4th International Autonomous Greenhouse Challenge

Autonomous indoor dwarf tomato production by artificial intelligence with low carbon footprint

Criteria, rules & regulations

Version: 6 October 2023

Introduction

In this document we share criteria, rules and regulations for teams who want to participate in the 4th 'International Autonomous Greenhouses Challenge', organised by WUR and sponsored by Tencent. We invite multidisciplinary teams to grow a dwarf tomato crop fully autonomously in one of WUR's high-tech greenhouses with a focus on a low carbon footprint. We invite teams to bring in their crop and AI expertise and passion and join the Challenge.
This document describes the rules of the challenge, the Online challenge and Hackathon and the Greenhouse Growing Experiment.
All information can also be found at www.autonomousgreenhouses.com.

Eligibility of teams

- The Challenge is open to students and researchers from universities and research centres, experts from start-ups and companies.
- Teams are multi-disciplinary, combining the following expertise: 1. artificial intelligence/sensors technology/data science 2. crop physiology/crop management/horticulture production. This expertise must be demonstrated by professional or academic engagement.
- Teams have at least 3 individual members. Individual members are members of the team and subscribe to and participate in the Challenge.
- At least one team member must be a student.
- Each team will appoint a team-captain who acts as contact person between the team and the WUR organisers.
- We encourage teams from different countries and continents to participate. We encourage cooperation of different experts from different start-ups and companies.
- Good English language skills are required.

Registration

- To register, teams are required to submit the completed registration form available on the website from 1 November 2023 onwards.
- The submission must include:
    - detailed information on all individual team members
    - a short smartphone video of the team showing their approach and motivation
- The team should meet all eligibility criteria (stated above).
- The registration form can be found on www.autonomousgreenhouses.com and must be filled in completely. Follow the instructions on the website to submit it. You will get a confirmation email of your subscription.
- The registration form must be completed and submitted before **31 December 2023 23:00 h GMT**.
- After this date WUR organisers and an independent jury will select eligible teams (stated below). You will get a final confirmation email of your eligibility and your participation.

Confirmation of participation and participation process

- A maximum number of **25 teams** will be admitted to the Online Challenge and Hackathon. The selection is made based on:
    1. Eligibility criteria (stated above). A team must meet all eligibility criteria.
    2. Timing of subscription.

This event is organised by Wageningen University & Research and is sponsored by Tencent. We also thank the following companies: Quantified for providing substrate sensors, Biobest for being partner in pest detection and biological control, Hortilux for providing LED lamps for the pre-trial and Lensli Substrates for proving substrates for the pre-trial.

3. Team composition (variety on expertise/skills, companies/start-ups/organisations, variety on nationalities, variety in gender) and motivation (based on your submitted video). An independent jury helps the WUR organisers in the selection.

- WUR will inform all duly registered teams whether they are eligible and have been admitted to the Challenge until **31 January 2024.** The organisers' and jury's decision will be final and will not be subject to debate.
- WUR retains the right to consider registrations until 31 January 2024, if a minimum number of five teams has not been reached.
- All admitted teams must participate in the *Online Challenge* in the period of **1 April to 1 June 2024** to show their machine learning and computer vision skills (see hereafter) and in the *Hackathon event* at WUR (Bleiswijk, NL) on **6-7 June 2024** to show their skills and present their approach in front of a jury. The five best teams will be selected for the Greenhouse Growing Experiment during the Hackathon event.
- A maximum of five teams will be admitted to the *Greenhouse Growing Experiment*, the fully autonomous dwarf tomato production experiment, taking place from **August to December 2024**. During the Greenhouse Growing Experiment the teams must fulfil a predefined task (see hereafter) for fully autonomously growing a dwarf tomato crop. The team performing best according to predefined criteria will win the Challenge.
- The winner of the 4th Autonomous Greenhouse Challenge will be announced during the *International Autonomous Greenhouses event* in **January 2025**.
- Due to the size and complexity of the competition, teams should consider that funds for travel and a substantial amount of time as well as dedication are required. Following the experience of the previous edition, an estimation of the dedicated time is given: 2 months availability during the Online Challenge period. 2 months for preparation of A.I. algorithms and strategy before the crop cycle starts in the Greenhouse Growing Experiment plus time for communication. Thus, by entering the competition the teams acknowledge the above and commit to adequately preparing for the competition and conducting the greenhouse experiment for its entire duration.
- Note that participation (of at least the team captain) in the Hackathon event (6-7 June 2024) and the International Autonomous Greenhouse event (January 2025) is obligatory. Both events are for all teams to interact, share experience within the Autonomous Greenhouse Community and learn more on the topic. Both events will be broadcasted publicly to announce the winners for the next stage and the final winner by an international jury of experts.

