Development of a System for Intelligent Plant Monitoring and Cultivation

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Abstract.

Cultivation in protected environments and indoor systems requires continuous monitoring. Labor shortages and delays in management decisions compromise productivity, uniformity, and efficiency. Assessments of plant stand, vegetative vigor, nutritional status, and the incidence of pests and diseases still rely on visual inspections conducted over limited periods, reducing diagnostic accuracy and response time. Although automation technologies are advancing in horticultural production, available equipment and sensors often exhibit low interoperability, limited data integration, and high costs. These limitations hinder technological adoption, especially among small- and medium-scale producers. Based on this context, the objective was to develop a low-cost intelligent cultivation and monitoring system based on the Super LED Plant (SLP) platform, designed to enable remote management and support rapid, data-driven decision-making. The platform is applicable to multiple automated production systems, including greenhouse cultivation, indoor vertical farming, and plant nurseries. The hardware and software components were developed at EPAMIG - Instituto Tecnológico de Agropecuária de Pitangui (ITAP), located in Pitangui, Minas Gerais, Brazil. The system integrates a high-resolution camera equipped with artificial intelligence-based image analysis algorithms and environmental sensors for continuous monitoring of air temperature and relative humidity. It allows integration with irrigation controllers, ventilation systems, and artificial lighting, enabling automated operation according to predefined agronomic parameters and crop-specific programming. Images were captured at predefined intervals for system calibration and stored in a cloud database, enabling historical data analysis and full traceability of crop development. Access is provided through the SLP software interface, which displays a real-time intelligent monitoring dashboard. The interface supports on-demand image acquisition, automated plant health diagnostics, and configurable alerts whenever deviations from programmed environmental thresholds or plant performance indicators are detected. Validation trials for sensor calibration and plant identification were

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conducted using seedlings of lettuce, tomato, bell pepper, chili pepper, and sugarcane. The system accurately assessed plant stand across all tested species, with no false negatives recorded from seedling emergence to fully developed transplants based on visual comparison. In addition to stand evaluation, the platform enabled assessment of plant vigor through comparative image analysis, discrimination between healthy and visually stressed plants, detection of symptoms associated with nutritional deficiencies based on leaf color patterns, and identification of insects and damage on leaf surfaces. Environmental sensor readings remained consistently calibrated when compared to reference instruments throughout the experimental period, confirming the reliability of data acquisition under operational conditions. The SLP platform, integrating image-based diagnostics and environmental sensing within a single low-cost architecture, provides a practical and accessible tool for precision horticulture, supporting crop management across different developmental stages and production systems. Expanded field validation is ongoing to assess long-term system performance, detection accuracy across additional species, and commercial viability under real production conditions.

Keywords. *Artificial Intelligence, Internet of Things – IoT, Programming. Horticulture, Image analysis.*

Introduction

Protected cultivation systems, including greenhouses and indoor vertical farms, have expanded significantly in Brazil over the past decade. These systems demand continuous technical monitoring to maintain optimal agronomic performance across multiple parameters simultaneously, including plant stand uniformity, vegetative vigor, nutritional status, and pest and disease incidence (Kamilaris and Prenafeta-Boldú, 2018).

Despite the controlled nature of these environments, routine diagnostic evaluations still rely predominantly on visual inspection by trained operators during limited daily observation periods. This approach introduces inherent limitations in both spatial coverage and temporal resolution. A single operator cannot systematically evaluate every plant in a commercial greenhouse within practical time constraints, and symptoms that develop between observation periods may progress to irreversible damage before detection. Labor shortages in Brazilian agriculture further compound this challenge (Liakos et al., 2018).

Commercial automation solutions for plant health monitoring frequently present low interoperability between manufacturers, restricted data integration capacity, and high acquisition and maintenance costs that are incompatible with the economic reality of small and medium-scale producers who manage the majority of protected cultivation area in Brazil.

