Research Article

Palletizing Robot Application in the Corrugated Box Industry

Attapol Malaikaew and Kitipong Jaojaruek*

Department of Mechanical Engineering, Kasetsart University Kamphaengsaen Campus, Nakhonpathom, Thailand

* Corresponding author. E-mail: kitipong.j@ku.th

Abstract
There is a widespread use of corrugated boxes containers in Thailand, nowadays. There was a 13% increase in the use of corrugated boxes which is equivalent to 23,773 tons from 2016 to 2017. Corrugated boxes production is mostly automated; however, these are still stacked manually on the pallets for transportation. Two workers are usually needed to lift the bundles of boxes weighing 8.50 kg. The average production per day is 50,000 pcs. or 5,000 bundles with a total weight of 42,500 kg and a pallet stacking height of 2,700 mm. The aim of this study is to use the 4-axis robot arm with an external servo motor to substitute the labor-intensive palletizing tasks thereby improving the overall production and cycle time of repetitive tasks in industrial systems. Through the application of the palletizing robot, the operation of the system can easily be setup by just one operator. Users can easily operate and modify the width, length, and height of the boxes. The robotic simulation was programmed through the formulated equations that finds the position of boxes on the pallet to create its moving path. The robot works together with another machine. Experiments was done in order to determine moving path. Results showed that cycle time improved to 8.63% with a maximum error of ± 5 mm from the real position.

Keywords: Robot arm, Corrugated boxes industrial, Palletizing pattern, Palletizing robot

1 Introduction

Technological innovations such as production automation are used extensively in manufacturing industries. Repetitive and mundane tasks that require accuracy and unlimited performance are slowly being replaced by robots instead of human workers. One of which is robotic palletizers which are commonly used in industries like corrugated boxes manufacturing industry. Corrugated boxes are commonly used for packaging and delivering different kinds of products to consumers. Thailand Corrugated Boxes Association reported that there was a 4% economic growth in the corrugated boxes industry from 2012 to 2016. It is forecasted that the economic growth for the next 3 years is estimated to increase about 2.5 to 3% mainly depending on the food & beverage, automotive, and consumers product industries [1].

Corrugated boxes manufacturer uses automation for their production processes except the palletizing task [2]. Palletizing is done by at least two workers whose task is to stack the boxes on the pallet to prepare the products for delivery. This has a cycle time of only 150 boxes per minute which cannot keep up with the Flexo machine (corrugated cardboard boxes production machine) that can speed up its production cycle to 180 boxes per minute. Cycle time is inevitable to improve since it affects the number of products that can be done and delivered on time. Ten pieces of corrugated boxes are tied together each weighing 8.50 kg. The average production per day is 50,000 pcs. or 5,000 bundles with a total weight of 42,500 kg and a pallet stacking height of 2,700 mm. This amount of weight being lifted per day causes health problems such as

physical injuries to workers [3]. This often causes the workers to resign since it requires labor-intensive work process. To prevent worker related problems, a 4-axis robot arm with an external servo motor was used to further drive the efficiency of the work process in this study. Because mechanism of the robot arm is appropriate about speed and working length of the pallet compare with another mechanisms [4]. Furthermore, the price of the robot arm has continuously declined for the past five years making it a cheaper alternative suitable for palletizing system applications. Several robot arm companies have palletizing system applications [5] however, these systems are not completely suitable to be used by corrugated boxes industries due to some limitations since it requires frequent changing of the product's size depending on the customer's requirement. Furthermore, it is also necessary that operators must be well trained and knowledgeable in handling the robot in order to operate it.

This study aims to improve the production process of corrugated cardboard boxes industry by developing an efficient and suitable robotic palletizing system that will increase the production's cycle time. The system will also allow simple setting up of the robot by filling in the width, length, height, pattern, and job order of boxes on its touch screen interface that even operators can easily follow and control. The system is also programmed with equations that automatically calculates the position of boxes on the pallet and the moving path of robot. No need to use technician or knowledgeable in handling the robot in order to operation. The gap between bundles of box placement was limited to not exceed 30 mm because it can cause damage to the roller conveyor. Studying parameters are gap between boxes and cycle time of robot arm compare with working by two humans.

