Automatic Spraying System for Plants based on Leaf Image Detection by Using Raspberry Pi Camera Model V2

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Abstract: *The utilization of automated systems to increase crop maintenance efficiency, especially in fertilizer and pesticide application, has been prompted by advancements in precision agriculture technology. Using a camera module as an automated spraying controller to detect leaf images is one creative method. The integration of the Raspberry Pi v2 Camera Module with digital image processing methods in automated spraying systems is the subject of a comprehensive review of earlier research presented in this article. Actuator control in the system, analysis of leaf detection techniques, and a review of recent journal literature are some of the techniques employed. The study's findings show that real-time implementation of this technique which includes color thresholding and texture analysis for leaf detection can be accomplished with good accuracy. The Raspberry Pi v2 Camera Module offers advantages in color image and easy integration with microcontroller. In conclusion, an automated spraying system based on leaf image detection shows great potential in reducing chemical waste and improving spraying precision, although challenges remain related to lighting conditions and crop types. Further research is needed to improve system performance under various field conditions.*
Keywords: *automatic spraying, leaf detection, Raspberry Pi v2, digital image processing, precision agriculture*

Abstrak: *Pemanfaatan sistem otomatisasi untuk meningkatkan efesiensi pemeliharaan tanaman, terutama dalam penggunaan pupuk dan pestisida, telah didorong oleh kemajuan teknologi pertanian presisi. Penggunaan modul kamera sebagai pengontrol penyemprotan otomatis untuk mendeteksi citra daun merupakan metode yang kreatif. Integrasi Modul kamera Raspberry Pi v2 dengan metode pemprosesan citra digital dalam sistem penyemprotan otomatis merupakan subjek tinjauan komprehensif penelitian sebelumnya yang disajikan dalam artikel ini. Kontrol aktuator dalam sistem, analisis teknik deteksi daun, dan tinjauan literatur jurnak terbaru merupakan beberapa teknik yang digunakan. Temuan penelitian menunjukan bahwa penerapan teknik ini secara real-time, yang mencangkup ambang batas warna dan analisis tekstur deteksi daun, dapat dicapai dengan akurasi yang baik. Modul Kamera Raspberry Pi v2 memiliki keunggulan dalam ketajaman gambar dan kemudahan penggabungan dengan mikrokontroler. Kesimpulannya, sistem penyemprotan otomatis berbasis deteksi citra daun menunjukkan peluang yang besar dalam mengurangi limbah kimia dan meningkatkan presisi penyemprotan, meskipun masih terdapat tantangan terkait kondisi pencahayaan dan jenis tanaman. Penelitian lebih lanjut diperlukan untuk meningkatkan kinerja sistem dalam berbagai kondisi lapangan.*
Kata Kunci : *penyemprotan otomatis, deteksi daun, Raspberry Pi v2, Pemprosesan gambar digital, pertanian presis*

INTRODUCTION

Modern agriculture is undergoing significant transformation with advances in digital technology and automation. One rapidly developing approach is precision agriculture, a method that relies on data and sensors to optimize the use of resources such as water, fertilizers, and pesticides. In conventional farming practices, fertilizer and pesticide spraying is generally done manually, without considering the precise needs of each crop. This results in chemical waste, increased production costs, and negative impacts on the environment and human health. Therefore, an intelligent system capable of automatically spraying crops based on actual crop conditions is needed.

Using leaf image identification as a basis for decision-making in automated spraying systems is a new strategy being developed. Because leaves are the most vulnerable plant component to environmental changes and pest and disease attacks, they provide a critical signal for determining the need for spraying. This system can identify variations in leaf color, shape, and texture and then use this information to trigger selective spraying using digital image processing technology. This system relies on a digital camera device, specifically the Raspberry Pi Camera Module v2, which is capable of capturing high-resolution images in real-time. The camera is easily integrated with a Raspberry Pi microcontroller and can be combined with programming libraries such as OpenCV to perform leaf image segmentation and analysis (Restrepo-Arias et al., 2024).

Common image processing techniques used in these systems include color extraction, edge detection, and texture analysis, which are useful for separating leaves from the background and identifying visual changes. The results of this image analysis are then sent to a control system, which activates actuators, such as pumps or solenoid valves, to spray protective or nutrient solutions onto plant parts identified as requiring treatment. Previous research has shown that such systems can significantly reduce chemical consumption and improve spraying accuracy (Tufail et al., 2021). Beyond efficiency, this approach also supports more environmentally friendly and sustainable agricultural practices.

