Proceedings of the Estonian Academy of Sciences,
2019, **68**, 4, 413–420
https://doi.org/10.3176/proc.2019.4.11
Available online at www.eap.ee/proceedings

MANUFACTURING
ENGINEERING

Methodology for implementing universal gripping solution for robot application

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Received 12 April 2019, accepted 7 May 2019, available online 19 November 2019

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Abstract. In recent years the affordability of robots and the progress in collaborative robotics has been of great benefit for the manufacturing industries. The repetitive, monotonous and eco-unfriendly tasks are being assigned to the robots, which can work in parallel with humans, making the tasks easier for them. Industries are frequently introducing robots on the factory floor for maximizing production. Competition on the market is motivating robot manufacturers to work out solutions where return on investment would take as little time as possible. End effector is the most important part of a robot for making specific operations. The end effector market has also grown and brought innovation in the area of grasping objects with different shapes with a single gripper. However, problems persist due to the need for a gripper, which could handle a diverse range of products for certain applications. This paper discusses an approach of handling different products with a single end effector. Selecting a gripper for a certain application takes time and effort. Universal gripping solution can provide extra benefits and save costs. Here, a methodology is proposed to design a proper universal gripping solution for a specific use case. The article is mainly focused on pick-and-place applications.

Key words: robot gripper, universal gripper, 3D printed gripper, gripper selection.

1. INTRODUCTION

Since the first inclusion of industrial robots in early 1960s, industries have welcomed robots on the factory floor due to the vast range of applications [1]. Robotic systems can be implemented starting from automotive industries up to small scale machining centres. Although implementing a robotic system can be expensive, it is efficient, productive and accurate; also, the return on investment is assured in a shorter period. Besides the cost of the robot, the main secondary costs of robotizing process are the expenses on peripheral devices like grippers or the end effectors, feeders, tooling, and fixtures [2]. According to Robotiq blog [3], depending on the material, a robot gripper can cost from 10 to several thousand dollars.

The grippers are essential part of a robotic system to manipulate products. In industrial application, most of the tasks are of pick-and-place type where robot picks up a part, manipulates it and puts it in a defined place. According to the Robotics Division Manager of Staubli Corporation in North America [4], 60% of the robotic applications in that region are covered by some sort of handling processes. Therefore, in these types of ap-

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plications, grippers are the most important components of the system as they ensure proper gripping of a product and transport it securely without any damages.

Selecting gripper for a certain application can be challenging task. It depends on many factors. The success of choosing suitable gripper depends on its versatility and gripping range.

Nowadays, gripper manufacturers are innovative and produce grippers with multiple gripping solutions, i.e. outside gripping, inner gripping; and gripping objects of both rectangular and cylindrical shapes with a single gripper. Nevertheless, there is always need for universal grippers being able to perform specific tasks. In this article, an approach of selecting proper gripper and the methodology for achieving universal gripping solution are discussed. Furthermore, a use case is analysed by implementing the methodology presented in this article.

2. STATE-OF-THE-ART

In the context of the present article, universal gripping solution does not necessarily represent the idea of using only one gripper to produce company's whole product range, although it would be the primary option. This article focuses on the applications, which concern small batch productions where changes are inevitable. Therefore, flexibility and productivity are the utmost desired qualities of the gripping department. Definition of universal gripping regarding this article is based on readily available gripping system used in the robotic work cell for producing the company's whole product range.

At present, there are already some universal gripping solutions available on the market, based on this definition. For example, automatic gripper changing systems, multiple gripper frames, end of arm tooling (EOAT) etc., are the most commonly used solutions. However, different solutions can have different costs. For example, implementing single gripper with multiple finger options is cheaper than multiple gripper solution. Some of these solutions are readily available and manufactured by many different companies; some solutions can be implemented by in-house engineering for cost minimization. This section of the paper presents state-of-the-art solutions for universal gripping.

