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Automation of Bag Feeding for Enhanced Efficiency in Mushroom Grow Media Filling Systems

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Abstract: Automation of agricultural machines is an essential thing for improving productivity, product quality, and labour efficiency. This study focuses on design, fabrication, and testing an automated bag-feeding unit to enhance the performance of the existing mushroom grow media filling machine. In the industry, small-scale machines are available for filling mushroom-growing media, but they still require manual labour to load the bags. Throughout this project, we automated that the bag feeding system includes a bag mouth opening system, gripper and moving mechanism, automated bag holder mechanism, PLC (Programmable Logic Controller) control panel, and auxiliary components. A key enhancement is the rack-and-pinion mechanism for bag holder movement and sealing of the mixing chamber for better efficiency. Performance was evaluated by over 50 feeding cycles. The average cycle duration was 73.9 seconds, with a success rate of 84%. Failures were due to conveyor issues (6%), gripper insertion failures (6%), and vacuum bag pickup failures (4%). These results indicate why we need to improve the conveyor and gripper systems in the small-scale mushroom grow media filling machine. PLC-based control and modular automation will improve scalability and adaptability for these kinds of agricultural applications. As future work, we will address failure modes, optimize components, and explore system adaptation for other farming protocols, advancing precision agriculture through cost-effective methods and trying to achieve a fully automated small-scale mushroom-growing media filling machine.

Keywords: Bag feeding unit, Bag holder, Filling machine, Mushroom.

1. Introduction

In the past few years, the mushroom sector in Sri Lanka has grown significantly, increased consumer demand for fresh mushrooms and an exciting potential for export markets. Mushroom farmers are struggling with an enormous disturbance during this expansion due to the lack of automated processes involved in their cultivation [1]. In Sri Lanka, most of the machines employed for filling mushroom grow bags are still manually bag fed, which creates high labour costs, time-consuming and task-induced fatigue in labourers, resulting in inconsistency in bag fillings. It is also affecting the quality and quantity of mushroom cultivation improvement. Considering the backbreaking task of manual bag feeding to the machine, it is a highly inefficient activity for its attendants [2] [3]. Hence, we have proposed innovations to ease and improve the production rate of mushroom cultivation in Sri Lanka. The introduction of any grow bag feeding unit represents a significant opportunity to address these problems and revolutionize farming methods concerning mushroom activities in the country.

We aim to produce an automated bag feeding unit for the existing small-scale mushroom-growing media filling machine. This will enable growers to increase efficiency, minimize operational input costs, and thus maximize their profit. Using a collaborative effort for research, design, and prototyping, we ultimately aim to offer a feasible and cost-effective solution that tackles the challenges specifically faced by mushroom growers in Sri Lanka [4] [5]. It hopes to achieve innovation and transformation in agriculture, thus ushering in growth and change in the sector. Mainly, we continue and make testing of the project with a width of 5”- 7” and 12”- 15” length polyethene bag with 0.07 – 0.08 mm thickness. These are the common range of dimensions of polythene bags, which are mostly used in small-scale mushroom cultivation in Sri Lanka. The conventional form of farming has transformed due to the use of automation and efficient technologies.

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It has quickly changed the landscape of agriculture. Mushroom cultivation is by far one of the main growth sectors of innovation development [6]. This process is labour-intensive and requires high precision to guarantee regular harvests and the quality of the product. The integration of automated systems into mushroom cultivation processes has the potential to substantially reduce labour requirements, improve scalability, and improve operational efficiency [7]. This paper investigates the design, implementation, and performance evaluation of an automated bag feeder device that has been integrated into a small-scale existing mushroom growing media filling machine. Mushroom cultivation consists of several complex steps that include substrate preparation, bag filling, sterilization, inoculation, and incubation. Among these steps, bag filling is the most laborious one and demands careful manual distribution of the grow media throughout the bags [8]. Traditionally, this task was done either manually or partially automatically. The manually operated systems have shown themselves to be irregular and not efficient. Automating the bag feeding step will help with speed, error reduction, and improved productivity. In rethinking their possibilities, we set up an automated bag feeding unit that consists of highly developed mechanical, electronic, and control system components.

