Automatic Offline Program Generation in Robotic System for Palletizing Rice Bags

Kun-Chieh Lin*, Meng-Cheng Liu , Kai-Chieh Tsao

***Abstract*—The stacking of finished products is an important stage of automation process in the manufacturing industry. In order to improve the traditional stacking process that relies majorly on manual labor, various fields in the industry have gradually introduced automated robotic arms into stacking operations. However, the diversity in dimensions of the bags and the pallets often makes it difficult for the operator to set up and adjust the robot parameters and positioning for stacking. Moreover, the arrangement of the soft bag is different from that of the hard boxes due to its flexibility and non-uniform dimensions, which makes it difficult to adjust the robot positions and parameters. This paper introduces an automatic stacking system for soft bags that can be used with medium to large payload robot arms for faster stack configuration and robot code generation. Automatic stacking calculations are performed for different soft bag sizes and pallet specifications to produce the best arrangement and combination, and the stacking orientation in different layers are optimized for stability and feasibility of stacks to achieve longer heights. Finally, the generated robot trajectory is imported into the robot arm controller, and the stacking can be performed automatically while reducing the technological and programming burden from the factory operators.**

***Index Terms*—Industrial Automation Systems, Manufacturing automation, Robots.**

I. INTRODUCTION

Numerous automated systems are now equipped with robotic arms to enhance work efficiency. These robotic arms can be broadly categorized into anthropomorphic robotic arms, collaborative robotic arms, and industrial robotic arms. In both agricultural and industrial production, robotic arms find widespread applications in the handling and stacking of various materials. These materials include a diverse range, including cement, fertilizer, grain, flour, animal feed, building materials, and chemical raw materials.

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According to the annual report of the Council of Agriculture, Executive Yuan Taiwan (AD 2018-2022), the average annual rice yield is approximately 1,763,151 metric tons. However, an aging agricultural population coupled with the increased inclination of younger individuals towards the technology industry has created a conundrum. The rice milling industry, particularly, has been unable to augment its output due to a scarcity in the workforce. This shortfall presents a substantial challenge that, if unaddressed, may impact the long-term sustainability of the industry.

The orderly stacking of bags using a robotic arm hinges upon two crucial elements: (1) the stability of the grippers, and (2) the calculation of an efficient arrangement of bags on a pallet. In the domain of gripper mechanism design, Tanner et al. (2001) presented a pioneering mechanism design competent at handling various types of agricultural products [3]. Moreover, in industrial applications, Ali et al. (2011) designed a smart gripper equipped with vision sensors, and this gripper consists of two fingers with integrated force sensors to regulate the applied force [4]. Additionally, Hatano's (2007) study on an advanced autonomous rescue robot utilized force sensors on the robot's fingertips to mitigate debris disintegration during operations [5].

Moving on to the modern agricultural context, Han et al. (2016) proposed a practical jig design for soft bags, which is capable of integrating seamlessly with conveyor belts. This facilitates horizontal retrieval and supporting actions, thus minimizing bag wear [6]. Upon reviewing the aforementioned literature, it becomes apparent that ensuring the stability of grippers demands consideration of the specific characteristics of the materials being handled. Nevertheless, none of these studies adequately address the impact of robot arm speed and motion posture on the gripping process. This aspect is significant as high-speed operations of the robotic arm might pose a risk of material dropping due to insufficient clamping tightness and fixation. Therefore, this area requires further research to enhance the efficiency and safety of robotic arm operations.

The construction of the stack system is a critical aspect that warrants attention. In recent years, there has been a growing body of literature dedicated to exploring the automatic recognition of objects and the implementation of robotic arms equipped with 2D and 3D vision technology for efficient material stacking [7-10]. Notably, researchers have proposed innovative approaches, such as the utilization of the Region Growing method and Progressive Probabilistic Hough Transform (PPHT), to tackle interference factors that may arise due to varying lighting conditions. These methods have been extensively validated, confirming their robustness and feasibility [11]. However, it is important to acknowledge that in complex agricultural environments, additional challenges arise. Factors such as the presence of dust particles and the intensity of light play a crucial role in determining the accuracy and reliability of visual positioning systems. These environmental conditions can significantly impact the performance of the stacking system and present challenges for on-site personnel responsible for its maintenance and repair. Addressing these challenges and developing effective strategies to mitigate their effects is essential for ensuring the optimal functioning of the stack system in agricultural settings.

