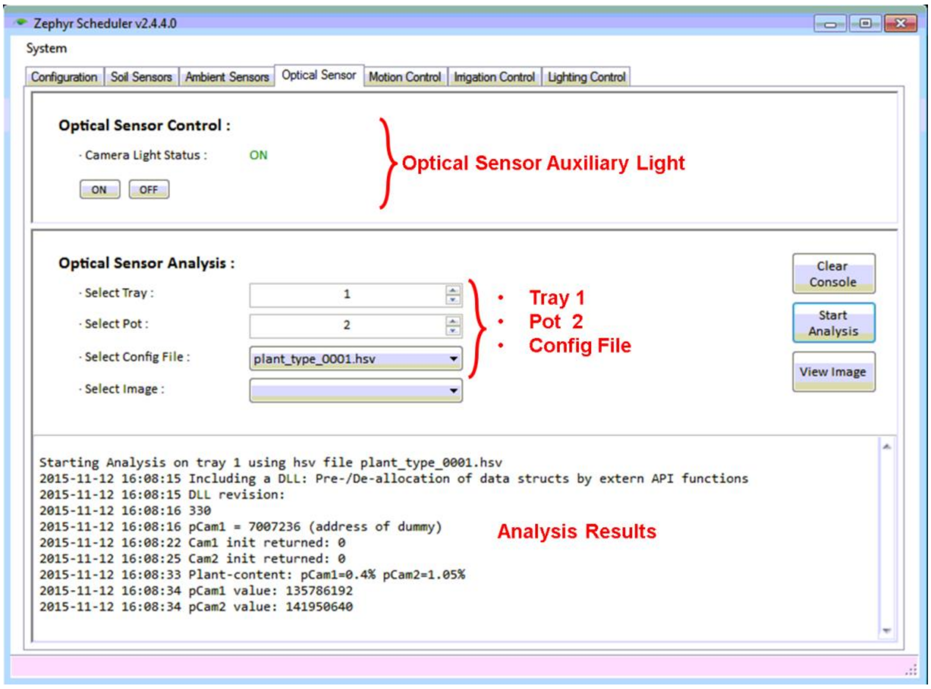


Figure 23 New analysis done, tray 1, and pot 2

2.1.6. HeightMap tool

2.1.6.1. General information

Each image `<filename>.png` should be accompanied by an `<filename>.info` file. The respective `<filename>` consists of the Date, Time, and CameraSerialNumber.

The `<filename>.info` file contains text with information needed in the processing:

- the current revision of the software that generated the image
- the chosen Area-of-Interest (AOI) within the camera field of view
- the pixel-offset between the cameras in a given pair
- the selected HSV parameters for extraction of the foliage content, namedHmax,Hmin,Smax,Smin,Vmax,Vmin, and can be edited manually.

2.1.6.2. HeightMap normal processing sequence

1. After starting up the `HeightMap.exe`, choose the folder/directory containing the images with the *File->Select Directory* menu item. The chosen folder should appear in the field *Working directory* at thebottom of the window.

2. Select one of the desired images with the *File->Open* menu item.

- The application automatically computes the plant/green content in each image, based on the data in the `<filename>.info` files.
- The foliage-only images are displayed side by side, and the percentage is shown in the *Plant content* fields.
- NB: A pair of images must exist, tagged with the same time-stamp.
-

