ISSN: 18158129 E-ISSN: 18151027
Volume 16, Issue 01, March, 2019

Design and experiment of a robotic manipulator for automated net-wrapper production

Son Tran Doan[1], Quan Vo Tuong[2]

Department of Manufacturing Engineering, Faculty of Mechanical Engineering, Ho Chi Minh city University of Technology, Vietnam National University HCM, 268 Ly Thuong Kiet, District 10, Ho Chi Minh City, Vietnam[1,2.]

Abstract— The spring roll is a quintessence of Vietnamese cuisine that is enjoyed by many different cultures around the world. Nowadays, there are 3 types of spring rolls in the markets: Rice paper spring roll, Bia spring roll and net-wrapper spring roll. As of now, net-wrapper is either manually made or produced on semi-automatic machines, which only automate forming process, so that workers are still needed in the production process. This study deals with the design of a robotic manipulator that connects to the semi-automatic machine to take the net-wrapper out of the mold instead of manual operation. The experimental results with the developed prototype demonstrate the effectiveness of the proposed design. This study contributes to improve the semi-automatic production and improve the productivity from 28% to 80% depending on the net-wrapper's diameter as well as workers' working conditions. This new solution will greatly contribute to food industries in the world as well as working environment for agricultural production in Viet Nam.

Keywords— Net-wrapper, PLC, robotic manipulator, pneumatic.

1. Introduction

A net-wrapper is made of rice flour and/or wheat flour mixed with water. The net-wrapper consists of interspersed strands forming a circular shape (Figure 1a), and used to make spring rolls (Figure 1b). Table 1 gives the typical specifications of net-wrappers. Nowadays, the production process is either manual (Figure 2) or semi-automatic (Figure 3) [1]. In the semi-automatic process, the net-wrapper's shape is formed by combining a circular motion of a heating disk and an elliptical motion of a powder can, but the process of lubricating the heating disk and removing the net-wrapper from the heating disk is still performed manually.

a)

b)

Figure 1 a) Net-wrapper cake [2] b) Net-wrapper rolls [2]

Table 1 Specifications of net wrappers (Specified by companies and customers)

Diameter Ø of a cake (mm)	Thickness of a cake (mm)	Diameter of the thread (mm)	Weight (gram)
160	0,5 – 0,7	0,2 – 0,3	4 - 4,5
180	0,5 – 0,7	0,2 – 0,3	5 - 5,5
200	0,5 – 0,7	0,2 – 0,3	6 - 6,5
220	0,5 – 0,7	0,2 – 0,3	7 – 8

1.1. Manual production process

Many Vietnamese food companies and households still manufacture net wrappers manually in Figure 2. The workers use a small can with multiple holes at the bottom to create the typical pattern of a net-wrapper. They put liquid powder of starch into a can and move their hands to follow a given trajectory to create the pattern of the net wrapper. The starch falls down onto a hot pan heated by either gas or electrical power to create a net wrapper. This type of manual production has many problems to be solved such as low productivity, less uniformity and insanitary. The workers also suffer from significant stress.

Figure 2 Manual production process of net-wrappers [1]

1.2. Semi-automatic production process

With the rapid increase in net-wrapper demands in local and global market, Ho Chi Minh University of Technology and Son Viet Co. have designed and manufactured hundreds of semi-automatic machines for many companies and households. The shift from manual to mechanized production has vastly improved productivity and quality. The current semi-automatic machine is illustrated in Figure 3.

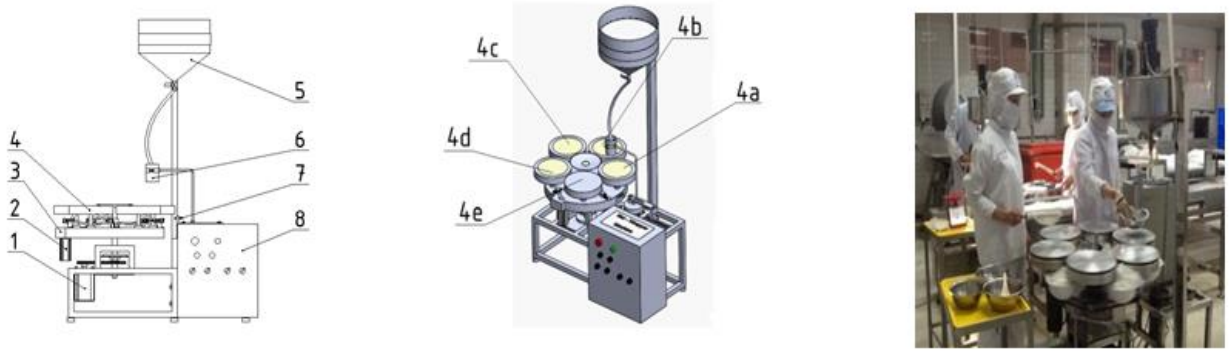


Figure 3 a) 2D and 3D models of semi-automatic machine b) Photo of semi-automatic machine

Notion: (1) Motor driving large disk; (2) Motor driving heating disks; (3) Large disk; (4) Heating disks; (5) Powder tank; (6) Powder can; (7) Slider-crank mechanism; (8) Electric box; (4a) Net-wrapper's forming position; (4b, 4c, 4d) Cooked net-wrapper; (4e) Net-wrapper's removing position by hand.