It consists of several systems, including the grow bag mouth-opening system, the gripper and moving device, the bag holder-based moving device, the PLC Control Panel, and secondary equipment such as conveyors and mixing units, which work in conjunction to enable smooth operations [9]. Some of the distinguishing features of this system could include a rack-and-pinion mechanism for automation of the bag holder movement and a sealed mixing chamber that improves hygiene and process stability. This modular setup allows for the integration to complement already existing small-scale mushroom-growing media filling machinery and fits varying scales of orders quite easily. The Grow Bag Mouth Opening System is the main part devoted to the exact handling of grow bags [10] [11]. The device consists of a NEMA 23 motor (National Electrical Manufacturers Association), vacuum pump, suction cups, and a horizontal moving structure to grip the grow bags and demand for their opening before being filled. Also, the 'moving mechanism' for the Gripper sounds good with NEMA 17 and NEMA 23 Motors, linear bearings, and screws enabling controlled and proper motion of Gripper arms. The Bag Holder Moving Mechanism consists of a rack-and-pinion setup that allows for smooth and uniform movement of bags through the filling station. Control is made through a PLC architecture providing a centralized control to coordinate all subsystems of the machine. All control functions for the task are performed using the PLC and include the following necessary motor drives, power supply and a user interface. The PLC was then incorporated to interact with the command and offer centralized coordination for controlling all subsystems within the machine. The PLC allows for system monitoring and control in real time, with motor drives, power supply, and so on, interfaced with a Human-Machine Interface (HMI) for user monitoring.

The circuit wiring incorporates stepper motors, limit switches, and TB6600 stepper motor drivers to achieve exact programmed movements. In effect, this control system enabled accuracy and high-level repeatability of the system in operations. In the pilot run, 50 automated cycles were tested to evaluate the efficiency of the incoming bag feeding operations. Key performance indicators such as cycle times and success rates of movements were noted to assess the system’s efficiency and dependability. The overall success rate was 84%. Although the results were good, certain areas must be improved. Failures in conveyor transfer, insertion of the gripper, and pickup of the vacuum bag accounted for 16% of cycles, indicating the need for both mechanical and the programme-based improvements. The outcomes of this work extend way beyond mushroom farming. The use of flexible design combined with advanced control systems in the automatic unit means that it can be modified for other farming processes, especially those involving accurate handling and filling operations. To reduce dependence on physical labour for better operating stability, the system fits in with the more general objectives of sustainable and cost-competitive farming.

This paper is structured in the following manner-the next section elaborates on the system's design and its components. The experimental setup and data evaluation methodology have been elaborated upon next. Test runs are presented and analysed with an emphasis on investigations into those failures that occurred and on what can be done to better the system. Finally, broader implications of this work and pathways for future research are discussed. The most important development in the automation and simplification of mushroom growth is creating an automatic bag feeding unit. By addressing these shortcomings in the bag-filling process for output, reducing costs, and making them repeatable, mushroom farming solutions can be improved. This provides valuable insight into farming technology and offers context that can support further innovation in the future.

2. Material and Method

2.1 Fully Developed Machine

As seen in Figure 1, the fully developed machine and its parts have several automatic components that operate efficiently and accurately to fill the mushroom grow bag.

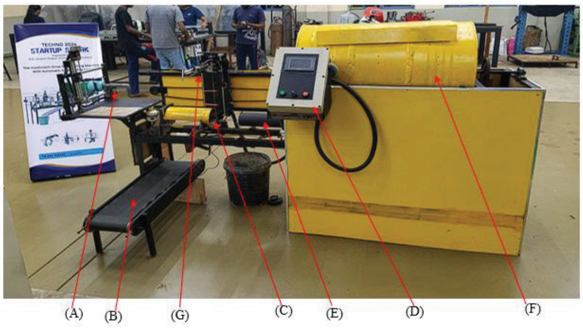

Figure 1 - Fully developed machine and its parts

The grow bag mouth opening system (A) opens the bag and keeps it in position to make it easier to fill, thereby reducing handling. The gripper & moving mechanism (B) will grip and move the bags by virtue of smooth functioning. The bag holder automate moving mechanism (C) will provide a gentler distribution of the grow bags for proper positioning, correction of errors, and avoidance of mistakes. The plc control panel (D) is the master controller that can control the entire process performance, monitoring it, and real-time automating control over machine functions. The grow media outlet pipe with screw conveyor (E) evenly discharges the substrate and allows enhanced control over integrity in the process of filling while preventing material loss. The grow media mixer (F) will ensure the appropriate mixture of substrate components, thus establishing the basis of the work quality during the operation of filling. The conveyor (G) moves filled grow bags to the next stage of operation without causing bottlenecks. All these parts integrate and thus increase productivity while decreasing the reliance on labour input, ensuring a higher degree of automation into mushroom farming. Figure 1 shows, machine parts list and identification letters.

