Proc. of the 9th Intl. Conf. of Asian Society for Precision Engg. and Nanotechnology (ASPEN 2022)
15–18 November 2022, Singapore. Edited by Nai Mui Ling Sharon and A. Senthil Kumar
doi://10.3850/978-981-18-6021-8_OR-02-0037

Flexibility wires of circular connector automatic disassembly process with the finite element analysis

Yu-Ren Lin, Yu-Cheng Lin, Chao-Ching Ho#
Department of Mechanical Engineering, National Taiwan University of Science and Technology, 1, Sec. 3, Zhongxiao E. Rd., Taipei 10608, Taiwan
Corresponding Author / Email: hochao@ntut.edu.tw , TEL: +886-2-2771-2171 Ext: 2020, FAX: +886-2-27764889

KEYWORDS: Precision machining, Finite Element Package, Shape optimization

Circular connector four-core wires are made with winding in the cable and the wires of different colors are not distributed fixedly within the cables. The exact position of the four wires inside the cable cannot be determined due to the cables are stripped. In addition, the core wire is flexible, and it is easy to bend in any direction due to external force interference. Because of the above two factors, it is difficult for this process to be fully automated. The purpose of this work is to use the finite element analysis software to simulate the flexibility of the core wire in the four-core cable and design a Separate module that only uses a single-axis-robot and a stepper motor. The core wires wound within the cable are separated by the designed Separate module, which facilitates the subsequent welding process and improves the production efficiency, and reduces labor costs.

1. Introduction

Connectors are important components of electronic products in industrial development. They are responsible for transmitting analog or digital signals, acting as a bridge for information transmission between electronic products. In recent years, the application of connectors has been widely promoted in the fields of artificial intelligence, robotics, electric vehicles, 5G communication, industry 4.0 and smart homes. Therefore, the demand for circular connectors has also increased significantly [1]. Although the circular connectors automatic welding machine has been developed in the market, there are still two processes that need to be completed before the welding operation. The first step is to strip the PVC insulation of the cable and the second step is to align the cores according to the manufacturing specification, ready to be soldered to the connector. But in fact, the second step still requires a lot of labor, especially the operator needs to separate the circular-connector core wires before welding and put them into the welding jig in the specified order. However, the disadvantages of manual operation are low consistency, low efficiency, and low productivity. Therefore, in the development of the automation industry, robot automation operations are gradually used to replace operators. However, the robot's control is mainly the rigid body control, but the core wire of the circular connector is flexible. Hence, it is difficult to realize automatic operation. X. Li and C. C. Cheah proposed a regional feedback control method in [2], and also proposed the task-space sensory feedback control of robot manipulators in [3]. J. E. Slotine and L. Weiping proposed the adaptive controller with better tracking accuracy than the PD controller or computed-torque schemes in [4]. G. Niemeyer and J.-J. E. Slotine proposed an adaptive tracking control scheme for robots with unknown kinematic and dynamic properties in [5]. M. Takegaki and S. Arimoto proposed in [6] with a new feedback method for dynamic control of manipulators. When the robot operates the winding core wires, the position and shape of the core wires are easily changed by external forces, so it is difficult to handle with conventional robot manipulation technology [7]. X. Li, X. Su and YH Liu proposed in [8] a vision-based robotic manipulation technique to solder flexible PCBs, enabling robots to automatically contact and actively deform flexible PCBs into desired configurations. In addition, X. Li, X. Su, Y. Gao and Y. H. Liu also proposed a new vision-based controller for robotic grasping and manipulation of USB wires in [9], [10], which developed a two-layer structure and was embedded in the controller, but the experimental assumption is that the USB cores have been separated and sorted.

The purpose of this research is to use the finite element analysis software Abaqus to simulate the flexibility of the core wires in the

©2022 ASPEN 2022 Organisers. ISBN: 978-981-18-6021-8. All rights reserved.

circular-connector cable and employ the computer-aided design software Solidworks to design the Separate-jig, and design a Separate-module with a simple mechanism. Then a 3D printer was used to convert the design into a solid to verify the Separate-module. Finally, we implement with Python and Arduino software to automate the preprocessing of the soldering operation.