Operation principles of this type of machine are as follows: When the large disk (3) moves the heating disk (4) to the position(4a), the large disk stops, the net-wrapper shape is formed by the rotational movement of heating disk (4) and the elliptical motions of a powder can (6). After the forming process (2.5 - 4.5 seconds), the large disk (3) rotates again with the rotational angle α=360/5 to move the next heating disks into position (4a). At position (4 e) the net-wrapper is removed from the hot heating disk. Because the net-wrapper tends to stick to the heating disk, its surface is frequently lubricated by cooking oil. During the entire process, the slider-crank mechanism and the heating disks work continuously. In the semi-automatic process, the finished net-wrapper must be removed manually, so that the productivity in practice is much lower than the theoretical productivity of machine due to the time required to lubricate the heating disk and remove the net-wrapper by the worker. Although the forming process is automated, at least 1 to 2 workers are still needed to mix the powder and feed it to the tank, and lubricate the heating disks with cooking oil and remove net-wrappers from the hot heating disk. Net-wrapper sticks to a hot disk, which makes it difficult and hazardous for workers to remove. The net-wrapper is very thin and circular in shape. It sticks to the hot heating disk's surface, which rotates at a considerably high speed. These properties make it difficult to automate the net-warpper removal process.

2. ROBOTIC MANIPULATOR DESIGN FOR AUTOMATED PRODUCTION

2.1. Approaches to automated net-wrappers production

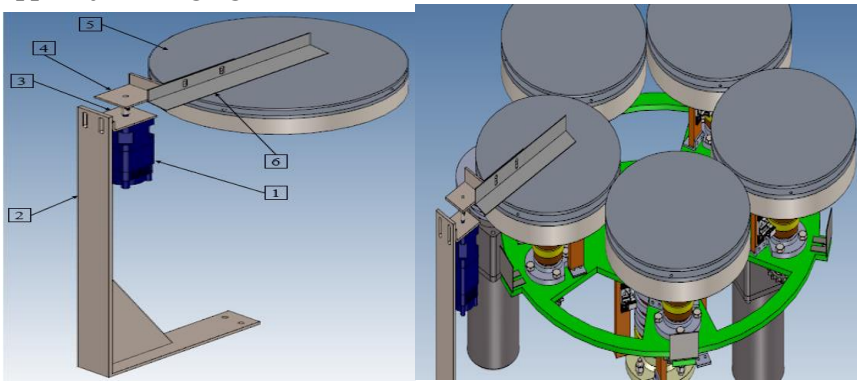
In order to improve the semi-automatic device for fully automation, the followings approaches are considered in the current machine design:

1. The net-wrapper tends to stick into the surface of the heating disk, so that the worker usually applies cooking oil after removing net-wrapper from the hot disk. In the proposed design, a non-stick coating is applied to the surface of the heating disks. Net-wrappers taken out from the heating disk that are still hot and easy to stick, so a rotational mechanism ensures that the cakes are arranged in a circular pattern to preventing the net-wrapper form overlapping each other (Figure 4).
2. A pump is installed in order to automate the material supply process.
3. A robotic manipulator controlled by a programmable logic controller (PLC) is designed and installed in the machine in order to automate the net-wrapper removal process. The design of the manipulator is presented in this paper.

2.2 Conceptual design

In order to automate the net-wrapper removal process, two methods are proposed:

Removing net-wrapper by a swinging arm



(a) (b)

Figure 4 Removing net-wrapper by swinging arm

Principle: After the formed process, the large disk rotates 72^0, moving the heating disk to the position of the swinging arm, the swinging arm contacts the net-wrapper and sweeps to remove it out of the heating disk. The driving motor speed of the swinging arm is synchronized with the start/stop interval of the large disk.

Advantages: Due to Simple design and easiness to manufacture, it can be quickly assembled with the available semi-automatic machine, providing low cost.

Disadvantages: Net-wrappers will be deformed and/or folded leading to large defects.

Robotic manipulator

The structure of the developed machine which is illustrated in Figure 5

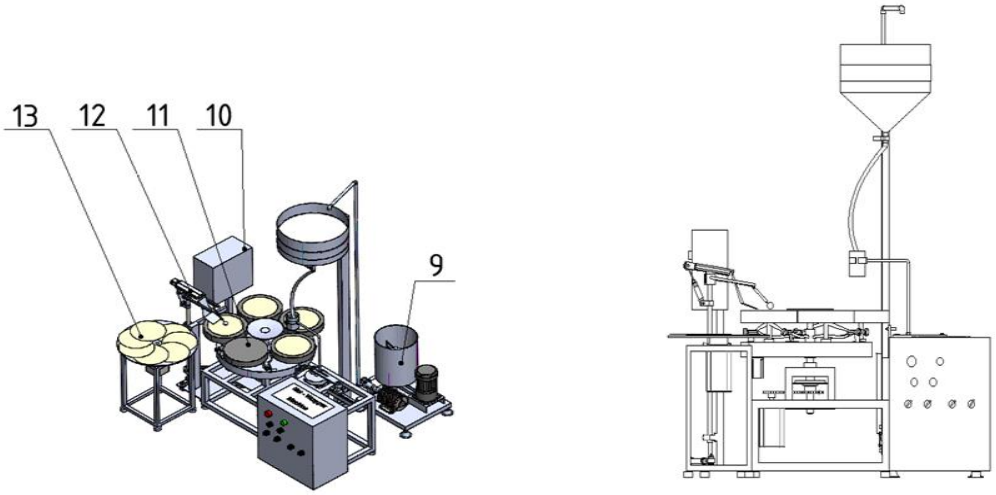


Figure 5 Mechanism design with the manipulator arm for automatic net-wrapper removal. Notation: (9) Mixing and Pumping mechanism, (10) Electrical control box, (11) Heating disk, (12) Manipulator arm, (13) Product arrangement mechanism.