2.2 Grow Bag Opening Mechanism

This automatic system is meant to easily open bags used for growing plants, such as mushrooms or other hydroponic foods. It improves the process of making bags for filling with growing medium by instantly opening them, saving time and lowering the need for human operations. The bags are opened by motors and levers working together [12]. The motors move the gripper, and the levers open the bags softly. This makes sure that the bags are open wide enough to hold them firmly. This makes it easier to fill the bags with dirt, nutrients, or other things for plants without spilling or losing anything. As shown in Figure 2, this machinery is especially useful in farming activities where large numbers of grow bags need to be made quickly and successfully [13]. By employing such a system, growers may improve efficiency, maintain the same standards in bag preparation, and focus on other aspects of plant cultivation, making it a practical solution that significantly contributes to operational productivity by simplifying the initial stages of developing grow areas.

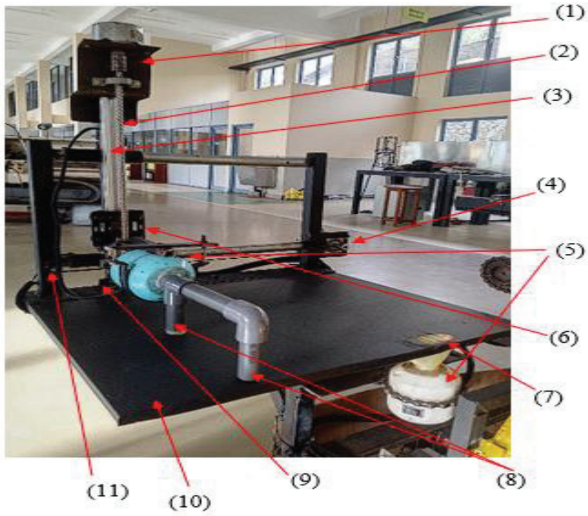

Figure 2 - Grow bag mouth opener

In Figure 2, the motor shaft coupling (part 1) is important for connecting the motor shaft to the lead screw (part 2), as it will ensure that it transmits rotational force from the motor shaft without slippage while absorbing misalignments and thus reducing mechanical wear. The lead screw (part 2) is another piece, having a threaded component of 8mm and a threaded part that converts rotary motion into linear motion, which makes the positioning of mechanical components very accurate. The aluminium V profile (part 3) supports the structural guide responsible for aligning the movement of V configuration components. The NEMA 23 motor & timing belt (part 4) gives a high torque driving force for the greater load and ensures synchronized and accurate movements across the system. The vacuum pump (part 5) gives the pulling power to hold things in place by creating a pressure difference, while the vacuum vent (part 7) assists in regulating the air pressure inside the pump for greater precision. These suction cups (part 8) make use of this vacuum to effectively lift or hold onto things. The V slot gantry plate (part 6) enables the combined horizontal and vertical motion along with the metal profile, enabled by movable load-carrying track wheels (part 9) for smooth movement of the platform. The polythene bag stage (part 10) offers firmness for gripping bags during filling, while the horizontal movement structure (part 11) includes mechanical systems, such as belts or lead screws, that provide controlled and accurate horizontal motion.

2.3 Gripper & Gripper Moving Mechanism

In this setup, the Gripper & Gripper Moving Mechanism is required to grasp and move an object with accuracy and stability [part 15]. It utilizes a mechanical structure of parts such as NEMA 17 (part 1) motors, lead screws (part 4), as well as a rigid gantry structure. These gripper arms incorporate gripper fingers (part 7) that adjust according to the object it needs to grip, while the NEMA 23 (part 9) motors give the right amount of power to grip any object firmly [14]. This action is coupled with left-right lead screws (part 4) and lead screw nuts (part 5) to translate the rotational motion of the motors into linear motion, either extending or retracting the gripper along the smooth guide rods (part 8). If these rods are used in conjunction with linear bearings (part 10), not only will the motion be accurate, but jarring movements that could interfere with the handling process will be minimal. The entire assembly is supported on an aluminium V profile (part 3), which acts as a track, and moves the V slot gantry plate (part 2) that forms the movement structure. This kind of setup provides a controlled and stable environment for the gripper, making it a reliable part of the machinery for applications such as assembly and packing as shown in Figure 3.