Numerous studies have examined the use of object feature detection algorithms as tools for understanding environmental compositions and extracting relevant data [12, 13]. This procured data is then employed in computer simulations, serving to facilitate learning within the robotic system [12, 14]. This method offers considerable benefits, particularly in the development of stack software for robots, by enabling the offline calculation of a multitude of potential stack arrangements [15]. Notably, this approach eliminates the need for complex imaging or computer systems, thus simplifying the implementation process and enhancing efficiency.

Presently, the rice milling industry employs offline stacking software, the primary focus of which is to collect data concerning the dimensions of pallets and the commonly employed arrangement patterns for rice bags [12, 13]. This gathered information is subsequently integrated into the software during an initial setup phase. Although this methodology is adequate for the current requirements of the industry, it falls short when confronted with the need for a more diverse range of stacking methods [14].

In response to this, the present research paper introduces a novel offline program solution that utilizes a rectangular bin packing and 3D arrangement algorithm. This program automates the process of calculating the optimal arrangement and combination of rice bags and generating robot code, thereby increasing the efficiency and ease of the stacking process. The intended outcome of this research is to provide a more efficient and manageable solution for the stacking task within the rice milling industry, with potential implications for enhancing productivity and reduce manual programming from robot arm automation solutions.

The structure of this manuscript is organized as follows: Section II details the design and development of the robotic arm stacking system and the grabbing mechanism. Section III elaborates on the 2D and 3D rectangular spatial packing method (RSPM) implemented for rice bags. In Section IV, we discuss the results derived from the application of this system and its relevant scenarios. Finally, Section V provides the conclusion of the study, summarizing the main findings and their implications for the field.

II. Robotic Arm Stacking System

This study utilizes the Yaskawa Motoman-MH180-120 model robot arm stacking system, which has a maximum load handling capacity of 120 kg. The system is furnished with a robot arm gripper, specifically designed for handling rice bags, and conveyor equipment for positioning. The pallet placement region is configured to accommodate pallets with dimensions up to 1500 x 1500 mm, offering flexibility in the stacking system by catering to a variety of pallet sizes frequently used in the industry. Figure 1 provides a detailed representation of the overall stacking system architecture.

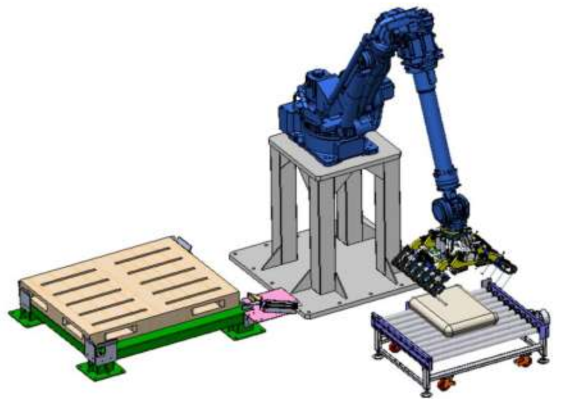

Figure.1. Robotic Arm Stacking System

In an earlier implementation at a rice factory, the gripper structure proposed by Han et al. (2016) was adopted, as shown in Figure 2. However, this design displayed four significant shortcomings:

1. The swift movement of the robotic arm resulted in the slippage of rice bags.
2. The cautious withdrawal of the fork during stacking, to avoid damaging soft bags, reduced the efficiency of the process.
3. The horizontal withdrawal design of the mechanism constrained the workspace.
4. The grabbing mechanism failed to effectively align with the stack destination's center point, leading to inconsistent arrangements of the rice bags.

