4th International Autonomous Greenhouse Challenge

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

Criteria, rules & regulations

Version: 15 March 2024

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 **20 February 2024 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.
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 **29 February 2024.** The organisers' and jury's decision will be final and will not be subject to debate.
- WUR retains the right to consider registrations after the deadline, if a minimum number of five teams has not been reached.
- All admitted teams must participate in the *Online Challenge* in the period of **2 April to 31 May 2024** to show their machine learning and computer vision skills (part A and B, see hereafter) and in the *Hackathon event* at WUR at Bleiswijk, Netherlands on **6-7 June 2024** to show their skills in an additional task and present their approach in front of a jury (part C and D). 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, being prepared and 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. They can earn additional points by performing an additional task (see hereunder). 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 2 April and 31 May 2024.
- Teams are subscribed and have received a notification that they are eligible until 29 February 2024.
- Teams get 8 weeks of preparation phase (2 April to 31 May) for both parts of the Online Challenge A. The Computer Vision Challenge and B. The Climate and Crop Control challenge.

Part A Computer Vision Challenge
- For the Computer Vision Challenge teams will get access to a series of 268 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 to information on the ground truth plant traits: plant height, plant fresh weight, leaf area, number of red 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 96 unseen dwarf tomato plant images provided after the preparation phase under limited time constraint.
- For each picture and plant trait, the prediction error will be calculated based on the difference between estimated values (teams' computer vision algorithm) and ground truth values (WUR manual measurement) of all traits. Access keys and an exact description is given to participating teams in a technical document at the start of the Online Challenge. The team with the lowest error will be ranked first for this part of the Online Challenge.
- Images will be made available to teams in batches. A larger set (268) will be made available in the first week of the 8 weeks preparation phase for training purposes. Subsequently, 3 smaller validation sets (±40 images) will be made available once every 2 weeks. Teams submit their prediction results on these validation sets within the given timeframe. A public ranking board will show the intermediate results of teams' performance. The ground truth of each validation set will be disclosed one day later for teams who have submitted their results.

- At the end of the 8 weeks, on 31 May, a final test set of images (96) will be provided to teams for the final evaluation of their performance, at a fixed time and with a limited time constraint. Only the performance on this final test set will determine the final ranking of teams. This final ranking will be announced publicly during the Hackathon event. The team with the highest ranking will be first for this part of the Online Challenge.

Part B Climate and Crop Control challenge
- For the Climate and Crop Control challenge, teams will get access to a simple greenhouse climate and dwarf tomato production model (simulator) during the 8 weeks preparation phase.
- The simulator consists of a given set of outside climate conditions, a given greenhouse type and given greenhouse actuators (ventilation, heating, lighting, CO_2 injection, screening). It needs to be provided with a series of climate setpoints per timestep as inputs, which will activate the available actuators that control the inside greenhouse climate. The realised inside climate variables 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 variables over time will be provided as output.
- A precise definition of the final plant product which must be reached will be given (e.g. plant with minimum weight of x g ripened fruits). Prices will be connected to the final product and costs will be connected to 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 prices and therefore creates income.
- Teams will have to develop machine learning algorithms to feed the simulator with the optimised control parameters to maximise net profit, consisting of the income minus the costs of resources and greenhouse space occupation.
- 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 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.
- Throughout the challenge, two simulators will be used. Simulator A is available for training the control algorithm and is accessible throughout the challenge. At specified times, typically every other week, Simulator B will be open to the teams for testing their algorithm within a limited timeframe (1 hour). Simulator B will be parameterized similar, but slightly different than Simulator A, to test the robustness of the control algorithm. While Simulator B is open for testing, Simulator A will be extended in its range of control options. This way, over the course of the challenge, teams can improve the robustness of their controller.
- The test results of Simulator B will be used to create a public ranking board that will show the intermediate results of teams' performance according to the net profit. The team with the highest net profit will be ranked first.
- At the end of the online challenge, on 31 May, a final version of simulator B will be provided to teams for the final evaluation of their performance under limited time constraint. The net profit on this final test will determine the teams' ranking for this part of the online challenge. The final ranking will be announced 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. Teams without a physically present representative will be excluded from the competition.
- During the Hackathon event the results of the A. Computer Vision and B. Climate and Crop Control 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 in different fields of greenhouse horticulture, engineering 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 (35%), B. Climate and Crop Control Challenge (35%) C. Additional task (15%) and D. Strategy (15%) 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 September to December 2023, preparation will take place in August.
- A maximum of **five teams** will be admitted participating. The selection is done during the Online Challenge (part A and B) and the Hackathon event (part C and D).
- 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 WUR organizers before the start of the experiment for the sole purpose 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 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 randomly 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, drip irrigation 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 add 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 have to send their sensors and a detailed description for connection to the Organizers. Organizers will install the additional sensors in the teams' greenhouse compartment before the start of the experiment. Teams will get time to be able to test the connection of their sensors together with the principle functioning of their algorithms before the experiment starts. Detailed rules will be provided to the teams directly after the Hackathon event in a technical document.

