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Short Communication

Preliminary Study of An Automated Plant Tray Loader for Plant Factory

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Abstract: As the demand for sustainable and efficient agricultural practices continues to rise, plant factories have emerged as a viable solution to meet the growing global need for fresh produce. An automated plant tray loader prototype has been developed to reduce labor requirements by automating the loading of plant trays onto cultivation racks. The purpose of this article is to present the design, development, and evaluation of the prototype. Usability and performance evaluations demonstrate that while the system may prevent physical discomfort, it is difficult to use, thereby reducing its practicality. To improve its practicality, its positioning and coordination need to be improved.

Keywords: plant factory; smart farming; hydroponic system; automation

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1. Introduction

In recent years, the rapid advancement of technology has transformed agricultural practices, particularly in controlled environment agriculture (CEA). Among the various forms of CEA, plant factories have emerged as promising solutions to address the growing demand for sustainable food production in urban areas, while also mitigating challenges such as climate change, land scarcity, and resource limitations (Gómez *et al*., 2019). Central to the efficiency and productivity of plant factories is the optimization of cultivation processes, which requires the integration of automation and robotics for enhanced precision and scalability (Sánchez-Molina, *et al.*, 2024). One crucial component of this is the automation of plant tray loading. Examples of plant tray loading automation can be seen in companies such as AeroFarms (Kozai, *et al.*, 2019), Iron Ox, Fifth Season, Infarm, Agricool, and AppHarvest (Peters, 2023). However, these solutions are specifically tailored to the unique needs of their respective setups, making them unsuitable for direct implementation in the current MARDI plant factory configuration.

The process of placing the trays with seeds into the troughs is known as transplanting while the process of removing the trays with ripe vegetables from the troughs is known as harvesting. Manual transplanting or harvesting involves a worker standing on a lifting platform and going up or down the racking levels (Figure 1). In the long run, this activity puts a strain on the workers' back and may cause dizziness.

Figure 1. Manual harvesting in MARDI plant factory

Therefore, there is a need to replace manual labor with a mechanized system. The design and implementation of the automated loader system involve a multidisciplinary approach, integrating principles from mechanical engineering and electrical engineering. Key components of the system include robotic arms equipped with end-effectors for tray manipulation, vision systems for real-time object detection, and control system for positioning and coordination.

2. Materials and Methods

2.1 Design Specifications

In MARDI plant factory, leafy vegetables such as lettuce are grown in a controlled environment. The vegetable seeds are planted in trays which are then placed on top of troughs. Each tray can accommodate up to 50 plants, as illustrated in Figure 2.

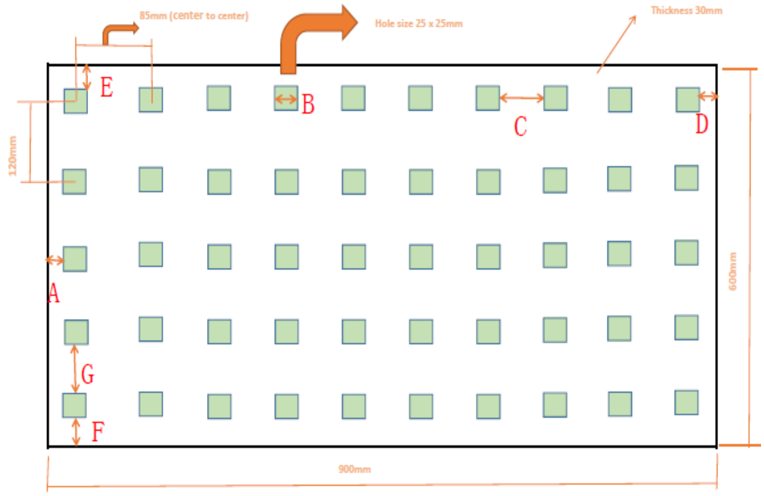

Figure 2. Illustration of plant tray

The average weight of a harvested plant is around 250 g. Additionally, each trough contains four trays. The troughs provide the necessary water and nutrients for the seeds to grow. They are placed on multi-level racks where each level holds one trough. The racks are separated from each other by 900 mm. The rack and trough are illustrated in Figure 3.

