Effectiveness and profitability of automation technologies in greenhouse productivity and food security

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Abstract. This paper examines the innovative impact of an automated system developed by the research and production company Gardens of Chechnya, which combines computer vision technologies and image data analysis methods to effectively assess plant health at the embryonic stage. Traditional visual data analysis methods have been labour-intensive and time-consuming, creating barriers to crop production and quality. The automated system developed for the company's scientific needs, based on computer vision, has excellent accuracy, allowing it to examine plants at a new level and detect even the slightest signs of disease and infection. This innovation speeds up the assessment process, reducing it from days to hours. The mobility of the system allows it to be used in various agricultural conditions, which simplifies the assessment of plant health. By making it easier to assess plant health, this innovation promises increased yields, reduced disease spread and faster results, meeting global goals for food security and sustainable agriculture.

1 Introduction

Greenhouse farming represents an agricultural management approach that has demonstrated its effectiveness in expediting food production. This method offers a viable solution to address the foremost challenge of our era: ensuring a stable food supply. Technology has played a pivotal role in surmounting the constraints, mitigating adverse impacts, and guaranteeing the resilience of greenhouse farming systems [1].

The global food production landscape confronts substantial hurdles, particularly in light of a projected population of 9.6 billion by 2050 [2]. Urbanization, agricultural decline, and the spectre of climate change place considerable strain on global agriculture. Greenhouse agriculture has evolved from rudimentary open-field cultivation to sophisticated controlled ecosystem farming systems, which now play a pivotal role in the urban agriculture landscape [3]. Technological advancements and enhancements have facilitated scientific solutions to optimize plant production within greenhouse environments in densely populated urban areas.

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Furthermore, the implementation of an automatic control system within greenhouses ensures energy efficiency and precise regulation of the microclimate, thus creating ideal conditions for crop growth. Smart greenhouses hold significant promise in upholding food security in the face of these challenges [4].

The current trajectory of human population growth, changes in food consumption habits, increasing demand, and food wastage are collectively placing unprecedented stress on our agricultural systems and natural resources [5]. Consequently, one of the most significant challenges humanity faces in the 21st century is ensuring an adequate food supply. The agro-ecosystem plays a vital role in food production, with approximately 275 million hectares worldwide dedicated to irrigated crops, growing at an annual rate of 1.3% [6]. To meet the projected food demand by 2050, global production needs to increase by 70%, which implies expanding agricultural land or intensifying existing land use [7]. However, expanding agricultural areas can lead to changes in land availability and use, resulting in the loss of natural ecosystems. Therefore, converting land for farming ranks as the second-largest global threat to biodiversity conservation, primarily due to deforestation processes.

In light of these challenges, there is a pressing need to develop technologically advanced, sustainable agricultural solutions, such as greenhouses, that can ensure food security without disrupting agro-ecosystems or causing environmental pollution. Greenhouses are designed to cultivate plants and often utilize transparent covers that allow sunlight containing photosynthetic radiation (PAR) because insufficient light can negatively impact crop quality. Unfortunately, conventional greenhouse designs, with their windows and roofs, are major contributors to energy loss, accounting for 20-40% of total energy loss [8].

Current greenhouses are primarily constructed using materials like glass, plastic, polyethylene, semi-plastic, and plastic fiber low-melt, all of which easily dissipate heat into the environment. Consequently, there is a need for smart greenhouses that incorporate cutting-edge technology, are cost-effective, and have minimal environmental impact [9]. The integration of solar systems is crucial to reduce greenhouse operating costs and maintain optimal microclimates within the structure, even in extreme conditions.

Addressing the limitations in harnessing solar energy for agricultural purposes demands immediate attention and further research. The conversion of arable land into photovoltaic (PV) plants is a relatively recent trend, with PV technology being used to generate electricity for heating, cooling, and lighting in greenhouses [10]. This approach reduces reliance on the power grid or fossil fuels. It has been proposed that energy-efficient greenhouses in colder climates, employing passive technologies like double glazing, can potentially fulfil up to 50% of their total energy requirements. Such passive technologies are considered the latest and most promising heating and cooling solutions, applicable in both northern and tropical regions. Nevertheless, the specific energy needs for temperature, light, and humidity control vary by region, as do the technologies employed in greenhouse operations.