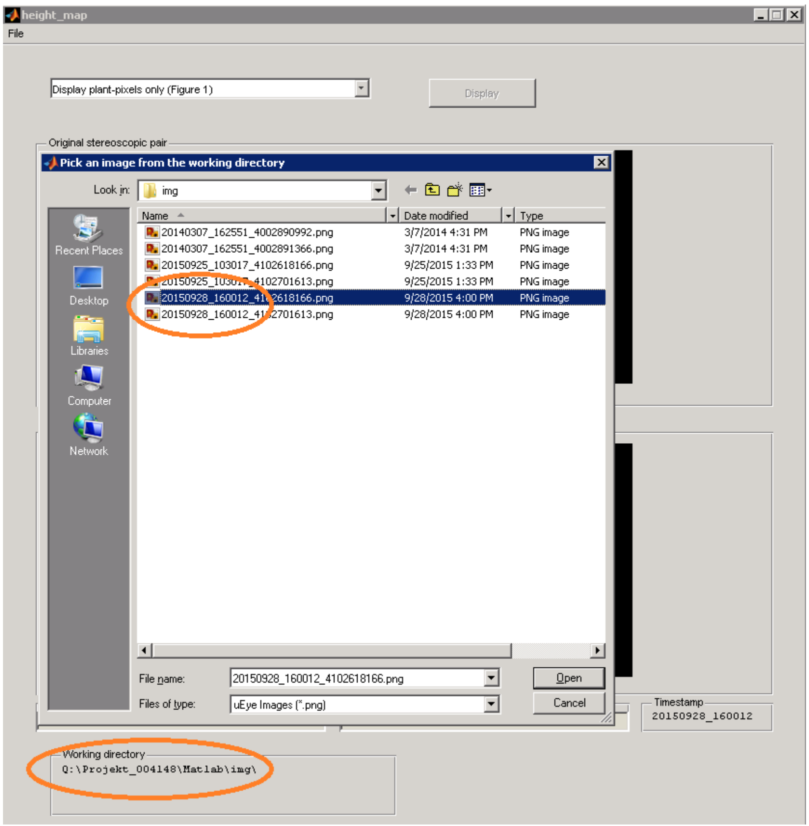


Figure 24. step 1-2

3. Select the item *Display plant-pixels only...* from the pull-down menuand press the *Display* button. A new window called *Figure 1* shows thedata contained in memory.

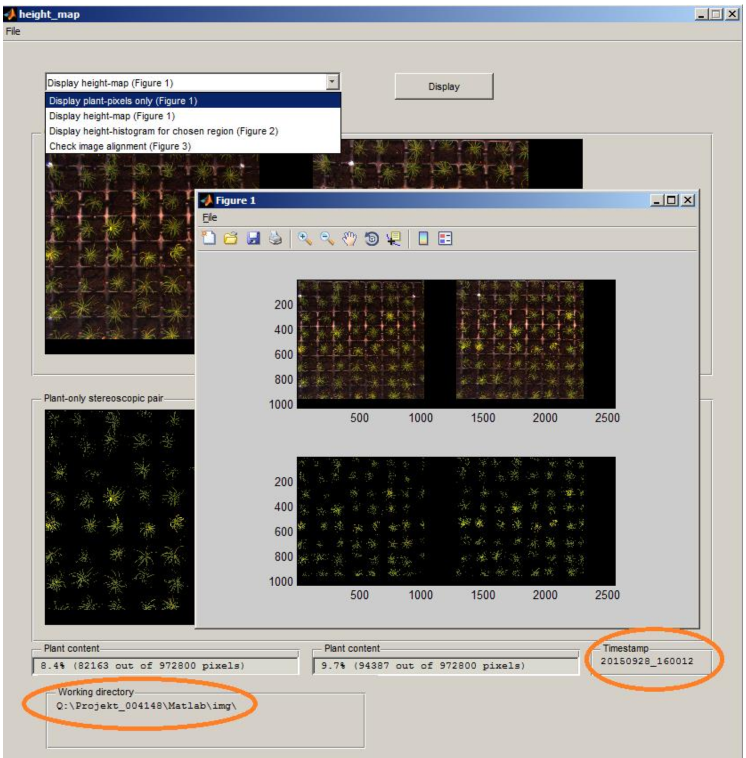


Figure 25*. step 2-3*

4. Select the item *Display height-map...* from the pull-down menuandpress the

Display button. The mapping process can be seen inFigure 1. Wait until the counter *Remaining levels* reaches 0.