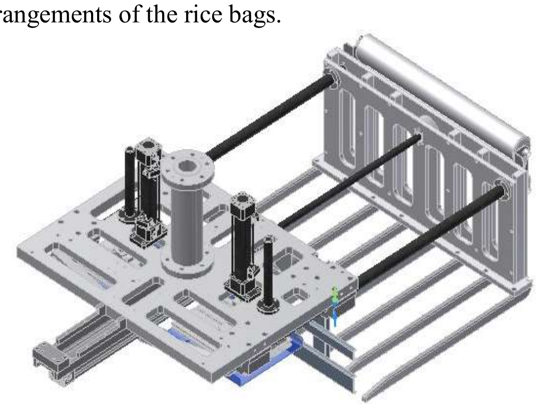

Figure 2 Illustration of the Grabbing Mechanism design proposed by Li Han et al. (2016).

As shown in Figure 3, the gripper mechanism developed in this study has several key advantages over the previous design:

1. The gripper's design enables precise control over the degree to which its jaws open and close using pneumatic cylinders. This versatility allows it to adapt to rice bags of different sizes and even irregular shapes.
2. This mechanism ensures rapid alignment with the stacking center, contributing to the efficient stacking of the rice bags.
3. To overcome the challenge of stability during swift

movements, a pressing plate mechanism is incorporated into the gripper. This addition effectively secures the rice bag, considerably reducing the risk of unintended displacement due to external factors.

As demonstrated in Figure 4, the gripper mechanism designed for this research was successfully implemented on the Yaskawa Motoman robot for stack testing. The rice bags used for testing had a weight specification of 30 kg and dimensions of 520x370x50 mm.

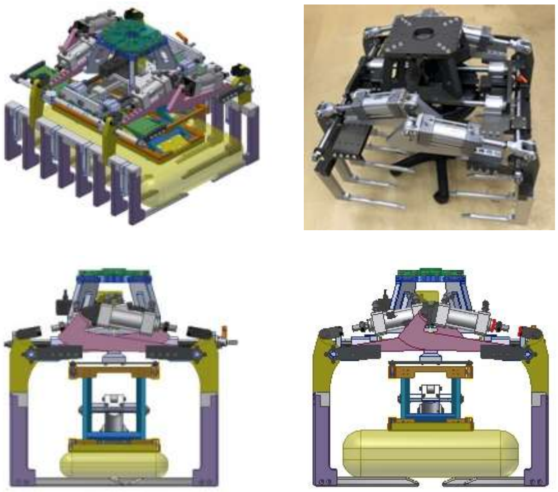

Figure 3. Design of Robotic gripper

Figure 4. Depicts the application of the gripper mechanism developed in this research on the YASKAWA robot.

III. 2D- & 3D -RECTANGULAR SPATIAL PACKING METHOD FOR RICE BAGS

The development of a robotic arm system for stacking rice bags is an essential step towards addressing the complexities and inefficiencies associated with various pallet sizes and rice bag types. Traditionally, the scripting required for robotic arm operations involved specialized programmers, a process that could prove time-consuming and prone to errors. This study takes an innovative step forward by proposing an algorithmic method to automate the stacking process, thus facilitating an efficient and precise packing of rice bags on rectangular pallets. Building on the principles of the rectangular packing method, a novel calculation process for stacking rice bags is devised, as illustrated in Figure 5.

This computational stacking process begins by setting the dimensions of the pallet, followed by defining the quantity and individual dimensions of the rice bags. A list array, corresponding to the number of rice bags, is then created. The next step involves dividing the pallet area into vertical and parallel rectangles, each designed to accommodate the specific dimensions of the rice bags. A package number label is extracted from the list array, and a rice bag is allocated to the next available space on the pallet, following the principle of positioning in the bottom-left corner. The system then assesses the need for a 90-degree rotation of the bag for optimal fit. This systematic arrangement of rice bags is repeated until the entire flat surface of the pallet is fully utilized.

