Development of automated high-speed depalletizing system for complex stacking on roll box pallets

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Abstract
The need for automated distribution systems has recently grown due to labor shortages and an increasing preference among consumers to shop online. The process of depalletizing roll box pallets (RBPs) requires skillful work in a limited space, but an automated RBP depalletizing system with a speed equal to or exceeding that of human workers has yet to be developed. We solved this issue using two technologies. One is a system design and the other is an algorithm for prioritizing the packages to be removed from the stack. We designed a high-speed depalletizing system that can be installed in a narrow space at the distribution site. Equipped with a compact linear actuator mechanism, the system utilizes an end effector that can handle multiple packages simultaneously. Moreover, by optimizing the process of transferring packages on the system, we increased the speed. Our algorithm for prioritizing packages allows the proper selection of packages held simultaneously for faster depalletizing. However, if the height of complexly stacked packages is not known, depalletizing is difficult. To solve this issue, we developed an algorithm with special rules. Finally, we conducted depalletizing trials with the latest prototype system using different arrangements of stacked packages, and achieved an average speed of 683 packages per hour.

Keywords: Mechanism design, Manufacturing and automation, Logistics, System design

1. Introduction

The distribution industry is increasingly affected by consumers shifting away from retail and toward e-commerce. Many studies have examined how to optimize the distribution process as a whole (Amato et al. 2005; Agustina et al. 2010; Liu et al. 2010). Roll box pallets (RBPs), which are similar to roll containers and can be transported by truck and moved by workers (Onishi et al. 2016), are used in automated warehouses, retail cross-docking centers, and other distribution sites. The process of depalletizing (i.e., unloading the contents of RBPs) requires speed and strength. In Japan, it is becoming increasingly difficult to retain a stable workforce for a long time due to the declining birthrate and aging population. In the case of distribution centers, there is a particularly urgent need for automating the process of depalletizing.

In this paper, we focus on the depalletizing work in which packages stacked in roll box pallets are transferred to a conveyance line for sorting. We developed a system that can quickly depalletize RBPs as an important practical technology for automating the entire logistics process. Currently, depalletizing is still done almost entirely manually, and it is desirable to reduce the burden on workers caused by the physical handling of heavy packages. Using robotic systems to automate factory work is relatively easy because the shape and size of target items are standardized, and thus the work is standardized. In contrast, a system that can handle a variety of packages without damaging them is necessary for depalletizing because the target packages vary in size and weight. In the past, it has been standard practice to prepare a relatively large workspace exclusively for each robotic system. However, the areas near conveyance lines in distribution centers are just large enough to accommodate human workers (Fig. 1). Because systems must perform skilled work in a
limited space, a new mechanism matching the site is required.

In this study, we first considered a compact linear actuator mechanism design as shown in Fig. 1 (Nakamoto et al. 2016). The mechanism could be installed in a narrow space at the distribution site and utilizes an end effector (EE) that can handle multiple packages simultaneously in each cycle (Section 2). After the mechanism design was determined, we optimized the process to allow for safe, high-speed movements (Section 3). The packages used for home delivery of goods are cuboids of unknown size, and they are seen only from the top surface so the width and length of the package can be determined, but not the height. We considered a rule for selecting multiple packages simultaneously using this limited information, and, after validation, we applied the rule to our system (Section 4). Finally, we conducted depalletizing trials with the latest prototype system using different arrangements of stacked packages and achieved an average speed of 683 packages per hour (Section 5).