2.1. Gripper changing solution

Multiple grippers can be used for gripping different parts. The solution is applicable when parts with different gripping requirements are involved, e.g. pneumatic gripping, magnetic gripping etc. Different grippers are placed in a rack and specific type of gripper is selected according to the specific group of parts being in operation. Changing the gripper will essentially increase the cycle time of the process, as it is unproductive. It also depends on the changing mechanism of the gripper. Two following changing mechanisms are applicable for this type of application:

(1) Automatic tool changer. Automatic tool changers are mounted on the robot wrist on which the gripper is mounted. These are usually disk-type automatic tool changers. Fig. 1 [5] illustrates some common tool changers. The changing disk of the robot is fixed and gripper's work is organized by electrical, pneumatic or electromagnetic control. In case of such modular system, fixing the gripper on the robot takes little time. The cost of such solution is higher as the automatic tool changer increases the cost;

(2) Manual tool changer. In case of manual tool changers, whenever the change of a gripper is needed, it has to be done by human hand. This potentially poses some challenges. A human operator needs to be present while the tool is changed. The cycle time increases as the production is stopped while the changing process takes place. However, using this solution minimizes the cost. Figure 2 [6] is an example of manual tool changer.

Fig. 1. Automatic tool changer [5].

Fig. 2. Manual tool changer [6].

2.2. Multiple gripper frame

In this method, a frame is attached to the wrist of the robot, which can connect two or more grippers at the same time. The grippers remain connected with the robot all the time. Usually, most of the solutions provide attaching two grippers at a time. For more grippers, custom made frames are needed. There are some challenges concerning this type of solutions. First, the load increases as the robot carries the grippers all the time. Second, it decreases the speed of operation. Third, it increases the cycle time. However, the cycle time will be shorter compared to the gripper changing solution. Figure 3 [7] exemplifies the idea of a multiple gripper frame.

2.3. Finger changing solution

Robotic grippers usually have jaws or fingers that interact with components. In case of finger changing solution, multiple finger sets can be used for gripping different parts. This type of solution can be applied only if gripper meets all gripping requirements needed for different kind of parts. Specifications that need attention are: stroke of a gripper, gripping speed; and gripping force.

In case of this method, all necessary finger sets are placed in a rack. Fingers can be changed automatically by automatic screwing and/or detaching, while the robot holds its position. Fingers can also be changed manually, which would increase the cycle time.

This method is used when finger-based grasping is the only applicable choice. This solution is less expensive than the two previous solutions as only one gripper is used for whole spectrum of components.

2.4. Finger dimensioning

This is the most cost effective option of all methods where one gripper can meet the gripping requirements of all parts. In case of this method, only one finger set is used and patterned according to the gripping surface area. This limits gripping of multiple shaped objects. Usually, grippers are sold with some general fingers or without any fingers. Some gripper manufacturers modify the design of the fingers for some additional cost. Modification can also be done in-house either by machining or 3D printing, depending on the material used for the fingers. Machining is possible for steel fingers. Designed fingers can be printed easily due to the development of 3D printing technology. However, 3D designing and printing or milling require time. Determination of gripping area of different parts is also challenging [2]. This method can provide the shortest cycle time.

2.5. End of arm tooling (EOAT)

End of arm tooling is another method of using multiple gripping units at the same time. In case of this method, the robot wrist is connected to a frame, which carries all gripping tools necessary for different steps of the process. This type of system is applied in case of heavy duty robots when the need for different tools is greater than any other system can provide; or gripper needs to carry heavy loads. In practice, these types of solutions are challenging and expensive but they are beneficial due to different gripping tools with multiple control mechanisms connected to the robot at the same time. An example of EOAT is shown in Fig. 4 [8].

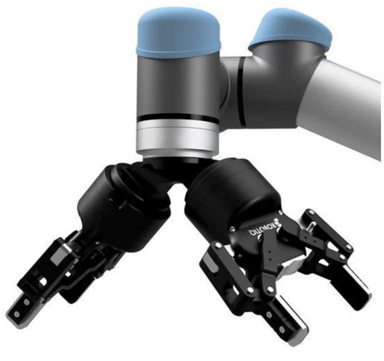

Fig. 3. Multiple gripper frame [7].

