A Case Study on Automated Manipulation for Hooking Wiring of Flexible Flat Cables

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Abstract— **This paper describes a case study of Flexible Flat Cable(FFC) manipulation. We focus on a task of the hooking wiring, and propose methods for achieving it. First, we arranged the procedure of hooking wiring. In order to wire stably, we determined how to place and insert FFCs into the hooks. Next, with the premise of using a dual-arm robot, the role of each arm was decided. Then, we designed and produced end-effectors to achieve those roles. Finally, the effectiveness of the proposed methods was proven by means of actual experiments using a workpiece equipped multiple types of hooks. Some findings through the experiments are also introduced qualitatively.**

Index Terms— **Flexible Flat Cables(FFC), manipulation.**

I. Introduction

Deformable linear objects such as strings and cables exist in various scenes and have various uses. For instance, a string can be used to the purpose of tying up a plurality of articles, and a cable is used to the purpose of conveying electric current, electric signals and the like to electrical equipments. If it is possible to automate manipulation tasks with respect to such deformable linear objects, it seems that there are many applicable situations.

In this paper, we deal with the manipulation of cables that are incorporated inside electric appliances. Needless to say, manufacturing of electric appliances requires wiring with many cables into a workpiece is a laborious work. However, the work requires precision and due to the difficulty caused by the flexibility of the cable, it currently depends on human workers. Therefore, if this automation is possible, it can contribute to cost reduction of manufacturing. Among the various work involving cables, the authors pay attention to the wiring work of flexible flat cables (FFC) into workpieces. That is, fit the FFC into the hook part on the workpiece so that the cable does not move on that workpiece.

FFC is a flat, thin cross section cable, which is characterized in that multiple cores are mounted together. Therefore, it is excellent for the purpose of connecting multiple inputs and outputs collectively. Also, it requires less space for mounting. For these reasons, FFC is used in various home appliances. However, since FFC is flat, it is anisotropic in bendability and it is not normally considered to wire in a twisted state. Therefore, when compared with round type cables, restrictions are large on the handling.

As far as we know, there is almost no down-to-earth techniques on the automation of FFC wiring. Therefore, in this study, we set a FFC wiring for a specific workpiece, organize the tasks there, and then present a solution. We present the procedure of wiring using characteristics unique to FFC. Also, the configuration of end-effectors for a dual-armed robot suitable for FFC handling. Basically, these are task-dependent technologies, but there are many parts to be know-how for the other operations of FFCs. Therefore, after implementing the hooking wiring targeted in this study, we will qualitatively organize how to structure it. We expect that this result should be useful for application to fitting to other parts and other work using FFC etc.

The contributions of this study are summarized below.

- As a popular method for installing the FFC in a predetermined place, we focus on a hooking which is one step of wiring work. Through implementing the hooking, we have extracted know-how on FFC manipulation.
- We propose a procedure and hooking methods suitable for wiring of FFC.
- We propose a novel design of end-effectors suitable for the hooking of FFC, and also propose the manipulation method of FFC using them.

Due to these contributions, we made possible hooking wiring by a dual-arm robot. Although the situation targeted in this study is limited, we find the attention points and technological elements in hooking wiring qualitatively, therefore we report them in this paper.

The structure of this paper is as follows. In Section II we introduce related work. In Section III we analyze the hooking wiring and then explain our approach. Section IV explains a method for achieving hooking wiring. We propose the motion to insert a FFC into a hook using the reaction force of the FFC. We also propose novel end-effectors that make it easy. Section V introduces experimental results using a dual-arm robot and Section VI summarizes this study.