Online Challenge procedure

- The Online Challenge takes place during the period of 1 April and 1 June 2024.
- Teams are subscribed and have received a notification that they are eligible until 31 January 2024.
- Teams get 8 weeks of preparation phase (1 April to 1 June) for both parts of the Online Challenge A. The computer vision challenge and B. The machine learning challenge.

Part A computer vision challenge

- For the computer vision challenge teams will get access to a series of ca. 500 images of dwarf tomato plants during the preparation phase.
- Images are taken with a RGBD camera under defined conditions and contain images of individual dwarf tomato plants of different varieties in different growth stages and grown in different growing conditions. Each image is connected with information on the ground truth plant traits, such as e.g. plant height, plant fresh weight, leaf area, number of leaves, number of fruits, ripeness stage of the fruits.
- Teams use the images to develop a computer vision algorithm. This algorithm will have to be able to estimate the plant traits of a series of ca. 150 unseen dwarf tomato plant images provided after the preparation phase under limited time and memory constraint.
- For each picture and plant trait the absolute difference between estimated value (teams' computer vision algorithm) and real value (WUR ground truth manual measurement) will be calculated and normalised. The total sum of absolute normalised difference will be calculated per team. An exact description is given to participating teams in a technical document at the start of the Online Challenge. The team with the lowest difference will be ranked first for this part of the Online Challenge.
- Images will be made available to teams in batches. A larger set will be made available in the first two weeks of the 8 weeks preparation phase for training purposes. Subsequently 6 smaller sets will be made available once per week in the following weeks. Teams must submit their prediction results once per week at a given time. A public ranking board will show the intermediate results of teams' performance. The ground truth will be disclosed one day later.
- At the end of the 8 weeks a final set of images will be provided to teams for the final evaluation of their performance under limited time and memory constraint. The final ranking will be shown publicly during the Hackathon event. The team with the highest score will be ranked first.

Part B machine learning challenge

- For the machine learning challenge, teams will get access to a simple greenhouse climate and dwarf tomato production model (simple simulator) during the preparation phase.
- The simple simulator consists of a given set of outside climate conditions, a given greenhouse type and given greenhouse actuators (ventilation, heating, lighting, screening). It needs to be provided with a series of climate setpoints (ventilation strategy, heating strategy, lighting strategy, screening strategy per timestep) as inputs. The input climate setpoints will activate the available actuators, which will control the inside greenhouse climate. The realised inside climate parameters will be provided as a feedback value. Crop management consists of defining plant density (number of plants m^{-2}) over time. Since the crop growth in the simulator is determined by the realised greenhouse climate, also the crop growth parameters (e.g plant fresh weight, leaf area, fruit fresh weight and ripeness stage of the fruits) over time will be provided as output.
- A definition of the final plant product which must be reached will be given (e.g. plant with minimum of x fully ripened fruits with a minimum weight of x g). Prices will be connected to the final product and all resources used.
- The climate control strategy will determine the use of resources, mainly energy (for heating, for electricity for artificial light) and therefore creates costs.
- The crop management strategy will determine greenhouse space occupation and therefore costs.
- Total fruit fresh weight of the average dwarf tomato plant is provided as the main output. This determines product price and therefore create income.
- Teams will have to develop machine learning algorithms to feed the simple simulator with the optimised control parameters to maximise net profit.
- Technical information on the simulator working principle, an access key and detailed information on the procedure will be sent to all eligible teams at the start of the preparation phase.
- During the preparation phase teams can interact with the simple simulator for algorithm development. During the Online Challenge this algorithm should be suitable to control the growth of a virtual crop in a virtual greenhouse under changed conditions (e.g. other weather conditions, different greenhouse type, different dwarf tomato type) and limited time constraints.
- There will be different versions of the simulators with slightly different simulation parameters (e.g. other weather conditions, different greenhouse type, different dwarf tomato type).
- A first version will be available during the first two weeks of the 8 weeks preparation phase of the Online Challenge with limited access (typically 1000 times per hour), to train the algorithms of the teams.
- A second version will be available to test the trained model during the next 4 weeks, with limited access (typically 1000 times per day). Teams will have to provide their optimised control parameters based on their developed algorithms to maximise net profit at a given time once per week. A public ranking will show the intermediate results of teams' performance according to the net profit.
- A third version will be available during the last 2 weeks for testing and re-training where necessary.
- At the end of the 8 weeks a final version of the simulator will be provided to teams for the final evaluation of their performance under limited time and memory constraint. The final ranking will be shown publicly during the Hackathon event. The teams with the highest net profit will be ranked first for this part of the Online Challenge.