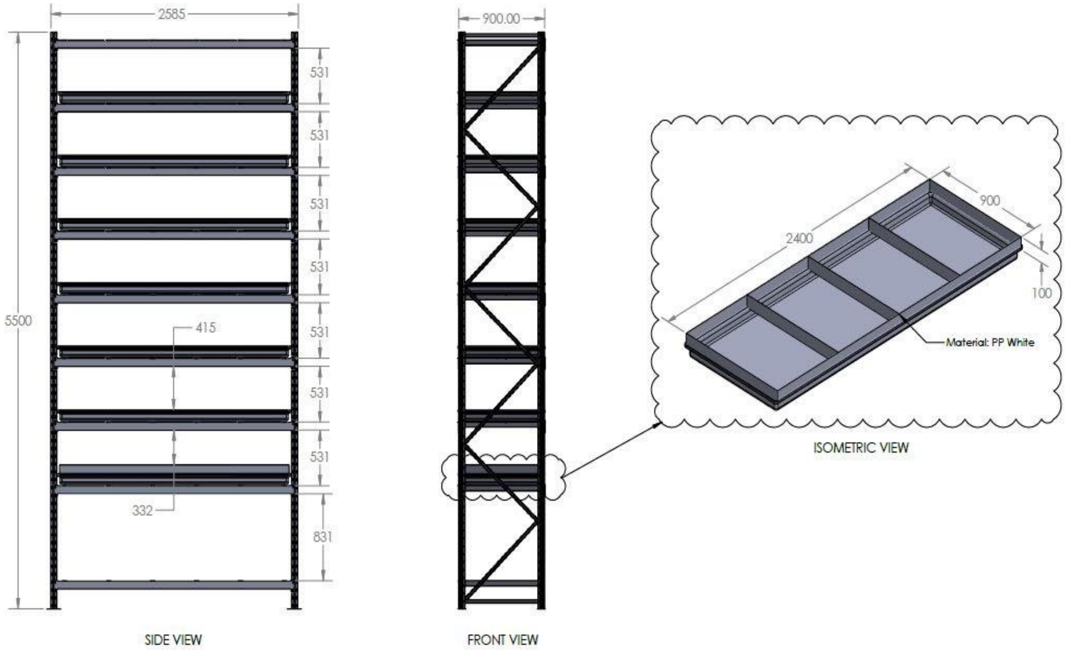

Figure 3. Illustration of plant rack and trough

For the initial prototype, the emphasis has been on the loading mechanism itself. The loading mechanism must take into consideration the tray's size, material, design and trough placement to avoid as much modification as possible to the current planting system. Therefore, a single-level automated plant tray loader has been developed to place or remove one tray into or from the trough at a time. Based on the plant factory size and racking dimensions, the main design specifications of the loader system are shown in Table 1.

Table 1. Design specifications of the loader system

No	Subject	Details
1	Minimum load carrying capacity	15 kg
2	Maximum width	900 mm
3	Main features	Automated tray pusher and retriever
4	Height of operator handle	94 – 115 cm from the ground
5	Wheels	Front wheels: fixed castors Back wheels: swivel castors with locks