2. Background

The U.S. Department of Defense created the original specifications for the military-grade circular connector in the 1930s. This was due to the demand for very severe tactical and aeronautical applications. These connectors were known as type AN (for Army-Navy). The original specifications set the standard for the various military circular connectors. In this study, the four-core cable was selected as the research object. Before the cable and connector is welded, the core wires must be sorted. The sorting process has two steps. The first part is the separation operation, and the second part is the core wires sorting operation, as shown in Fig.1. The separation operation is to separate the core wires from each other, and then classify and fix wires according to the specifications in the separation operation. Since the 2018 U.S. Patent [11] realizes the method of separating the wire from the winding state, this method requires more cost and a professional design of the mechanism. Therefore, this research uses Abaqus to simulate the flexibility of the core wires and uses Solidworks to design the Separate-jig. After many simulation experiments, the most effective separation fixture was gradually designed. Then use the 3D printing method to manufacture Separate-jigs that are difficult to process with traditional machining techniques, and then use the Separate-features to perform separation operations to achieve economical and efficient Separate-module. The wire sorting process can be realized through research [12], and then the pre-processing part can be done before core wire welding can be achieved.

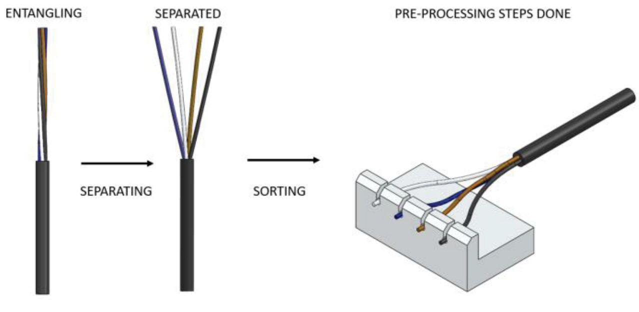

Fig.1 Pre-processing steps before core wires soldering include wire separation and wire sorting.

3. Separate-module

This chapter describes the overall hardware configuration of the automatic Separate-module designed for the Separate-jig. From the circular-connector core wires simulation to the Separate-jig and the overall machine design in order, including the use of a single-axis robot, stepper motor, camera, fixed jig, motor driver, power supply, and Arduino control board.

3.1 Start with the design of separate clamp

This section describes the design of the separation jig model using the computer-aided design software Solidworks. Because the Separate-jig manufacturing method is difficult to manufacture by general traditional processing methods, therefore, it is integrally formed using 3D printing technology, as shown in Fig. 2.

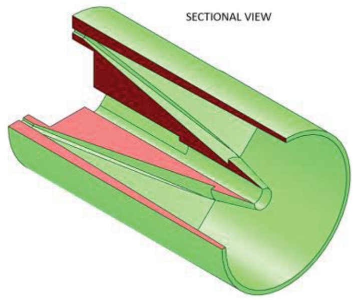

Fig. 2 Design Separate-jig that are difficult to manufacture with traditional machining techniques.

The feature design of the Separate-jig is divided into three parts, the first part is the cone that extends the core wires outward, the second part is the inner cone that limits the extension range of the core wires, and the third part is the Separate-feature that separates the core wires from each other, as shown in Fig. 3.

Fig. 3 Three features of separate clamps to separate wires.

3.2 Simulation of wire with separate hook

In this section, Abaqus finite element analysis software is used to simulate the flexibility of the core wire in the circular connector cable. Because the circular-connector core wire contains two materials: The PVC sheath and copper wire, and the copper wire affect the flexibility of most core wires, therefore, in order to simplify the experimental simulation results, the core wire material will be set to copper wire characteristics. The density of the core wire density is set to 8.96 $g{\cdot}cm^{-3}$, the Young's modulus in the elastic properties is 120 GPa and the Poisson's ratio is 0.34. After setting the core wire characteristics, the environment and space model setup is performed. It includes the Separate-jig, the four core wires and their relative positions, the degrees of freedom of the core wire in the virtual space, and the relative motion between the core wire and the Separate-jig. As shown in Fig. 4.

