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Smart Checkpots – Proof of concept for a mobile pest and climate monitoring system in greenhouses

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Abstract

For timely and sensible plant protection measures in ornamental plant cultivation under glass, reliable information on the population development of pests and beneficial insects as well as on the climatic conditions in the crop is essential. The usual pest monitoring by regular inspection of yellow sticky traps is labor-intensive and requires specialized staff capacity. The usual static recording of climate data provides a picture of the varying distribution of climatic conditions in the greenhouse. With an increasing number of measuring points, the local resolution can be enhanced. Nevertheless, it is difficult to draw direct conclusions about individual crop sets, especially if these are moved during cultivation, e.g. with mobile tables in and between greenhouses.

In the research project "Smart Checkpots - Optimized Plant Protection for Ornamental Plant Production", an automated, mobile monitoring system for pest infestation and beneficial insects as well as for temperature and humidity measurement is being developed. The system consists of “swarms” (representing a variable number) of networked Checkpots placed like “artificial plants” directly in the crop during the entire production process. Each Checkpot carries a yellow sticky card, a camera and a climate sensor and records an image of the yellow sticky card along with the current temperature and relative humidity at a selectable interval. These data are used for visualization of pest occurrence and fungal infestation risk as well as input parameters for decision support models for plant protection measures. An integrated radiometric recording of the Checkpot positions, based on Bluetooth Low energy 5.1 technology, ensures the permanent allocation of the collected data to the monitored crop sets, and enables a set-accurate decision on measures.

This conference paper presents the results of the implementation and review of this concept. It is focused on the accuracy of position data acquisition during a three-hour parallel operation of three Checkpot prototypes in two horticultural enterprises with error-free data transmission to a central computer every quarter of an hour. For image and climate data, only the basic feasibility had to be proven. Furthermore, first concepts concerning data and user interfaces were developed.

1. Introduction

Timely, efficient, and ecological plant protection in greenhouse cultivation requires precise pest and climate monitoring. To this end, population dynamics of pests and beneficial insects are recorded by regular visual inspection of yellow sticky traps placed in the crop (Heinz et al. 1992). The labor-intensive counting of trapped insects requires adequate staff capacity and can be challenging, especially during peak work periods. More recently, yellow boards have been further developed into colored LED traps (Stukenberg and Poehling 2019) and numerous automated evaluation methods have been investigated, based on modern image processing and artificial intelligence techniques (Böckmann et al. 2021, Rustia et al. 2021). Nevertheless, none of these optimizations has been widely adopted in practice and yellow sticky traps are still in use in many farms.

The measurement of temperature and humidity in the greenhouse is usually done stationary above the crop (Bhujel et al. 2020). In this context, the introduction and use of wireless sensor network (WSN) technology allows an increase in the number of sensors with little effort and thus an increase in the spatial resolution of the measured climate data (Kochhar and Kumar 2019). The collected data can be processed in crop climate models as input parameters and can be used to predict pest incidence and fungal risk of crop protection (Tantau and Lange 2001).

In cultivation of ornamental potted plants, an additional challenge is that crop sets are moved in and between greenhouses during the production process. This means that the stationary measurement data and the predictions of the model calculations are only of limited use for the individual crop sets. From this, the following goals and requirements are necessary for the proposed optimized monitoring system in ornamental plant cultivation:

- Autonomously working system with mobile units for data acquisition.
- Automated recording of pests/beneficial organisms and temperature/humidity.
- Continuous recording of the position of the individual mobile units in the greenhouse.

In this project, such a monitoring system is implemented in the form of a number of networked “artificial plants” (Smart Checkpots) that are placed between the cultivated plants, run through the complete production process with them, and during this time continuously provide data on pest and beneficial insects populations, crop climate and their spatial position in the greenhouse. These data are transmitted to a central computer unit, where they are processed and stored. They can be clearly assigned to the monitored crop set.

This conference paper presents the implementation and review of the concept. As the assignment of the measurement data to the crop set during operation is of crucial importance in this project, the proof of concept focused on the position detection system and the verification of its accuracy. Only the basic feasibility of acquisition and transfer of image and climate data had to be demonstrated. Checking the quality of the image and climate data was not part of the investigation at this stage of the project. The objective therefore is defined as follows: Design and creation of three functional prototypes of a mobile pest and climate monitoring system with low-cost components for simultaneous operation in a greenhouse environment. The basic system has to reach the following benchmarks:

1. Position, climate and image data are acquired, sent to a host computer during operation and recorded at a sampling rate of 15 minutes.
2. The position detection of several checkpots used in parallel during operation should not exceed the error limit of 50 cm at a data acquisition rate of maximum 15 minutes.
3. The position accuracies are determined using manual laser distance measurements vs. checkpot measurements in test series to be repeated several times and statistically evaluated using box plots and 2D heat maps.