1.1 Related work

A palletizing speed of 1,400 pph (packages per hour) was previously achieved by Sonoda (1995), who argued that depalletizing is more difficult to automate than palletizing due to the shifting of packages during transport and because the positions of human depalletizers are fixed; these factors have delayed the automation of depalletizing. The palletizing system that they developed stacks packages of a single size in an orderly manner on a flat pallet and has already achieved a high speed. However, high-speed depalletizing of RBPs requires the acquisition of the target position from up-to-date information about the arrangement of the stacked packages and also requires that the handling arm move to different points during each cycle of the process, which makes such a system more difficult to develop. Recent studies have looked at developing a depalletizing system for stacked cardboard boxes that have toppled, shifted, or been stacked in complex ways. Many studies have tackled the issue of target acquisition (Hashimoto et al. 1999; Katsoulas et al. 2002; Zhang et al. 2009; Prasse et al. 2011, 2013, 2016), and some systems have been developed recently (Yaskawa Motoman robot 2013; PICK WORKER 2016). However, there have been no studies on a high-speed depalletizing system for various complex arrangements of packages arbitrarily or heuristically stacked on RBPs by human workers. One report on a depalletizer that can determine each pick cycle had a low cycle time of 13.0 s (Holz et al. 2015), which is equivalent to about 277 pph. According to the product details of a commercially available depalletizer (IHI AI Auto Depalletizing System 2017), the system’s speed is 450 pph. Given that the process speed for manual depalletizing is about 500 pph, our aim was to achieve a speed greater than 500 pph. RBPs have a cage-like structure that keeps packages stable and prevents them from falling to the ground as well as maintaining spatial alignment in the X, Y, and Z directions. However, because stacking patterns tend to be complex, a special strategy is required for selecting packages based on information captured by a camera.

2. Compact mechanism design to handle multiple packages

Presently, palletizing/depalletizing operations are performed using a combination of multi-axis industrial robots. There are several issues to consider when using industrial robots for high-speed depalletizing of RBPs. (1) Heavy payload robots are too tall to be installed at most sites without renovations to the building. (2) It is generally difficult for human operators to plan the various trajectories of an articulated arm. (3) The type of EE (i.e., with a suction, pinching grip, or scooping) depends on the target shape (i.e., box, cylinder, sphere, or other). While recent studies have begun to address
this issue by using the hold position determined by the physical model of the various EE types (Domae et al. 2014; Ogata 2017; Mahler et al. 2016, 2017), the best EE for automation is still the suction gripper, which is used on the top surface of the target object. Our targets were cardboard boxes of different sizes. Our prototype therefore employed a linear actuator to solve issues (1) and (2), and an RGB-D camera to acquire three-dimensional information on the planes of the cardboard boxes and suction pads.

![Fig. 2 Determination of the end effector design: The width of the end effector and the vertical displacement of the suction pad were selected as the design parameters.](image)

The first aim for our depalletizing system was to be able to handle complex stacking arrangements of packages weighing up to 30 kg, to be within 1–2 m² in size, and to achieve a processing speed of 500 pph, which is equal to that of a human worker. Accordingly, it is necessary to keep the average number of simultaneous holds at 1.5 or more when considering the operation speed of the actuator. Therefore, we developed a system with a compact body that can handle multiple packages and has a wide EE (Fig. 1) with a buffer in the Z direction that enables contact with packages of differing heights from above. The width of the wide end effector is 600 mm and the vertical displacement of the suction pad is 60 mm. These were chosen as design parameters of the end effector (Fig. 2). In order to keep the average number of simultaneously held packages at 1.5 or more, they were selected from the simulation considering packages of about 250 mm in width. In the simulation, several packages from among the packages located on the highest position that the EE can make contact with while maintaining sufficient space, are removed during each cycle and this is repeated until the packages disappear. The length of the end effector is set at 300 mm, which is the maximum value of the mechanical space limitation. The system is equipped with a supporting conveyor, on which a small conveyor belt is driven up and down separately from the handling arm. There is a possibility of a package held by vacuum suction dropping due to inadequate suction and/or too quick acceleration/deceleration during conveyance. To minimize this risk, the package...
picked up by the handling arm is immediately transferred to the conveyor, which moves the package on the conveyance line and then discharges it. During our experiments, the processing speed of the prototype reached 494 pph for eleven different sizes of packages stacked in a complex arrangement (Nakamoto et al. 2016).

3. Improvement of hardware design

After the mechanism design was determined, we optimized the system processes to allow for safe, high-speed movements. This was necessary because many of the components have numerous setting parameters. In this section, we examine the design of the hardware discussed in the previous section to improve the processing speed. In our depalletizing system, when each actuator is set to its maximum speed, the possibility of a package falling or colliding with other packages increases as the arm moves while holding packages in a narrow and cluttered space because the acceleration at the edge of the EE is too great. The settings therefore need to be optimized and configured separately for each component to minimize the acceleration at the edge of the hand. To make the improvements, we followed the DMAIC (define, measure, analyze, improve, control) methodology (Pyzdek et al. 2014). We used a cause-and-effect matrix to select system factors and input them into a system simulator to determine the expected speed performance based on combinations of settings. To minimize the handling parameters, we extracted a few factors using analysis of variance. We applied a central composite design to obtain additional data on where the process was operating, and used response surface designs to derive a regression formula. Response surface methodology is a combination of statistical design and numerical optimization techniques used to optimize processes and product designs (Myers et al. 2004). We conducted our analyses using Minitab 16 software and Microsoft Excel.