Fig. 4. End of arm tooling [8].

3. GRIPPER SELECTION

At the initial stage of any project, it is suggested to choose suitable gripper according to the task. Gripper selection can be daunting due to huge variety of different options and enormous list of specification sheets. Pham and Yeo [2] describe a part family based and a knowledge based gripper selection processes. From both processes, the first one is more cost-effective while the latter one solves wide range of tasks. In their article, they also present five governing factors for gripper selection: components, tasks, environment of the system, robot, and gripper itself. Each of these factors are listed with some measurable features, which should be taken into consideration while choosing the gripper. These factors are presented below in Fig. 5 [2].

As all these factors depend on the application, the focus of this paper will be on the gripper selection. The part family grouping [2] is followed by additional conclusions. Following steps are proposed for gripper selection, considering the product range of any specific applications:

Step 1 – component study. The aim of the first step is to study the components in detail. The final goal of this step is analysing the gripping surfaces of the components. 3D CAD model of the components can help if physical components are not available. Part family distribution can be made after engineering potential gripping surfaces. This distribution can be done by determining the most common surface areas of parts and dividing them into smallest number of groups. The number of groups will determine the number of grippers required for the application. Other factors which are determined during this step are: component material of gripper fingers, weight of the parts, temperature tolerance, applicable force for the parts; and the orientation of the parts while being in operation. This step will validate the decisions of next steps.

Step 2 – gripper attribute selection. From the results of step one, the important specifications of the gripper can be decided. From numerous specifications of a gripper, the crucial ones are presented below:

- Gripping mechanism. From the results of Step 1, gripping mechanisms have to be determined for all parts. Gripping mechanisms include the types of controllers and the types of tools needed for gripping, e.g. parallel gripping, angular gripping, inner gripping, vacuum gripping, magnetic gripping etc. In this step, control mechanism for the gripper should be determined, as additional equipment like compressed air supply for pneumatic, fluid supply for hydraulic and power supply for electric grippers are essential;
- Stroke width. The gripping surface area of the whole range of parts should be determined in Step 1. Depending on the gripping surface width, from minimum to maximum, the stroke width of the gripper can be selected;
- Gripping force. Gripping force of the gripper depends on several factors. This property is important, as it will guarantee safe handling and transportation of parts. An equation is presented in [9–11] to calculate force for any type of components. The equation is presented below:

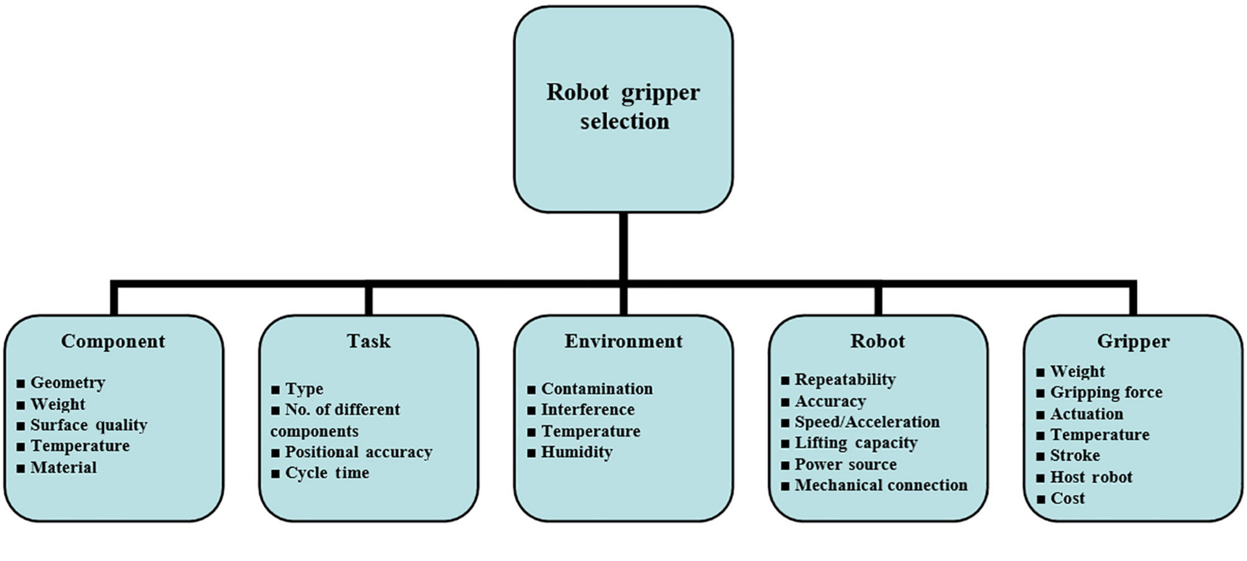

Fig. 5. Governing factors for gripper selection (adapted from [2]).

$$F > m\,(g + a) / \mu * \text{safety factor}, \quad (1)$$

where, F is the force (N); m is the mass of the product (kg), g is the gravitational acceleration (9.81 ms^{-2}), a is acceleration (ms^{-2}), and μ is the coefficient of friction between gripper finger and the work piece. Safety factor is added according to the application. The total required force will be the sum of the fingers of the gripper. While [9–11] suggests to apply 10 to 20 times more gripping force than the part weight, [11] suggests to add four times more force for friction grip than encompassing grip. They also suggest to consider the finger length and the overhang as it affects the gripping force. On the website [12], there is a list provided for coefficient of friction between different types of materials;

- Gripping speed. Gripping speed is also important as it varies between grippers. Gripping speed can affect the cycle time of the process;
- Repeatability. Repeatability of a gripper is another important property for critical applications. This property ensures the gripper's position accuracy of repetitive task over a certain cycle period;
- Operating temperature. This aspect is important for working environments with high temperature, as grippers can operate in certain temperature range;
- Mounting type. Mounting type of the gripper should integrate with the robot. If mounting type does not match the robot wrist configurations, there will be additional costs.

Step 3 – universal gripping method selection. Following Steps 1 and 2, makes selection of specific kind of universal gripping mechanism from the methods presented in Chapter 2 (State of the art) easier. It is suggested to make measurements and decisions carefully in Steps 1 and 2, as it can help to save costs.

The procedure can be followed using the process flow shown below in Fig. 6.

4. USE CASE ANALYSIS

This chapter analyses a use case for universal gripping method selection. A range of switch mode power supply (SMPS) transformer coils are used for selecting the gripper and achieving universal gripping. For this use case, 54 individual SMPS transformer coils with different sizes, shapes and weights were used. The aforementioned steps were followed to achieve the result:

Step 1. In this step the whole range of parts were studied in detail. The weight, width of gripping surface, material of a part; and orientation of gripping were determined for each part. The weight of the parts varies between 0.02 kg to 0.1 kg. All parts are made of plastic. The gripping surface area varies between 7 mm and 66 mm. Next, all parts were divided into two groups based on the gripping surface. Figure 7 presents two groups.

There are two possible gripping areas for the cylindrical-shaped coils on the left picture: (1) inside gripping by opening the jaws; (2) outside gripping by closing the jaws, objects are grasped from the top.

The rectangular-shaped coils on the right picture can be gripped by their outer frame.