The incorporation of the rectangular packing method serves to streamline the stacking process, thereby enhancing the operational efficiency of the proposed robotic arm system. This method reduces the need for generating multiple scripts to cater to diverse pallet sizes and rice bag variations, provides a flexible and adaptive solution to meet the stacking requirements of the agricultural industry.

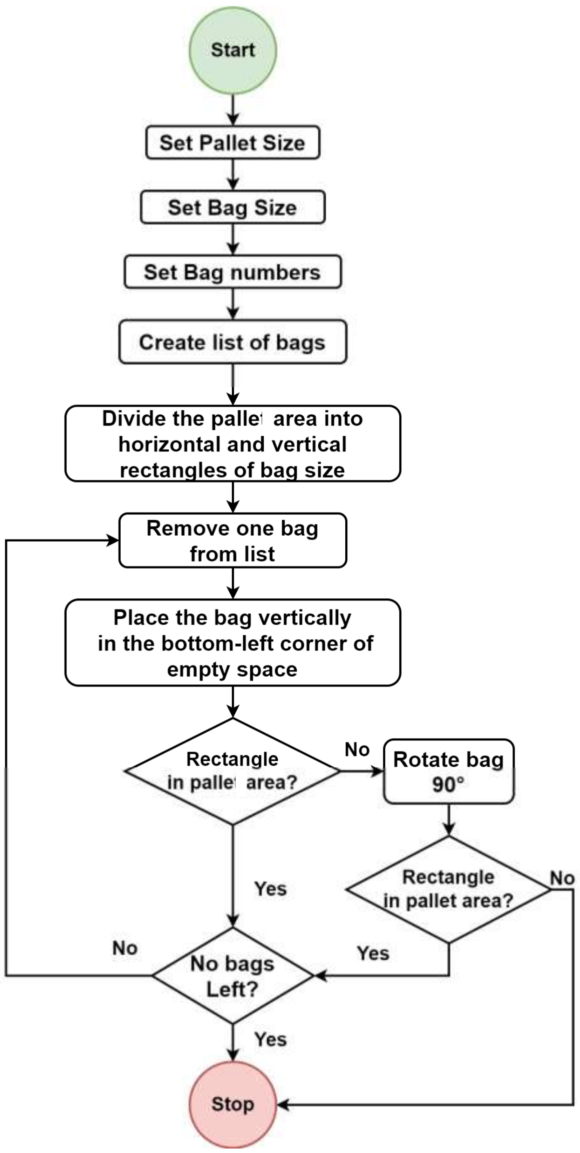

Figure. 5. Rice package stack logic flow

To exemplify the practical application of this method, a case involving 30 kg braided rice bags with dimensions of 700x480 mm and a pallet size of 1400x1100 mm is considered. Utilizing the 2D rectangular packing method, an optimal bag arrangement is calculated. The resultant configuration allows for a single layer of the pallet to accommodate five bags - two arranged horizontally and three vertically, as depicted in Figure 6. This arrangement efficiently generates the necessary coordinate parameters for each stack of rice bags.

However, the proposed stacking process takes into account considerations beyond 2D spatial optimization. To ensure stability of the stack, the arrangement of the second layer adopts a turning and overlapping method, with the upper layer bags positioned to cover different bags in the lower layer, resulting in a stable configuration.