NEMA 17 (part 1) works as a stepper motor, giving exact turning movement to drive devices. It is often used for positioning via computer control in robotic systems [15]. Electrical bursts are turned into individual mechanical moves, usually moving a lead screw (part 4) or belt system. The V slot gantry plate (part 2) fits a fixing base and structural support for different machine components, allowing smooth movement along the aluminium V profile (part 3). Interfacing with movable load-carrying track wheels (part 9) or bearings, it enables linear motion along metal shape tracks. As a structural rail, the aluminium V profile (part 3) provides a stable track for the gantry plate and other moving components. Its V-shaped design ensures coordinated and stable movement of rollers or wheels placed on the gantry plate [16]. The left-right lead screw (part 4) further improves accuracy by turning rotational motion into linear motion, allowing exact placement of components along its path. The matching lead screw nut (part 5) connects with the screw, ensuring controlled linear motion without turning as it moves along the screw’s length. Both arms have movable grippers (part 6), which improve the system's ability to move materials because they can grab and move items needed for automatic processes. When motors or gas systems are activated, these arms can tightly grasp and release items. The gripper fingers (part 7), designed to fit different shapes, securely hold objects. They are often enhanced with coatings or special designs for better grip. The smooth guide rod (part 8) provides an exact path for linear bearings (part 10), allowing them to move with minimal resistance, ensuring smooth linear motion.

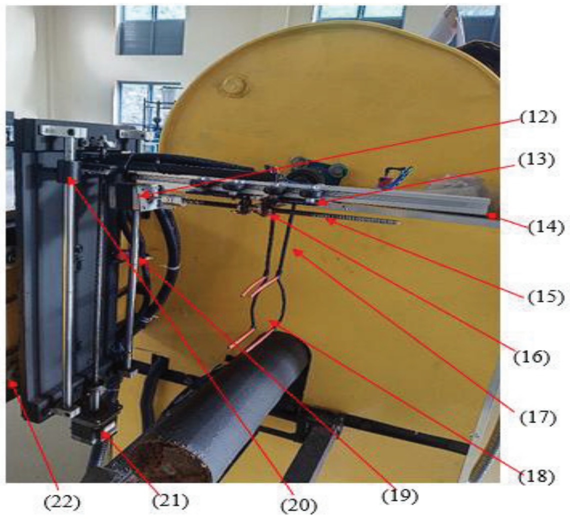

Figure 3 - Gripper & gripper mover

As shown in Figure 3, the NEMA 23 (part 9) stepper motor offers more power than the NEMA 17 (part 1), enabling it to drive heavier or more resistant loads [17]. Linear bearings (part 10) allow loads to move along a straight line with precision. The horizontal movement structure (part 11) combines structural elements, bearings, and drive systems like belts or screws to provide controlled movement of connected parts across the machine. The rear view of the gripper mover machine part experiments, with both structural and functional components that give good and stable motion to the bag handling process, as illustrated in Figure 4. The movable system balance wheel (part 12) performs an important function of providing stability and preventing unwanted tilting and misalignment during its operational phases. To this, the movement mechanics supported by U Groove Wheels (part 13) guide the system along its designated path while minimizing friction and ensuring motion with precision. The chain drive system, as detailed in Figure 4, is firmly secured by a Fixed Chain to the Structure (part 14), providing a constant transfer of motion without causing slackness. Thus, the free-chain end (part 15) exhibits a little motion ability towards the free slide drive mechanism. Finally, a wheel guide made up of a metal rod (part 16) confines all the moving parts to a definite path during working, preventing deviation of operation, and increases the working efficiency of the gripper system. All these qualities combine to grant the machine stable accuracy in the placing of grow bags without much human intervention. Thus, the free-chain end (part 15) exhibits a little motion ability towards the free slide drive mechanism. Finally, a wheel guide made up of a metal rod (part 16) confines all the moving parts to a definite path during working, preventing deviation of operation. It increases the working efficiency of the gripper system. All these qualities combine to grant the machine stable accuracy in the placing of grow bags without much human intervention.