Step 2. As all required parameters of the parts are achieved, the gripper specifications can be determined. The gripping mechanism for all parts can be either pneumatic or electric 2-finger parallel gripper. The first option would be the most cost-effective solution. If the first group has to be gripped from inside, 3-finger gripper is required. The stroke width needed for the gripper is between 4–69 mm as the minimum and maximum width of gripping surface varies between 7–66 mm. Gripping force of all parts varies between 16.33 N and 32.66 N, considering 20 times more force than the work piece weight. The coefficient of friction is considered 0.3 for plastic to plastic. Therefore, based on given data, Robotiq 2F-85 gripper with adjustable fingers was selected, with a stroke of 85 mm, and force range from 20 to 235 N. It is also compatible with the previous robot UR5. This gripper is controlled by electrical power source and moves fingers by servomotor;

Step 3. To achieve universal gripping, finger-dimensioning method was used. This would be the most inexpensive solution with shortest cycle time. The ranges of parts also fall in 2 groups, which can be achieved by designing fingers that can grasp both circular outer

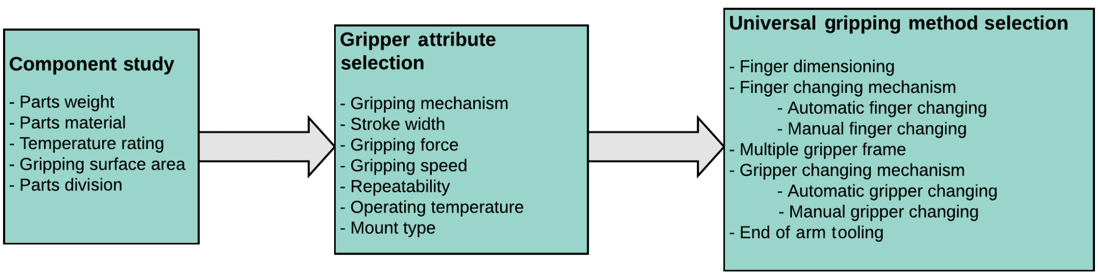

Fig. 6. Process flow for achieving universal gripping.