2. Data, Methods and Approach

The monitoring system designed is called “Checkpots”. They should be able to go through the normal horticultural production process as “artificial plants”. The first design concept was based on a standard planting pot with a diameter of 11 cm (TEKU VCG 11, Pöppelmann Kunststoff-Technik GmbH & Co. KG, Lohne, Germany) and various 3D-printed parts which were developed individually, as shown in Figure 1. This concept ensures that the Checkpot can be handled automatically in the production process as all the other plants and additionally it can be adapted to pots of any bigger size by a pot-in-pot concept easily.

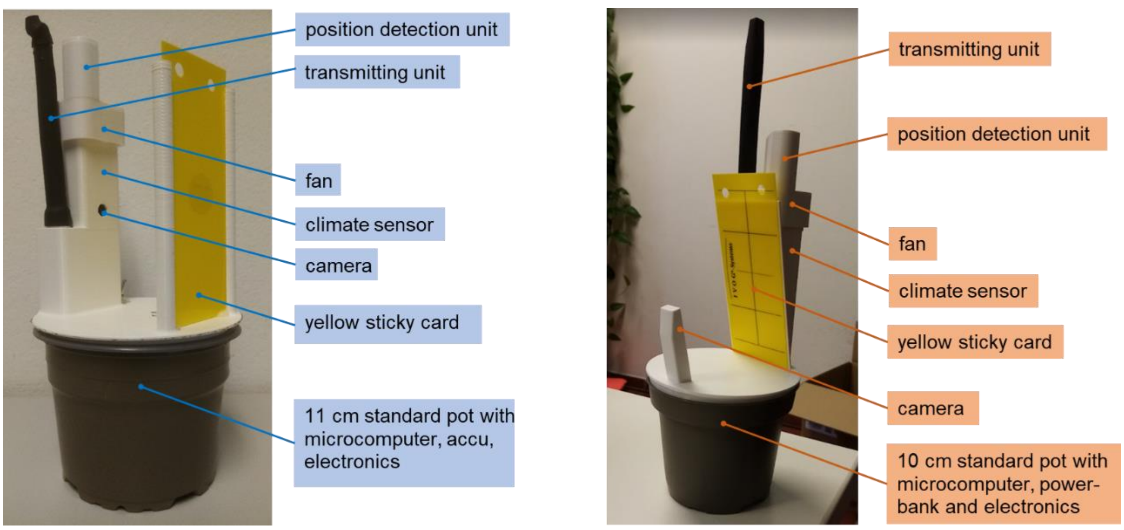


Figure 1: First prototype generation of the Checkpot for the proof of concept with marking of the main components (left) and second optimized prototype generation (right).

For the prototype development a Raspberry Pi Zero 2W (The Raspberry Pi Foundation, Cambridge, UK) as the central computing unit, a power management module including a real time clock and batteries as power supply were integrated in the pot. The upper part of the Checkpot structure carried the yellow sticky trap (standard size: 5 cm x 12 cm). For photography, a Raspberry Pi Zero Cam V2 with 5 MP resolution and a 120° wide-angle lens (The Raspberry Pi Foundation, Cambridge, UK) was integrated into the tower-like setup opposite the yellow sticky card. This setup also included the combined Sensirion SHT40 temperature and humidity sensor (Sensirion AG, Stäfa, Switzerland) to measure climate data. To ensure a representative measurement of the actual intercrop climate, ambient air was sucked into the tower by a built-in fan and flowed around the sensor.

The transmission of the image and measurement data from the individual Checkpot to the central unit for processing was carried out using WLAN. Accordingly, a WLAN module with a separate antenna was provided in each Checkpot. The position of the Checkpot in the greenhouse was determined using a radiometric measurement based on Bluetooth Low Energy 5.1 location system for position data acquisition. In this system, a stationary array of antennas forms a measurement space that is scalable with the number of antennas. Within this measurement space the position of mobile position detection units (tags) is determined using the triangulation method. These tags were integrated into the cap as shown in Figure 1.

The tests for the proof of concept were carried out with three Checkpot prototypes in parallel operation, each over a period of three hours. For this purpose, an area of approx. 400 m² in the greenhouse was equipped with the necessary antenna technology for position data acquisition as shown in Figure 2. Within this area, nine measuring positions (MP1 - MP9) were measured with laser range finders as a reference.