During development, this system can also be integrated with Internet of Things (IoT) and artificial intelligence (AI) technologies, enabling remote monitoring of crop conditions and automated decision-making based on historical data. The Raspberry Pi, as a data processing hub, offers advantages in flexibility and low cost, making it suitable for use by small- to medium-scale farmers. However, several technical challenges remain to be addressed, such as the impact of lighting conditions on image quality, variations in plant morphology, and hardware resilience to extreme weather conditions in the field. Therefore, it is important to understand the various technical approaches implemented in previous studies to evaluate the system's effectiveness and potential for further development (Sharma & Shivandu, 2024).

Based on this background, this study was designed to review the literature related to automatic plant spraying systems based on leaf image detection using the Raspberry Pi Camera Module v2. The research questions include : how image processing methods can be used to detect leaves in real-time, how system integration between cameras, microcontrollers, and actuators is carried out, and what the advantages and disadvantages of the systems that have been developed are. The purpose of this study is to summarize relevant scientific results, evaluate the technology used, and provide insights into opportunities for its application and development in the future. This research is expected to provide benefits as academic and technical reference material for the development of precision agriculture systems, especially in tropical regions such as Indonesia, which still face limitations in the adoption of modern technology.

RESEARCH METHODS

This study uses a systematic literature review approach with a descriptive qualitative method, which aims to review and analyze various scientific publications related to an automated plant spraying system based on leaf image detection using the Raspberry Pi Camera Module v2. This research design does not involve direct experiments, but focuses on theoretical and technical reviews from reliable sources. The study was conducted to gain a comprehensive understanding of the design, implementation, and potential development of an image-based spraying system in supporting precision agriculture. The literature analyzed was limited to the period 2020 to 2025, to ensure that the data and technology reviewed are up-to-date and relevant to current technological developments.

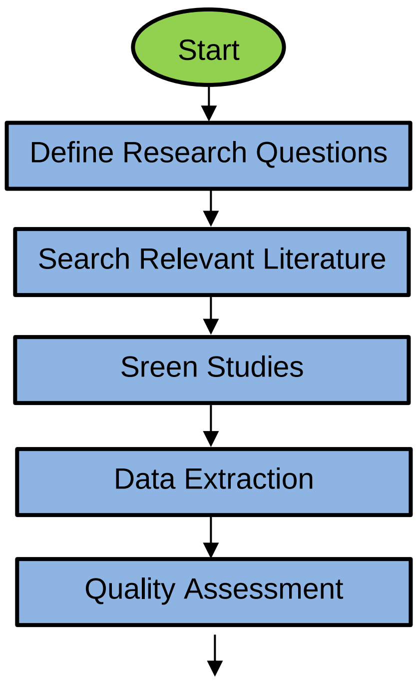
The study population included all scientific publications discussing the topic of automated spraying systems based on leaf image processing, specifically those using a Raspberry Pi v2 camera. The sample was selected purposively based on relevance to the main theme, completeness of technical information, and availability of method and result data. The sampled articles were national and international scientific journals, conference proceedings, and academic research reports that had undergone peer review or equivalent scientific assessment.

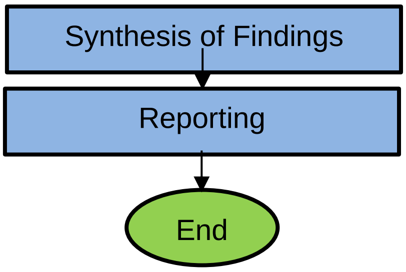
Data collection techniques were conducted through scientific database searches, including IEEE Xplore, ScienceDirect, SpringerLink, Scopus, and Google Scholar for domestic literature. Keywords used included "automatic spraying system," "leaf image detection," "Raspberry Pi Camera Module v2," "smart agriculture," and "image processing in agriculture." Search results were selected based on abstracts and keywords, then analyzed for content to determine suitability with the research focus.

Because this research is qualitative literature, the instrument development was carried out in the form of an article analysis sheet, which contains parameters such as the type of camera and sensor used, image acquisition and processing techniques, the type of plant tested, the leaf segmentation or classification method, the type of actuator, and the results of the system implementation. This sheet serves as an aid in grouping and comparing each publication objectively.

The data analysis technique used is content analysis, which is an approach to systematically interpreting and synthesizing the meaning of document content (Vespestad & Clancy, 2021). The analysis stages include (1) topic identification, (2) classification of the methods and tools used, (3) evaluation of system effectiveness, and (4) formulation of a synthesis of findings in the form of a comprehensive review. This technique is suitable for reconstructing technical understanding from various approaches that lead to similar goals.

With this method, it is hoped that this research will not only produce a mapping of the technology that has been developed in the last five years but also provide critical insights and concrete recommendations for the development of a more efficient and adaptive automatic crop spraying system in the future.