Hackathon event

- On **6-7 June 2024**, a Hackathon will take place at WUR, Bleiswijk, The Netherlands.
- Participation is mandatory for all admitted teams of the Online Challenge prior to further participation in the Greenhouse Growing Experiment.
- At least the team leader has to be physically present on location. All team members are invited.
- During the Hackathon event the results of the A. computer vision and B. machine learning challenge will be revealed.
- A new additional task will be given to the teams to solve within a given timeframe during the event. Information to prepare for the Hackathon event will be sent to all eligible teams before the start. The additional task will form part C. of the evaluation.
- An international jury, consisting of experts from science and industry in both fields, greenhouse horticulture and artificial intelligence, will judge the teams' performance during the Hackathon. The composition of the jury is announced via the website.
- Additionally, the teams will have to motivate and explain their strategy and planned approach for the main Challenge in front of the jury during a short presentation.
- Teams can get points for D. their strategy for the Greenhouse Growing Challenge based on the following elements:
    - Novelty with respect to overall scientific community, application on horticultural domain (**novelty**)
    - Capacity to operate without manual interventions, thus fully autonomously (**functionality and integration**)

  - Easiness of implementation on large scale (**robustness and scalability**)
  - Contribution to sustainability aspects (**sustainability**)
- The jury will make a ranking of all teams based on the given points.
- Based on all points gathered per part a. computer vision challenge, B. machine learning challenge C. additional task and D. strategy the jury will make an overall ranking. The five best teams will be selected. The jury's decision will be final and will not be subject to debate.

Greenhouse Growing Experiment procedure

- The Greenhouse Growing Experiment, a fully autonomous dwarf tomato production, will take place August to December 2023.
- A maximum of **five teams** will be admitted participating. The selection is done during the Hackathon event.
- The goal of the Greenhouse Growing Experiment is to produce a fully autonomous dwarf tomato crop with high sustainability and profit.
- For that, selected teams will have to develop a fully autonomous algorithm and submit it to the organizers before the start of the experiment to control a dwarf tomato crop in their own assigned greenhouse compartment.
- WUR will provide a greenhouse compartment for each team with the equipment described below. WUR will provide each team with a list of digital information they get and information on the possibilities and limitations of the control equipment in a technical document before the start of the experiment.

Greenhouse compartments, actuators and sensors:
- Each team will be responsible for one greenhouse compartment. Each team has only access to their own algorithm and to the detailed data of their own compartment.
- The greenhouse compartments are located at WUR, Violierenweg 1, 2665 MV Bleiswijk, The Netherlands. All compartments have the same size and equipment.
- The greenhouse compartments are designated to the teams in a random manner by the jury.
- All greenhouse compartments are equipped with actuators to control inside growing conditions. The actuators are: ventilation windows, heating systems, screening system, artificial lighting, fogging, hydroponic growing gutters with irrigation with a team-defined nutrient mixture, and CO_2 dosing.

Sensors:
- All compartments are equipped with standard sensors to control the actuators through a standard greenhouse climate computer, also available on site. Main standard sensors are available to measure: temperature, humidity, CO_2, PAR light, pH, EC, amount of irrigation and energy consumption. A standard RGBD camera will be provided to follow the crop growth and development. Teams will be fully responsible for own crop observation during the growth cycle.
- Each team will be allowed to install their own additional sensors and cameras to monitor additional climate, irrigation and crop parameters in order to get additional information if they think this would improve their performance. Before the start of the first crop cycle, teams will get physical access to their own greenhouse compartment to install their additional sensors (if any), to test the connection and to test the principle functioning of their algorithms.

Data collection and digital interface:
- All data measured by standard sensors and all control actions taken are available through a digital data interface for each team. Teams must ensure an automatic interaction with their submitted algorithm. Teams are responsible for the algorithm development.
- WUR will continuously obtain performance criteria per compartment and share them with each team during the crop cycle. A summary of all compartments will with the public on a live digital dashboard.
- Final harvest data (e.g., fruit fresh weight, ripeness stage of fruits) will be measured by WUR manually and made available to the teams at the end.