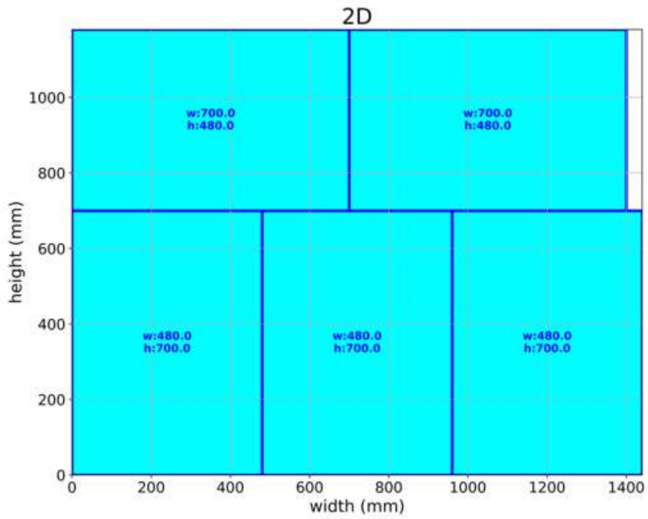

Figure. 6. 2D arrangement method for 30KG size of rice bag

By extending the 2D arrangement method to consider the height of each rice bag and the total quantity of bags, the stacking process evolves into a 3D arrangement. A simulation demonstrating this is illustrated in the figure showing 50 bags of 30 kg rice arranged in 10 layers. Throughout the calculation process, the center coordinate point for each bag's position can be generated, providing the robotic arm with precise unloading locations, as shown in Figure 7.

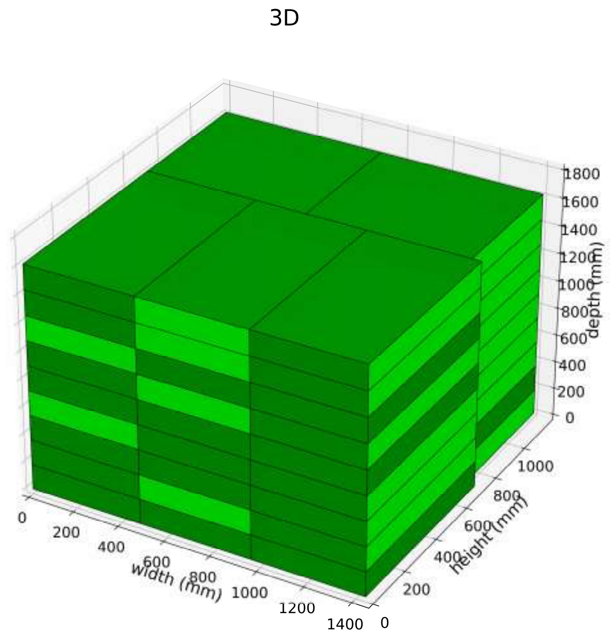

Figure. 7. 3D stacking model for 30KG size of rice bag

In typical rice milling operations, filled rice bags tend to be relatively soft, requiring a stable stacking arrangement for safe storage. The 3D stacking arrangement pattern presented in Figure 8 addresses this issue by demonstrating a 180-degree position difference between odd-numbered and even-numbered layers, an alternating layout that ensures enhanced stability for the entire stack. This ingenious arrangement successfully mitigates potential problems caused by the softness and irregular shapes of filled rice bags. The incorporation of this strategy into the stacking process provides an effective solution for handling diverse rice bag sizes and weights, thereby significantly improving the overall efficiency of storage and handling operations within rice milling factories.