Recent advances in computer vision and artificial intelligence have created new possibilities for automated plant health assessment. Deep learning algorithms trained on annotated plant image datasets can identify visual symptoms of stress, disease, and nutritional deficiency with accuracy approaching or exceeding trained human observers under controlled conditions (Barbedo, 2019). When integrated with automated image acquisition scheduling and continuous environmental sensing, these technologies offer a pathway toward comprehensive monitoring at reduced cost and operational complexity.

The objective of this study was to develop and validate a low-cost intelligent monitoring system based on the Super LED Plant (SLP) platform, integrating AI-based computer vision with environmental sensing for continuous plant health assessment across multiple protected horticulture production systems.

Materials and Methods

System Architecture

The SLP system was developed at Empresa de Pesquisa Agropecuária de Minas Gerais

(EPAMIG) = Minas Gerais Agricultural Research Agency - Pitangui Institute of Agricultural Technology (ITAP), Pitangui, MG, Brazil). The platform SLP (Fig. 1) integrates a high-resolution camera equipped with AI-based image analysis algorithms and environmental sensors for continuous monitoring of air temperature and relative humidity within the protected environment.

Fig. 1 – Capture for image by Super LED Plant – SLP

Note: Image captured of pepper seedlings by SLP.

Images are captured at predefined intervals according to a configurable schedule for each crop and phenological stage. Each image is immediately processed by the AI algorithms, which classify plant health status in real time by evaluating visual indicators across four primary stress categories (Fig. 2): water stress (through changes in turgor and leaf color), nutritional deficiencies (through automated chromatic analysis of leaf tissue), pest and insect presence (through detection of organisms and feeding damage on leaf surfaces), and disease symptoms (through morphological anomaly detection in plant structure and coloration).

Fig. 2 – Applying filters for AI-powered analysis in software SLP.

Note: Image captured of pepper seedlings showing the presence of pest insects, aphids and mealybugs.