2.2 Process Workflow

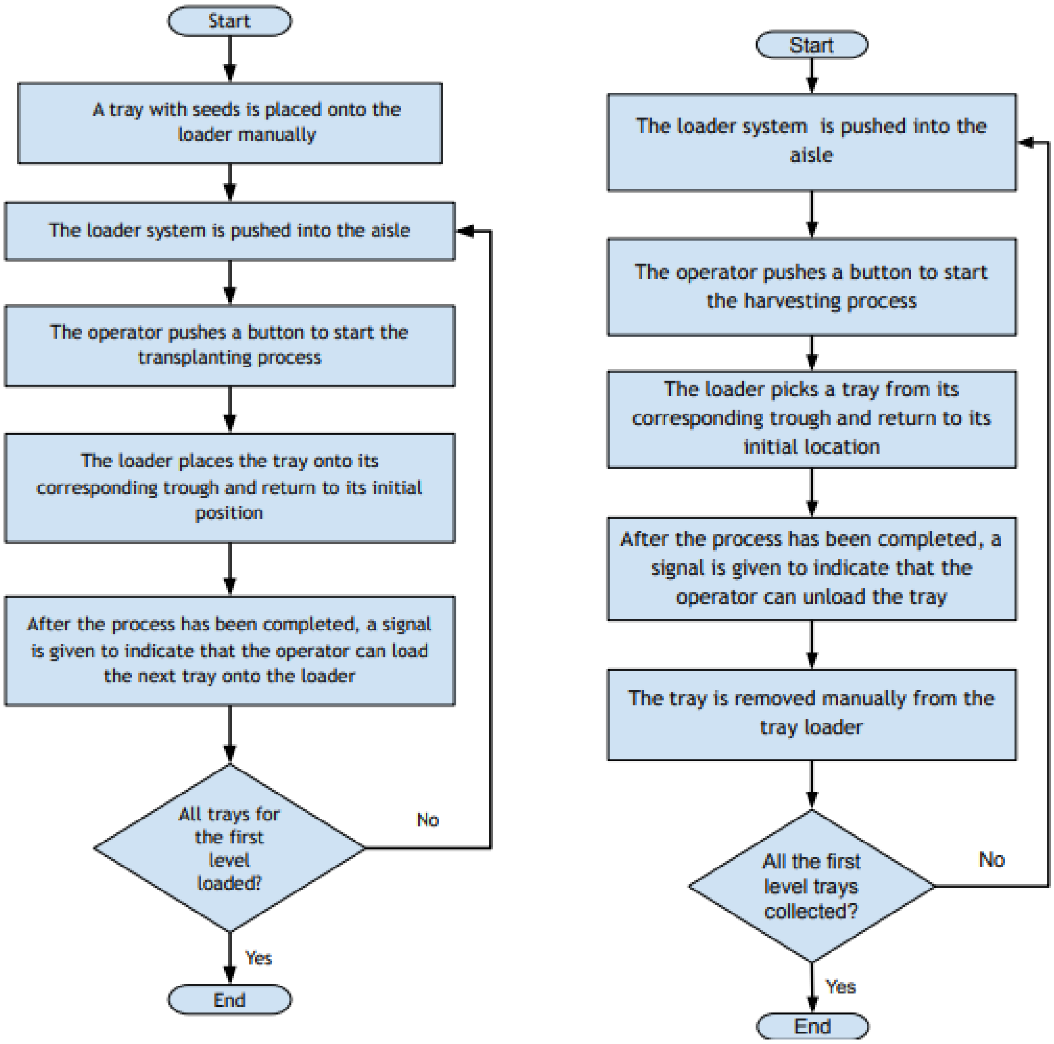

Figure 4. Flow chart of transplanting (left) and harvesting (right) processes

The workflow is summarized in Figure 4. During transplanting, an operator places the tray with planted seeds onto the loader. Then, the loader is pushed into the racking aisle where the tray is to be placed. After that, the operator pushes a button to start the transplanting process. The loader then places the tray onto its corresponding trough and returns to its initial position. After the process has been completed, a signal is given to indicate that the operator can load the next tray onto the loader. The steps are then repeated until all the troughs are filled. On the other hand, for harvesting process, similar steps are followed except that the loader picks up trays with ready-to-harvest plants instead of placing trays with planted seeds.

2.3 Prototype Fabrication

An off-the-shelf hand lifter has been modified to realize the prototype. The manual lifting mechanism has been replaced by a motor to automate the process of lifting the loader and aligning it with the trough. Arduino platform has been used to control the horizontal and vertical movements of the loader and is placed in a controller box. Since the planting system is hydroponic, there will be water spill when placing or removing the trays from the troughs. Therefore, a plastic container has been placed below the tray platform to reduce the water spill. The loader uses two different linear actuators including a trapezoidal screw actuator to extend the tray platform. A rotating platform is used to enable the loader to work on either side of the racking aisle. Figure 5 and Figure 6 show the system prototype and close-up view of the loader/ retriever mechanism.