Teams' algorithms:
- The teams will receive a training dataset/s of a dwarf tomato production under different growing conditions in the same greenhouse compartments before the start of the experiment (well in advance), which they might use to train their algorithms. The teams will get access to the parameterised virtual greenhouse climate and crop growth model (simulator) of WUR to obtain artificial training data if desired.
- The teams will further get access to individual plant and canopy development in time, which they might use to train their algorithms. Further information will be provided at a later stage.
- Teams will implement their algorithm interacting with the digital data interface provided and perform initial tests 2 weeks before the start of the experiment. Team will submit the algorithm to the WUR organizers (e.g. as executable), the algorithm takes the control of their greenhouse compartment from the day 1 of growing experiment (= transplanting date). WUR organizers will treat the algorithms confidential, the ownership remains with the teams. The algorithms will be fully deleted after the challenge. Submission is only needed to avoid changes made by teams

manually.
- The fully autonomous algorithm of the teams will have to make choices with respect to the control settings to control the crop production fully autonomously. Each team will be able to extract necessary data from the greenhouse compartment and couple it to their own artificial intelligent algorithms to fully autonomously decide on the control settings for the next day/period. The algorithm will send the control settings automatically back to the system (the greenhouse climate computer) to control the actuators automatically and steer the crop.

Points for net profit:
- The team with the highest net profit of the autonomous dwarf tomato production in their compartment will rank 5 points. The net profit will be determined by e.g. the following elements:
  - Production (kg m^{-2} $cycle^{-1}$) and price of product (€/kg product), taking into account quality aspects (e.g. Brix of fruits)
  - OPEX with focus on energy use (MJ kg^{-1}) and (high) price of energy (€/MJ) for heating and electricity
  - CAPEX of greenhouse equipment (e.g. LED capacity)
- The exact details on the economic evaluation will be provided to the participating teams before the start of the experiment.

Points for autonomy:
- Any access to the Virtual Machines (VMs) during the experimental growing period for modifications on the control software made by the teams will be registered as a proof of less autonomy of their algorithm.
- In case interventions are needed teams need to ask access to the VM which will be granted in a given timeframe only.
- In case of interventions, the number of interventions will be documented with the lowest number of interventions ranking 5 points. More interventions will yield in a lower number of points.

Points for additional pest monitoring and control:
- Other additional points can be gained by automatically detecting pests in the greenhouse using computer image analysis. For that six pictures weekly taken from yellow sticky traps will be automatically provided to the teams by TrapEye® cameras and a digital interface. With computer vision algorithms teams must detect species of different pest insects on the traps and count them correctly.
- The result will be automatically compared with ground truth data. For each picture the absolute difference between estimated value (teams' computer vision algorithm) and real value (ground truth) will be calculated and normalised. The total sum of absolute normalised difference will be calculated per team.
- The lowest sum of normalised difference will rank 5 points. Higher differences will yield in a lower number of points.
- For training purposes a set of pictures and their ground truth data will be provided to teams before the start of the Greenhouse Growing Challenge.
- Since not all the pests can be monitored via yellow sticky traps, additionally data will manually be obtained by scouting of all crop parts by an WUR expert. This additional data (pest species and numbers) will be added to a digital interface (CropScanner®) for the teams weekly during the experimental period. Teams will be invited to advise on biological control measures in their compartment to gather extra points.

Judgement:
- Teams will grow a dwarf tomato crop in a designated greenhouse compartment. The overall best performing team will win the Challenge.
- An international jury, consisting of experts from science and industry in both fields, greenhouse horticulture and artificial intelligence, will monitor the Greenhouse Growing Experiment.
- The judgement will consist of three elements:
  1. Net profit of the crop production realised (60%)
  2. Autonomy of operation (20%)
  3. Additional pest monitoring (20%)
- The jury will announce the winner during the Final Event.