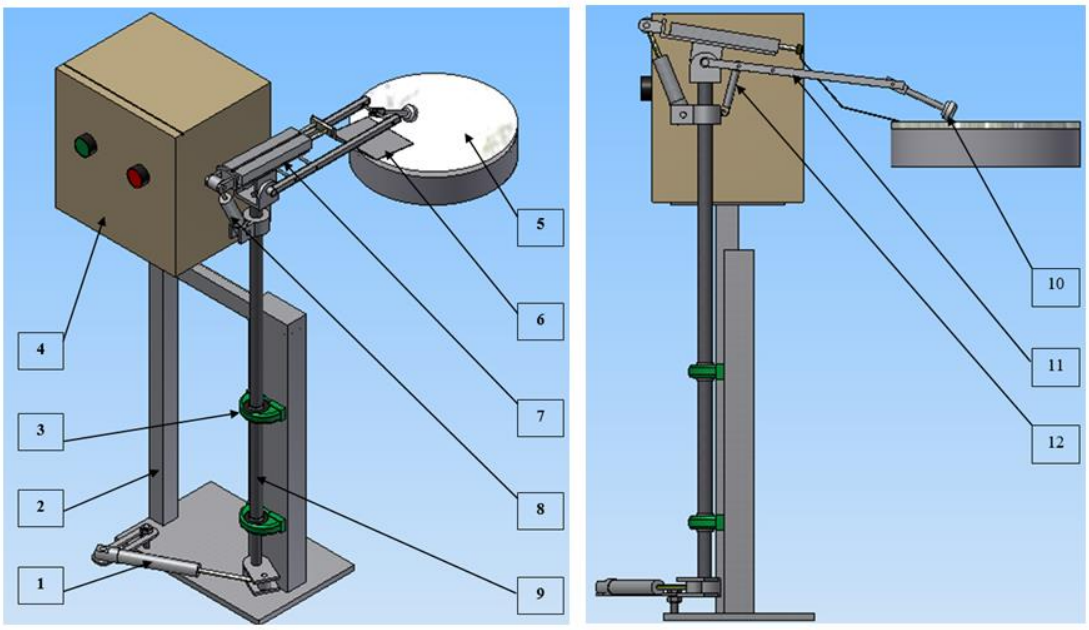


Figure 6 The design of the pneumatic manipulator

Notion: (1) Single cylinder 1; (2) Frame; (3) Bearing; (4) Control box; (5) Heating disk; (6) Lifting cake part; (7) Double cylinder 2; (8) Single cylinder 3; Rotational shaft; (10) Roller; (11) Clamping arm; Spring

2.3 Specific design

The structure of the manipulator arm is shown in Figure 6. The manipulator arm is a pneumatic system controlled by a PLC. Three pneumatic cylinders are used to control the position of the lifter. In addition, roller (10), clapping arm (11) and spring (12) assist the net-wrapper removal process.

2.4 Operation Principle

In order to make the system be fully automatic, a design of 3 DOFs pneumatic manipulator to bring the net-wrapper out of the heating disk is proposed. The manipulator includes 3 cylinders with three 3/2 valves. The first cylinder is used to control the rotational position of the manipulator; the second cylinder is used to control the angle of its end effector; the last cylinder is used to control the operation of lifting the rice cake out of the heating disk. The operation of the manipulator must be synchronously controlled with the 5 positions of the heating disks. With the angle 720, when the heating disk rotates to the desired position, the manipulator takes the net-wrapper out of the heating disk automatically. Figure 7 shows the operation principle of the manipulator:

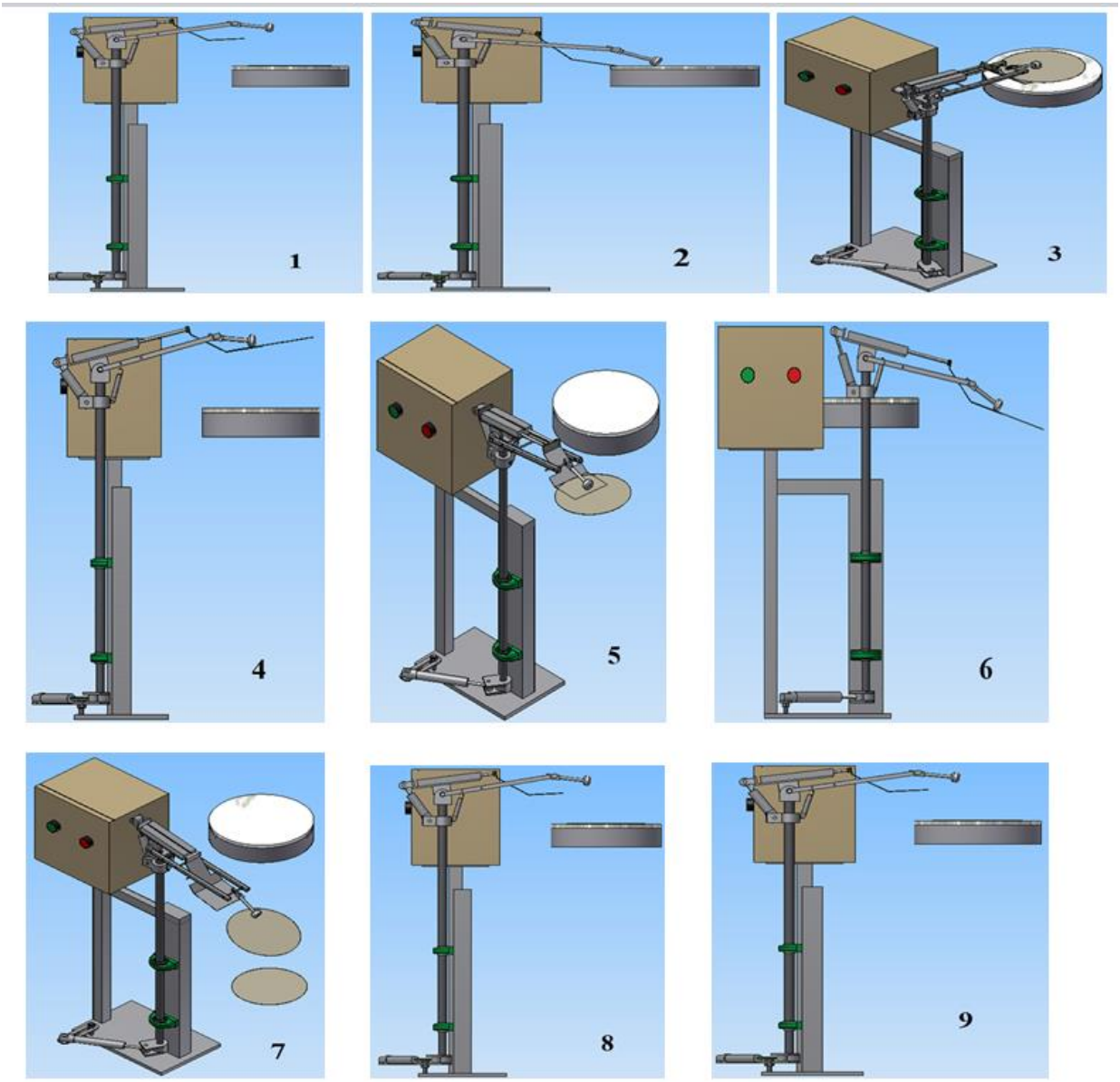


Figure 7 The 9 steps of the manipulator arm operation

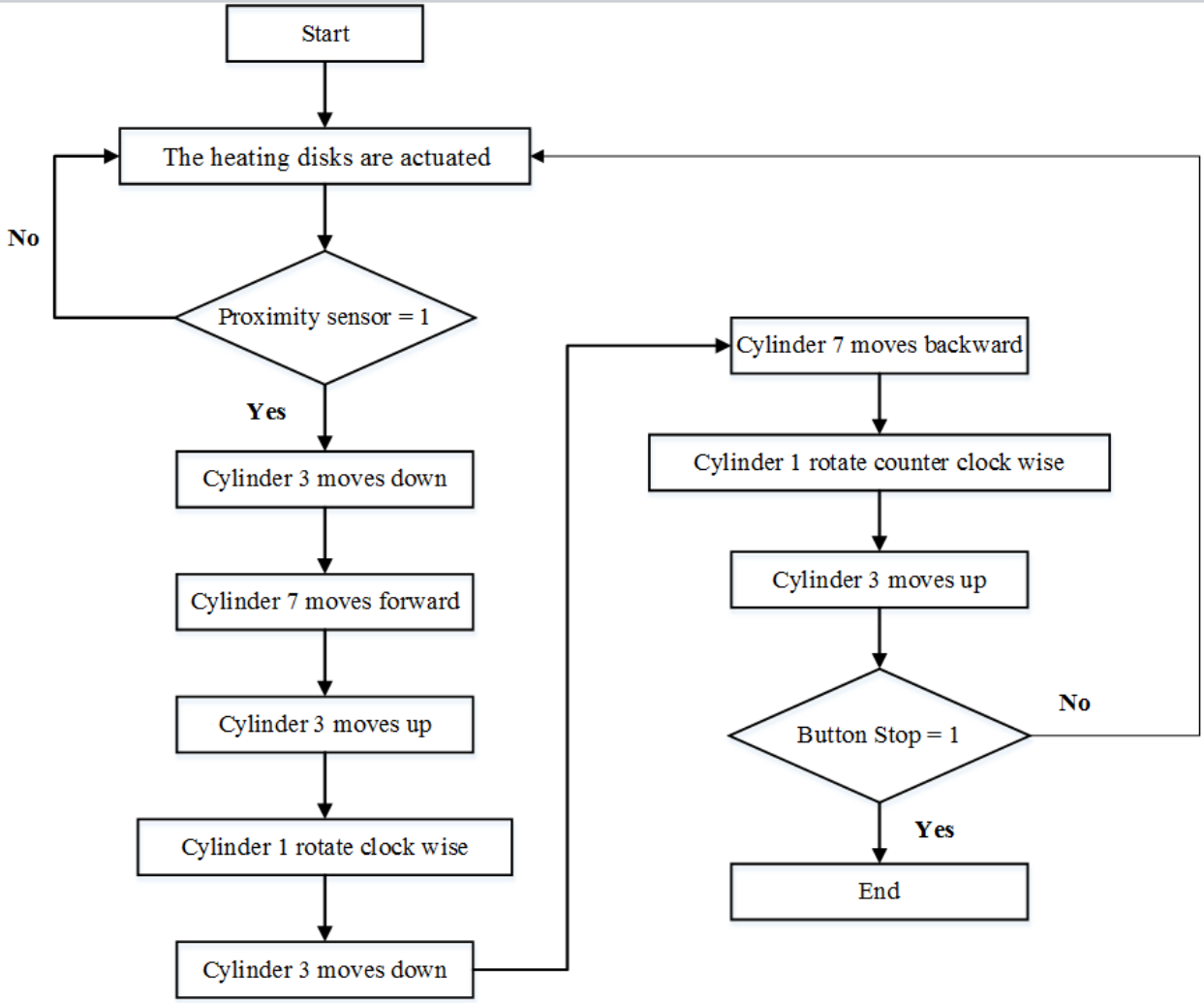


Figure 8 Control algorithm for pneumatic manipulator

The whole pneumatic manipulator includes 3 cylinders. There are total 9 steps of the manipulator to bring the net-wrapper out of the heating disk as follows and shown in Figure 7.

(1) The initial position of the manipulator. At this position, the manipulator waits for the heating disk to rotate to the desired position.
(2) The single cylinder (8 in Figure 6) activates (moves down) to the edge position of the heating disk
(3) The double cylinder (7 in Figure 6) moves forward in order to let the lifting cake part takes the net-wrapper and hold by the rolling part.
(4) The single cylinder (8 in Figure 6) activates (moves up) to lift the lifting part with the net-wrapper out of the heating disk.
(5) The single cylinder (1 in Figure 6) activates to rotate the rotational shaft (9 in Figure 6) (clock wise) to move the net-wrapper to the final position.
(6) The single cylinder (8 in Figure 6) activates (moves down) to prepare releasing the net-wrapper to the finishing position.
(7) The double cylinder (7 in Figure 6) moves back ward to release the net-wrapper.