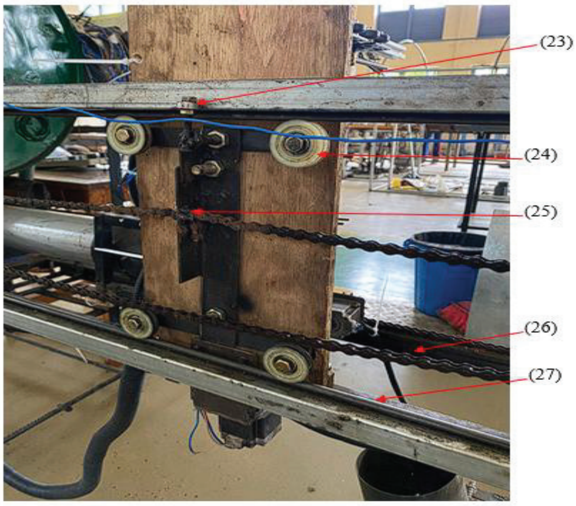

Figure 4 - Back view of the gripper mover

2.4 Bag Holder Automate Moving Mechanism

This is the 'Bag Holder Automate Moving Mechanism' in the layout and is an essential component. It will facilitate the process of bag filling in the automated system. The positioning of the growing bag holder (part 28) is by NEMA 23 (part 29) motor movements and other control systems to achieve perfect positioning. It can also position the bag holder beneath the dispenser or the filling nozzle, and when the bag is full, it can then move it aside again. This automation guarantees that bags are filled in even and uniform manner and with efficiency and in the process reducing manual work. It provides the means for the mechanism to efficiently and quickly handle the bags, which allows for increasing the efficiency of the production line. Therefore, the indispensability of the automated filling is demonstrated as in Figure 5. Automation helps with uniform and even filling of bags with great efficiency while reducing manual labour. Automation also provides the means for this mechanism to move bags easily and quickly, thus increasing efficiency along with the production line.

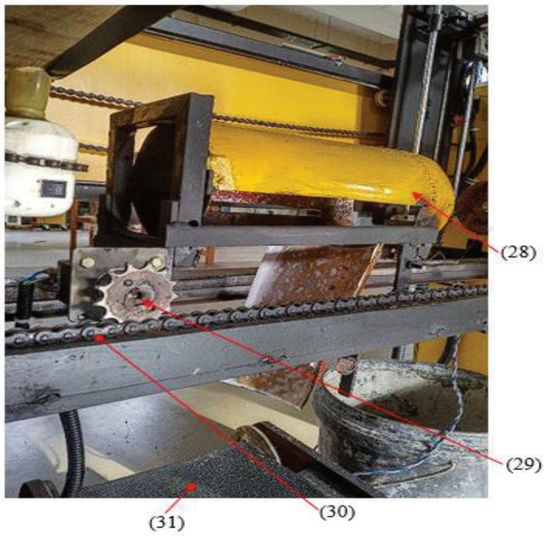

Figure 5 - Bag holder automate mover

The last feature is the rack-and-pinion mechanism that consists of metal chains (part 30), which plays a key role in transforming a rotary motion to linear, thus giving smooth and accurate guidance to the bag holder [18]. Lastly, the filled-bag conveyor (part 31) removes the filled bags from the system, further integrating automation into the process, thus making it more efficient.

2.5 PLC Control Panel

System Control Panel (part 32) is the intermediary of an automated machine. The general strategic goals contain essential components to steer and coordinate procedural activities. Within this panel, the Programmable Logic Controller (part 33), which is the PLC, serves as the controller [19]. It receives signals from limit switches in addition to carrying out instructions as per written code. Motor drives (part 34), which are also located within the panel, act on the signals received from the PLC (part 33) to control the strokes and force of the machine motors. It aids towards development of correct mechanical activity. Further, the power supply (part 35) unit in the panel changes and controls electrical power to the correct range for all elements and protects them from electrical problems. This panel just aligns all principal functions of the machinery and allows making it work effectively and generate no hazards. It makes a part and parcel in any Automated System Setup. In fact, it is the control room for automated equipment. It has all the basic parts used to actuate and regulate the functioning of the machine. Figure 6 shows PLC control panel's part name and numbers list.