II. Related work

Cables can be classified into deformable linear objects. Studies on state recognition and automated manipulation of deformable linear objects has been proceeded since the past [1-6]. In particular, there are many studies based on knot theory. Knot theory is a kind of topological geometry in mathematical expression of string knots. Based on this theory, a manipulation planning method using a topological representation of a string called P-data [4], and a manipulation planning method using a transition graph of a string [5], have been proposed. In addition, from the standpoint of shape recognition of strings, a string shape description method that outputs a point chain model has been proposed [6]. The goal of these studies was to make knots or loosen. It was implicitly supposed that the string to be manipulated was circular in cross section, highly soft, and not anisotropic. This premise might be suitable for some types of cable handling. On the other hand, it is difficult to use for the manipulation of fitting a cable in a appliance workpiece etc., as in this study. Further, there are not many know-hows against the manipulation of FFC with anisotropy.

There are several researches and developments aimed at automating cable wiring in factory environments such as [7]. The work shown in [8] and [9] achieved the connection into basal plate using cables with connectors. The focus of these studies is recognition and manipulation of the connector part. Therefore, movement of a cable is taken into consideration within a range based on whether or not the connector can be brought to a desired position. On the other hand, since such manipulation contents are fundamentally different from the work of fitting the cable part into workpiece, the required technological elements differ greatly from this study.

III. Our approach

As explained in the previous section, the automation of FFC wiring is a subject which has not been targets so far. In this background, in addition to the difficulty of dealing with the amorphism and anisotropy of FFC, the required work must be precise such as fitting. For this reason, these operations are now carried out manually in factories at emerging countries. However, there is a certain need for automation.

Based on the above, we take the FFC hooking wiring as a study topic. The term ”hooking wiring” means a work of inserting a part of a FFC into a protruding hook formed in a workpiece of a product. This is one common task relating to FFC. A worker at the factory performs this work deftly according to the characteristics such as the shape, deformation, elasticity of the FFC. Therefore, we noticed that by implementing the hooking wiring, it is possible to extract important know-how for FFC manipulation automation.

Figure 1 shows the work focused on this study. This photograph shows a situation in which the hooking wiring of the white FFC has already been completed. The black workpiece have six hooks shown by red circles, a white circle and a blue square. The difference of the color of the circles indicates that the hooks are distinguished according to their shapes.

The goal of this study is to insert the FFC into each of the hooks indicated as No.1 to No.6, and create the condition shown in Fig. 1. The FFC is fixed by hooking it hems into

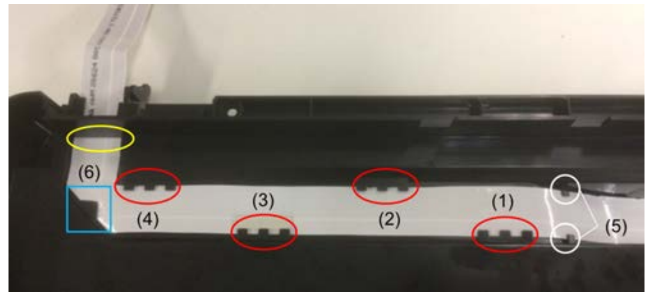

Fig. 1. Housing for FFC wiring and the wired result

these hooks. To focus on the hooking operation, it is assumed that a part of the FFC is held by the end-effector of the robot in the initial state. Also assume that the workpiece is always in the same position with respect to the robot. The robot has two manipulators. That is, wiring work is started from the state holding the FFC by one end-effector, and the hooking wiring is proceeded by moving each arm as necessary. Based on the above, the elements should be studied are set as follows.

1) Arrangement of wiring procedure: We need the procedure of hooking work which can alleviate the difficulty caused by the amorphous nature and anisotropy of FFC. In addition, we will examine a method of cable manipulation that enables stable hooking wiring.
2) Novel end-effectors and its method of use: We need the function of the end-effectors suitable for the purpose of fitting the FFC into hook. Since it is based on the use of a dual-arm robot, we assume that the role can be divided by the left and right end-effectors.

FFC is a flexible object and can take various shapes. This means that various manipulation procedures can exist for the hooking wiring. That is, if deformation of the FFC is within an allowable range, it is free to select which hook to be hooked next time. In general, the difficulty of the work changes according to the selection. For example, if the FFC is greatly bent, the reaction force of it becomes large and it becomes difficult to control the shape. There is also the possibility of causing plastic deformation and breakage of the FFC. In addition to that, although it is not difficult to understand the state of the FFC with respect to the part being gripped, but for the parts far from the gripping position, it is rather difficult to grasp the shape state of the parts. From the above, it is desirable to have a procedure that requires less bending and does not require large movement of the FFC.