(8) The single cylinder (8 in Figure 6) activates to move up.
(9) The single cylinder (1 in Figure 6) activates to rotate the rotational shaft (9 in Figure 6) (counter clock wise) to bring the whole lifting part to the initial position.

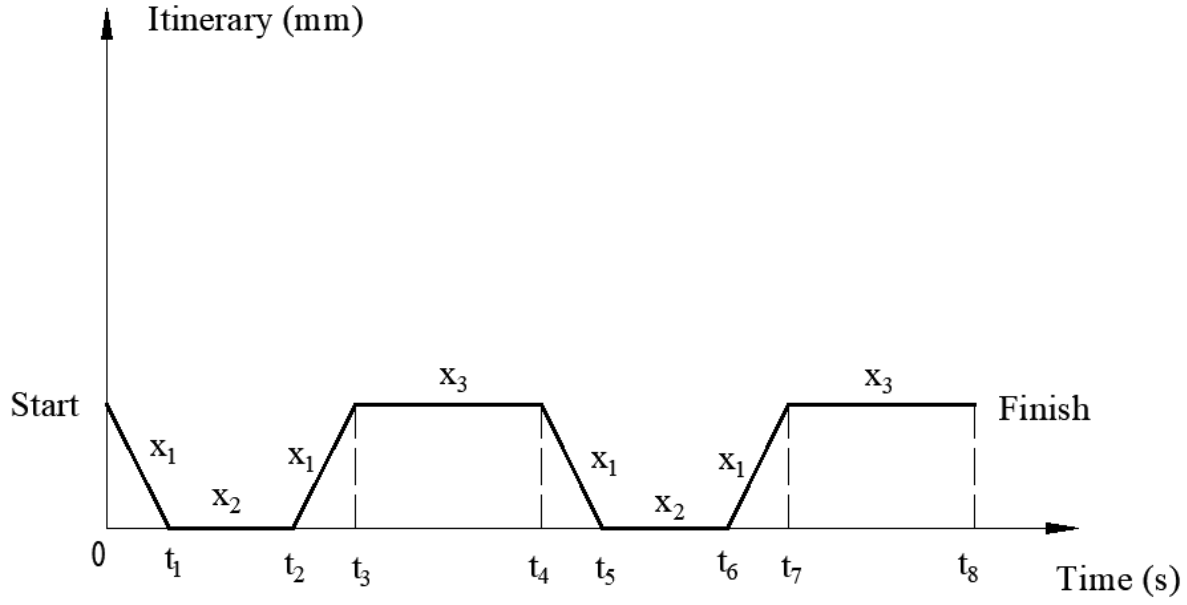


Figure 9 Time chart of the manipulator's motion

These 9 steps repeat continuously, in which the total time from the 1st step to the 9th step in order to bring the net-wrapper out of the heating disk is about 3 seconds. However, the speed of this process can be increased or decreased by adjusting the control valve of the cylinders.

The most important control problem is the need to synchronize the rotational speed of the heating disk for 5 positions of the net-wrapper with the motion speed of the pneumatic manipulator. For this reason, a proximity sensor is used to detect the exact position of each heating disks on the large disk. When the large disk moves the heating disk to the desired position detected by the sensor. The manipulator executes with the whole 9 steps and then waits for the next position of the consecutive heating disk. The algorithm and time chart to control the pneumatic cylinder in cooperating with the heating disk is shown in Figures 8 and 9.