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 before the start.
- 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., total fruit fresh weight of ripened fruits) will be measured by WUR manually and made available to the teams at the end.

Teams' algorithms:

- The teams will receive a limited training dataset/s of a dwarf tomato production under different growing conditions in the same greenhouse compartments directly after the Hackathon event, which they might use to train their algorithms. The teams will get access to the parameterised virtual greenhouse climate and simple crop growth model (simulator) of WUR to obtain artificial training data if desired.
- Teams will develop their algorithm in such a way that it is able to interact with the digital data interface provided and that it is able to control the dedicated greenhouse compartment.
- 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.
- Teams will get time to be able to test their algorithms together with the installed sensors and digital interface in an empty greenhouse before the experiment starts. Detailed rules will be provided to the teams directly after the Hackathon event in a technical document.
- Teams will submit the algorithm to the WUR organizers. WUR organizers will mount the algorithms on a Virtual Machine, the algorithm takes the control of the greenhouse compartment first in an empty greenhouse for testing purposes. After a testing period, teams will be allowed to send an updated version of their algorithms which will be again mounted on the Virtual Machine. The algorithm will take over the control of greenhouse and crop from 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 and for security reasons.
- In case teams need to make modifications on the control software and resubmit a new version of their algorithm, this will be registered as a proof of less autonomy of their algorithm. Teams will be allowed to make a maximum number of changes, each change will lead to a serious penalty on the net profit of the production. Detailed rules will be provided to the teams directly after the Hackathon event in a technical document.

Points for net profit:

- The team with the highest net profit of the autonomous dwarf tomato production in their compartment will get the highest number of 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)
  - Interventions on the algorithm leading to less autonomy will lead to an additional cost
- The exact details on the economic evaluation will be provided to the participating teams directly after the Hackathon event in a technical document.

Points for additional pest control:

- Other additional points can be gained by the control of pest management by beneficials in the greenhouse. The control will be on a common pest by different types of beneficials.
- During the challenge, each team will get accounts for an online platform, in which information regarding pests and their control actions is logged.
- For that 3 pictures weekly taken from yellow sticky traps will be automatically provided to the teams by TrapEye® cameras via a digital interface. Since not all the pests can be monitored via yellow sticky traps, additionally data will be obtained manually 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 weekly biological control measures based on the digital information.
- Teams can gather extra points for this task.

Judgement:

- Teams will grow a dwarf tomato crop in a designated greenhouse compartment. The overall best performing team with the highest number of points will win the Challenge.
- An international jury, consisting of experts from science in different fields of greenhouse horticulture, engineering and artificial intelligence, will monitor the Greenhouse Growing Experiment.
- The judgement will consist of two elements:
    1. Net profit of the crop production realised (75%)
    3. Additional pest control (25%)
  - 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 2023 – 20 February 2024: Subscription open for teams via www.autonomousgreenhouses.com
- Until 29 February 2024: Confirmation of admission of teams.
- Until 21 March 2024: Teams will get technical information for the Online Challenge (part A and B)
- 28 March 2024 12-14 h CET: Online seminar for participating teams
- 2 April to 31 May 2024: Online Challenge (part A and B)
- 31 May 2024: Final scoring for Online Challenge
- 6-7 June 2024: Hackathon event at WUR, The Netherlands (part C and D). Selection of 5 teams for the Greenhouse Growing Experiment.
- Beginning of June – Beginning of August 2024: 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, sending additional sensors and submission first version of algorithms
- August 2024: Teams will get digital access to their greenhouse compartment to test algorithms, interaction with of digital data interface, interaction with sensors, receiving data and sending controls in empty greenhouse, submission final version of algorithms
- 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.
- All images and their connected ground truth provided during the challenge are background of WUR and will be owned by WUR. Images and their ground truth will be published by WUR and can then be accessed publicly open source after the Hackathon phase. Teams are not allowed to publish any images and ground truth data retrieved during the challenge before this dataset is made publicly available by WUR.
- All greenhouse data collected by WUR during the greenhouse experiment of the challenge are background of WUR and will be owned by WUR. This greenhouse data will be published by WUR and can then be accessed publicly open source after the 4th Autonomous Greenhouse Challenges has finished. Teams are not allowed to publish any of this data retrieved during the challenge before the dataset is made publicly available by WUR.
- 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 only with the goal of ensuring autonomous control and security 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.