3.1 Analysis of performance of prototype

Figures 3 and 4 show the depalletizing flow of the prototype. Figure 4 also shows some of the inputs and outputs of the system. Based on this, and through group discussion and utilization of the cause-and-effect matrix, we determined the ten main factors that affect the processing speed (Fig. 5). We also created a simulation by inputting the settings for these factors along with sample data of the packages stacked on the RBP. From the simulated results of the time taken in
Acceleration of conveyor moved

Acceleration of arm on X1 axis

Velocity of conveyor rotation driven

Velocity of arm on Y axis

Velocity of arm on Z axis

Wait time for reduction of air pressure

Sampling number

Acceleration of arm on Y axis

Velocity of LRF scanning

Velocity of arm on X2 axis

Acceleration of arm on Z axis

Using the simulation, we could determine the relationships between these factors and the processing speed. A quadratic polynomial was considered, and the interaction among each factor was measured. We rearranged the equation until the interaction P-value (shows possibility that the coefficient is zero) of each coefficient was less than 0.005. The results of the response surface design for this regression are shown in Fig. 7; there are six graphs for the processing speed, which illustrate the combinations of two factors with the other factors fixed at particular values. From this, we identified the general direction of optimization. The figure shows that when controlling $A_{X1} \cdot V_{X1}$, $V_{Z}$, $A_{Z}$, and $V_{Z} \cdot V_{Y}$, the acceleration of EE cannot be varied to maintain a processing speed of 500 pph. On the other hand, when controlling $A_{Z} \cdot A_{X1}$, while varying $A_{Z}$ tends to change the processing speed, varying $A_{X1}$ has little effect. This means that $A_{X1}$ can be set at an arbitrary low value to restrain the vibration at the edge of the EE. From the above, we found that the key for improving the system is the proper configuration of $V_{X1}$ and $V_{Z}$, and the reduction of $A_{X1}$.

Fig. 5 Cause-and-effect matrix. The causes are listed in the rows by selecting “C” (controllable) from the type of input shown in Fig. 4. The effects are listed in the columns by selecting the output shown in Fig. 4. The numbers in the matrix indicate the degree of effect (0: no effect, 1: little effect, 5: some effect, 9: most effect) scored by evaluators. The ten main factors are selected by sorting the rows using the sum total.
Table 1 Ten factors at two levels

| Factors | Low (current) | High (available) |
|---------|--------------|------------------|
| \(A_{x1}\): A of arm on X1 axis \([m/s^2]\) | 10 | 45 |
| \(A_{x2}\): A of arm on X2 axis \([m/s^2]\) | 6 | 45 |
| \(A_{y}\): A of arm on Y axis \([m/s^2]\) | 2 | 45 |
| \(A_{z}\): A of Convoyer \([m/s^2]\) | 1 | 45 |
| \(V_{x1}\): V of arm on X1 axis \([m/s]\) | 0.7 | 2.5 |
| \(V_{x2}\): V of arm on X2 axis \([m/s]\) | 0.4 | 1.5 |
| \(V_{y}\): V of arm on Y axis \([m/s]\) | 1.0 | 3.5 |
| \(V_{z}\): V of Convoyer \([m/s]\) | 0.6 | 2.0 |
| \(A\): Acceleration; \(V\): Velocity |

Table 2 Results of analysis of variance (Top 20 effects)

| Factor | Effect | \(A_{x}\) | \(A_{x}*A_{y}\) | \(A_{x}*A_{z}\) |
|--------|--------|-----------|----------------|----------------|
| \(A_{x}\) | 136.119 | 14.255 |
| \(A_{x}*V_{z}\) | 52.023 | 13.507 |
| \(V_{x1}\) | 38.576 | 9.477 |
| \(V_{x2}\) | 31.376 | 5.575 |
| \(A_{y}\) | 27.487 | 4.935 |
| \(A_{y}*A_{z}\) | 23.702 | 4.197 |
| \(V_{y}\) | 17.777 | 3.955 |
| \(A_{x}*V_{x1}\) | 16.674 | 3.814 |
| \(V_{x1}*V_{x2}\) | 14.552 | 3.68 |
| \(A_{z}\) | 14.516 | 3.526 |