FFC has a flat shape and is elastic. In hooking work, it is considered that work can be carried forward efficiently by making use of this property actively. In other words, it is better to take a countermeasure such that the FFC naturally enters the hooks by using the reaction force generated when the FFC is twisted slightly. This is rather smart approach than inserting the FFC while gripping it fixedly by an end-effector. In this manipulation, the end-effector might have a role of limiting the movement of the FFC. Since this study is based on the use of a dual-arm robot, it is possible to study the manipulation method of FFC with reference to human motion. However, attaching an articulated dextrous end-effector such as a human hand is difficult to introduce from the viewpoint of cost and system complexity. Therefore, it is necessary to arrange the function of human hands by simple end-effectors specialized for FFC wiring.

IV. A Wiring Method

A. *Preliminary examination for FFC manipulation automation*

First, we tried to do the wiring work by ourselves. At that time, there were the following situations where it would be difficult for cable manipulation to be performed.

- When a FFC was largely bent, it became difficult to grasp the current shape of the FFC.
- When bringing a part of the FFC close to a hook, the reaction force from other positions of the FFC was large and it was difficult to keep placing the FFC near the hook.
- Wiring work considering with the length of FFC is difficult. For instance, in the case shown in Fig. 1, hooking work starts from No. 5 hook, proceeds No. 1 to No. 4, and ends at No.6. In the final hooking, there was a case that the length of the FFC was insufficient or a sag was formed.

All the above is due to a fact that the amorphous nature and elasticity of the FFC are not considered well.

Through these experiences, the hooking procedure was roughly set as follows.

- Before hooking the FFC, leave the FFC in an extended state along the shape of the wiring place.
- Pass one end of the FFC through the hole in the upper left part shown in Fig. 1. This creates a semi-fixed end and makes it easy to control the shape of the FFC.
- Hooking work is proceeded from No.5 hook. That is, the motion of the FCC is restricted using the hole, then hooking is performed from the part close to the hole so as to minimize the deformation of FCC.

B. *A wiring motion*

In this subsection, we explain how to set detailed motion of two robot arms for hooking wiring. In the hooking manipulation, it is necessary to properly control the shape of the FFC and insert it into each hook. To examine it, we define action units for simple purpose such as suppressing, pulling, sliding. Then we arrange the roles of the two arms. Although there are three types of hooks in the wiring target in Fig. 1, we first consider the wiring method for the hooks No.1 to No.4 depicted by red circles. Since these hooks are alternately arranged with a certain distance, only one hook can be considered in one hooking manipulation.

Figures 2 and 3 show the proposed hooking procedure into a hook. Let assume that a FFC is near a hook and is held by one robot hand. In the hooking wiring, a hem of the FFC should be inserted to the hook protruding from the workpiece. The original purpose of doing this is that the FFC after wiring is difficult to move. Therefore, a depressed area where is the same width of the FFC exists near the hook. Therefore, considering the existence of the area, the movement of wiring should be decided.

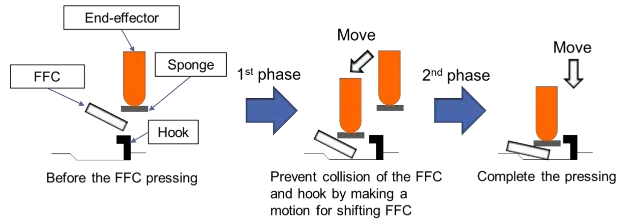

Fig. 2. Pressing action of FFC

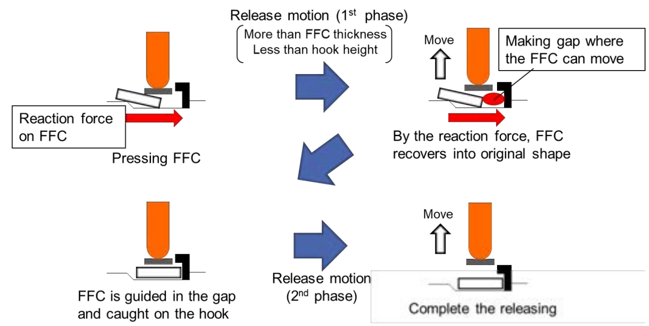

Fig. 3. Releasing action of FFC

The followings are explanations of the procedure along each figure:

- Holding the FFC (Fig. 2): Let assume that the positional relationship between a FFC, an end-effector and a hook is as shown in the left side of Fig. 2. First, there is a procedure to press the FFC against the workpiece so that it can be stably inserted to the hook. To avoid interference with the hook, push the FFC by lowering the end-effector diagonally (the center panel of Fig. 2), then lowering the end-effector vertically (Fig. 2, right). At this time, it is allowable that the FFC and the hook separate to some extent.
- Unhand the FFC (Fig. 3): Next, the manipulation of inserting the FFC into the hook is performed using the reaction force of the FFC. First, while holding down, press the FFC with the other end-effector and then pull it in the direction of the red arrow. After that, pulling up the end-effector slightly, then the FFC floats up, and the force trying to return to the hook side works on the FFC. An important point here is that the end-effector prevents the movement of the FFC into the upward direction.

Unlike the hooks No.1 to No.4 focused on the above, there are two facing hooks in No.5. Below, we explain the strategy of hooking. First, as shown in Fig. 4, the pressing manipulation is performed. Here, a point different from hooks No.1 to No.4 is that the end-effector is inclined in advance. The end-effector is vertically lowered from this state and bring the higher hem of FFC into contact with one hook. This action places the

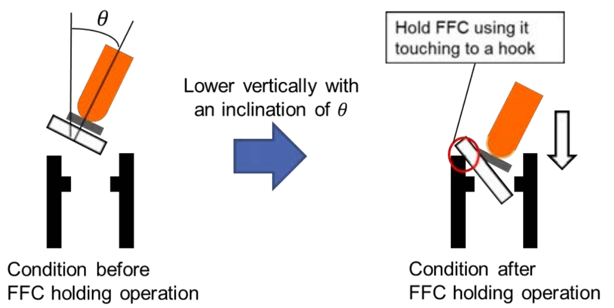

Fig. 4. The motion procedure(1) of wiring of hook No.5

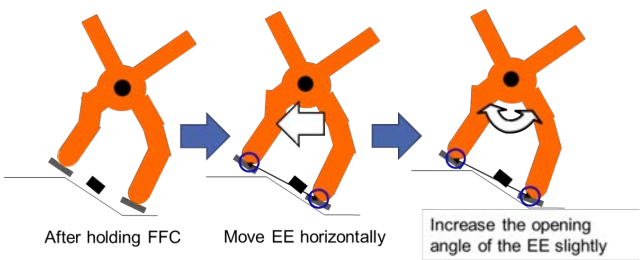

Fig. 5. The motion procedure(2) of wiring of hook No.5

other hem of the FFC in the gap between two facing hooks. However, since this operation alone can only insert into one hook, the manipulation shown in Fig.5 is added. In this figure, the same place in Fig.4 is shown by changing the viewing angle by 90 degrees. The black square at the bottom center indicate a hook. Here, it shows that the longitudinal direction of the FFC is pressed by two points. From this state, by adding the movement of the end-effector so as to increase the distance between the two points. Then, a downward force is generated on the FFC, and a hem of the FFC is moved under the hook.

C. End-effector design

In the procedure described in the previous subsection, the following two roles are required for the two end-effectors.