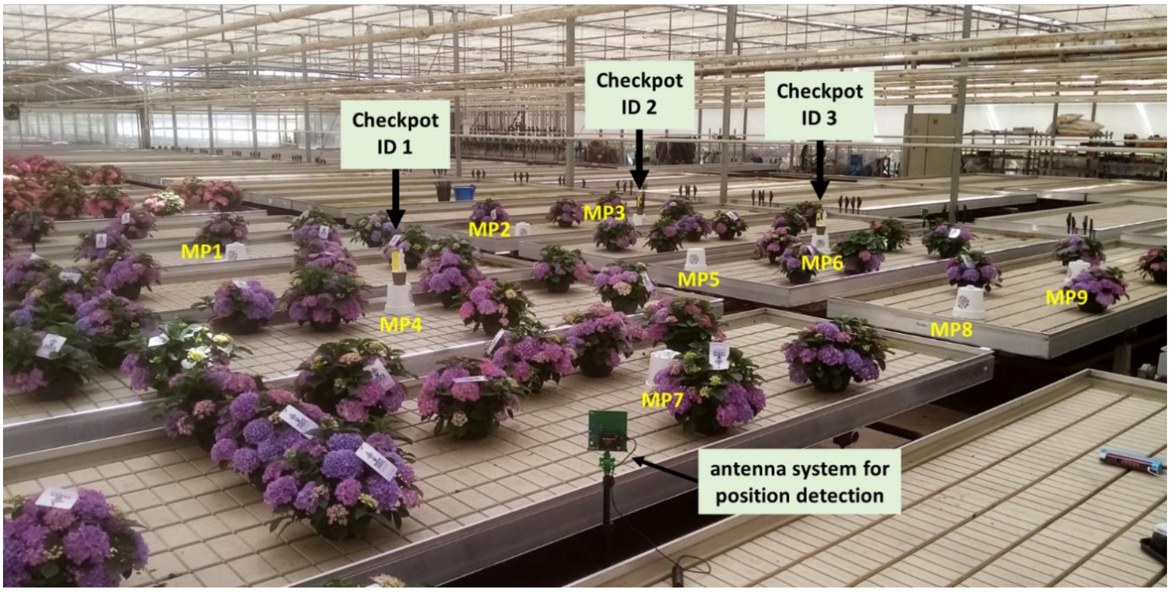


Figure 2: Measurement setup in the greenhouse. The nine measuring positions are marked with MP1 to MP9 (yellow), the positions of the Checkpots with Checkpot ID 1 to Checkpot ID 3. In the foreground, the antenna system for position detection can be seen.

At 15-minutes intervals, the Checkpots were moved manually to alternating, previously randomly determined measuring positions, and in each case the acquisition and transmission of the following data was carried out:

- An image of the yellow trap carried.
- The temperature and humidity of the ambient air sucked into the Checkpot.
- The position data of the Checkpot in the greenhouse.

3. Results and Discussion

Three functional Checkpot prototypes were built and tested successfully in two different greenhouses. The WLAN transmission of the image data in JPEG format at 15-minute intervals took place in the three-hour test sequence without any problems, as did the transmission of the measurement data for temperature and humidity. These were condensed with the date, time, Checkpot ID and other data in a CSV file for transmission (Figure 3). A detailed analysis of the image data and a validation of the determined climate data was not part of the milestone at the time of the concept review. In the further course of the project, it will be investigated whether the camera used ensures sufficient image quality to capture the target organisms and to count them automatically using computer image processing methods. For this purpose, the option of taking the photos at night under specific LED illumination is to be examined in particular. Similarly, studies are planned to validate that the temperature and humidity data collected are indeed representative of the crop climate. The volume and routing of the aspirated ambient air passed over the sensor are the subject of design optimization.

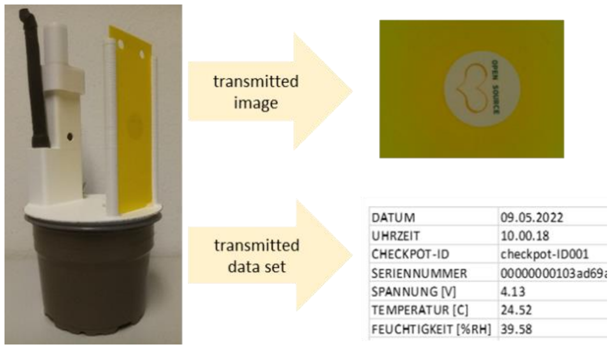
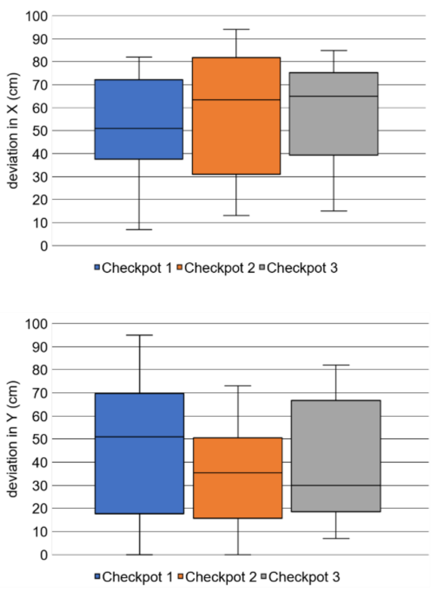


Figure 3: Checkpot prototype (left), transmitted image data of yellow sticky card (top right) and transmitted CSV data file (bottom right).