In this project, we automated the bag feeding unit in a small-scale mushroom grow media filling machine by using a Programmable Logic Controller (PLC) system. Currently, we are developing a ladder program to control the system. We are utilizing a Mitsubishi FX3U-48MT PLC card as the controller of our setup. Additionally, the system incorporates various limit switches, stepper motors, and TB6600 motor drivers to achieve precise and reliable automation.

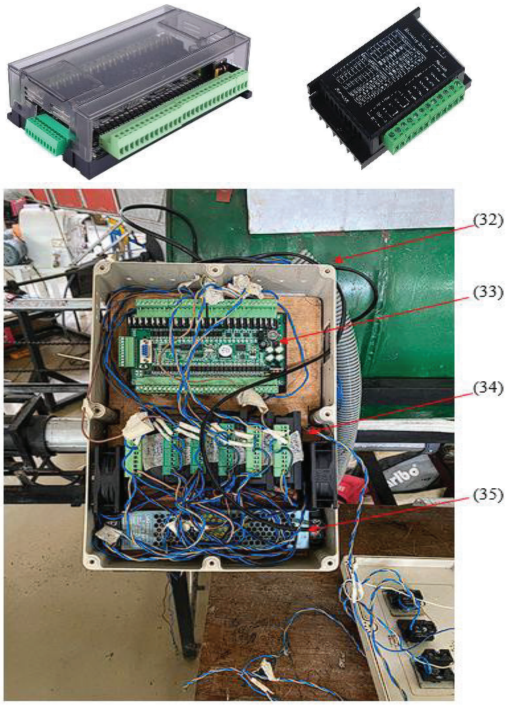

Figure 6 - PLC control panel

2.6 Composite Circuit Wiring of the Fully Developed Machine

The motion mechanisms are driven by Stepper Motors (part 37), driven by TB6600 Stepper Motor Drivers (part 38), to enable precise positioning and smooth movement as mentioned in below Figure 7. The positioning of the stepper motors is managed along with Limit Switches (part 36) to determine where the travel must stop without running over. The overall control of the Bag handling system, which is vacuum based, is enabled with the help of Vacuum Units (part 40). These units provide vacuum suction to pick up and place the bags as indicated in Figure 7. Furthermore, the Mixing Motor (part 42) is included in the system that controls the mixing of the grow materials to obtain a uniformly mixed substrate before filling. The wiring layout thus formulated optimizes the entire working of the system with minimum errors and increased reliability of the automated system. The circuit of this automated mushroom grow bag filling machine has been designed in such a way as to allow for its precise manipulation and co-ordination of all its components. The circuit receives its power through a 24V Power Supply unit (part 43), which generally powers the PLC unit (part 39), stepper motors, and other connected components. The PLC unit (part 39) acts as a centralized control to follow inputs and outputs, which regulate the operations of the machine [20]. It communicates with HMI unit (part 41) for monitoring and control of various functions provided through an interactive interface to users.