- End-effector for pressing FFC: It is possible to reliably press FFC by the tip of the end-effector. It is necessary to consider not only the positional relationship with the hook but also the width of it. If it is a thin hook, the robot can press FFC with a point, but when inserting FFC into a wide hook, it is needed to consider the possibility that the bended FFC will be caught in the hook at the time of insertion. In addition, as shown in Fig. 5, it is required to have a mechanism capability of holding the FFC at two points and thereafter changing the distance between the two points.
- End-effector to hold FFC: It is possible to hold FFC properly, and twist can be added to the FFC so as to create a reaction force. On the other hand, after the insertion work for one hook is completed, it is necessary to move to another hooking, so it is necessary to move the holding position of the FFC as necessary.

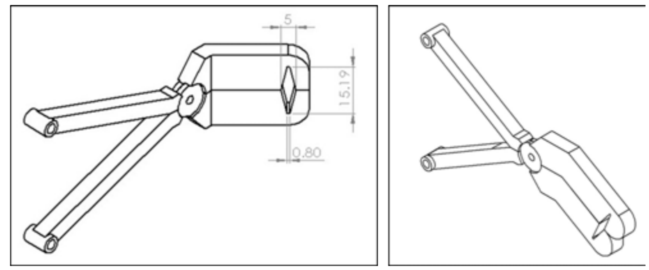

Fig. 6. End-effector design (left: for FFC operation, right: for FFC folding

Based on the items, we designed end-effectors.

Figure 6 shows the proposed end-effectors. It is assumed that they are attached to the tip of two fingered hand, respectively. The tip of them can be opened and closed. The left side is for holding FFC; the FFC is caught in the rhombic hole part. It is possible to grasp the FFC so that it does not move, and if it is slightly opened, then it is possible only to move the end-effector in the longitudinal direction of the FFC. Meanwhile the right side figure shows an end-effector for pressing the FFC. The distal end portion is circular, and this portion is brought into contact with the FFC. In the actual wiring work, a sponge is additionally attached to the tip portion so that the pressing manipulation is stabilized.

Below, we explain how we have reached to the idea for the right end-effector shown in Fig.6. Since this end-effector is expected to play a role of appropriately pressing FFC, we first examined what kind of tip shape is suitable. Specifically, the prototypes of the shape of the tip were four kinds: point shape, spring, linear shape, circular shape as shown in Fig. 7. An experiment was conducted by manually as to which shape is effective to hold down the FFC. The point to watch out here is that the hook No.1 to No.4 are about 15 mm in width and have a comb shape in which three narrow hooks with 4 mm in width are lined up. Therefore, unless the robot can hook the FFC to all the three, the work is not successful.

As a result of the examination, a circular shape was judged to be appropriate. Each trend and problems are listed below. In the case of the point shape, the FFC can be held down by minimizing the holding area. However, when the FFC was bent in the vicinity of the holding place, it was difficult to insert the FFC into all three hooks organizing one hook on No.1 to No.4. Also, in the case of point grounding, the degree of freedom of rotation about the axis perpendicular to the plane of the workpiece remains in the FFC. Because the frictional force generated between the cable and the workpiece is small, slippage occurs during cable operation.

Therefore, the tip was kept the point shape, and a spring structure was made up to the root part. Then, we tried to lower the tip of the end-effector in an oblique state. This enabled to increase the pressing area and make the shape of the ground contact surface adaptive. As a result, many problems of point grounding have been solved. On the other hand, it was difficult to fit in the hooks by pushing against the hook No.5 which requires a larger pressing compared to other hooks. In addition,

Fig. 7. Shapes of tip of end-effector: From the left, point grounding, spring, rectangular, circular.

	Right EE	Left EE	Subject & effect
Holding	O		Hold FFC neighboring a hook
Pulling up		O	Avoid collision between EE and housing
Rotation 1		O	Recover FFC into a state without twisting
Shift		O	Move FFC near to next hooking
Pulling up	O		Avoid collision between EE and housing
Rotation & move	O	O	Right EE: move to a position for next hooking Let EE: twist FFC for next hooking
Twist & pull		O	Reduce a reaction force for while holding FFC
Holding x2	O		Hold FFC and avoid it moving to the top of hook
Hook		O	Hooking
Release	O		Induce FFC under hook using reaction force

Fig. 8. Hooking procedure, motion primitives, subject and effect. EE means end-effector.

although the problem of failing to hook the cable to all three protrusions in each of the hooks No.1 to No.4 was improved, it was not completely solved.