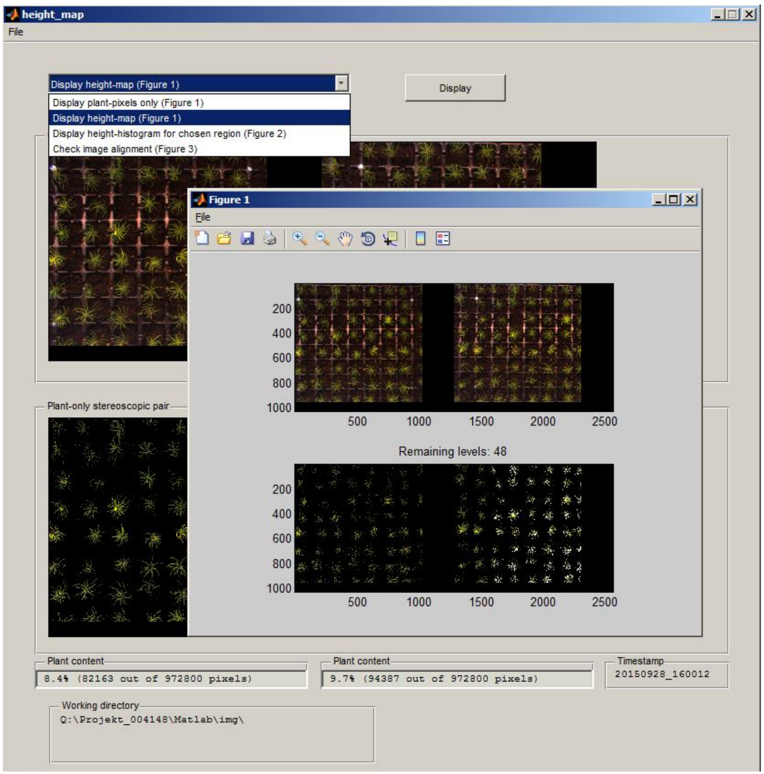


Figure 26 *step 4*

5. Select the item *Display height-histogram for chosen region...*from the pull-down menu and press the *Display* button.The histogram is then shown in a new window named *Figure 2*.

- In the absence of a calibration file named `init-data\conversion_formula.m`, only the *Mean unnormalized height*is shown, measured in pixels.
- In the presence of `init-data\conversion_formula.m`, also the computed*Meannormalized height* is shown accordingly.
- NB: `conversion_formula.m` contains text in the form of a function: `y = a + b*x + c*x^2 + ...`, which should be derived by the user byanalyzing the growth of a typical plant over time.

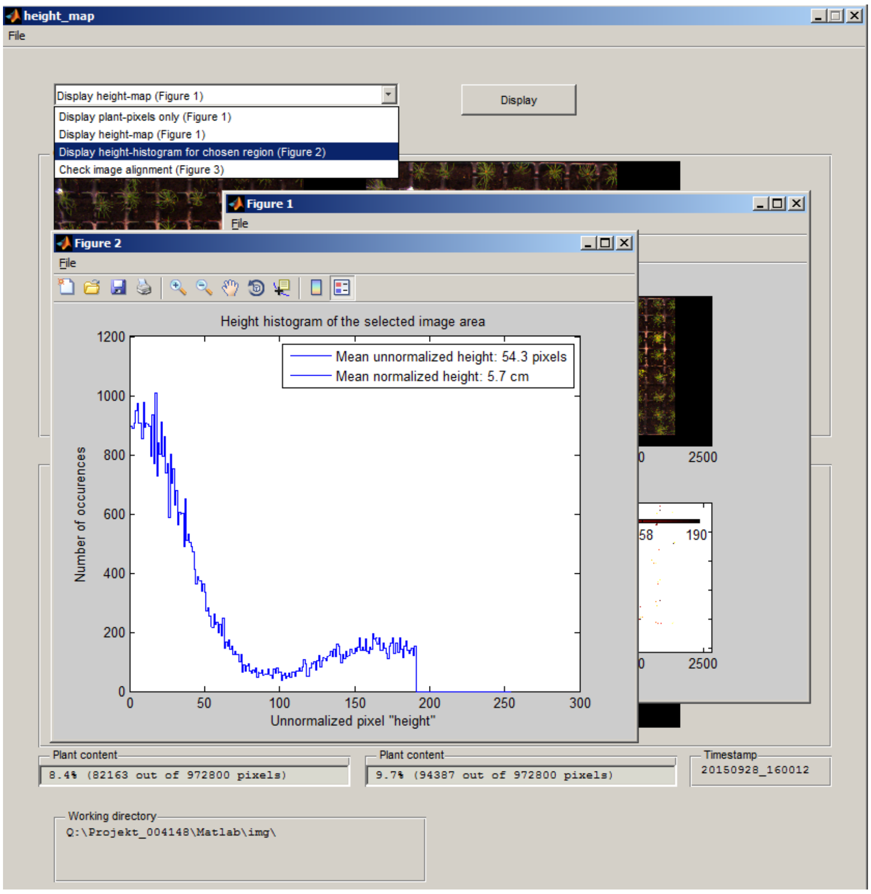


Figure 27 *step 5*

6. The procedure can be repeated from Step 2) for all image pairs in the chosen *Working directory*.

- The item *Check image alignment...* from the pull-down menu is useful for demonstration purposes. The process of plant-pixel correlation canbe visualized in a separate window called *Figure 3*.

2.1.6.3. HeightMap processing with changed HSV parameters

Occasionally, the `Zephyr Scheduler` user may accidentally choose the wrong `.hsv` file for a given plant type. While the `Zephyr Scheduler` will save the complete image information in `<filename>.png`, the `<filename>.info` files will contain the wrong HSV color parameterization.