©2022 ASPEN 2022 Organisers. ISBN: 978-981-18-6021-8. All rights reserved.

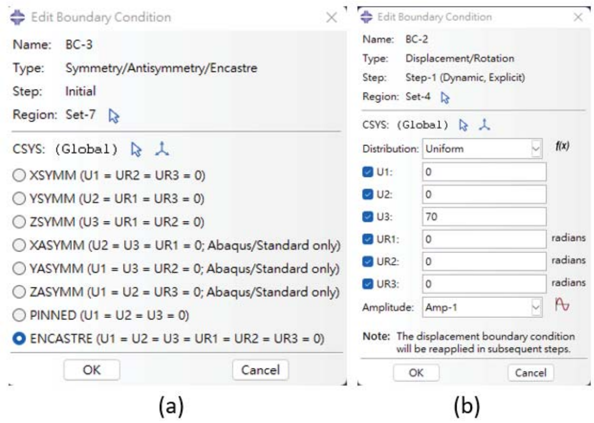

Fig. 4 Simulate the relative motion of the core wires and the Separate-jig by Abaqus. (a) Fix the six degrees of freedom at one end of the core wires. (b) Set the moving distance of the Separate-jig.

Then, through the built-in finite element analysis method of Abaqus, the mesh of the core wire and the Separate-jig can be automatically generated through a simple setting, and the final setting is completed, and then the effect of the core wire separation can be simulated, as shown in Fig. 5.

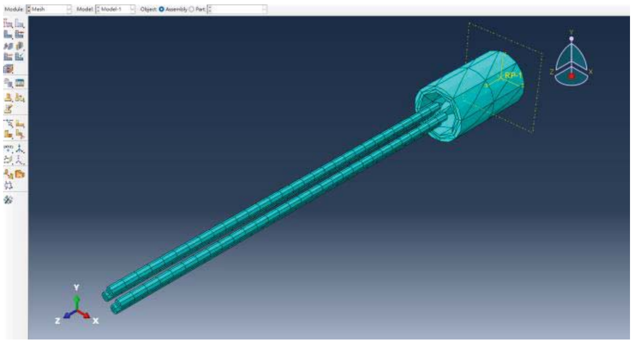

Fig. 5 Generated mesh to perform finite element analysis with Abaqus.

The simulation experiment is shown in Fig. 6. With the simulation results, the Separate-jig is designed and optimized to improve the success rate of the Separate-module.

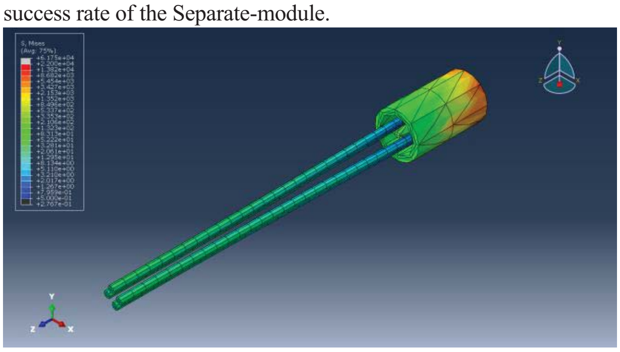

Fig. 6 Improve Separate-jig by simulation analysis

3.3 Mechanism design

This section describes the design of the separate module equipment by the computer-aided design software Solidworks, as shown in Fig. 7. The equipment list is as follows:

- Single-axis robot: NEMA 23HS7430
- Stepper motor: NEMA 17 With Encoder
- Camera: USB endoscope inspection camera
- Power supply: MEANWELL-LRS-350-12
- Arduino mega board: MEGA2560 R3
- Stepper motor driver: TB6600 Stepper Motor Driver