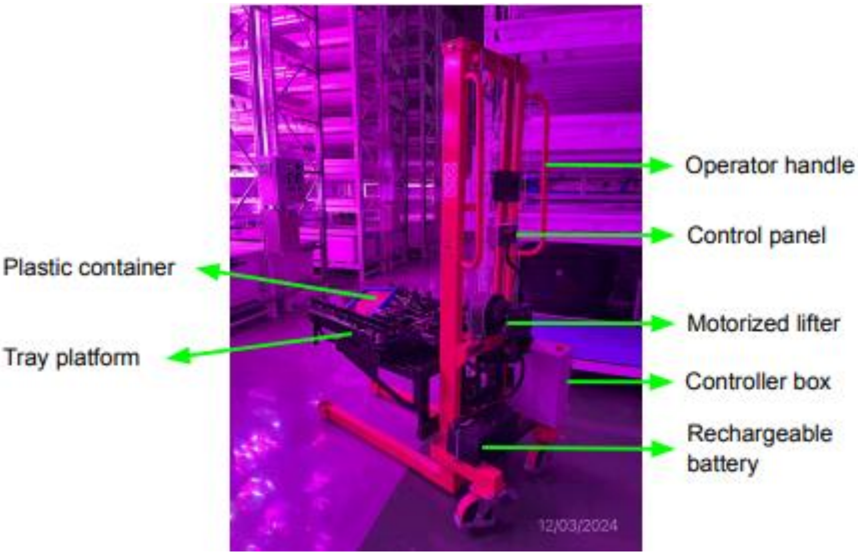

Figure 5. The system prototype and its components

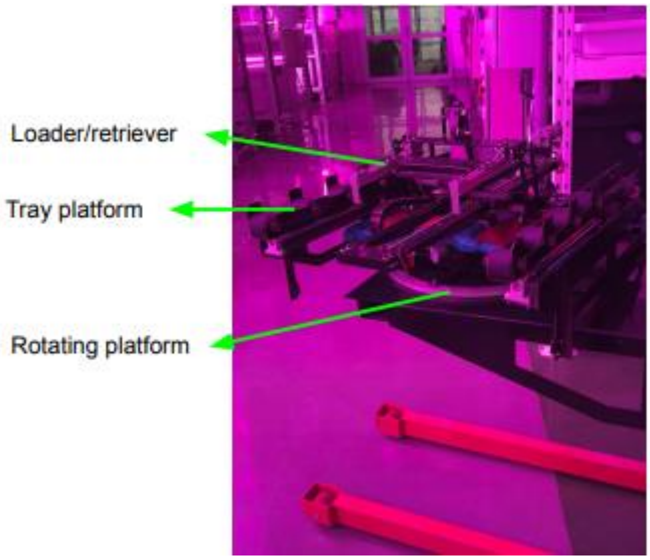

Figure 6. Close-up view of the loader/ retriever mechanism

2.4 Verification of the System

To evaluate the system's practicality in terms of its impact on the operator's physical comfort and its assistance in easing their workload, a survey was conducted among six MARDI staff. These participants were the only individuals regularly involved in the transplanting and harvesting operations at MARDI's plant factory. The survey aimed to evaluate their acceptance of the new innovative system compared to the traditional manual method. The participants have been asked to operate the system to harvest a planting tray. After completing the task, they have been asked to answer the survey.

3. Results and Discussions

3.1 Verification Results

Figure 7 shows the results of the survey in terms of physical comfort and ease of use, while Figure 8 shows overall acceptability of the system.

(a) (b)