2 Methodology and Technology

2.1 *Palletizing system*

Corrugated boxes production undergoes through the following steps: corrugated paper is fed into the Flexo machine then painted in the color mold unit, cut through the slotter unit, smeared with glue on the flaps and then stacked into bundles having 10 pcs each as shown in Figure 1 below [6]. Afterwards, these are palletized in preparation for delivery. Shown in Figure 2
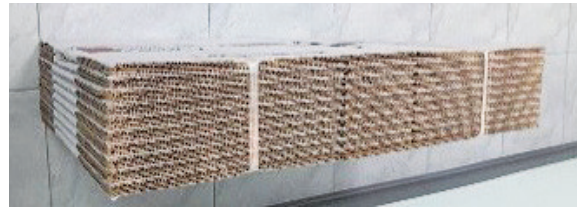

Figure 1: Corrugated boxes from production process.

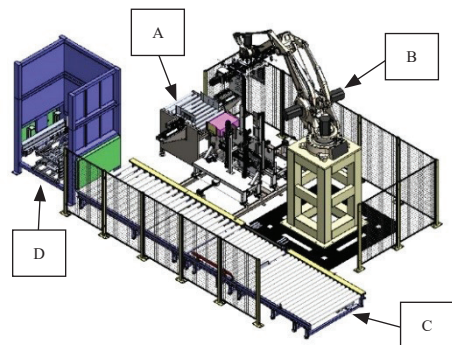**Figure 2**: Stacking process by workers.

Figure 3: 3D drawing machine in palletizing system.

is the manual stacking of corrugated cardboard boxes without the use of robotic palletizing system.

The palletizing system used in this study is shown in Figure 3. The system consists of the following parts: feeder (A), robot arm (B), conveyor (C), and pallet magazine (D).

The feeder collects two bundles of boxes. These bundles are picked up by the robot arm which then places it on the pallet at the stacking area of the conveyor. Once pallets are fully loaded it is then moved
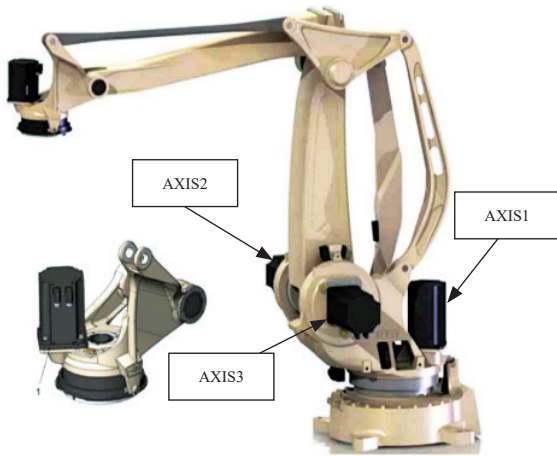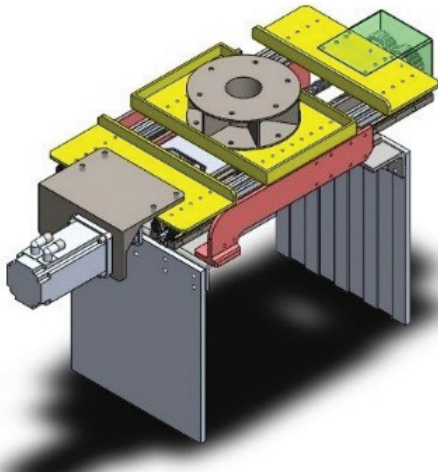
Figure 4: Robot arm PAL180-3.1.

Figure 5: Gripper and servo motor.

out and the pallet magazine feeds another pallet to the conveyor.