X1: Actuate Single cylinder (Number 8 in Figure 6)
X2: Actuate Double cylinder (Number 7 in Figure 6)
X3: Actuate Single cylinder (Number 1 in Figure 6)

The originality of the study is the synchronization of a semi-automatic machine and a robotic manipulator to create a fully automated system, which improves not only productivity but also working condition and hygiene. For improving the productivity of the whole system, an automated line is also designed as shown in Figure 10.

In Figure 10, one station includes one semi automation net wrapper and one manipulator. We can arrange many stations along with the conveyor to improve the productivity of the whole automation system, which is called the High Productivity Net Wrapper System (HPNWS). Besides, the rotating speed of the semi automation net wrapper, the operation speeds of the manipulator and the conveyor can be adjusted independently. Therefore, we can choose the most suitable speeds of the whole system to meet different requirements for specific industries.

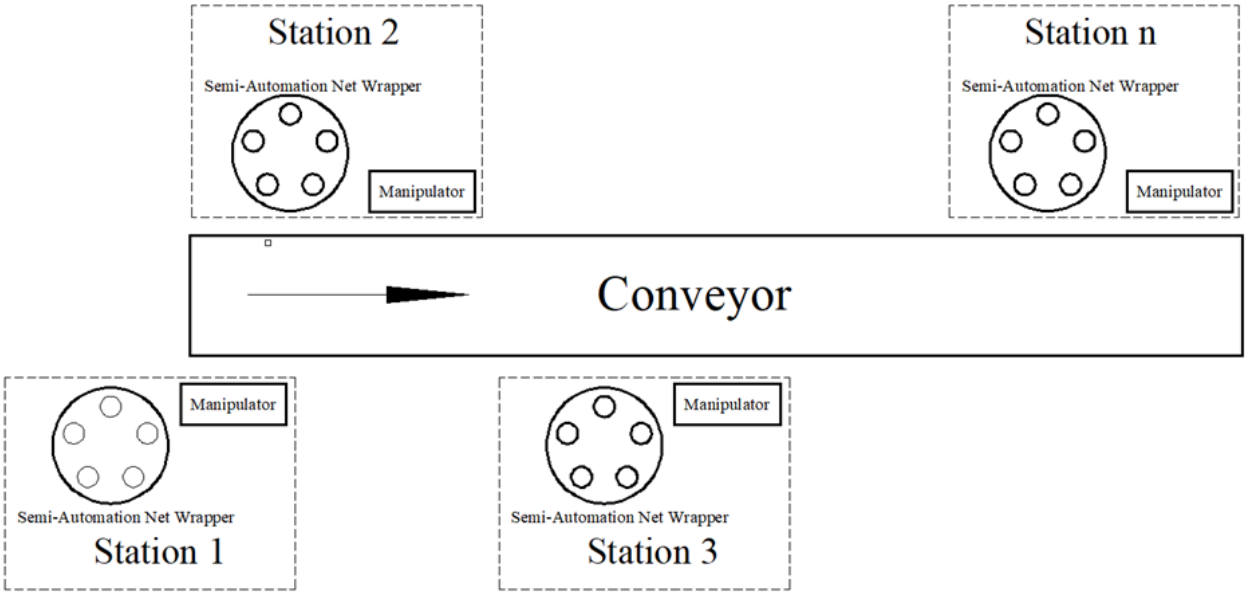


Figure 10 Arrangement of the automated high productivity net wrapper system

3. EXPERIMENTAL VERIFICATION

3.1 Objectives

The objectives of the experiment are to evaluate the productivity of net-wrapper production for various net-wrapper diameters when using the robotic manipulator compared to the manual net-wrapper removal process. The experiment also verifies the effectiveness of the actual operation of the machine compared to the design principles, as well as the solutions for the technical issues faced at the design stage such as material selection, mechanical structure control circuit and reliability of electronic components. It is ensured that the quality of net-wrappers removed from the heating disk is at least equivalent to manual removal operation, the net-wrapper is not deformed due to the force of the manipulator arm and the net-wrapper is not folded when pinned by the manipulator arm and when dropped. The operating time of 9 positions can be adjusted to meet the total time of forming a product from 2.5 to 3 seconds. The linear or rotational speed of the cylinders should not cause excessive vibration for impact.

3.2 Evaluation of the productivity and quality when using the manipulator arm

The productivity is investigated by adjusting the production speed of the net-wrapper. In the semi-automatic machine, depending on the net-wrapper's diameter and weight (Table 1), the forming's time can be varied from 2.5 seconds to 4.5 seconds by adjusting the timing relay, while the heating disk and slider-crank mechanism's speeds are fixed because worker is appropriate with these fixed speeds. Using the automatic manipulator arm, the speed of the heating disks and slider-crank mechanism can be increased, thus the forming time can be reduced.

3.3 Experiment process

The manipulator arm is installed with the semi-automatic machine of Hoa Y company (Cai Be district, Tien Giang province, Vietnam) as illustrated in Figure 10 and is experimentally verified there.