Table 3 Four factors at three levels

| Factor | Low | Middle | High |
|--------|-----|--------|------|
| \(V_{x1}\) [m/s] | 0.7 | 1.6 | 2.5 |
| \(A_{x1}\) [m/s^2] | 1.0 | 23.0 | 45.0 |
| \(V_{z}\) [m/s] | 0.6 | 1.3 | 2.0 |
| \(A_{z}\) [m/s^2] | 1.0 | 23.0 | 45.0 |

Table 4 Additional sample data

| \(V_{x1}\) [m/s] | \(A_{x1}\) [m/s^2] | \(V_{z}\) [m/s] | \(A_{z}\) [m/s^2] | Processing speed [pph] |
|-----------------|-----------------|-----------------|-----------------|----------------------|
| 0.7             | 1.0             | 1.0             | 1.0             | 379.923              |
| 2.5             | 1.0             | 0.6             | 1.0             | 376.215              |
| 0.7             | 45.0            | 0.6             | 1.0             | 408.185              |
| 2.5             | 45.0            | 0.6             | 1.0             | 422.215              |
| 0.7             | 1.0             | 2.0             | 1.0             | 349.073              |
| 2.5             | 1.0             | 2.0             | 1.0             | 349.325              |
| 0.7             | 45.0            | 2.0             | 1.0             | 376.715              |
| 2.5             | 45.0            | 2.0             | 1.0             | 388.638              |
| 0.7             | 1.0             | 0.6             | 45.0            | 489.688              |
| 2.5             | 1.0             | 0.6             | 45.0            | 490.184              |
| 0.7             | 45.0            | 0.6             | 45.0            | 559.699              |
| 2.5             | 45.0            | 0.6             | 45.0            | 582.716              |
| 0.7             | 1.0             | 2.0             | 45.0            | 537.000              |
| 2.5             | 1.0             | 2.0             | 45.0            | 538.790              |
| 0.7             | 45.0            | 2.0             | 45.0            | 617.589              |
| 2.5             | 45.0            | 2.0             | 45.0            | 651.512              |
| 0.7             | 23.0            | 1.0             | 23.0            | 594.206              |
| 2.5             | 23.0            | 1.0             | 23.0            | 625.243              |
| 0.7             | 23.0            | 1.0             | 23.0            | 521.164              |
| 2.5             | 23.0            | 1.0             | 23.0            | 623.966              |
| 0.7             | 23.0            | 1.0             | 23.0            | 579.596              |
| 2.5             | 23.0            | 1.0             | 23.0            | 628.824              |
| 0.7             | 23.0            | 1.0             | 23.0            | 386.862              |
| 2.5             | 23.0            | 1.0             | 23.0            | 630.681              |
| 0.7             | 23.0            | 1.0             | 23.0            | 622.078              |

Table 5 Results of optimization

| Controlling factor | Optimized result | Unit | Constraint condition |
|--------------------|------------------|------|----------------------|
| \(V_{x1}\) | 2.5 | m/s | Range: 0.6-2.5 |
| \(A_{x}\) | 5.99 | m/s^2 | Range: 1.0-45 |
| \(V_{z}\) | 0.6 | m/s | Range: 0.6-2.5 |
| \(A_{z}\) | 11.61 | m/s^2 | Range: 1.0-45 |

Dependence factor

| Acceleration at the edge of the hand \(\sqrt{A_{x}^2 + A_{z}^2}\) | 13.06 | m/s^2 | Minimized |

Response

| \(Sp\) | 500 | pph | Configured setting |

Fig. 6 Example of the simulator results for the depalletizing process. The vertical axis shows the phase counter of the flow, the position of the conveyor and arm, or the velocity of the actuators. The green text above the graph is the main flow processes shown in Fig. 4.

Fig. 7 Response surface designs.

Table 7 Results of analysis of variance (Top 20 effects)
We used this formula to solve the problem of how to maintain the processing speed and how low is the acceleration at the edge of the EE with Microsoft Excel (R) solver. Finally, we determined the settings of four factors that minimized the acceleration at the edge of the EE and maximized the processing speed (Table 5). As a result, we determined the optimal component settings with specification trade-offs. We also found that the process of acquiring information wastes a lot of time at Phase 1, as shown in Fig. 6. We solved this by positioning the camera on top of the RBP so that the acquisition process could be performed in parallel with the other processes.