At a later time, the user may edit the `<filename>.info` files with the proper values for Hmax, Hmin, Smax, Smin, Vmax, and Vmin. At that point, the sequence above can be repeated with the new HSV color parameters:

1. Steps 1)-2) allow recomputation of the plant/green content for a given image pair.

2. Steps 1)-6) allow also for complete recomputation of the height-map for a given image pair. Note that both `<filename>.info` files should be edited in that case.

2.2. Configurable parameters - Automated mode

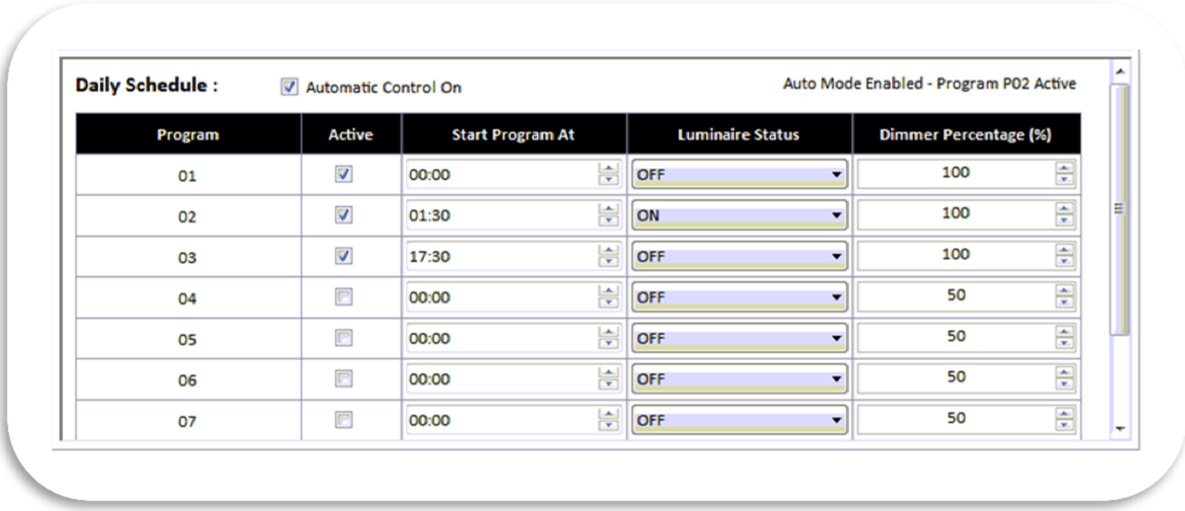
Certain actions are always performed in the same way and with regular intervals. This makes them ideal to be automated within the system.

2.2.1. Lighting system setup

The automated lighting control is once more managed by the ***Zephyr Scheduler App***. It basically consists of a list of programs that can be individually activated.

The control loop checks the programs in a hierarchical way, so that whenever two programs are valid the one with the highest number is the one that runs. For instance in the example below, program 01 starts at 00:00, and from that time onwards it switches off the lights. However as program 02 is also activated, and 02 prevails over 01, after 01:30 the lights are turned on, at 50% intensity.

Finally, program number 03 makes sure the lights are switched off at 17:30. The result is that each day the plants receive a total of 16 hours of light.


Daily Schedule : ☑ Automatic Control On — Auto Mode Enabled - Program P02 Active

Program	Active	Start Program At	Luminaire Status	Dimmer Percentage (%)
01	☑	00:00	OFF	100
02	☑	01:30	ON	100
03	☑	17:30	OFF	100
04	☐	00:00	OFF	50
05	☐	00:00	OFF	50
06	☐	00:00	OFF	50
07	☐	00:00	OFF	50

Figure 28 Example of lighting schedule

This is a simple but efficient way to approach the automated control of the lights. From the beginning it was decided that light protocol would be daily based, so it was not considered necessary to add different day configurations. Also, as the chamber is closed to the outside and the conditions are constant it was not necessary to use the light sensor to modify light conditions during the cycles.

2.2.2. Rotation system setup

The chamber rotation is ultimately controlled by the ***Zephyr Scheduler App***. There is not an exclusive automated rotation program per se, but rather the movement of the chamber is associated to other automated processes that require specific tray positions.

What it is possible is to set the rotation speed of the trays. By setting the rotation speed and direction the system will ensure that the chamber keeps that rotation setting continuously, according to the needs of the plants of the cycle.