On semi- automatic machines, depending on the diameter and weight of the cake, the shaping process can change three parameters:

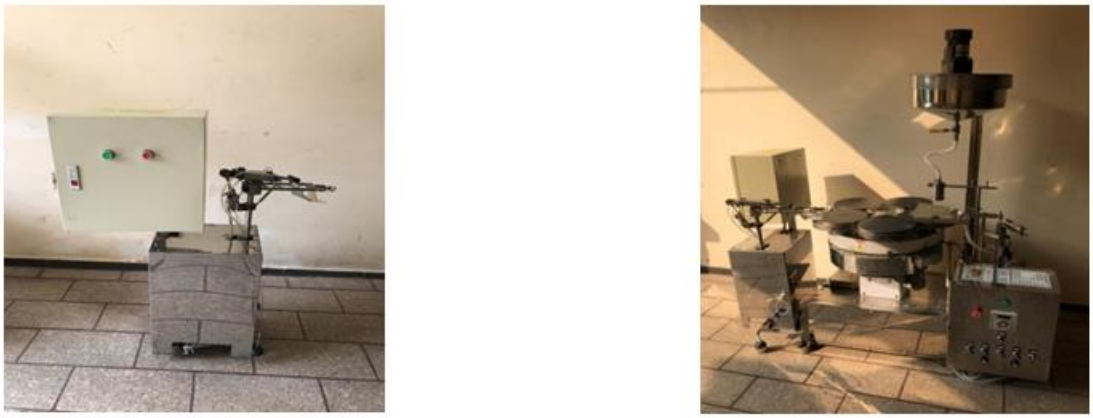


Figure 11 a) Proposed manipulator prototype b) Manipulator is installed in semi-automatic machine

Rotational speed of heating disk is varied from 48 rpm to 56 rpm, Rotational speed of slider-crank mechanism's driving motor is varied from 95 rpm to 120 rpm and forming's time is varied from 2.5 seconds to 4.5 seconds. If rotational speed of heating disk and rotational speed of slider-crank mechanism's driving motor are increased, a forming's time will be decreased. When a cake is taken by hand, forming's time is from 3.2 to 4.5 seconds, rotational speed of heating disk and rotational speed of slider-crank mechanism's driving motor are fixed. On the proposal machine, the forming's time can be reduced depending on the removal process's time of a manipulator arm: forming's time is 2.5 seconds, and removal process's time is 2.2 seconds (Figure 12).

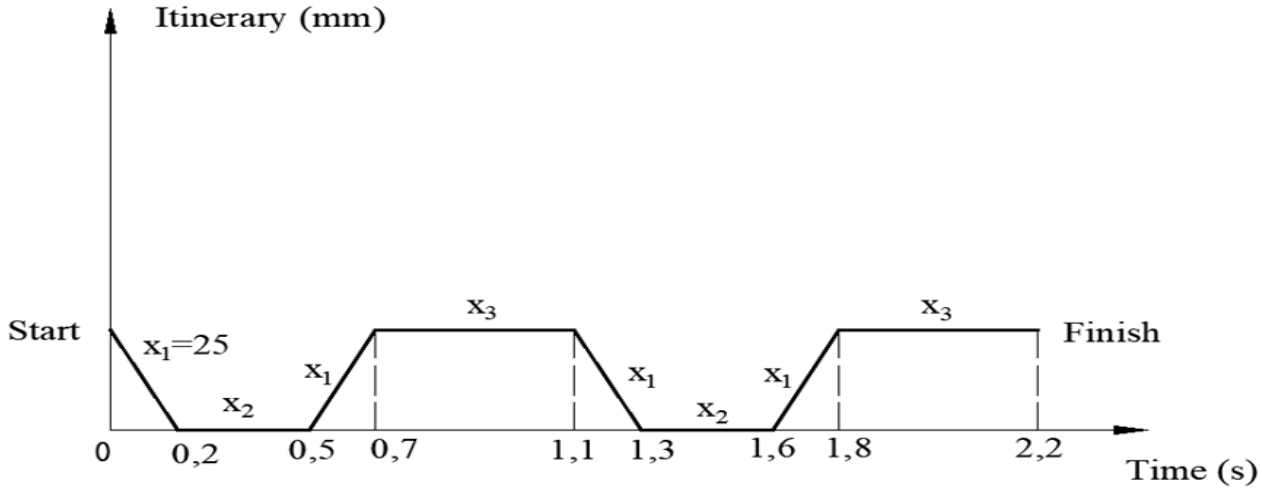


Figure 12 Time chart of a manipulator arm for experimentation

Table 2 Forming, removal and rest time of the manual process (Ø =160 mm)

Forming process's time	Removal process's time	Rest time	Deformation	Folding	Productivity

3.2 second	3.1 second	1 second	None	None	1,125 units/ hour

Case 1: Net-wrapper's parameters: Diameter of cake, Ø = 160 mm, Weight = 4~4.5 g (Table 1)
a. Manual removal process
n_1 = 48 rpm, n_2 = 95 rpm, r = 25 mm
n_1: Rotational speed of heating disks
n_2: Rotational speed of slider-crank mechanism's driving motor
r: Moment arm of slider-crank mechanism
n_1, n_2 can be adjusted by frequency converter
Forming process's time of a net-rapper can be adjusted by a timing relay

b. Automatic Removal Process
n_1 = 54 rpm; n_2 = 102 rpm; r = 25 mm

Table 3 Forming, removal and rest time of the automatic process (Ø =160 mm)

Forming process's time	Removal process's time			Rest time			Deformation and/or folding	Productivity
2.5 second	X_1= 4*0. 2s= 0.8s	X_2= 2*0.3s= 0.6s	X_3= 2*0.4s= 0.8s	X_1= 0.3s	X_2= 0.3s	X_3= 0.3s	None	1,440 units/ hour

Case 2: Net-wrapper's parameters: Diameter Ø = 220 mm, Weight = 7~ 8 g
a. Manual Removal Process
n_1 = 48 rpm; n_2 = 95 rpm; r = 38 mm
Note: n_1, n_2 is fixed to prevent workers from feeling dizzy.

b. Automatic Removal Process
n_1 = 56 r/rpm; n_2 = 120 r/rpm; r = 38 mm
Rest time of X_1, X_2, X_3 is equal.