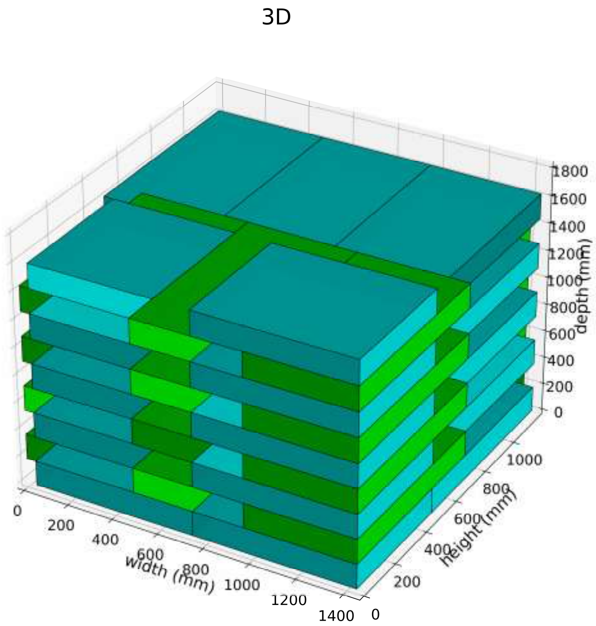

Figure. 8. The better 3D stacking model for 30KG size of rice bag

IV. Result

This study details the conceptualization and realization of an advanced offline expert system for automating the stacking of rice bags, delineated in Figure 9. The system comprises several essential components. The initial stage involves the introduction of various parameters such as pallet size, rice bag dimensions, rice bag weight, the quantity of bags to be stacked, as well as the coordinates for the retrieval and deposition of the bags. These parameters constitute the crucial variables that govern the system's functionality. Secondly, the system provides a logical visualization of the two-dimensional rectangular arrangement. This feature facilitates users with a prior glimpse into the stacking process, thereby enabling a pre-implementation assessment of the proposed arrangement.

The third component of the system offers a preview screen for the three-dimensional arrangement for visualization, complete with a guidance function that allows users to choose the most appropriate stacking method. This function fosters an interactive engagement with the rice bags and ensures an optimized stacking configuration. The final component incorporates an informational display feature that provides users with valuable insights, such as the optimal number of bags per layer for maximum efficiency and the degree of utilization of the available space. The compilation of these data supports informed decision-making.

The development of this software system brings significant convenience by eliminating the need for programmers to perform complex coordinate calculations. Furthermore, it streamlines the process of adapting to different types of rice bags, as the software interface simulates the stacking of rice bags using a robotic arm. Consequently, a substantial amount of development time can be saved.

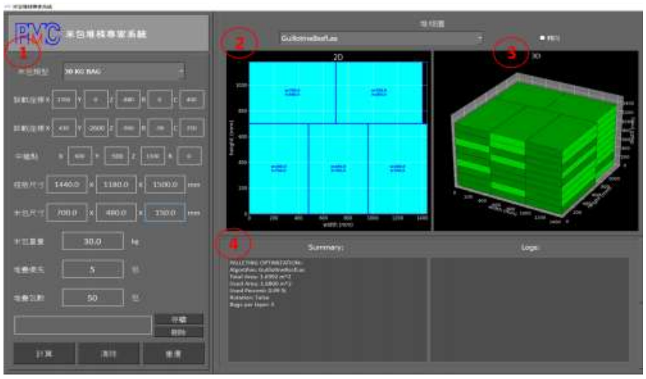

Figure. 9. Offline expert system for stacking rice bags

The generation of stacking points begins with the input of the pallet type specifications, rice bag type specifications, quantity, and stacking conditions. To validate the system's efficiency, the study incorporates a pallet with dimensions of 1440mm × 1180mm × 1500 mm and rice bags measuring 700mm × 480mm × 150 mm. Utilizing these conditions, the software calculates the optimal arrangement employing a two-dimensional arrangement logic. It provides the user with a preview of the proposed rice bag arrangement, among other pertinent functionalities. This feature enables the identification of the most efficient stacking methods.

It is noteworthy that the stacking of soft bags such as those used for rice differs considerably from stacking rigid boxes. The former necessitates an adjustment of each bag's overlap through stacking settings to achieve an optimized stacking effect, as demonstrated in Figure 10.