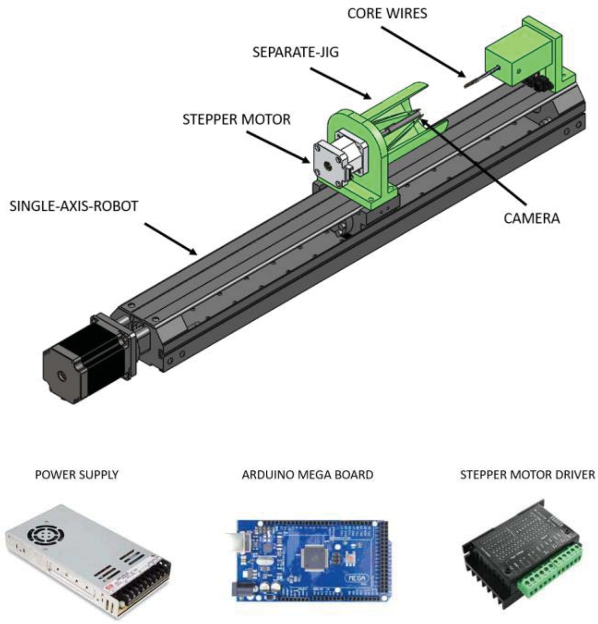

Fig. 7 Mechanism design and all separate module hardware devices.

When assembling, a cross line will be drawn on the screen, and it will be used to align the Separate-feature in the Separate-jig, to control the motor to perform the separation line operation, as shown in Fig. 8.

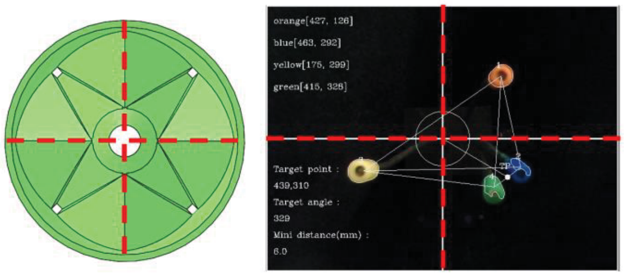

Fig. 8 Align the separate features with the cross-line on the screen.

4. Experiment

This work uses a single-axis robot and an Arduino control board to design a simple and convenient tool for separating circular-connector core wires. First, use Abaqus to simulate the

©2022 ASPEN 2022 Organisers. ISBN: 978-981-18-6021-8. All rights reserved.

flexibility of the core wire, and use the simulated characteristics to design and optimize the separation jig, design the most suitable separation jig for core wire separation, and write a set of image processing programs in Python. Finally, the above contents are integrated to complete the automatic separation of the core wire.

4.1 Experimental design

In this research, to control the motor to perform automated operations, we used the programming platform Visual Studio Code to write Python programs and design the human-machine interface before the experiment, as shown in Fig. 9. The part in the red frame in the figure can control the single-axis robot and the stepper motor, respectively. The blue part in the figure is the single-axis robot and the motor position display field. The STOP button can forcefully end all programs; regardless of whether the stepper motor or single-axis robot is in motion or not, it will stop and end the program to ensure the safety of the machine. The part in the yellow frame in the figure is the real-time image display area, and the core wire coordinates and the information required to separate the core wires are displayed in this area. The green frame in the figure is the display area of the separated core wire status, and the separated core wire button is used to execute the automatic core wire separation operation. The experimental process is shown in Fig. 10.