2 Methods

This work was carried out in several stages based on the main objectives of the study. The main objectives included assessing innovative technologies, using the example of a specific organization, the ability to quickly assess the state of plant health and agricultural sustainability. To achieve the objectives, a literature review was conducted in areas such as agriculture, biology and computer technology. Also, to assess the practical significance of innovative technologies, we examined the research and development of the scientific and production company "Gardens of Chechnya".

3 Results and Discussion

3.1 Exploring Technologies for Enhanced Greenhouse Productivity and Food Security

There is a pressing need to investigate cost-effective and efficient technologies that can be deployed in operational greenhouses to boost production and ensure food security. The adoption of greenhouse technologies is experiencing rapid growth, with a focus on creating optimal conditions for plant growth and safeguarding crops against pests [11]. This section provides an overview of the development of various greenhouse technologies, considering their applications in diverse climates worldwide.

Heat Pump (HP): Heat pump technology plays a crucial role in establishing controlled heating and cooling environments within greenhouses [8]. Its versatility makes it a preferred choice for regulating the microclimate inside greenhouses, offering distinct advantages over alternative technologies.

Lighting: Greenhouses also utilize lighting systems to enhance efficiency. While the specific types of lighting employed may not always be explicitly stated, lighting is an essential factor, particularly for certain vegetables and fruits. Photosynthesis relies on photosynthetic radiation (PAR) or visible light wavelengths, and insufficient PAR can adversely affect the colour and size of harvested produce. To address this issue, various studies have explored artificial lighting methods, including intra-canopy lighting, photoperiodic lighting, and lighting with different wavelength combinations [12]. Research into lamp types and light wavelength emissions from artificial lighting sources has become a critical aspect of greenhouse cultivation.

High-Pressure Sodium (HPS) Lamps: HPS lamps find application in greenhouses with ornamental plants to control flowering, benefiting crops like chrysanthemums and velvet sage. The ability to manipulate radiation levels enables farmers to regulate flowering times in line with market demand [13]. However, LEDs offer a cost-effective alternative with superior results compared to HPS lamps, even outperforming fluorescent lamps (FL). Studies have demonstrated that green LEDs, in particular, have a more positive impact on plant growth than white FL lighting. These findings align with research showing that LED lighting surpasses both HPS and LED lighting sources.

Photovoltaic (PV) Panels: In contemporary greenhouse design, PV panels have gained popularity as energy providers, offering a broad spectrum of capabilities. PV applications extend to active heating, cooling, and lighting within greenhouses [8]. The practicality of PV integration in greenhouses has grown due to decreasing costs and improved efficiency. To mitigate the limited impact of PV panels, researchers have explored techniques such as concentrating sunlight on PV surfaces, employing technologies like Fresnel lenses and parabolic trough concentrators.

Automatic Control Systems: Managing a greenhouse system, considering factors like humidity, temperature, lighting, and CO2 levels, may seem straightforward but is inherently complex. Therefore, the implementation of an automatic control system is not only cost-effective but also highly valuable. Achieving low energy consumption in greenhouses is possible through adaptive climate control, integrated control algorithms, the installation of insulating covers, and effective energy management practices. Automatic systems offer several advantages, including the regulation of soil moisture, temperature, and humidity within the greenhouse [13]. In contrast, manual systems suffer from various disadvantages, including high costs and inaccurate control. Hence, there is a growing trend towards automated systems that capitalize on shrinking sensor sizes, promising to enhance greenhouse efficiency and yield.

Food security represents a complex challenge that extends beyond mere food production. Food production primarily addresses the aspect of food availability, which depends on supply and distribution. However, food security encompasses multiple dimensions, including food access and utilization. The task of providing sustenance for a projected 9-10 billion people by 2050 has been a longstanding concern [2]. Numerous strategies have been proposed to tackle this challenge, such as closing yield gaps, enhancing crop productivity through technology investment, reducing food waste, and adopting multi-purpose systems. Achieving food security requires a coordinated, multifaceted global approach.