4. Design of rule for target selection

Here, we examine the target selection algorithm to maintain the processing speed. The packages used for home delivery of goods are cuboids of unknown size, and are seen only from the top surface so the width and length can be determined but not the height. Using the brightness of RGB images and the detection of rectangles (Fig. 8), we can assume the location of the top surfaces of boxes and the size in terms of width and length. The detection precision is on the order of about 10 mm but can sometimes be wrong in the case of packages with a printed image or logo; therefore, we used packages without any printing on the top surface for the experiment.

We considered a rule for selecting multiple packages using this limited information, and, after validation, we applied the rule to our system. In the previous section, we discussed the mechanism for handling multiple packages and system optimization. In this section, we examine the package selection process for reducing the number of picking cycles and improving the speed of depalletizing RBPs. We introduce three constraints in Section 4.1, and the method to satisfy them and to keep the ratio of simultaneous holds above 1.5 in Section 4.2.

4.1 Three constraints to reduce the number of picking cycles for safe handling

An example arrangement of packages is shown in Fig. 9. We assess the three packages in a line but their height is unknown. From the camera information, we can estimate the width and length, but not the height until the package is picked up. We have three picking options: the hand picks the package in the middle, on the left, or on the right. In option 1, the two packages are too far apart to be picked up by the EE simultaneously; an attempt could cause the EE to knock over one of the packages or strike the RBP cage. In option 2, the tallest package is selected first, and then the remaining two packages are selected and picked up simultaneously. The depalletizing system can thus handle all three packages in just two cycles. In option 3, where the tallest package is not selected first and is not selected even after the second cycle (see option 1 for the reason), the average number of simultaneously held packages drops since the EE picks them up one at a time. As a result, the system needs three cycles to handle all of the packages. In option 3, the EE has a limited rightward range because the right side of the RBP cage prevents further movement. Consequently, the two right-side packages cannot be selected together because doing so might place pressure on the left-most (tallest) package and damage it. These are very simple examples but they illustrate our earlier finding: if the system transports multiple packages simultaneously, in order to reduce the number of cycles, (1) the tallest package must be picked. On the other hand, because the front of the RBP is open during depalletization, the remaining packages at the front of the RBP are at risk of falling. Also, the picked packages are moved upward and transported toward the front of the RBP (X minus direction in machine coordinates) at each picking cycle during phases 3 and 4, as shown in Fig. 3. Therefore, (2) the front-most package must also be picked. Lastly, (3) the hand must pick as many packages as possible. Next, we propose the selection rules in accordance with the above constraints (1), (2) and (3).
4.2 Proposed target-selection rules

Selecting targets

This section describes the flow of target selection. Our recognition system uses input from an RGB-D camera to generate information on the rectangular top surfaces of the packages. The possible widths and relative heights of top surfaces of all targets to be held simultaneously depend on the size of the EE. We consider that the employed algorithm reduces the cycle number of the approach to the targets with the size of the EE fixed in advance. Figure 10a shows the flow for selecting the main target. First, the tallest top surface is selected and set as detected (S1) to satisfy constraint (1) and any other top surfaces that lie within the shadow of the EE (when touching the tallest top surface) and are of a similar height are set as detected (S2). If the tall difference of the other top surfaces is within 60 mm (defined in Section 2) based on the tallest top surface, they are regarded as being in the tallest group. The front-most detected top surface is then identified as satisfying constraint (2). If that top surface extends more than 100 mm (this value is estimated from the minimum size of packages) further forward than any other detected top surface, it is selected in place of the main target; otherwise, the main target is kept (S3). Figure 10b shows the flow for selecting from among the sub-targets detected at step S2 as in the tallest group except the main target. The center point of each sub-target is checked to see whether it should be included, and the size of the EE determines whether the sub-target can be held simultaneously with the target (S4). Next, whether the overlap area covered by the EE is sufficient to maintain the suction area (Fig. 11) is checked; more than 80% of the top surface must be below the EE to be retained (S5). Furthermore, the overlap area must not be smaller than what the suction pads can hold (S6). If all sub-target criteria are met, the top surface is selected as a target. Steps S4–S6 are repeated for each sub-target.