2.2.3. Irrigation system setup

Watering the plants falls under the category of periodic actions that can be automated, and the ***Zephyr Scheduler App*** is the tool to do it.

The entire irrigation program can be configured by setting up with the following options:

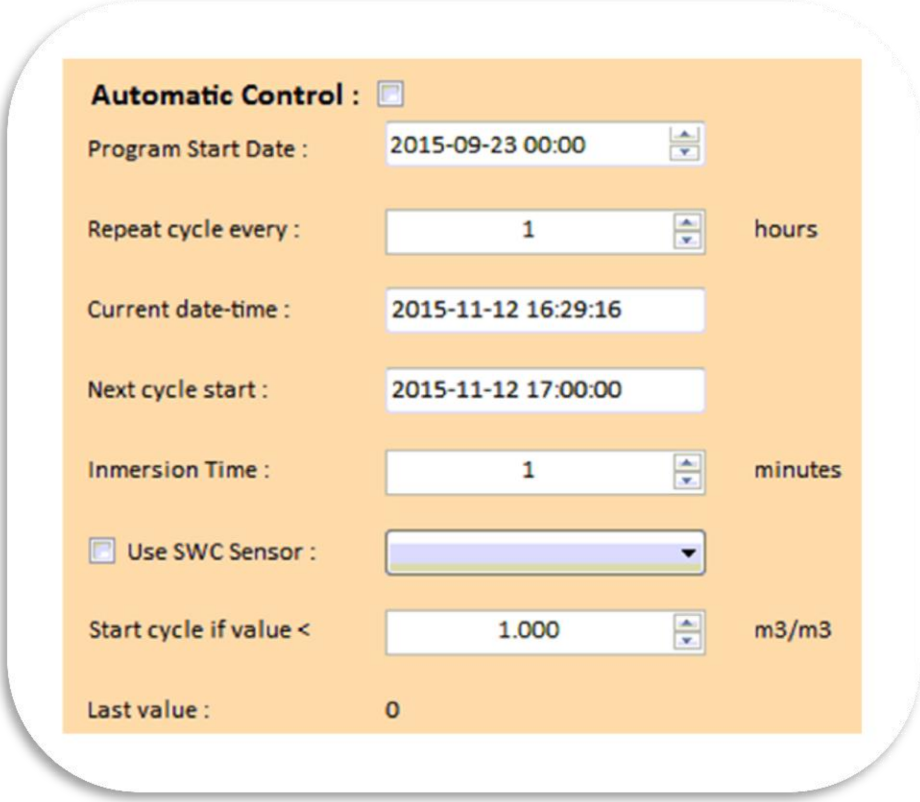


Figure 29 Example of watering cycle configuration

First of all it is necessary to indicate the start date of the program. The system will use this date and time as the origin to calculate when a new watering cycle is due.

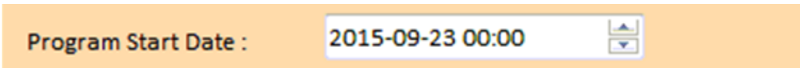


Figure 30 Water cycle start date

Secondly, the period (in hours) must be set. Starting from the start date, and considering the current date and time, the system will calculate when it should start, and the next cycle label will update accordingly.

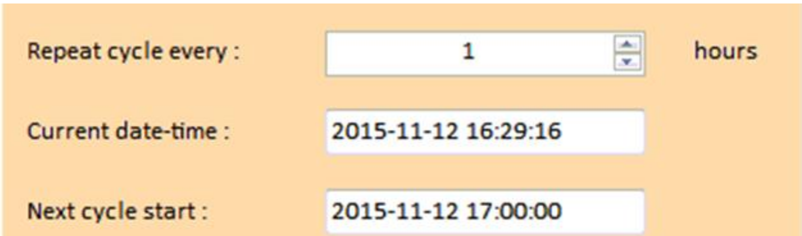


Figure 31 Water cycle period

For example, in the example above, the origin start date is 2015-09-23 00:00. The cycle is supposed to repeat every hour so the system automatically calculates when it is should start in the following manner:

- **Time:** 2015-09-23 00:00 (origin value)
- **Added Time:** 1 hour (repeat cycle value)

Time	Current Time	Use as Next Cycle Start ?
2015-09-23 00:00	2015-11-12 16:29	NO
2015-09-23 00:00	2015-11-12 16:29	NO
2015-09-23 00:00	2015-11-12 16:29	NO
2015-09-23 00:00	2015-11-12 16:29	NO
... and so on, until eventually we surpass the current time		
2015-11-12 17:00	**2015-11-12 16:29**	**YES!**

In this case the system calculates full hours from an origin that it a full hour itself (00:00). However, if our origin had been for example 2015-09-23 00:35 the cycle would start every hour at the minute 35. In our example this would mean starting at 2015-11-12 16:35.