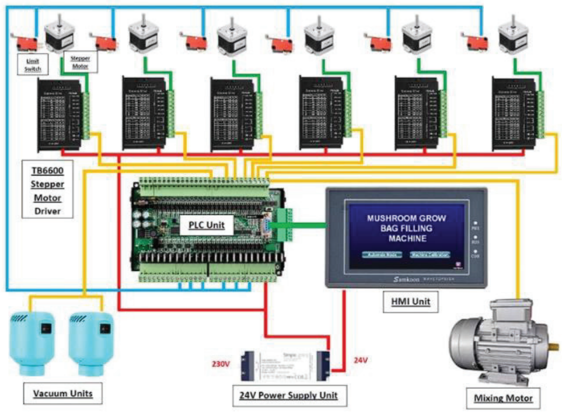

Figure 7 - Circuit wiring of the fully developed machine

3. Results and Discussion

The circuit of this automated mushroom grow bag filling machine has been designed in such a way as to allow for its precise manipulation and co-ordination of all its components. The circuit receives its power through a 24V Power Supply unit (8), which generally powers the PLC unit (4), stepper motors, and other connected components. The outcome yielded valuable data on cycle time, success of each movement along the production line, and improvement opportunities. The operational cycle of the machine consists of an orderly repetition of a set of 17 related motions grouped into four main categories. They are pick-and-place operations-mechanisms, bag-opening mechanisms, gripper movements, and filling operations. These stages were performed with little human intervention, suggesting that the mushroom-growing operation has a huge potential for automation. Such actions carried out by the pick-and-place mechanism included striking, lifting the polythene bag using a vacuum, and then moving it horizontally towards the vacuum vent. Instead of bringing it back for another cycle, the vacuum was returned to its original position. The bag opening mechanism correctly used vacuum to place and configure the grow bags so that the gripper could stab and hang it in place ready for filling. The movements of the gripper exhibited the precision in engineering that the machine was built for: gripper insertion and jaw expansion, horizontal travel to the inlet pipe, and the final vertical alignment of the bag were of high importance. Such movements ensured that the grow bag was positioned correctly for filling, dramatically minimizing errors. The filling operations involved forward and backward movement of the bag holder, transfer of filling media, and final movement of the conveyor that takes filled bags for further processing. So, below Table 1 shows result of each individual movement times.

Table 1 - Results with Individual Movement Times

Cycle	Vacuum Downward (S)	Vacuum Upward (Carry) (S)	Vacuum Horizontal(S)	Vacuum Down to Vent(S)	Vacuum Up Vent(S)	Gripper Insertion(S)	Gripper Jaws Expansion(S)	Gripper Horizontal to Inlet(S)	Gripper Vertical Down(S)	Gripper Insertion to Inlet(S)	Bag Holder Forward(S)	Filling(S)	Bag Holder Backward(S)	Conveyor Movement(S)	Total Cycle Time(S)
1	2.4	2.9	4.0	2.6	2.8	4.2	8.4	4.7	3.9	3.0	5.5	7.1	6.3	3.0	73.4
2	2.6	2.7	4.1	2.5	3.0	4.4	8.6	4.9	3.7	2.8	5.3	6.9	6.1	2.8	73.8
3	2.5	2.9	4.2	2.4	2.9	4.3	8.5	4.8	3.8	2.9	5.4	7.0	6.3	2.9	74.0
4	2.7	2.8	4.0	2.5	2.7	4.4	8.3	4.9	3.9	2.8	5.6	6.8	6.0	3.1	73.9
5	2.6	2.7	4.1	2.6	2.8	4.3	8.5	4.7	3.8	2.9	5.2	7.1	6.2	2.9	73.9
6	2.4	2.8	4.3	2.5	3.0	4.2	8.6	4.8	3.7	2.8	5.5	6.9	6.4	3.0	74.2
7	2.5	2.9	4.0	2.7	2.9	4.1	8.4	4.7	3.9	3.0	5.4	7.0	6.2	2.8	74.4
8	2.6	2.8	4.1	2.6	2.7	4.3	8.5	4.9	3.8	2.9	5.6	7.2	6.3	2.9	74.6
9	2.5	2.7	4.2	2.5	2.8	4.4	8.6	4.8	3.7	2.8	5.3	7.1	6.1	3.1	74.4
10	2.6	2.9	4.3	2.4	3.0	4.2	8.5	4.7	3.8	2.9	5.5	6.8	6.4	2.9	74.2

Consequently, the average overall cycle time of the machine was about 74 seconds, with some fluctuations across some cycles. Major contributors to cycle times were vacuum-downward motion (about 2.5 seconds), gripper insertion (4.3 seconds on average), and bag filling (seven seconds on average). The longest of these single movements was gripper jaw expansion, which took on average very similar times of eight-and-a-half seconds across cycles. With all these durations throughout the times of operation, the performance of the machine, nonetheless, remained steady to ensure precision and repetitiveness of operation.

3.1 Success Rate Analysis

During the tests, 42 out of a planned 50 operational cycles were successfully conducted, resulting in an overall success rate of 84%. Figure 8 shows that it performs reliably well. Due to the high success percentage, we are able to ensure this modification will address the problem and overcome the manual bag feeding time consumption, as well as the ease of the labour for its task. However, certain modes of failure were sporadic. Conveyor transport for filled bags failed three times, the gripper insertion into growing bags failed three times, and the vacuum system failed to pick up the grow bag twice. Although these failures were few, they surely underscore possibilities for mechanical improvement and programming adjustments.