As another attempt, we used a shape that can be grounded on a rectangular surface, it was effective for fitting to a wide hook. However, when the inclination of the faces between the end-effector and the workpiece could not be matched, the holding down rather became unstable. Also, when the other end-effector holding the cable was lifted slightly, unnecessary force was applied to the cable with the corner of the rectangle. Based on the above, the tip shape of the end-effector was formed into a thick circular shape. In this case, stability of the presser was the highest because the cable fits the end shape of the end-effector with a natural curvature.

D. Wiring procedure

In order to implement the hooking wiring using the proposed method and end-effectors described in the previous subsections, the manipulation by a dual-armed robot is organized including the cooperation of both arms. Figure 8 shows the procedure of the hooking wiring for each of the hook No.1 to No.4. It consists of 11 action primitives in total, with each purpose and effect being as shown in the rightmost column. To quickly accomplish the work, it is better to have fewer action primitives, so we focus on making each primitive more efficient in determining this procedure. For example, the sixth primitive ”rotation and move” consists of independent manipulations in each arm. Therefore it can be executed at the same time because they do not interfere with each other.

Based on the motion primitives shown in Fig. 8, robot motion is implemented. In hooks No.1 to No.4, since the hooks with same shape are alternately arranged spatially, we make it possible to move smoothly to the next hooking after one hooking ended. In addition, we implement one wiring into one hook as one function. When we input the position and direction of a hook, the motion sequence of the robot arm for achieving the motion primitives is automatically generated. Because of the above, it was made possible to perform a hooking wiring to multiple hooks by a simple and prospective coding.

V. Experiments and discussion

A. Experiments

For the hooking wiring introduced in Section II, experiments using an actual robot were conducted. We used the dual-arm robot HIRO manufactured by Kawada Industries. This robot has one degree of freedom on the yaw axis on the waist and six degrees of freedom on one arm. Original end-effectors were opposed two fingered hands. Since the end-effectors designed for this study was a scissor type as shown in Fig. 6, a jig was attached to the original end-effectors so that each of the two roots of the proposed end-effectors could adhere to the finger belly.

Figure 9 shows snapshots of the wiring work. A FFC was held in advance by the end-effector of the left arm, and was settled near the hook. First, hook No.6 was a hooking target. The insertion method in this case was to press the cable against the workpiece at a position slightly away from the hook and then to translate in the hook direction. Since it was simple and there were no noteworthy problems, we will not explain it in detail in this paper. After that, the robot repeatedly pressed and released the FFC by the end-effector on the right to perform the insertion into the hook No.1 to No.4 in order, and finally the hooking into hook No.5 was carried out. As a result of repeating the experiment that conducted a wiring work to six hooks with 20 times, the number of successes was 17: The success rate was 85%.

B. Discussion

All three failures occurred in the inserting the cable into hook No.5. That is, with respect to hooks No.1 to No.4 and No.6, the success rate was 100%. From this, it can be said that the proposed method using reaction force from the cable was suitable for an automation of FFC manipulation. On the other hand, there were two main cases of failure in hook No.5. One was a case where the FFC was insufficiently pressed and the other was a case of failing to hook the FFC to one of the hooks. Regarding the holding down as shown in Fig. 5, the FFC is pulled toward both ends. This is a work of pressing the FFC against the workpiece with the end-effector. However, the pulling operation has uncertainty and there was a case where slipping occurred. As another approach of manipulating the FFC, we tried a method: bending the FFC in a cross-section direction as a mountain shape and passing the bent shape between the facing two hooks. However, it was abandoned because of the difficulty to control the shape of the FFC when pressing both ends of the bent cable against the workpiece.