The deviations of the positions of the three Checkpots detected during the test run in the greenhouse are shown in Figure 4: in the upper part of the figure, the measured deviation in the X direction, in the lower part, the deviation in the Y direction. On the left, the deviations are each shown condensed in a boxplot. On the right, the deviations for all twelve measuring cycles are listed in tabular form and marked with a color code from green (small) to red (large) as a heat map. The three data sets have similar medians and a relatively high



	deviation in X-direction (cm)		
meas. cycle	Checkpot 1	Checkpot 2	Checkpot 3
1	7	67	39
2	9	85	65
3	76	13	78
4	55	37	15
5	81	81	54
6	61	82	84
7	37	38	34
8	39	94	65
9	47	23	67
10	46	60	65
11	82	81	40
12	61	29	85

	deviation in Y-direction (cm)		
meas. cycle	Checkpot 1	Checkpot 2	Checkpot 3
1	29	55	75
2	14	73	7
3	69	49	41
4	52	51	17
5	44	31	23
6	58	46	27
7	50	40	45
8	3	21	15
9	0	14	82
10	95	7	26
11	88	24	33
12	70	0	74

Figure 4: Results of the position detection during the test run. The deviations of the positions detected in X- and Y-direction as boxplots (left) and tabular as heatmaps (right).

scatter. In all measurements, a margin of error of 1.0 m is not exceeded. With this result, assumed that the Checkpot is placed in the center of a 2 m wide planting table, the Checkpot can already be assigned to the particular table and thus the assignment of the measurement data to a specific crop set is guaranteed.

Nevertheless, a significant reduction in the achievable error margin can be expected in the further course of the project. On the one hand, the selected Bluetooth technology is still in the development and optimization stage, and an additional generation of antenna technology is planned to significantly increase precision. On the other hand, various optimization opportunities exist on the software side, which will be investigated in future (e.g. elimination of outliers and application of statistical methods in data analysis). An error limit of < 0,5 m is targeted in the course of the project to ensure that also Checkpots located at the edges of a table can be definitely assigned to it. In general, the mobile recording of image and climate data and the allocation to individual crop sets by simultaneously recording the position of the sensors represents an improvement on the approaches previously known from the scientific literature.

4. Conclusions and outlook

With the three Checkpot prototypes, all requirements of the "proof of concept" benchmarks could be met. In parallel operation in the greenhouse, the photo of the yellow sticky card and the measurement data on temperature and humidity could be transmitted via WLAN to the central computer. The error limit of < 1 m achieved in determining the position of the Checkpots ensures sufficient accuracy to assign the data to a plant table and thus to a crop set. Concerning the Checkpot design the big tower-like structure opposite the yellow sticky card in the first design has proven to be disadvantageous for the approach of the insects, as it created a kind of shadow effect. Therefore, the prototype design needs to be revised. Figure 1 shows a possible solution on the right-hand side: the body opposite the yellow sticky card has been significantly reduced and houses only the camera.

Further development of the prototypes includes:

- Reduction of the error limit of the position data to < 0.5 m through optimizations of the hardware and software used.
- Improvements of image quality by optimizing the illumination and the camera optics.
- Optimization of battery runtimes and ensuring that the Checkpot is splash-proof.
- Improvement of insect catches by using alternative colors of the Checkpot, especially different shades of yellow were promising in preliminary tests.

In parallel, automated analysis of the yellow sticky traps was started using modern image processing and artificial intelligence algorithms. The data obtained, especially for thrips and leaf miners, will also be used to develop previously unavailable predictive models to correlate yellow sticky trap catches of these insects with crop infestations. A further focus of work is the development of the application software including secure data management, visualization of the collected data and a user interface, which is oriented towards horticultural practice. For this purpose, selected horticultural companies will be involved in testing and optimizing the customer suitability. The possibility of using mobile sensors to monitor pest infestation and climate data over the entire cultivation period in ornamental plant cultivation can provide an efficient support for decisions on plant protection measures.

Acknowledgements

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