With this method we can specify how many times a day we want to water the plants, always assuming a multiple of hours as the period between one cycle and the next one.

For example if we wanted to water once every 2 days, we would have to set the repeat cycle value at 48 hours.

Additionally, it is possible to add an additional setting to the watering program which involves considering the water content value of the soil sensor before starting the cycle. This would prevent watering when it is not needed.

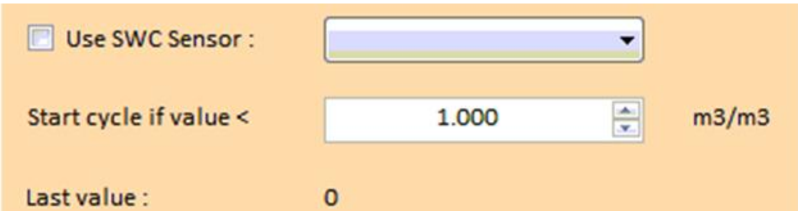


Figure 32 Using soil water content as cycle control signal

Finally, it is also necessary to indicate for how long each tray has to be submerged (in multiples of minutes). The system already takes into consideration that the first tray must wait for the tub to be filled before starting the minute count otherwise it won't be watered at all as the tub filling takes approximately 5 minutes.

Figure 33 Number of minutes each tray is watered

The last step consists in enabling the Automatic Control. It is best if this is done at the end as that way we avoid unnecessary cycle starts during the configuration.

Figure 34 Main switch to activate automatic control

2.2.4. Image capturing system setup

The image capturing system consists in capturing specific images of the plants during the cycle to control their height and greenness parameters.

3. *Pinus Sylvestris* experiment: controlled growth conditions setup

The following sections indicate how a user would proceed to configure the system to grow the *PinusSylvestris* species in the chamber.

Figure 35 Trays containing PinusSylvestris

3.1. Zephyr system initialisation

After positioning the pots in each of the trays, the actions to perform are:

- Ensure that the water tank is filled.
- Ensure that the batteries are charged or the system is plugged to the electric network.
- Situate the soil sensors in the most relevant pots, if needed
- Power up the different subsystems
- Launch the ***Zephyr Scheduler App***.

3.2. HVAC system setup: temperature and humidity controlled conditions

80% during germination 60% during growth

3.3. Lighting system setup: photoperiod and PAR exposure

The *PinusSylvestris* requires a PAR exposure of **90-100 µmol m-2 s-1**. The first step should be to check at what dimmer percentage value this is achieved by using the manual controls of the ***Zephyr Scheduler App***.

Figure 36 First step, determining adequate lighting conditions

Once that value is determined we can proceed to set up the automated lighting control programs. The *PinusSylvestris* requires **16 hours of total light each day**, starting at 05:00. This can be established in by setting up the following 3 programs:

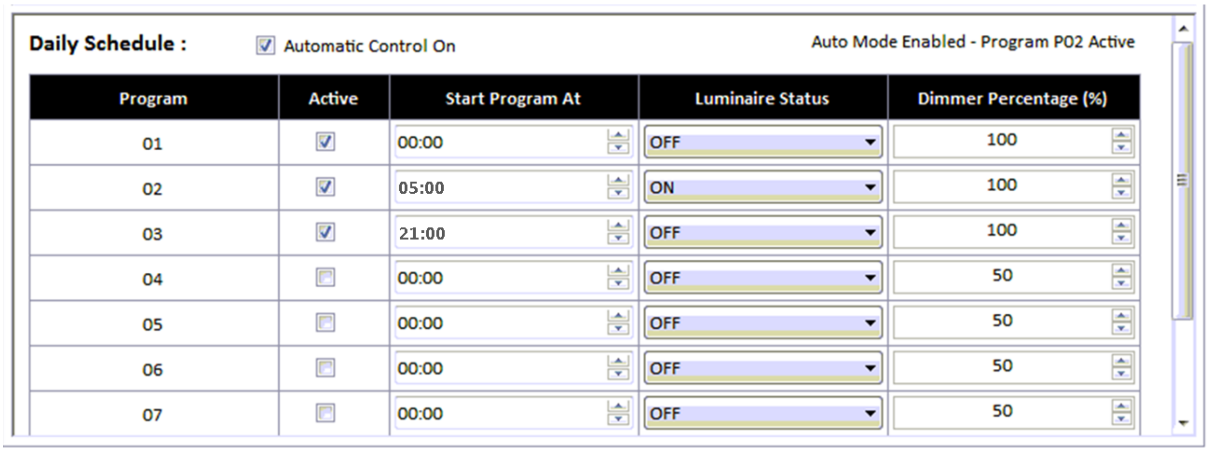


Figure 37 Setting up the lighting schedule

3.4. Rotation system setup: angular speed and direction

The default maximum speed (0.0174 rad/s) is considered adequate for this kind of plant; therefore no changes are needed there. The direction is irrelevant, so anticlockwise to avoid excessive dripping is valid.

3.5. Irrigation system setup: calendar scheduling and immersion time exposure

This plant needs a watering cycle every 3 days (72 hours), and between 5 and 7 minutes of immersion per tray (average of 6 selected).

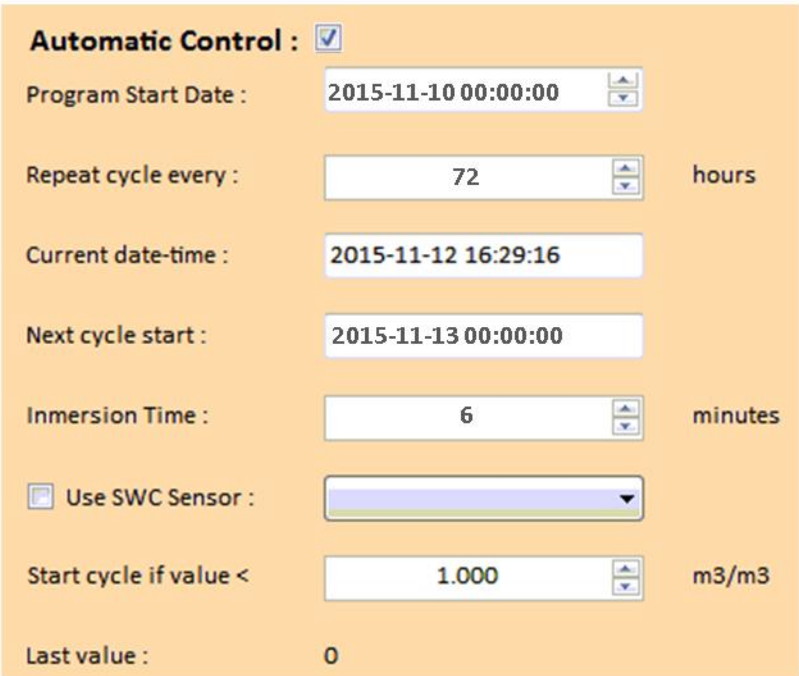


Figure 38 Pinus Sylvestris irrigation cycle setup

The cycle has been set to start at midnight, so that the entire watering takes place with the lights inside the chamber switched off.

3.6. Image capturing system set up: matrix positioning and capture period

By default the system assumes two pots per tray, and the robotic arm is able to position the cameras on top of them.

New image gathering positions can be setup if needed, but for the growth of these types of plants the standard setup seems sufficient.

4. ***Quercus ilex*** **experiment: controlled growth conditions setup**

The following sections indicate how a user would proceed to configure the system to grow the *Quercus ilex* species in the chamber.

Figure 39 Trays containing Quercus ilex

4.1. Zephyr system initialisation

After positioning the pots in each of the trays, the actions to perform are:

- Ensure that the water tank is filled.
- Ensure that the batteries are charged or the system is plugged to the electric network.
- Situate the soil sensors in the most relevant pots, if needed
- Power up the different subsystems
- Launch the ***Zephyr Scheduler App***.

4.2. HVAC system setup: temperature and humidity controlled conditions

70%

4.3. Lighting system setup: photoperiod and PAR exposure

The *Quercus ilex* requires a PAR exposure of **90-120 µmol m-2 s-1**. The first step should be to check at what dimmer percentage value this is achieved by using the manual controls of the ***Zephyr Scheduler App***.