In this study, we did not take a policy of modeling the

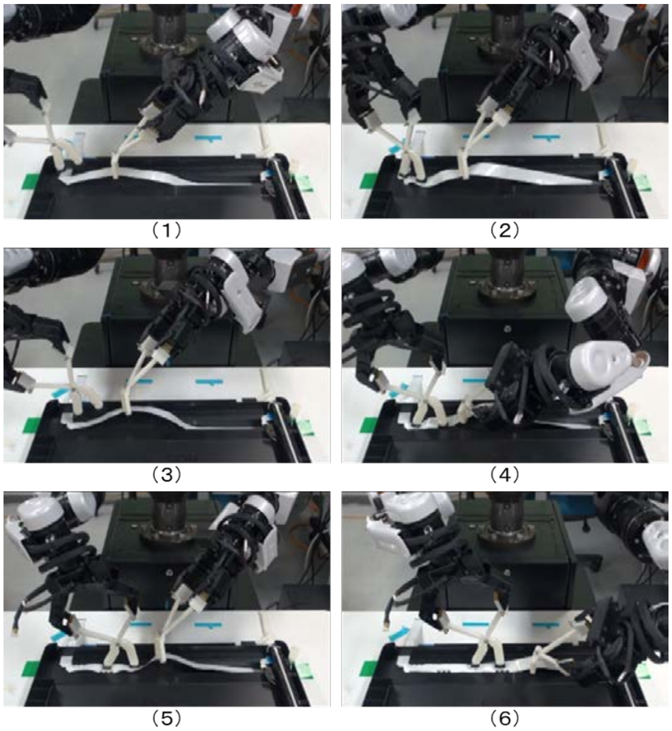

Fig. 9. Wiring experiment

physical behavior of cables. As a result, it became difficult to aggressively control the shape of the cable, but it was found that highly reliable hooking wiring is possible by a combination of pressing, twisting and releasing operation. On the other hand, for hook No.5, although human can take an approach to deform the cable into mountain shape and insert, the proposed method could not reproduce it. As an alternative method, we introduced a method to pull the cable from both ends, but it was not able to produce sufficient force because the direction in which the force should be exerted to fit in the hooks and the direction of the traction are orthogonal. Improvement of this method is a future task.

Of the findings obtained by this study, we summarize matters that are qualitative and could be applied to other FFC wiring work.

- The shape of the FFC before wiring work should be as close as possible to the position of the hook to be used for hooking. This is a procedure for preventing large deformation of the FFC during wiring and has the effect of stabilizing the work.
- By using two manipulators, work can proceed efficiently. Even when it is difficult to model FFCs, it is possible to assume high reproducibility for the behavior of FFCs by combining motions with the end-effector, which play the role of holding down, and the end-effector, which plays the role of twisting the cable.
- End-effector is required to continuously change the grasping place without largely moving the FFC. In this study, we devised a shape of scissors type and made it possible by changing the mode of fixing or sliding on the FFC by opening and closing it.
- The proposed motion of the hooking is defined for each hook. Each motion can be defined by a local coordinate system centered on each hook. That is, if the shape of the hook and the method of fitting are the same as No.1 to No.4 of the workpiece used in this study, one function can be commonly used by a plurality of hooks. This can reduce the labor of implementation.
- In the proposed wiring procedure, an action to avoid interference between end-effector and workpiece were inserted. The motion is given manually in this study, but if we properly define the CAD model of the end-effectors and the workpiece, this work can be automated easily and can merge with the previous action.

VI. Conclusion

In this paper we described a case study of Flexible Flat Cable(FFC) manipulation. We focused on a task of the hooking wiring, and proposed methods for achieving it. Based on the arrangement of hooking wiring, we proposed both wiring procedure and end-effectors design. Based on the assumption that a dual-arm robot is used to the hooking wiring, we also introduce effective wiring procedure. It is based on using the reaction force of the FFC and it is not necessary to clearly define the physical properties. We verified the feasibility of the proposed methods by means of actual experiments using a workpiece equipped multiple types of hooks. Also, we showed qualitatively arranged the findings obtained in this study.

Future work includes to verify the effectiveness of the proposed methods with various types of cables and workpieces.

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