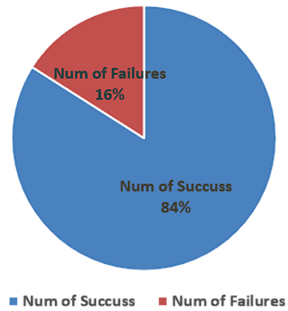

Figure 8 - Success rate analysis

3.2 Failures by Movement Type

The reliability of the machine's automated components has been critically evaluated, and the failures observed highlight the need for further improvement. The conveyor may have failed to transfer the filled bags from time to time due to some alignment or tensioning of the gripper mechanism. It appeared to have failed to insert into the grow bags, which demonstrates the need for more rigorous calibration and precision of deployment.

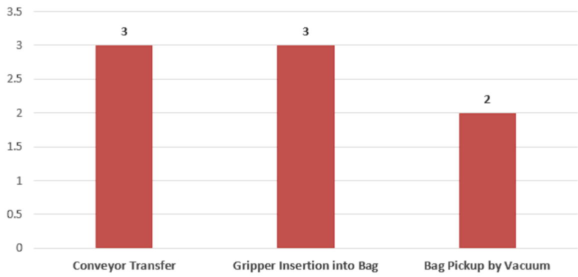

Figure 9 - Failures by movement type

The vacuum system's failure to pick up bags may have been attributed to the fact that they varied with the bags in terms of the type of material and that the vacuum pressure varied from bag to bag. Using mechanical modifications and systematic programming changes, all these issues could be bathed in more light concerning boosting the machine's performance. According to Figure 9, the analysis of failures during the operational cycle of the machines gives critical pointers for work areas for future refinements. In the observed 50 test cycles, three failures were reported on conveyor transfer, where the filled bag could not be successfully transferred to the next stage. Similarly, three had problems with the gripper working inside the bag, where the gripper did not position itself properly or conduct a full insertion, which affected the proper positioning of the bag for the filling. Two cycles also failed during the vacuum system, where the vacuum mechanism did not pick up the bag, or, in other words, lift it perfectly. At this point, we have identified precise points of failure that require focused enhancements to mechanical components and programming logic. For the conveyor systems, working on alignment mechanisms and better sensor implementation would help avoid transfer problems. Gripper insertion failures can be solved by optimizing the precision of the gripper's motion and refining the timing parameters for alignment. Improving the vacuum system's suction and positioning could create issues related to bag pickup. Although the machine shows considerable success rates, addressing challenges is critical to increase reliability, decrease downtime, and improve operational efficiency in the future development of the machine.

4. Conclusions

Automating the farming process is important to meet the needs of increasing efficiency, scalability, and sustainability in modern-day farming. This study presents the design, fabrication, and testing of an automated bag-feeding unit integrated into an existing mushroom grow media filling machine. The system was developed using a grow bag mouth opening mechanism, a gripper and moving mechanism, an automated bag holder movement mechanism, and a PLC-based control panel. These results demonstrate that advanced automation technologies can be effectively integrated into agricultural machinery, while the modular system design ensures ease of operation with minimal manual intervention. Its performance feedback was collected after 50 cycles of operation, which yielded an average of 73.9 seconds for each cycle and an 84% success rate. Some cycles of operation failed, and the failure analysis provided lessons for further improvements on aspects such as conveyor transfer, gripper inserting, and vacuum pickup operations. All these findings showed the need for continuous mechanical and programming improvements to enhance system reliability and performance.

This work reveals that the role of technology within agriculture extends beyond the immediate confines of the growing of mushrooms. Modular and adaptable, this system can fit various other applications in agriculture or crops needing precise handling and filling operations. Larger-scale automation promises to take away the dependence on human labour while also responding with greater permanence to specific path outputs. Therefore, such technology illustrates the ideals of sustainable farming and suggests additional advances for precision agriculture. To summarize, the findings of this study will support the belief that an automated bag-feeding unit will be revolutionary for the development of mushroom-growing by saving the time of labourers and reducing the fatigue of repetitive activities of manual bag feeding in the small-scale mushroom grow media filling industry. Future work will focus on improving the failure points identified in this study as well as developing a complete automated small-scale mushroom substrate filling equipment from this analysis.

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