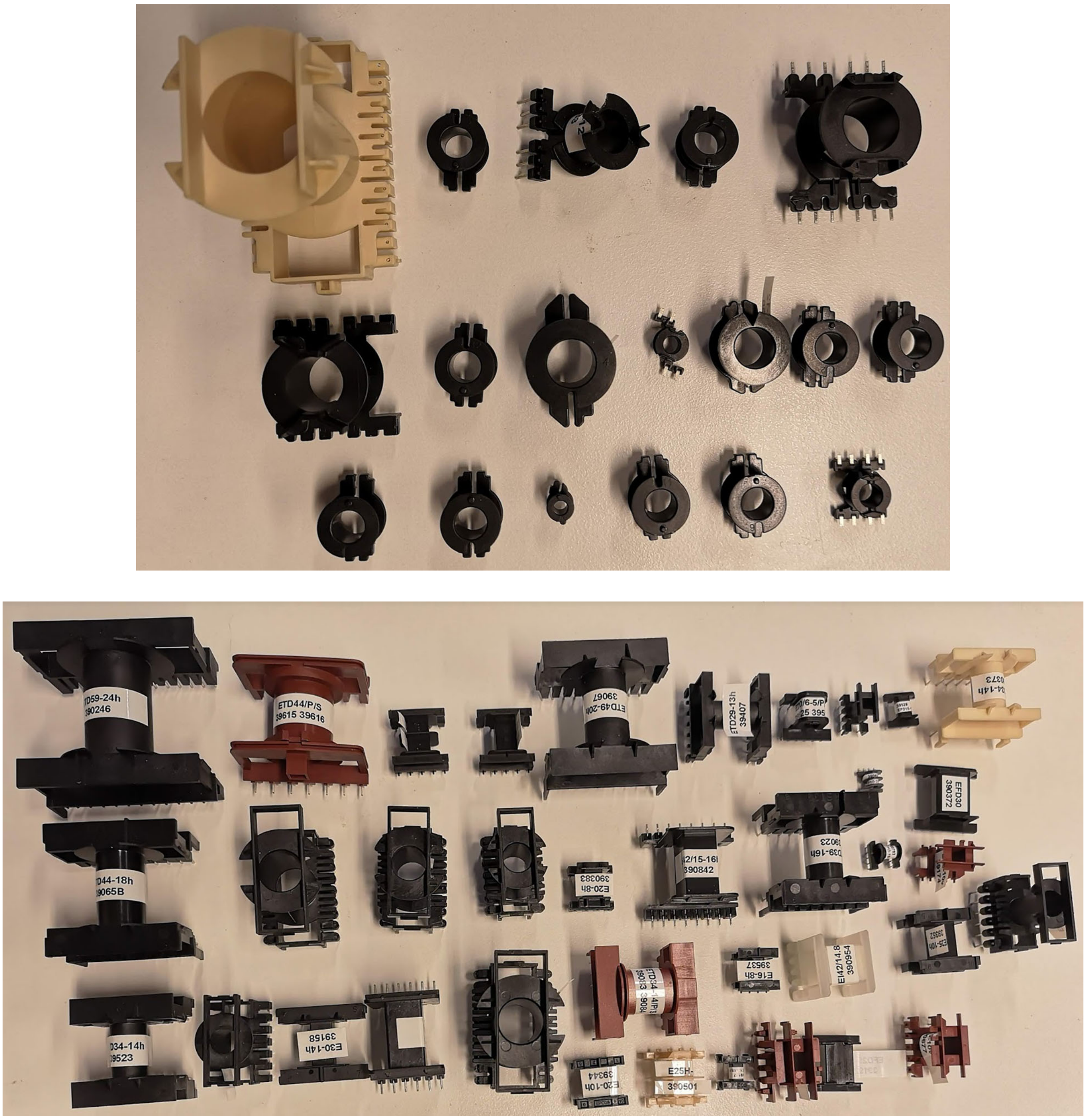

Fig. 7. Dividing parts according to the gripping surface area.

frame of the first group and rectangular outer frame of the second group.

SolidWorks software was used for 3D designing and Prusa printing machine for 3D printing. The outcome is presented in Fig. 8.

This finger configuration was achieved through some trial and error; and could achieve the gripping of both part groups. Some pictures of the gripped parts from both families are provided in Fig. 9.

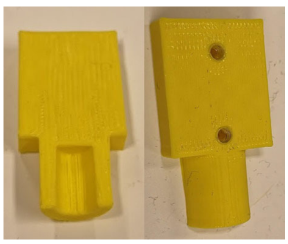

Fig. 8. Finger modification for the use case.