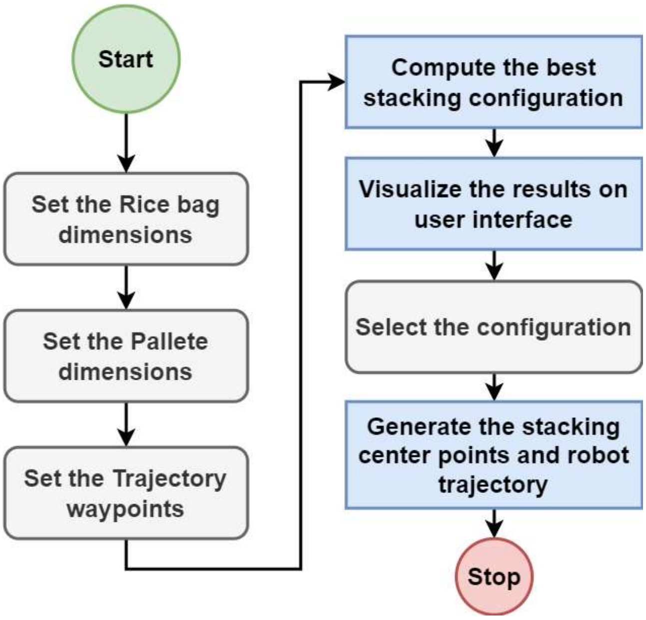

Figure 10. The process of generating stack points

The stacking point generation software displays the center coordinate point (X, Y, Z) and orientation (R_x, R_y, R_z) of each point on the interface. Should the rice bag stacking conditions require alteration, the point coordinates are immediately corrected. Each generated point can be stored as a CSV file for use in combination with robot program generation software. As showcased in Table I, the position and orientation of the first layer of the soft bag configuration are adjusted to center the rice bags. The orientation of the bags is shown as rotation around the z-axis, in conformity with the robot arm's coordinate system.

TABLE I
MASS AND CENTER OF MASS PROPERTIES OF MH12

Bag id	X	Y	Z	Rx	Ry	Rz
l1_b1	240	350	180	0	0	90
l1_b2	350	940	180	0	0	0
l1_b3	1050	940	180	0	0	0
l1_b4	720	350	180	0	0	90
l1_b5	1200	350	180	0	0	90
l2_b1	240	350	360	0	0	90

Figure 11 provides a visual representation of the employed robot arm trajectory calculation method for generating offline robot code. Through careful manipulation, we define the operational logic of the points via a specific sequence of operations, which is depicted as P2→P1→P2→P3→P4→P3→ P2. This sequential navigation pattern has been devised to ensure a smooth, efficient, and accurate transition of the robotic arm between a varieties of positions, thereby demonstrating a significant stride in improving operational efficiency. Complementing this, the software is designed to incorporate Input/Output (I/O) logic. This key integration serves to consolidate the execution of picking and placing actions for the rice bags at specified points - specifically P1 and P4 - thus streamlining the overall process.

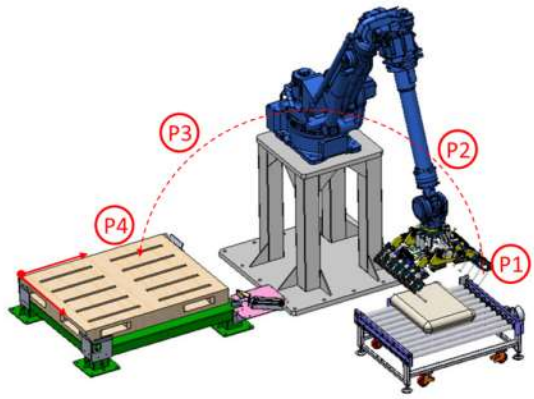

Figure 11. Robotic arm trajectory generation process for rice bag stacking from conveyor to pallet.