The International Autonomous Greenhouse Event

- The final International Autonomous Greenhouse Event will take place in January 2025 at WUR in Bleiswijk, The Netherlands. The exact date will be announced at a later stage.
- At least the team captains' presence at the Event is required, otherwise the jury is entitled to disqualify the team.
- The goal of the Event is sharing knowledge and experience among participants and making new multi-disciplinary and international connections among each other and with members of the international jury and the WUR experts. All teams will present their approach and results during the Greenhouse Growing Experiment, including an explanation of their integrated approach, their algorithms used and their contribution to sustainability.
- The jury will announce the winner. The team with the highest number of points (see above) will win the Challenge.
- We aim for organising an international public symposium and/or a series of online webinars to present the results to everyone interested. Teams will then be provided the opportunity to present themselves and their approach and future vision to a relevant international audience (e.g. academic, technologists, investors). The form of such a

symposium and/or series of webinars is unclear at the current stage. More detailed information will follow on the website.

Important dates

- 1 November – 31 December 2023: Subscription open for teams via www.autonomousgreenhouses.com
- Until 31 January 2024: Confirmation of admission of teams.
- March 2024: Teams will get technical information for the Online Challenge
- 1 April to 1 June 2024: Online Challenge
- 6-7 June 2024: Hackathon event at WUR, The Netherlands, selection of 5 teams for the Greenhouse Growing Experiment
- June 2021 – August 2022: Preparation time for teams to develop their algorithms, teams get training datasets, access to virtual greenhouse-crop simulation model, technical information for Greenhouse Growing Experiment
- August 2024 (week 34/35): Teams will get access to their greenhouse compartment, installation of additional sensors (if needed), implementation of digital data interface and testing and submission of algorithm.
- 2 September 2024: Transplanting small dwarf tomato plants, algorithms of teams take over control of their compartment.
- September - December 2024: fully autonomous dwarf tomato production with teams' algorithms, points for net profit, autonomy and pest monitoring, best performing team wins
- January (week 3/4): Final International Autonomous Greenhouse Event at WUR, The Netherlands; public symposium incl. winning ceremony.

Media, ownership & IP

- Each team will remain entitled to the intellectual property of the information, documents, videos and algorithms submitted by themselves in connection with the Challenge (background);
- By entering the competition, each participant automatically agrees to grant WUR the right to reproduce, disclose or use the submitted information, documents and videos for publicity and marketing purposes. This includes also WUR's right to publish teams' and participant names, additional photos and videos taken during the pre-Challenge, Growing Challenge and Final Event. This excludes WUR's right to publish teams' algorithms.
- By entering the competition, each team automatically agrees to share all collected data (foreground) from their own compartment including data from additional sensors and cameras installed in the compartment, with WUR.
- By entering the competition, each team automatically agrees to grant WUR the right to overall analyse and publish created data (foreground) of the Challenge. This excludes WUR's right to publish teams' algorithms.
- Teams' algorithms will be treated confidential by WUR organisers and not be shared with third parties. Teams are asked to submit algorithms (e.g. as executable) only with the goal of ensuring autonomous control during the Growing Experiment. WUR organisers will delete all algorithms after the execution of the challenge. Note: If teams want to publish their algorithms and approach, they are free to do so on their own decision.
- Participants acknowledge that the Challenge is public in nature and that information will be shared on a non-confidential basis, except when this concerns by teams developed algorithms and information or materials agreed beforehand to be confidential of nature. Participants acknowledge that this dissemination may preclude obtaining intellectual property protection. WUR excludes any liability in respect hereto.
- By submitting to the Challenge, each participant ensures that the submitted information and materials:
  - is the participant's own and original work;
  - does not infringe copyrights, trademarks or other intellectual property or other rights of any person or entity (such as rights of privacy, publicity);
- Any team found to have committed plagiarism, infringement of intellectual property rights and/or unlawful use of information will be disqualified.

General

- WUR reserves the right to modify any aspect of the competition. All teams will be informed about modifications in due time.
- WUR reserves the right to disqualify a team, if WUR deems the team or team member's behaviour in violation of the rules and regulations of the competition, or in case they have provided misinformation.
- WUR assumes no responsibility for incorrect or inaccurate information regarding the Challenge, or any late, lost or misdirected entries, whether caused by any of the equipment or programming associated with or utilized in this Challenge or by any human error which may occur in the processing of the registration in this Challenge.
- Participation is at each participant's own risk and expense. In order to cover expenses, teams are encouraged to search for sponsorships. Sponsors of teams get the possibility to be mentioned on our Challenge website www.autonomousgreenhouses.com.

- Participants are not allowed to use the WUR or the Tencent logo, unless it is part of means provided by WUR, such as flyers or other documents produced by WUR.

Contact

- Autonomous Greenhouse Challenge organizers can be contacted via: autonomousgreenhouses@wur.nl only.