In accordance with the process outlined above, the system could satisfy constraints (1) and (2) and secure the suction area.
Calculation of the overlap area and the search order in step S5 (Fig. 10b) depends on the main target location and the search order. There are four search areas: A (right front), B (right back), C (left front), and D (left back) relative to the main target (Fig. 11). The method for calculating the overlap area is different for each one. Moreover, in some cases, the search result differs depending on the search order. Fig. 12 shows the search processes and results from the search order ABCD and CDAB.

The process shown in Fig. 12(a) are as follows. In search area A based on package 3, other package is not found. In search area B based on package 3, package 4 is found and added as target. In search area C based on package 3 and 4, package 2 is found and added as target. In search area D based on package 3, 4 and 2, other package is not found. In the result, the selected targets are 3, 4 and 2. Therefore, only two cycles would be needed to handle all the packages: first (packages 3, 2, 4), second (package 1, 5). The process shown in Fig. 12(b) are as follows. In search area C based on package 3, package 2 is found and added as target. In search area D based on package 3 and 2, other package is not found. In the result, the selected targets are 3, 4, and 2. Therefore, only two cycles would be needed to handle all the packages: first (packages 3, 2, 4), second (package 1, 5).

- **Process for searching among targets**

Five samples of packages using cardboard boxes of 11 different sizes.

(a) ABCD

(b) CDAB

Fig. 13 Test patterns and simulated results of the proposed algorithm.
5 is found and added as target. In search area A based on package 3, 2 and 5, package 1 is found but is not added as target because of shortage the overlap area. In search area B based on package 3, 2 and 5, package 1 is found but is not added as target because of shortage the overlap area, too. In the result, the selected targets are 3, 2 and 5. At least three cycles would be needed to handle all the packages: first (packages 3, 2, 5), second (package 1) and third (package 4). From the above, we employed the search order as follows to reduce the number of picking cycles and to satisfy constraint (3). When the main target is located on the right part of the RBP, the searching would be started from the right front of main target using ABCD order. In contrast, when the main target is located on the left part of the RBP, the searching would be started from the left front of the main target using CDAB order. The suborders AB and CD prioritize front packages to keep satisfying constraint (2). This is equal to the process in which all targets are sorted using an index for safe after searching the entire search area, because the priority of the targets is the order generated for safely depalletizing the RBP.

Based on the above, we examined the proposed algorithm by simulator using five test patterns (Fig. 13). As a result, we found that the proposed algorithm can keep the average number of held packages over 1.5. In Section 2, we discussed the mechanism design that can hold an average of 1.5 packages through a simple simulation with only the tallest packages prioritized. In this section, we considered the package selection rules for safe depalletizing and confirmed that the proposed algorithm keeps the average number of held packages at more than 1.5.

5. Implementation and results

The previous sections described the compact mechanism design for depalletizing, its optimization, and improved rules for package selection. In this section, we report the empirical verification of the latest prototype system. In accordance with our experimental results, a slope conveyor was used to handle continuous processing and a link mechanism to increase the speed of the actuator on the X axis (Fig. 14). Figure 15 shows photographs of the system handling packages during the experiment. In these photos, the roll box pallet is viewed from the depalletizing system side. The numbered scenes show the EE holding multiple packages during each cycle. Figure 16 shows the test patterns and the experimental results for the processing speed, which achieved an average of 683 pph.

6. Conclusions

We developed an automated depalletizing system for complex arrangements of packages on RBPs and achieved a high speed. First, we considered a compact linear actuator mechanism design that could be installed in a narrow space at the distribution site, utilizing an EE that can handle multiple packages simultaneously during each cycle. After the mechanism design was fixed, we optimized the system processes to allow for safe, high-speed movements. The packages used for home delivery of goods are cuboids of unknown size, and are stacked in complex arrangements on RBPs. During depalletization, packages are seen only from the top surface so the width and length can be determined, but not the height. We considered several rules for selecting multiple packages simultaneously using this limited information, and, after validating them, we applied the rules to our system. Finally, we conducted depalletizing trials with the latest prototype system using different arrangements of stacked packages and achieved an average speed of 683 packages per hour.


Fig. 15 Photographs of strokes in the latest system.

Fig. 16 Test patterns and experimental results of the processing speed.

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