2.2 *Robot arm and gripper*

This study used PAL 180-3.1, 4-axis robot arm from COMAU Robotics (see Figure 4). It is a palletizing type robot arm with a positional repeatability of ± 0.1 mm and a payload of 180 kg. It uses an encoder for its position measurement system [7].

The gripper shown in Figures 5 and 6 is attached on the axis 4 of the robot which was designed with a ball screw pitch 10 mm and linear guide mechanism. It is driven by a servo motor which enables gripping
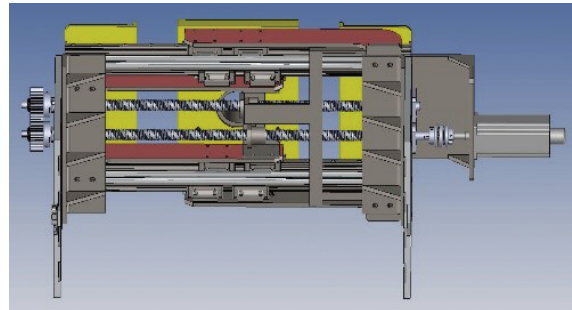

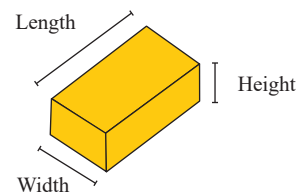**Figure 6**: Gripper and servo motor (bottom view).

Figure 7: Dimension of bundle.

mechanism that varies according to the input value of the box's dimensions entered by the operator.

2.3 *Equation for placement position*

The control unit of the robot arm is called C5G controller wherein the position of the robot arm can be modified. Since the gap in between bundles when it is placed on the pallet cannot exceed 40 mm (factory requirement) , it was programmed to have an allowable 10 mm gap including the thickness of the gripper plate that is 15 mm, hence having a total gap of 25 mm. Box's dimension shown in Figure 7.

The study used two pattern styles; one is stacking of three bundles per layer (as shown in Figure 8) and the other one is stacking of four bundles per layer (as shown in Figure 9). The odd layer is the pattern of placement for the first layer of the pallet (bottommost part) while the even layer is placed over the odd layer until one full loaded pallet completes 18 layers of bundles. The calculation uses the center of pallet: $X_n = X_0$, $Y_n = Y_0$ [8].

The position of each bundles are calculated using the following formulated Equations (1)–(28):
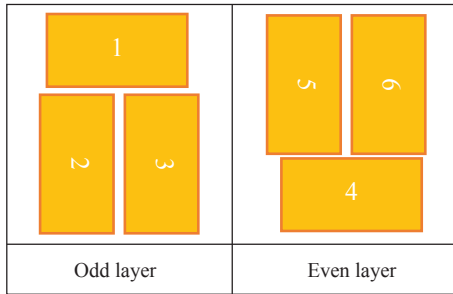
$$X_1 = X_0 \tag{1}$$

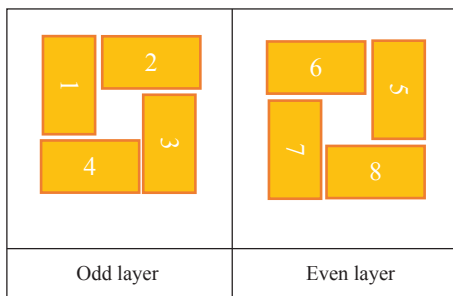**Figure 8**: Style of stack 3 bundles per layer.

Figure 9: Style of stack 4 bundles per layer.