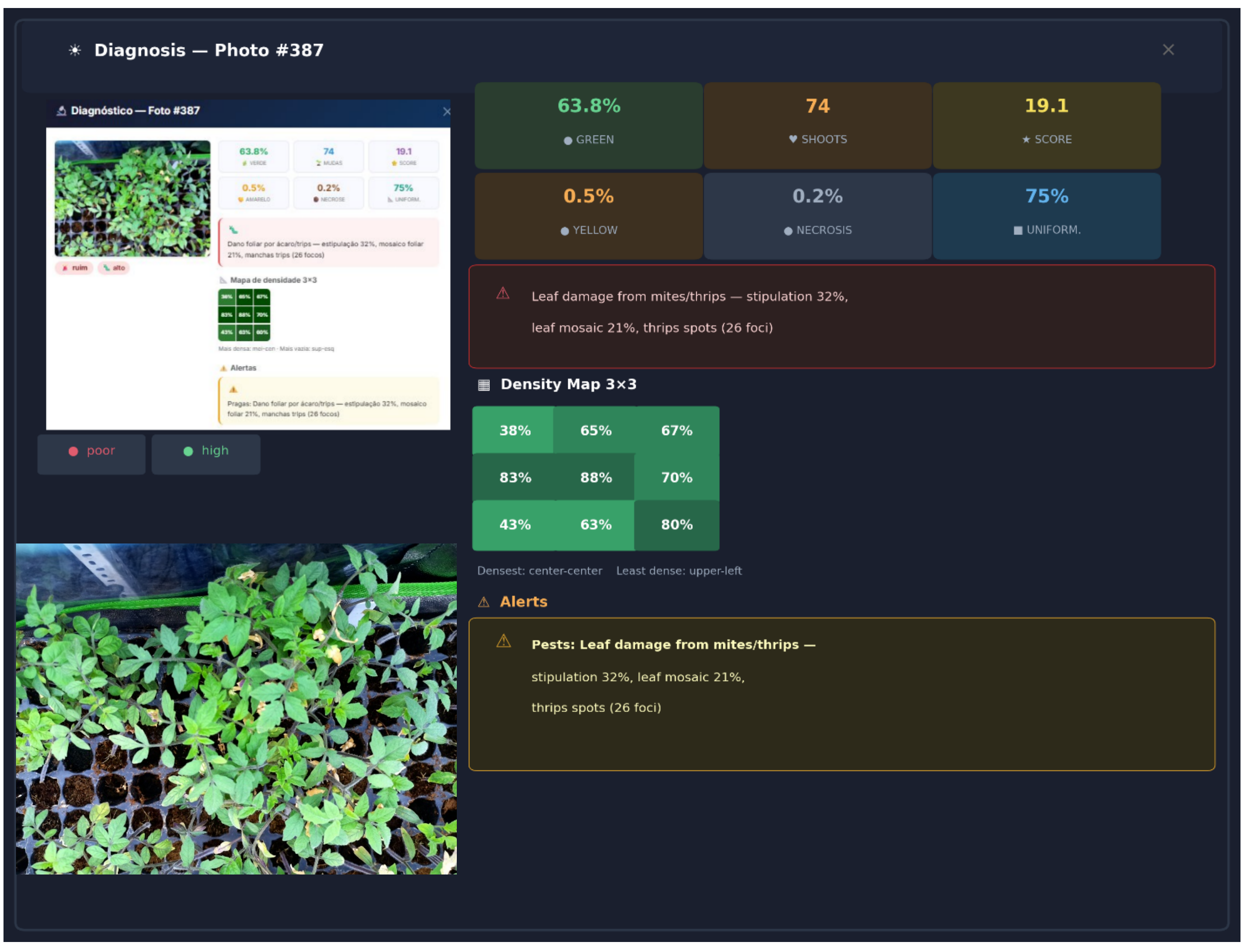
Each detected condition triggers a specific automated alert linked directly to the causal stress category, enabling targeted agronomic intervention rather than generalized threshold responses. Processed images and data are stored in a cloud-based database, enabling historical traceability, longitudinal crop performance analysis, and spatial mapping of stress occurrence within the production area.

Integration and Interface

The SLP platform supports direct integration with irrigation controllers, ventilation systems, and artificial lighting units, enabling automated actuation according to crop-specific agronomic parameters. The SLP dashboard displays a real-time monitoring interface accessible via desktop and mobile devices, consolidating sensor data, image diagnostics, and alert history in a single management environment.

The interface SLP system (Fig. 3) allows on-demand image acquisition, automated plant health diagnostics, and the issuance of alerts whenever deviations from programmed environmental thresholds or plant performance indicators are detected. This integration of environmental data with image-based diagnostics within a single platform provides a comprehensive view of crop status that neither data stream could deliver independently.

Fig. 3 – Diagnosing the condition of indoor plants using AI-powered analysis with change mapping and remote monitoring by SLP system.



Note: Analysis of tomato seedlings with leaf necrosis after recovery from forced nutritional deficiency. A cluster of insects undetectable to the naked eye.

Validation Protocol

Validation trials were designed to assess system performance across multiple species at distinct phenological stages. Test species included lettuce (*Lactuca sativa*), tomato (*Solanum lycopersicum*), bell pepper (*Capsicum annuum*), chili pepper (*Capsicum* spp.), and sugarcane (*Saccharum officinarum*). Trials were conducted under both greenhouse and indoor vertical farming conditions. Plant stand assessment accuracy was evaluated against manual counts performed by trained agronomists. The evaluation covered the complete developmental range from seedling emergence to fully developed transplants.

Results and Discussion

The SLP system achieved 100% accuracy in plant stand assessment across all five tested species, with zero false negatives recorded from seedling emergence to fully developed transplants. This result was consistent across greenhouse and indoor vertical farming conditions, indicating that the image analysis algorithms maintained reliable performance under varying light conditions and canopy structures.