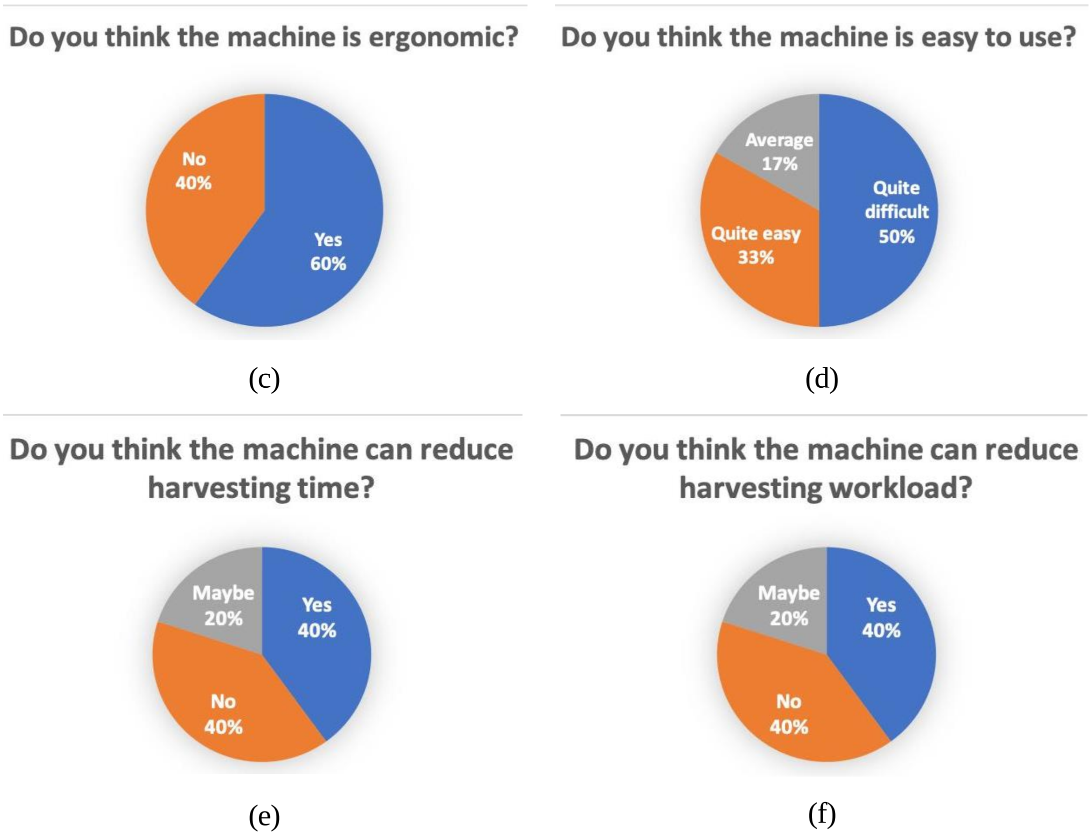

Figure 7. Survey results in terms of physical comfort and ease of use

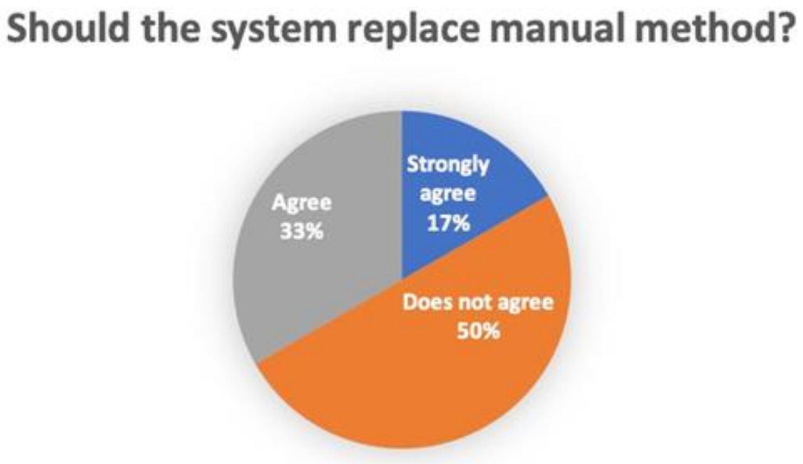

Figure 8. Overall acceptability

The first aspect we examined was the operator's physical comfort. A significant proportion, 67% experienced some dizziness, indicating a potential design flaw that needs addressing. Regarding neck or back pain, while half of the respondents reported no pain, a notable 50% experienced some level of discomfort, with 16.7% reporting significant pain. This highlights an opportunity to improve the system's ergonomics to better accommodate user needs. Despite 60% agreeing that the machine is ergonomic, the remaining 40% disagreeing reflects a disparity in user experience, suggesting room for improvement. The system's usability also seems polarized, with half finding it "quite difficult" and only a third finding it "quite easy." This suggests that user training or system redesign might be necessary to enhance ease of operation.

Next, we assessed the system's assistance in easing the workload. When asked if the system could reduce harvesting time, the evenly split opinions where 40% agree, 40% disagree and 20% unsure highlight mixed perceptions about the system's efficiency. This warrants further investigation to identify factors affecting these opinions. Similarly, responses on harvesting workload are split, with equal numbers feeling it helps or does not help reduce workload, and others remaining uncertain. This inconsistency points to variability in the system's performance.

Overall, half the respondents did not favour replacing manual methods with the system, while the other half supported this idea. This lack of consensus suggests that the system may not yet offer a compelling alternative to traditional methods.

4. Conclusions

In conclusion, the automated plant tray loader system marks a valuable innovation in plant factory technology, offering potential improvements in efficiency and reducing physical load on operators. However, to fully realize its benefits, further refinements are essential to enhance its user-friendliness and practicality, ensuring smoother integration into daily operations.

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Conflicts of Interest: The authors declare no conflict of interest.

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