$$Y_1 = Y_0 + \frac{lth}{2} + gap \tag{2}$$

$$X_2 = X_0 - \frac{wth}{2} - gap - 15 \tag{3}$$

$$Y_2 = Y_0 - \frac{wth}{2} - gap \tag{4}$$

$$X_3 = X_0 + \frac{wth}{2} + gap + 15 \tag{5}$$

$$Y_3 = Y_0 - \frac{wth}{2} - gap \tag{6}$$

$$X_4 = X_0 \tag{7}$$

$$Y_4 = Y_0 - \frac{lth}{2} - gap \tag{8}$$

$$Y_4 = Y_0 - \frac{lth}{2} - gap \tag{9}$$

$$Y_5 = Y_0 + \frac{wth}{2} + gap \tag{10}$$

$$X_6 = X_0 + \frac{wth}{2} + gap + 15 \tag{11}$$

$$Y_6 = Y_0 + \frac{wth}{2} + gap \tag{12}$$

$$X_1 = X_0 - \frac{lth}{2} - gap \tag{13}$$

$$Y_1 = Y_0 - \frac{wth}{2} - gap \tag{14}$$

$$X_2 = X_0 + \frac{wth}{2} + gap \tag{15}$$

$$Y_2 = Y_0 + \frac{lth}{2} + gap \tag{16}$$

$$X_3 = X_0 + \frac{lth}{2} + gap \tag{17}$$

$$Y_3 = Y_0 - \frac{wth}{2} - gap \tag{18}$$

$$X_4 = X_0 - \frac{wth}{2} - gap \tag{19}$$

$$Y_4 = Y_0 - \frac{lth}{2} - gap - 22 \tag{20}$$

$$X_5 = X_0 + \frac{lth}{2} + gap \tag{21}$$

$$Y_5 = Y_0 + \frac{wth}{2} + gap \tag{22}$$

$$X_6 = X_0 - \frac{wth}{2} - gap \tag{23}$$

$$Y_6 = Y_0 + \frac{lth}{2} + gap \tag{24}$$

$$X_7 = X_0 - \frac{lth}{2} - gap \tag{25}$$

$$Y_7 = Y_0 - \frac{wth}{2} - gap \tag{26}$$

$$X_8 = X_0 + \frac{wth}{2} + gap \tag{27}$$

$$Y_8 = Y_0 - \frac{lth}{2} - gap - 22 \tag{28}$$

2.4 Programming

2.4.1 Operation

The operator key in the size of bundles, stacking style, number of layer and job order on HMI. The system begins once the start button is pressed and the robot arm will work until the job order is done. The interface of the HMI was designed as shown in Figure 10 and interface from the robot company as shown in Figure 11.

Two patterns of stacking on pallet were done for testing: three bundles per layer and four bundles per layer. Each pattern were tested three times for three different size of boxes. The testing focused on the results of cycle time and gap between bundles. The cycle time is the working time to finish loading 18 layers
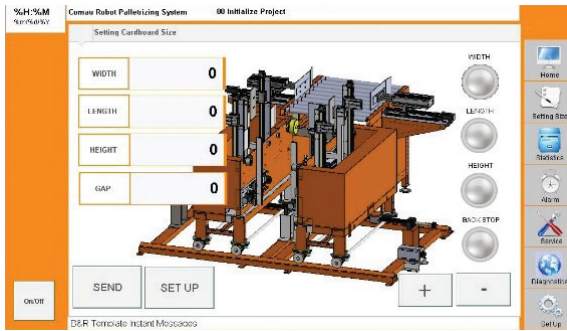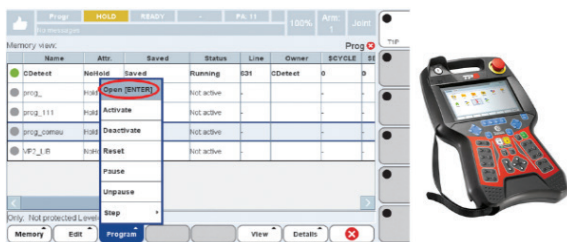
Figure 10: Operation screen on HMI.

Figure 11: Interface from the robot company.

on the pallet whereas the gap between bundles were measured using a vernier caliper. The measurements were done twice for the first four layers of the pallet for every pattern style.

2.4.2 Logical diagram

Robot arm programing structure program and procedure is shown in Figure 12 [9]. The program receives data and signal from the Human Machine Interface (HMI) [10].

3 Results and Discussion

This research determines the error in the distance of placing the bundles on the pallet as well as its cycle time.