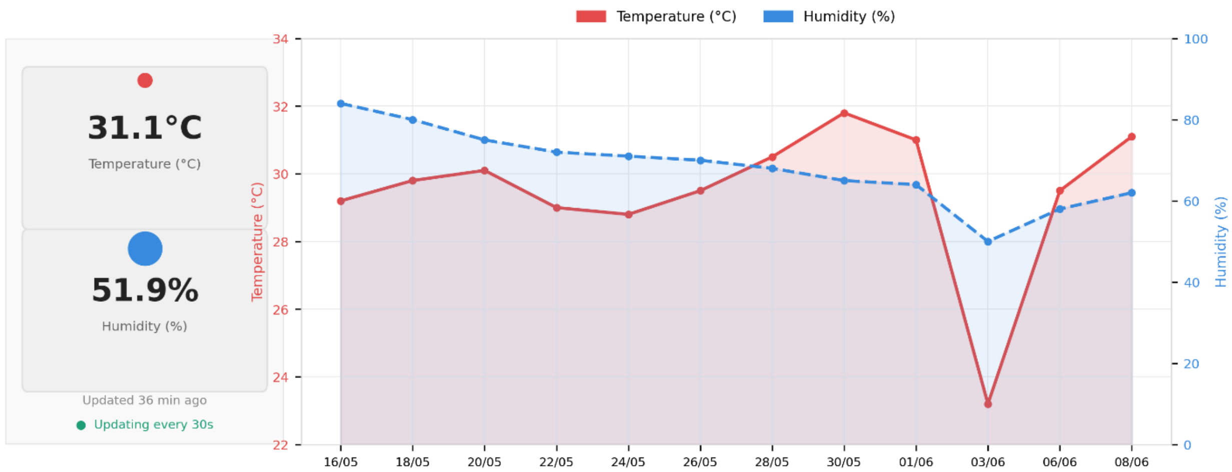
Table 1. Summary of SLP validation results across tested species and diagnostic capabilities

Diagnostic Capability	Result	Species Tested
Plant stand accuracy	100%	All 5 species
False negatives	0	All 5 species
Healthy vs. stressed discrimination	Successful	All 5 species
Nutritional deficiency detection	Successful	Lettuce, tomato, pepper
Insect identification	Early stage	Multiple species

The platform demonstrated diagnostic capacity across multiple stress categories within a single automated scanning cycle. The system successfully discriminated healthy from visually stressed plants based on comparative image analysis. Visual symptoms associated with nutritional deficiencies were identified through leaf color pattern analysis. Insect presence and associated feeding damage on leaf surfaces were identified at early infestation stages, before populations reached economically significant levels.

Environmental sensor readings remained consistently calibrated when compared to reference instruments throughout the experimental period, confirming the reliability of data acquisition under operational conditions. Temperature and humidity anomalies (Fig. 4) can be correlated with plant stress observations to identify causal relationships and optimize environmental control strategies.

Fig. 4 - Climate monitoring of the production system through SLP.



Note: Historical series of temperature and relative humidity behavior in an indoor growing system.

Conclusions

The SLP system demonstrated reliable and consistent performance across diverse production contexts, from seedling nurseries to advanced vegetative and reproductive stages. Plant stand assessment achieved 100% accuracy with zero false negatives across all five tested species, while multi-category stress detection capabilities were validated for nutritional deficiency identification, insect detection at early infestation stages, and discrimination between healthy and stressed plants.

The integration of AI-based image diagnostics with automated environmental actuation in a low-cost architecture represents a practical and accessible tool for precision horticulture. The modular architecture supports scalable deployment without dependence on proprietary hardware, reducing entry costs for smallholder producers. Expanded field validation is ongoing to assess long-term system performance, detection accuracy across additional species, and commercial viability under real production conditions.

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