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NOP
*1
MOVL P002 VL=800.0
WAIT IN#(1)ON
MOVL P001 VL=800.0
DOUT OT#(1)ON
TIMER T=1.0
MOVL P002 VL=800.0
MOVJ P003 VJ=50.0
MOVJ P004 VL=80.0
DOUT OT#(1)OFF
TIMER T=1.0
MOLJ P003 VL=800.0
MOVJ P002 VJ=50.0
JUMP *1 IF I001>0
END
```

Figure 12. INFORM robot script generated by the software

Our research further extends to scripting the robot using the INFORM programming language, a programming platform specifically crafted to cater to the needs of the DX200 Motoman robot arm controller. As displayed in Figure 12, the utilization of this language aids in facilitating precise control and coordination of the movements of the robotic arm throughout the process of stacking. The INFORM robot language has been chosen for its compatibility, thereby ensuring seamless integration with the existing controller and consequently enhancing the overall efficiency of the stacking system.

Figure 13. Factory floor image of rice stack after completing the palletization using proposed system.

Our findings were solidified by implementing a real-world test case scenario. The scenario utilized rice bags with a weight of 30 kg and dimensions of 700x480x150mm, in conjunction with a pallet measured at 1440x1180mm. The stacking point and robot arm language script generation software were utilized to automate the stacking program's creation. As shown in Figure 13, the stacking process executed by the robot code during the verification setup further underlines the proficiency and accuracy of the proposed system.

A comparative study was undertaken to underscore the efficiency of the proposed offline stacking system. This study compares the proposed system against manual labor and the traditional robot programming approach, with the findings detailed in Table II.

TABLE II
COMPARISON OF TIME REQUIRED BY DIFFERENT STACKING METHODS

Procedure	Setup Time (minutes)	Processing Time (minutes)	Stacking Time (minutes)
Manual Labor	-	-	15.0
Robot Programmer	30.0	-	8.0
Proposed System	1.0	0.5	8.0

In the manual labor scenario, the stacking time for placing rice bags on the pallet amounted to 15.0 minutes. No setup time was required in this case, as the process was entirely carried out by human labor and adjustments to stacking configurations are made entirely by human judgement.

The traditional robot programming approach, however, required a significant setup time of over 30.0 minutes for a new configuration. This time was needed to manually adjust the robot's positions using the robot controller to adapt to the specific pallet and rice bag dimensions. Despite this lengthy setup time, the resulting stacking time was significantly reduced to 8.0 minutes, showcasing the speed advantage provided by the robotic automation of the stacking process. It should be noted that the setup is only required once for a new pallet-bag configuration.

In contrast, the proposed offline stacking system demonstrated exceptional efficiency, outperforming both manual labor and traditional robot programming. In this system, the setup time was drastically reduced to a mere average 1.0 minute. During this period, the operator inputs the necessary parameters, such as pallet size, bag size, and other variables, via the user-friendly interface. The system then takes a brief 0.5 minute to compute the optimal configuration for the rice bags on the pallet and generate the corresponding robot code.

What sets the proposed system apart is its flexibility and accessibility. Traditionally, adapting the stacking process to accommodate a new pallet size or bag type would require the expertise of a robot programmer, leading to delays and additional costs. However, our proposed offline stacking system bypasses this hurdle entirely. Due to its intuitive interface and automated calculations, any operator can easily modify the stacking parameters and deploy a new configuration in mere minutes, regardless of their technical expertise.

V. CONCLUSION

In summarizing our research, we underscore the notable advancement achieved in the automation of rice bag stacking procedures. Our unique approach results in the development of an offline expert system that effortlessly generates optimized stacking paths and subsequently transforms them into actionable robotic scripts. The system was put to the test under real-world conditions within a rice milling factory, and its efficacy in creating efficient stacking instructions while smoothly integrating into existing automated production lines was clearly demonstrated.

Importantly, our research transcends the confines of rice bag stacking, opening up possibilities for its application across various industries where automated stacking solutions are sought. By largely reducing the dependency on manual labor, this innovative system promises heightened productivity and accuracy within production processes. Moreover, the comparison with manual labor and traditional robot programming methods, as detailed in Table I, makes a compelling case for the superior efficiency and adaptability of the offline stacking system.

Future research could explore the versatility of this system, adapting it to cater to a broader range of products and pallet sizes. Furthermore, the system’s integration with other automation technologies could be investigated to devise even more efficient production workflows. Such advancements could mark significant progress for automated stacking systems.

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