Figure 40 First step, determining adequate lighting conditions

Once that value is determined we can proceed to set up the automated lighting control programs. The *Quercus ilex* requires **12 hours of total light each day**, starting at 06:00. This can be established in by setting up the following 3 programs:

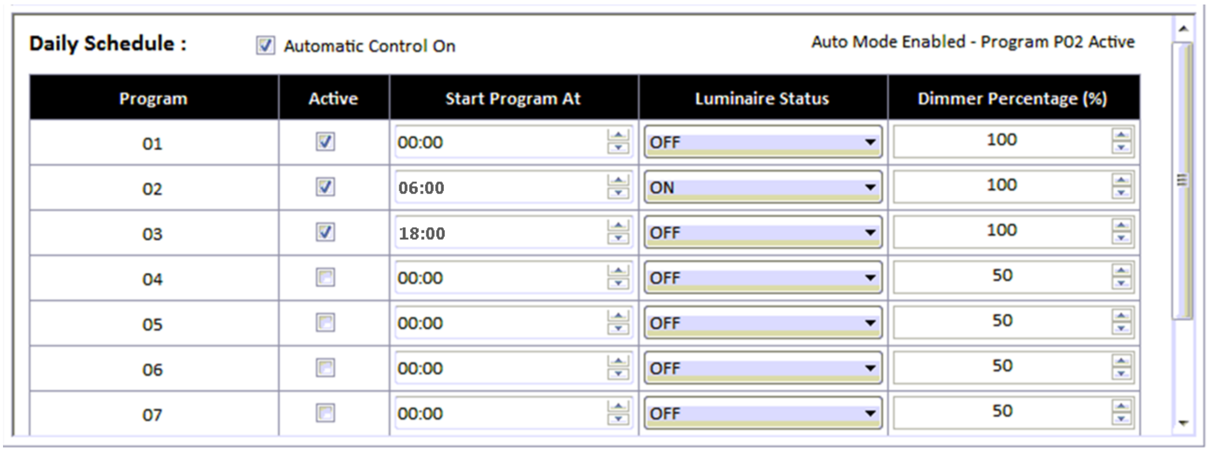


Figure 41 Setting up the lighting schedule

4.4. Rotation system setup: angular speed and direction

The default maximum speed (0.0174 rad/s) is considered adequate for this kind of plant; therefore no changes are needed there. The direction is irrelevant, so anticlockwise to avoid excessive dripping is valid.

4.5. Irrigation system setup: calendar scheduling and immersion time exposure

This plant needs a watering cycle every 2 days (48 hours), and between 8 and 10 minutes of immersion per tray (average of 9 selected).

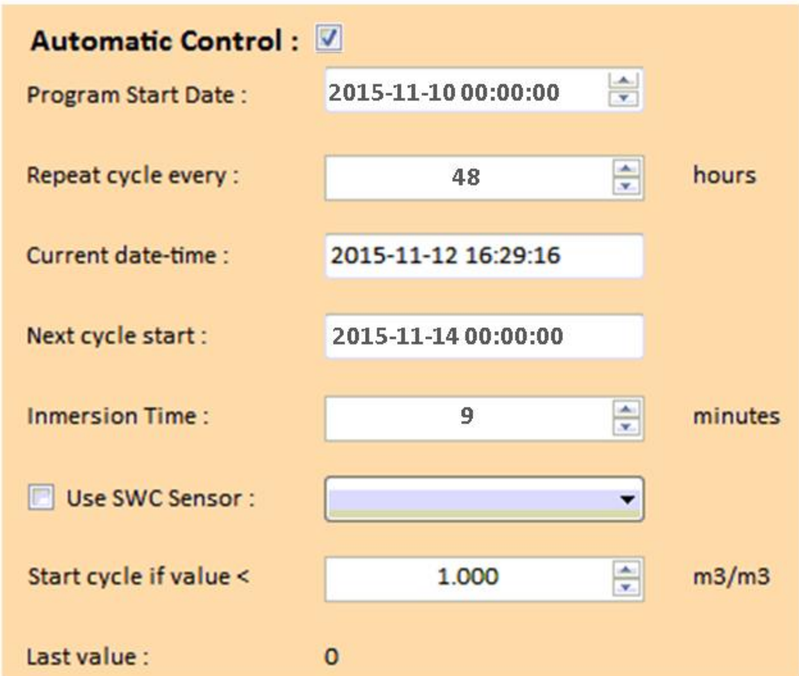


Figure 42 Quercus ilex irrigation cycle setup

The cycle has been set to start at midnight, so that the entire watering takes place with the lights inside the chamber switched off.

4.6. Image capturing system set up: matrix positioning and capture period

By default the system assumes two pots per tray, and the robotic arm is able to position the cameras on top of them.

New image gathering positions can be setup if needed, but for the growth of these types of plants the standard setup seems sufficient.