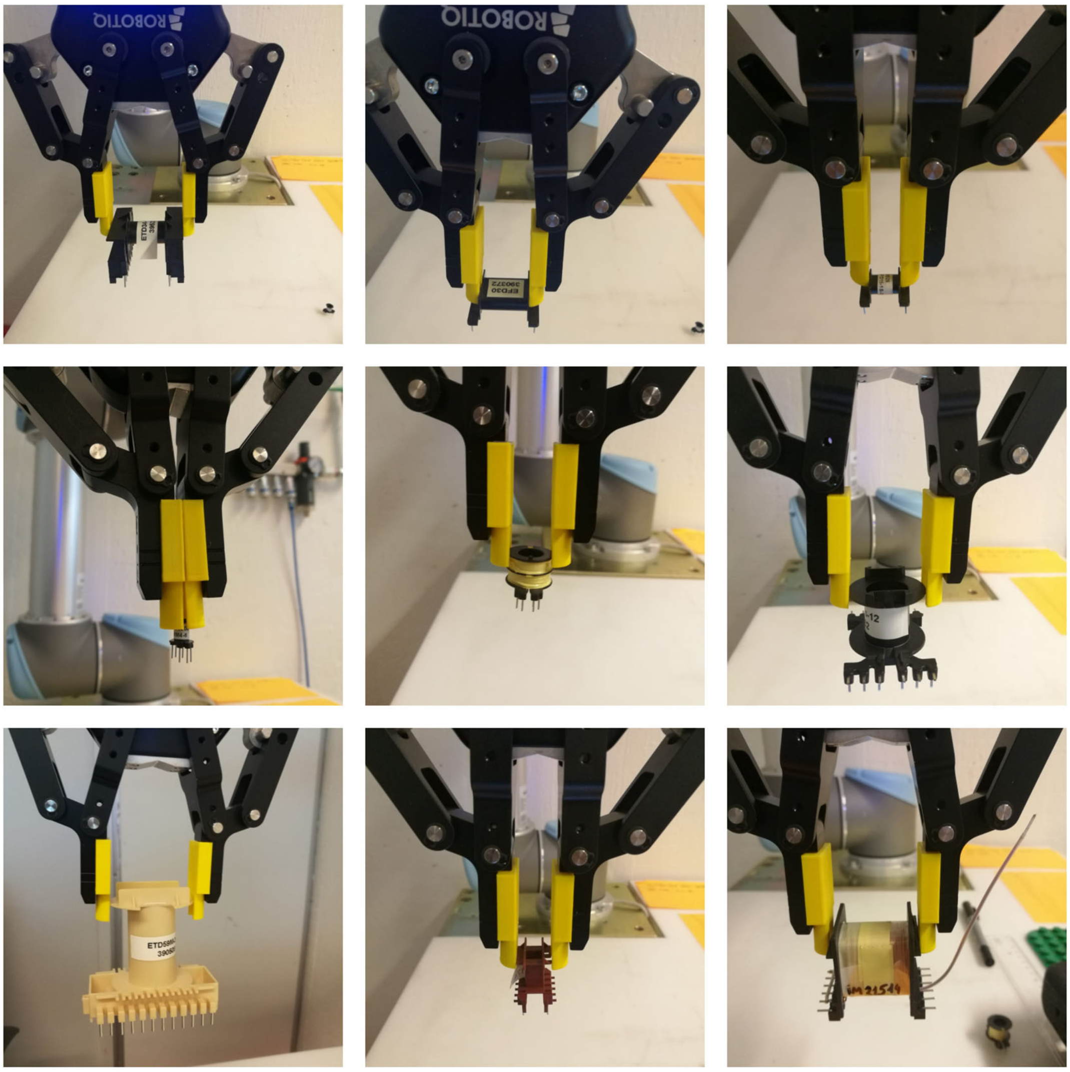

Fig. 9. Universal gripping for the use case using finger modification method.

5. CONCLUSIONS

Competition on the global market motivates companies to work out cost effective solutions with increased efficiency. As the prices of industrial robots are falling, more and more applications are robotized. This was not possible few years ago. Applications of small batches of products with diverse range need inexpensive solutions for full-scale automation. Following the discussed methodology can make gripper selection easier for applications that involve parts with different shapes, sizes and materials. Focusing on different steps and making proper decisions can save costs and achieve universal gripping solution, thus minimizing the overall costs of robotizing any processes. At present, there isn't any specific gripper selection methodology and relevant information for gripper selection requires expertise. This article can help to select proper gripper and to achieve cost-effective universal gripping system in the inicial phase of establishing a robot-based production.

ACKNOWLEDGEMENTS

The publication costs of this article were covered by Tallinn University of Technology and the Estonian Academy of Sciences.

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Universaalse haaramislahenduse rakendamise metoodika robotrakendusele

Mohammed Salman Azim, Andrei Lobov ja Artem Pastukhov

Viimastel aastatel on edusammud robootika valdkonnas olnud kasulikud eelkõige töötleva tööstuse jaoks. Korduvaid, monotoonseid ja mittekeskkonnasõbralikke tegevusi pannakse üha rohkem tegema robotid, mis võivad töötada paralleelselt inimestega, tehes nende töö kergemaks. Konkurentsivõimeline turg motiveerib robotitootjaid tagama investeeringute tasuvuse väga lühikese aja jooksul. Oluline arendusvaldkond on robotite haaratsid ja peamised probleemid selles valdkonnas on seotud erinevate toodete haaramisega ühe haaratsiga. Käesolevas artiklis on käsitletud üht lähenemisviisi ja metoodikat toote variatsioonide käsitsemiseks ühe haaratsiga.