Two paramount challenges facing humanity involve meeting the nutritional needs of a growing population and mitigating dangerous climate change while adapting to its inevitable consequences. Solving these challenges involves transforming our land management practices to minimize the adverse environmental impacts of food production. Technology plays a pivotal role in addressing resource scarcity and implementing socio-economic and environmental measures to enhance agricultural stability [14]. The greenhouse industry continually innovates by developing novel strategies and technologies to address crop-specific limitations, reduce environmental footprints, and meet evolving market demands.

The field of enclosed agriculture is undergoing a transformative phase thanks to advancements in precision technology, data processing, and smart farming. Protected agriculture has evolved from simple greenhouse structures to high-tech plant factories that optimize plant productivity and reduce human labour. These modern greenhouses function as integrated systems, often referred to as controlled ecosystem cultivation, controlled ecosystem plant production systems, or phytometry systems. Smart greenhouses leverage natural or artificial lighting to create optimal growth conditions for horticultural crops or plant research programs. They offer increased predictability, reduced production costs, and higher crop yields. Moreover, technology in smart greenhouses has expanded the options for irrigation water sources, breaking barriers by incorporating recycled water, desalinated seawater, or rainwater harvesting.

3.2 Innovative Technology in Plant Health Assessment

In a pioneering stride towards agricultural advancement, the research and production company Gardens of Chechnya has unveiled an automated system built upon the foundations of computer vision technologies and image data analysis methods. This ground-breaking innovation marks a significant leap in the quest for healthier crops and sustainable agriculture.

The system developed by Gardens of Chechnya is set to revolutionize the way we assess plant health, particularly focusing on detecting viruses and diseases in explants. Traditional methods of plant health assessment often involve labour-intensive and time-consuming processes that can hinder crop production and quality [15]. With the introduction of this cutting-edge technology, the agricultural industry can look forward to enhanced efficiency and accuracy.

The core of this system lies in its utilization of computer vision technologies. By employing high-resolution imaging and sophisticated algorithms, it can scrutinize plants at the microscopic level, identifying even the subtlest signs of disease or infection. This level of precision ensures that unhealthy plants are promptly isolated from their healthy counterparts, preventing the spread of diseases and ultimately bolstering crop yields [16].

One of the most significant advantages of this automated system is its ability to expedite the research process significantly. Traditionally, plant health assessments required hours, if not days, of manual labour. Gardens of Chechnya's innovation slashes this time down to a fraction, allowing researchers and farmers to obtain critical results quickly. This acceleration is particularly crucial in times of potential outbreaks, where prompt action can save entire harvests.

Moreover, this technology offers an unprecedented level of mobility to the research process. Unlike conventional methods that often demand specialized equipment or personnel, Gardens of Chechnya's system can be deployed in various settings, including farms, research laboratories, and even remote agricultural areas. This versatility promises to democratize plant health assessment, making it accessible to a broader range of stakeholders [17].

Gardens of Chechnya's automated system, built upon the foundation of computer vision and image data analysis, stands as a beacon of hope for the agricultural industry. By streamlining the assessment of plant health, it promises increased crop yields, reduced disease spread, and quicker results. As the world grapples with the challenges of food security and sustainable agriculture, innovations like these are indispensable in ensuring a brighter, healthier future for our planet.

4 Conclusion

This article provided an overview of modern greenhouses and controlled ecosystems, shedding light on their derivative technologies. It also highlighted advancements in environmental monitoring, regulation, and optimization. Furthermore, it is crucial to acknowledge that the increased costs associated with automation do not necessarily guarantee enhanced profitability. Therefore, an additional facet contributing to sustainability is the incorporation of knowledge-based decision-making support systems – essentially, model-based computer applications that address the cost-effectiveness of specific automation technologies.

Based on a comprehensive review of the literature, this study underscores the need for a more precise economic analysis and justification of the substantial initial investments associated with smart greenhouses and plant factories before embarking on large-scale commercial development. Computer simulation models and adaptive analysis software tailored for greenhouse applications are already available and can be further developed to facilitate Cost Advantage Analysis systems. Additionally, future research should consider the correlation between increased automation levels and actual profit growth, as this is a pivotal factor to justify widespread automation implementation and attain higher yields to ensure food security.

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