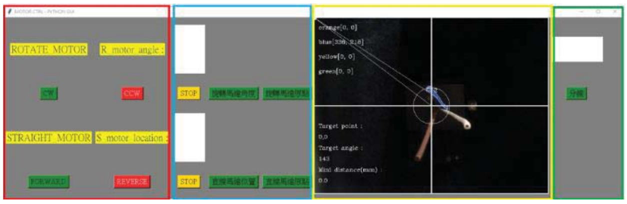

Fig. 9 Design a separate module GUI by Python

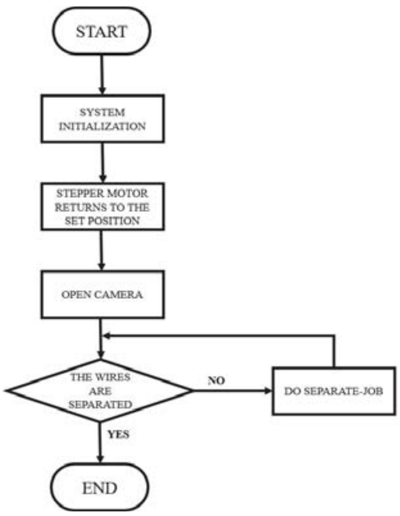

Fig. 10 Flow diagram of the automatic separation procedure

4.2 Wire Separation Process

Identify the end of the core wires within the shooting range of the lens and give them coordinates. Then use the coordinate values to calculate the shortest distance between each of the four core lines. Finally, control the motor to align the Separate feature of the Separate-jig with the center point of the shortest distance between the endpoints of the core wires to perform the Separate-job. The Separate-job process is shown in Fig. 11.

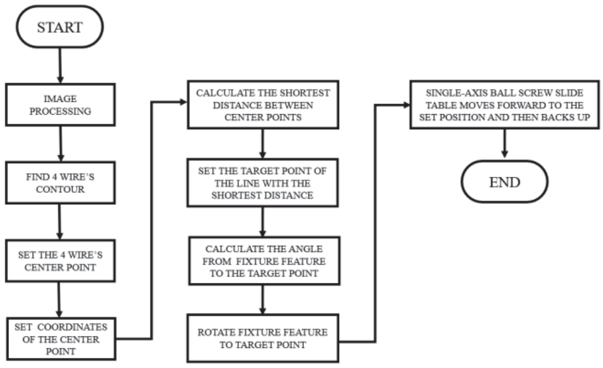

Fig. 11 Separate-job flow chart

5. Experimental Results

This chapter will first define the experimental goal and the success or failure of the wire separating process.

- Experimental goal: The distance between the four core wires is greater than 8mm, which allows the robot fingers to operate on the welding platform.
- Experimental success: The distance between the four core wires is greater than 8mm.
- Experimental failure: During automatic operation, the core wire is bent out of the camera range by the separation jig.

The actual experimental screen is shown in Fig. 12.

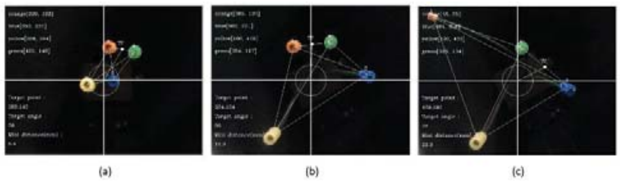

Fig. 12 (a) Initial state: The distance between the four core wires is less than 8mm; (b) Success: The distance between the four core wires is more than 8mm; (c) Fail: the core wire is bent out of the camera's range by the separation jig.

The experimental results are shown in Table 1. It can be seen from the table that the total success rate of the experiment is 94%, but the probability of success the first time is only 68%, so there is still room for improvement in the experiment. For example, the friction between the Separate-jig and the core wires determines the success rate of part of the wire separation operation. If the Separate-jig is changed to a smoother material or a higher-precision 3D printer is used to manufacture the Separate-jig, reducing the friction with the core wires will increase the success rate of the experiment.

Table 1 Experimental results.

©2022 ASPEN 2022 Organisers. ISBN: 978-981-18-6021-8. All rights reserved.