Three different size of boxes were tested for each stacking style having three bundles on each layer shown in Figure 13. Programming used 25 mm for gap. There were three sizes of bundles used during the testing which can be seen on Table 1. whereas the sample results of one of the tests are shown in Table 2. The overall result of the gap between bundles for each box sizes is shown in Figure 14.
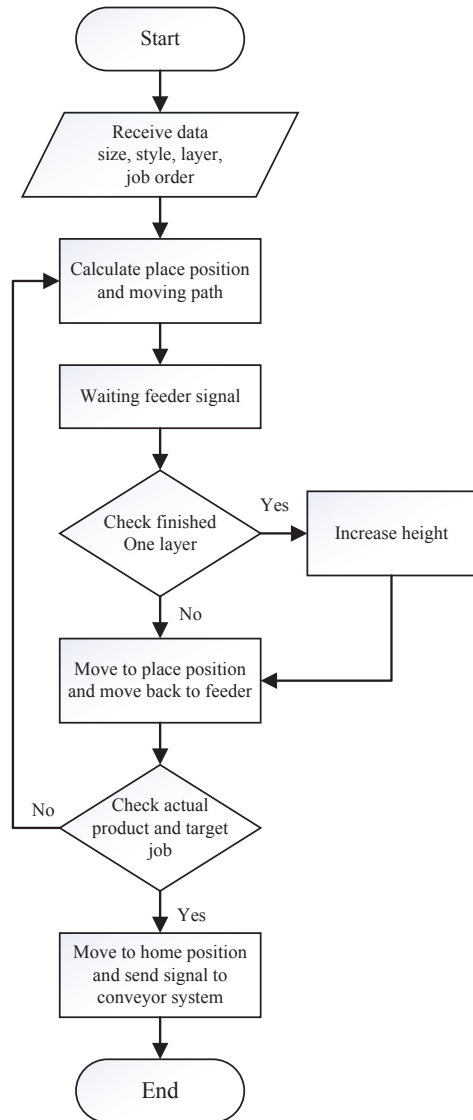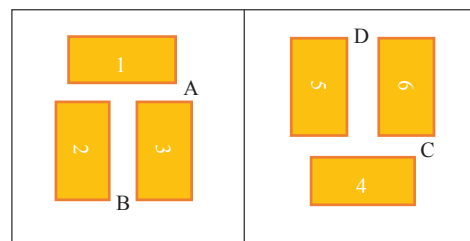

Figure 12: Logical diagram of program.

Figure 13: The point of measurement for the gap between bundles (3 bundles per layer).
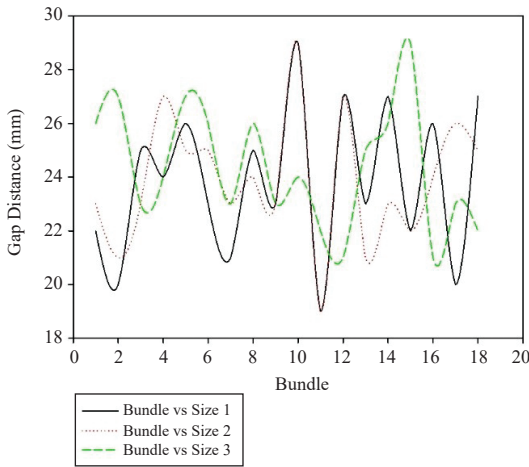
Figure 14: The graph of the distance of the gap between bundles for the three box sizes.

Table 1: The different sizes of corrugated boxes used for testing at three bundles per layer

Size	Dimension (mm)		
	Length	Width	Height
1A	932	435	133
2A	789	579	135
3A	841	596	134

Table 2: The resulting gap between bundles for size 1A having three bundles per layer

Layer	Distance Gap between Bundles (mm)			
	A	B	C	D
1–2	22	20	-	-
3–4	-	-	24	21
5–6	26	23	-	-
7–8	-	-	21	25
9–10	23	29	-	-
11–12	-	-	19	27
13–14	23	27	-	-
15–16	-	-	22	26
17–18	20	27	-	-