Table 4 Forming, removal and rest time of the manual process (Ø=220 mm)

Forming process's time	Removal process's time	Rest time	Deformation and/or folding	Productivity
4.5 seconds	3.1 seconds	1.4 seconds	None	800 units/ hour

Table 5 Forming, removal and rest time of the automatic process (Ø = 220 mm)

Forming process's time	Removal process's time			Rest time			Deformation and/or folding	Productivity
2.5 seconds	X_1= 4*0.2s=0.8s	X_2= 2*0.3s=0.6s	X_3= 2*0.4s=0.8s	X_1= 0.3s	X_2= 0.3s	X_3= 0.3s	None	1,440 units/ hour

4. Results

Workers can remove the net-wrapper manually as long as the forming process's time is not shorter than 3.2 seconds. If the forming process's time is shortened, the speed n_1 and n_2 is increased, causing dizziness for the workers. Using the manipulator arm to remove the net-wrapper, n_1 and n_2 can be increased, reducing the forming process's time and increase the productivity. The level of deformation and tearing is similar to the manual removal process.

Productivity when using the manipulator arm is higher than the manual process:
*For the Ø = 160 mm, productivity increases 28%.
*For the Ø = 220 mm, productivity increases 80%

The experiment is presented in a video recorded (video link in the reference) [3].

5. Conclusion

The robot manipulator is designed. The machine is manufactured and installed together with a conventional semi-automatic machine in a factory. The effectiveness is verified and the machine is currently being prepared for mass production in the factory. The manipulator arm is reliable in operation and non-defective. It can release workers from the hand task to remove the net-wrapper from the heating disk by hand.

The manipulator arm increases productivity especially for net-wrapper with larger diameter (220 mm) and makes it easier to maintain product's quality and organize production plans. The manipulator arm aids factories in monitoring production according to the principles laid out by Industrial 4.0 Revolution.

6. References

[1] Son, T.D. (2009). Research on shaping veins of net wrapper based on the combination of elements' moving and modeling the process of kinetic by two starch cans. Journal of Science and Technology Development, (12), pp.47-54.

[2] Joanne (2006). How to buy and use rice paper wrappers [internet]. Available from: https://www.inspiredtaste.net/13004/how-to-buy-and-use-rice-paper-wrappers/ [Accessed 2018].

[3] Son, T.D. (2018). IMG_1360 [internet]. Available from: https://drive.google.com/file/d/0BzBD7uhsIROjVFo2T2pLcWUtOGc0ZTlmcnFISW9fRFZsQTlR/view?ts=5bea46b4 [Accessed 2018].

[4] Beck, T.G. (1995). Mechanical measurements (2nd ed). Addison –Wesley Publishing Company.

[5] Huong, M.B. and Quan, V.T. (2016). Design and control of a specific hand-building machine applying for silk fabric. Vietnam Mechanical Engineering Journal, pp.48-53.

[6] Huong, M.B. and Quan, V.T. (2016). Applying natural cellulosic fiber for environment-friendly oil sorbent material part 2: A design & control of an automatic kapok fruits breaking system. Vietnam Mechanical Engineering Journal, Special Issue, pp.142-148.

[7] Norton, R.L. (1999). Design of Machinery (2nd ed). McGraw-Hill.

[8] Quan, M.D. and Quan, V.T. (2017). Design of a CPG-Based Close-Loop Direction Control System for Lateral Undulation Gait of Snake-Like Robots. International Conference on Advanced Technology for Communication (ATC 2017), Quy Nhon, Vietnam.

[9] Sclater, N. and Chironis, N.P. (2007). Mechanisms and mechanical devices sourcebook (4th ed). McGraw-Hill.

[10] Son, T.D. (2013). Design and manufacturing the automatic production machine for Bo Bia paper product. Vietnam Mechanical Engineering Magazine, 6, pp.27-32.

[11] Son, T.D. (2015). Towards automation production process to creating thin membrane from rice flour. Vietnam Mechanical Engineering Magazine, 6, pp.86-89.

[12] International Electrotechnical Commission (2003). International Standard IEC 61131-3: Programmable Controllers, Part 3: Programming Languages. IEC.

[13] Fabian, M. and Hellgren, A. (1998). PLC-based implementation of supervisory control for discrete event systems. In: Proceedings of the 37th IEEE Conference on Decision and Control (Cat. No. 98CH36171). IEEE, pp.3305-3310.

[14] Bao, Y. and Wu, Y. (2006). The Design of the Control Circuitry for an Universal Pneumatic Manipulator [J]. Machine Tool & Hydraulics, 9.

[15] Cajetinac, S., Seslija, D., Aleksandrov, S. and Todorovic, M. (2012). PWM Control and Identification of Frequency Characteristics of a Pneumatic Actuator using PLC controller. Elektronika ir Elektrotechnika, 123(7), pp.21-26.