NUMBER OF EXPERIMENTS	THE FIRST TIME SEPARATE JOB SUCCEEDED	THE SECOND TIME SEPARATE JOB SUCCEEDED	MORE THAN THREE TIMES SEPARATE JOB SUCCEEDED	SEPARATE JOB FAILED
1 - 10	6	4	0	0
11 - 20	8	2	0	0
21 - 30	6	2	1	1
31 - 40	7	3	0	0
41 - 50	7	1	0	2
Total	34	12	1	3

6. Conclusions

The wire core separation module currently used in the market needs more cost and a professional design of the mechanism. With the help of the new fixture design and visual feedback, the developed Separate-module line can quickly perform the line splitting operation. This economical and convenient separation module can overcome the shortcomings of the existing manually operated separation core wires and the separation modules on the market and increase the achievability of fully automatic welding of core wires.

In addition, the traditional image processing method is easily affected by the illumination change on the parameter setting, and this experiment distinguishes each core wire by adjusting the parameters in the HSV color space. But the color of the core wires is similar, so it is not easy to distinguish. Therefore, this experiment adds easily recognizable colors to the ends of the core wires. When the illuminance changes, the threshold parameters also need to be modified, which will cause misjudgment in the actual operation. Therefore, in order to increase the accuracy of the identification of each core, the relative position between the core wires can be segmented and obtained by using deep learning-based algorithms.

ACKNOWLEDGEMENT

This research was supported by the National Science and Technology Council of Taiwan under Grant no. 111-2218-E-002-031.

REFERENCES

[1] Global Connector Market (2021 Edition): Analysis By Product, End User, By Region, By Country Market Insights and Forecast with Impact of COVID-19 (2021-2026).

[2] X. Li and C. C. Cheah, "Global task-space adaptive control of robot," Automatica, vol. 49, no. 1, pp. 58-69, 2013.

[3] C. C. Cheah, and X. Li, Task-Space Sensory Feedback Control of Robot Manipulators, Springer, 2015.

[4] J.-J. E. Slotine and L. Weiping, "Adaptive manipulator control: A case study," IEEE Transactions on Automatic Control, vol. 33, no. 11, pp. 995-1003, 1988.

[5] G. Niemeyer and J.-J. E. Slotine, "Performance in adaptive manipulator control," The International Journal of Robotics Research, vol. 10, no. 2, pp. 149-161, 1991.

[6] M. Takegaki and S. Arimoto, "A new feedback method for dynamic control of manipulators," Journal of Dynamic Systems, Measurement, and Control, vol. 103, no. 2, pp. 119-125, 1981.

[7] Jose Sanchez, Juan-Antonio Corrales, Belhassen-Chedli Bouzgarrou and Youcef Mezouar, "Robotic Manipulation and Sensing of Deformable Objects in Domestic and Industrial Applications: A Survey," The International Journal of Robotics Research, vol. 18, pp. 3-11, 2018.

[8] X. Li, X. Su, and Y.-H. Liu, "Vision based robotic manipulation of flexible PCBs," IEEE/ASME Transactions on Mechatronics, 2018.

[9] X. Li, X. Su, Y. Gao, and Y. H. Liu, "Vision-based robotic grasping and manipulation of USB wires," IEEE International Conference on Robotics and Automation, pp. 3482-3487, 2018.

[10] Y. Gao, Z. Chen, M. Fang, J. Lin, and Y. H. Liu, "Vision-based grasping and manipulation of flexible USB wires," IEEE International Conference on Robotics and Biomimetics, pp. 1083-1088, 2019.

[11] X. Li, Z. Chen, Y. Gao, and Y. Liu, "Apparatus for Separating USB Wires," U.S. Provisional Patent Application, no.62/756, 2018.

[12] Y. Gao, Z. Chen, M. Fang, Y. H. Liu, X. Li "Development of an Autonomous Soldering Robot for USB Wires," 2020 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM), Boston, USA (Virtual Conference), July 6-9, 2020

©2022 ASPEN 2022 Organisers. ISBN: 978-981-18-6021-8. All rights reserved.