The speed for accomplishing one job order amounting to 540 pieces for each size are the following: size 1A has used 204.600 seconds with a cycle time of 158.358 pieces per minute, size 2A has a working time of 198.500 seconds with a cycle time of 163.224 pieces per minute whereas size 3A is 203.700 seconds for a cycle time of 159.057 pieces per minute.
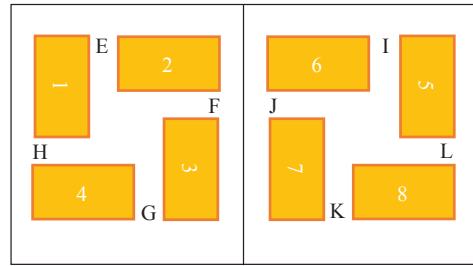

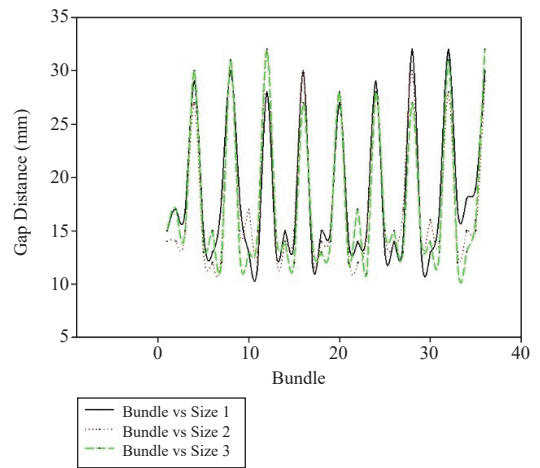**Figure 15**: The gap between bundles that was measured (4 bundles per layer).

Figure 16: The graph of the distance of the gap between bundles for the three box sizes.

Three different size of boxes were tested for each stacking style having four bundles on each layer shown in Figure 15. Programming used 15 mm for gap and for last position in the layer use 30 mm. There were three sizes of bundles used during the testing which can be seen on Table 3. whereas the sample results of one of the tests are shown in Table 4. The overall result of the gap between bundles for each box sizes is shown in Figure 16.

Table 3: The different sizes of corrugated boxes used for testing at four bundles per layer

Size	Dimension (mm)		
	Length	Width	Height
1B	732	466	142
2B	678	470	133
3B	726	533	140

Table 4: The resulting gap between bundles for size 1B having three bundles per layer

Layer	Distance Gap between Bundles (mm)							
	E	F	G	H	I	J	K	L
1–2	15	17	17	29	-	-	-	-
3–4	-	-	-	-	15	13	18	30
5–6	18	13	12	28	-	-	-	-
7–8	-	-	-	-	13	15	14	30
9–10	12	15	15	27	-	-	-	-
11–12	-	-	-	-	14	14	15	29
13–14	13	14	14	32	-	-	-	-
15–16	-	-	-	-	13	13	17	32
17–18	17	18	19	30	-	-	-	-

The speed for accomplishing one job order amounting to 720 pieces for each size are the following: size 1B is 273.500 seconds and cycle times is 157.952 pieces per minute. Size 2B working time is 159.822 seconds and cycle time of 163.224 pieces per minute. On the other hand, the working time for size 3B is 278.700 seconds and cycle time of 155.005 pieces per minute.

4 Conclusions

Based on the results, the developed program for automatically calculating the placement position using the formulated equations works well with the robotic palletizing system. The accuracy was seen based on the results presented from the tables discussed. In conclusion, the gap recorded for style 3 are 20 mm and 29 mm, respectively, for the smallest and the largest gap. Whereas 12 mm for the smallest gap and 32 mm for the largest gap for the recordings done for style 4. From the equation, the distance gap should be 35 mm with an allowable maximum gap of 4 mm which is the error from the position before placing the bundles. This error was caused due to the calculation from the height of the before layer when robot place the bundles, there are some hit between bundles. However, the robot arm can still be used within this application since the acceptable distance gap for V.S.S. Industrial Co., Ltd. is not more than 40 mm.