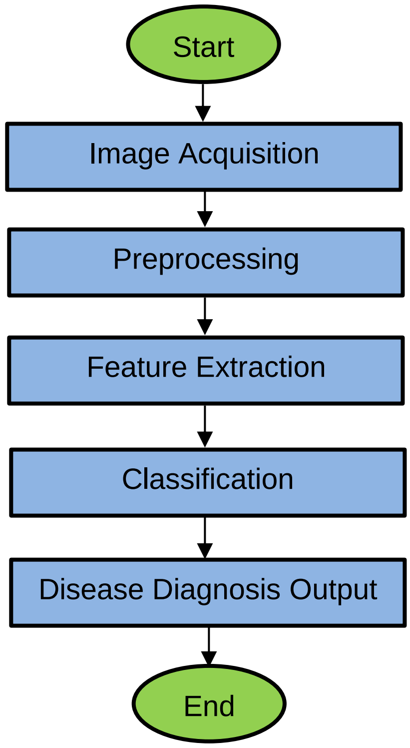
Flowchart of systematic review research methodology

RESEARCH RESULT

Based on the results of a review of a number of relevant scientific publications in the period 2020–2025, several main focuses were found in the development of an automatic plant spraying system based on leaf image detection with the Raspberry Pi Camera Module v2. In general, this approach was developed in three main technical aspects, namely: (1) leaf image acquisition and detection system, (2) hardware integration and sprayer actuator control, and (3) spraying efficiency and its impact on agricultural practices.

a. Raspberry Pi v2 Camera-Based Leaf Image Detection

Most studies have indicated that the Raspberry Pi Camera Module v2 is capable of producing images accurate enough to detect leaves in real-time in both outdoor and greenhouse environments. The most commonly used methods for leaf segmentation are HSV and RGB color thresholding, as well as edge detection combined with morphological operations to clarify the shape of leaf objects (Mohammed Amean et al., 2021) showed that the combination of the Raspberry Pi with the OpenCV library is able to consistently identify leaf objects even with slight changes in lighting. However, there are still limitations in images with complex backgrounds, where detection accuracy can decrease by up to 15–20% without optimal preprocessing.



Flowchart image processing for leaf disease detection

Several studies have also implemented leaf classification algorithms using simple machine learning approaches, such as k-Nearest Neighbor (k-NN) and Support Vector Machine (SVM), to detect leaves exhibiting disease symptoms or nutritional stress. This expands the system's functionality beyond simply detecting leaf presence to automatically recognizing leaf conditions, which then informs spraying decisions.

b. Automatic Spraying System Integration

The system circuit generally consists of a Raspberry Pi camera, a main control unit (Raspberry Pi board), and one or more spraying actuators, such as a mini DC water pump, solenoid valve, and automatic nozzle. The study results showed that this system successfully sprayed liquid only on areas detected as containing leaves or leaves experiencing certain symptoms, without overspray in empty areas. Communication between the camera module and actuators takes place through a Python-based control script, which can activate spraying dynamically.

Most design systems utilize the spray-on-demand principle, where spraying is only performed when certain leaf conditions are detected. A study by (Rakesh et al., 2025) showed a reduction in solution consumption of up to 40% compared to conventional spraying. In some implementations, the system's reaction time from detection to spray activation is in the range of 1–2 seconds, sufficiently efficient for small- to medium-scale agricultural applications. System Efficiency, Benefits, and Limitations.

In terms of efficiency, this system can reduce the volume of pesticide and fertilizer use by 30–50% in various test scenarios, primarily because spraying is done selectively. Furthermore, this system contributes to reducing farmers' exposure to hazardous chemicals, thereby improving occupational safety.

However, several limitations remain, such as sensitivity to excessive or insufficient lighting, variations in leaf shape and size between plant species, and the need for regular system recalibration. Some systems also require a stable power supply and network connection if they are to be integrated with IoT systems or cloud monitoring (Sharma & Shivandu, 2024). Another challenge is the Raspberry Pi's real-time processing capabilities, especially when using complex classification models.

c. Summary of Literature Study Findings

Based on the analysis, the Raspberry Pi Camera Module v2 is consistently effective for detecting leaves and controlling automated spraying systems. Most tested systems demonstrated chemical savings, improved spraying accuracy, and ease of integration with other components. The most frequently reported challenges included detection quality in open field conditions, limitations of leaf classification algorithms, and the need for efficient power for long-term use in remote agricultural areas.