With regards to the cycle time, the maximum speed recorded is 163.224 pcs/min while the minimum speed is 157.952 pcs/min. Take note, however, that
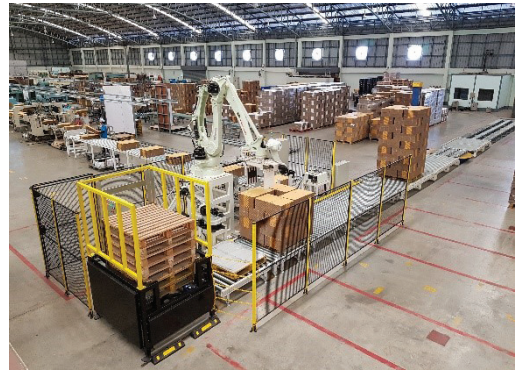

Figure 17: Palletizing system in the working area.

Figure 18: Stacking of boxes by robot arm.

the speed for placing the bundles in their respective position is not the same because of the stacking height. The motion time is dependent on the difference on the layer's height from the feeder machine. Nevertheless, the recorded speed is faster compared to the use of man power which is only around 150 pcs/min which overall increases the productivity of the production process.

This study shown robot arm can solved workers problem in palletizing process. It easy to use by operators. This solution can make robot arm very useful for corrugated boxes industrial. Summary testing is 3 months. The robot arm pick up boxes around 350,000 times with 75 different size of the boxes. There are error about robot's controller 6 times. It did not start new production job. No any big pick and place error until have to stop the operation. So, it proved that this work can serve very well for the real environment operation shown in Figures 17 and 18.

The researcher aims to further this study by focusing on improving the moving path of the robot arm

that will find the nearest moving path that can increase more the production's productivity and efficiency.

Acknowledgments

References

[1] J. Li, R. Zhang, Q. Guan, F. Cui, and K. Chen, "Analysis on the workspace of palletizing robot based on AutoCAD," in *Proceedings IOP Conference Series: Materials Science and Engineering*, 2017, vol. 241, pp. 1–4.

[2] S. Gallagher and J. R. Heberger, "The effects of operator position, pallet orientation and palletizing condition on low back loads in manual bag palletizing operations," *International Journal of Industrial Ergonomics*, vol. 47, pp. 85–91, 2015.

[3] W. Sriboon and B. Chanasak, *Mathematics of Engineerings and Scientists*. KMUTNB, Bangkok, Thailand, 2011 (in Thai).

[4] Packaging Industrial Intelligence Unit, "Report monthly packing list on august," Packaging Industrial Intelligence Unit, Bangkok, Thailand, 2017 (in Thai).

[5] COMAU Robotics services, "Programming language manual system software Rel. 2.30.xx," COMAU Robotics services, Grugliasco, Italian, 2014.

[6] J. J. Craig, *Introduction to Robotics Mechanics and Control*, 2nd ed. New Jersey: Prentice Hall, 1989, pp. 390–407.

[7] COMAU Robotics services, "SMART5 PAL 180-3.1 technical specifications," COMAU Robotics services, Grugliasco, Italian, 2014.

[8] M. Aburaia, E. Markl, and K. Stuja, "New concept for design and control of 4 axis robot using the additive manufacturing technology," in *Proceedings 25th DAAAM International Symposium on Intelligent Manufacturing and Automation*, 2014, pp. 1365–1369.

[9] S. N. Yu, S. J. Lim, M. K. Kang, C. S. Han, and S. R. Kim, "Off-line robot palletizing simulator using optimized pattern and trajectory generation algorithm," in *Proceedings 2007 IEEE/ASME International Conference on Advanced Intelligent Mechatronics*, 2007, pp. 1–6.

[10] How Products Are Made. (2018, Jun.). Corrugated Cardboard. How Products Are Made. Philadelphia, USA [Online]. Available: http://www.madehow. com/Volume-1/Corrugated-Cardboard.html