Table 1. Summary of Literature on Automatic Spraying Systems Based on Leaf Image Detection (2020–2025)

Number	Researchers	Year	Image Detection Method	Spray Actuator	Key Findings
1	Restrepo-Arias et al	2024	Thresholding (RGB) + OpenCV	DC mini pump + nozzel	Accurate leaf detection in indoor conditions; difficulty in complex backgrounds
2	Rakesh et al.	2025	Edge detection + texture	Automatic solenoid valve	System response time < 2 seconds; accuracy > 96% at stable lighting

3	Tufail et al	2021	HSV thresholding + SVM	DC pump + relay	Fluid efficiency increased by 40%; can detect diseased leaves
4	Amean et al.	2021	HSV thresholding + SVM	Selenoid valve + sprayer	The system performed well in the test field; difficulty adapting to outdoor lighting
5	Sharma & Shivandu	2024	IoT + AI classification	Electric nozzle + pressure regulator	Cloud-connected system; requires stable power and advanced AI processing

DISCUSSION

Based on the results of the review of various publications analyzed, it can be concluded that the automatic plant spraying system based on leaf image detection with the Raspberry Pi Camera Module v2 has shown significant potential in supporting precision agriculture practices. This discussion focuses on four main aspects according to the problem formulation, namely the effectiveness of the leaf image detection approach, processing and classification techniques, integration of hardware and control systems, and comparison and opportunities for system development.

First, from the perspective of leaf image detection technology, it was found that color-based segmentation methods (RGB or HSV) remain the primary choice due to their simplicity in implementation and relatively high accuracy under controlled lighting conditions. This is evident in the majority of studies that rely on color thresholding methods to distinguish leaves from the background. However, these systems exhibit decreased performance when applied to outdoor environments with variable lighting. This suggests that this approach still needs to be improved with adaptive algorithms or lighting preprocessing to achieve more stable and accurate results in the field.

Second, in terms of leaf processing and classification methods, studies such as those conducted by demonstrate progress by (Tufail et al., 2021) and (Sharma & Shivandu, 2024) utilizing machine learning-based algorithms, such as SVM and texture-based classification. This approach not only detects the presence of leaves but also recognizes leaf conditions, such as symptoms of disease or stress. This means the system not only automatically sprays based on leaf presence but also based on the urgency or need for treatment. This is a key advantage of AI-based systems over conventional manual systems, which tend to generalize across the entire crop area.

Third, in terms of hardware integration and actuator control, most systems are designed using a Raspberry Pi as the control center, combined with mini pumps, solenoid valves, and other supporting sensors such as humidity or temperature. The Raspberry Pi Camera Module v2 has proven compatible with most Python libraries, making it easier for developers to design efficient automated spraying systems. These findings indicate that such systems are highly feasible for practical implementation, especially in small- to medium-scale agriculture that does not require highly complex systems. A study by Widodo et al. (2023) supports this by showing that the system can reduce chemical solution usage by up to 50% in a single spraying cycle.

Fourth, compared with previous research that focused more on manual or timer-based spraying systems, image-based systems offer significant added value in terms of accuracy and efficiency. While all the studies reviewed share a common focus on efficiency and automation, differences lie in the leaf classification methods and the scale of testing. For example, some studies are still laboratory-based or small-scale, while others have begun integrating these systems into IoT networks and the cloud. These differences indicate that this technology is still in its infancy and open to further exploration, particularly in terms of real-time data processing and network integration.

Looking ahead, the potential for developing this system is vast. The integration of more complex AI technologies, such as deep learning (CNN), could enable more accurate leaf recognition, even in low-light conditions or complex backgrounds. Furthermore, integration with IoT opens up opportunities for spraying systems that can be controlled remotely via web-based or mobile applications. This is highly relevant to modern, data- and connectivity-driven agriculture. Furthermore, the development of a self-sufficient solar-powered system could also be a solution for applications in remote agricultural areas with limited electricity supply.

Overall, the results of this study demonstrate that the use of the Raspberry Pi Camera Module v2 in a leaf image detection-based crop spraying system has significant potential to address issues of spraying efficiency and accuracy. These findings confirm that with the right approach, this technology can not only solve the problem of non-selective manual spraying but also pave the way for a smarter, more resource-efficient, and environmentally friendly agricultural system.

CONCLUSION

The results of the literature review indicate a close relationship between the accuracy of leaf image detection, the effectiveness of image processing, and the efficiency of the automated spraying system built using the Raspberry Pi Camera Module v2. The higher the quality of leaf detection and classification, the more accurate the system is in determining areas that require spraying treatment, thereby directly impacting the reduction of chemical use and increasing the efficiency of agricultural processes. Good integration between hardware (camera, actuator, and controller) and software (image processing algorithm and system control) is the key to the successful implementation of this technology in the field. Therefore, it is recommended that further research focus on improving the accuracy of the detection algorithm through an artificial intelligence-based approach and increasing the system's resilience to changing environmental conditions, including extreme lighting and complex backgrounds. In addition, it is also important to consider the integration of autonomous energy and IoT-based control systems so that this technology can be widely applied in remote agricultural areas with minimal digital infrastructure and electricity.

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