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Gripper types and components in robotic bin picking

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Abstract. While automation is increasingly applied in production processes, it is still rarely used for the core picking activity in kitting and order picking. As picking activities often involves a large number of stock-keeping units (SKUs) with different characteristics, what gripper to use is a central aspect when robotics is applied. The aim of this paper is to improve the understanding of the relationship between gripper types and component characteristics in robotic applications for preparation of component kits. The aim is addressed by means of an experiment in a laboratory setting where a two-finger gripper and a vacuum-gripper are applied for grasping a variety of components in a kit preparation process. The two gripper types are studied with respect to important component characteristics for their suitability, and how the two gripper types compare from an efficiency standpoint. The paper's findings are useful for practitioners when introducing robotic bin picking. The paper also makes an important contribution to academia in studying the effects of robot picking applications empirically, laying grounds for focused future studies within this area.

Keywords: Kit preparation, Robot grippers, Order picking.

1 Introduction and aim of the study

In mixed-model assembly settings, where there is a large number of stock-keeping units (SKUs) that need to be handled, picking activities are often performed in the materials supply. For component kitting, in which components are picked and placed into kits and each kit supports one or more assembly operations for one product, the use of robotic picking could be an option for performing these processes, potentially enabling a lowered operating cost as well as a high reliability, as suggested by [1]. However, in component kitting for mixed-model assembly, components are often heterogeneous, differing in terms of, e.g., size, shape, weight and material. It is therefore difficult to find a robot gripper that has sufficient flexibility to achieve efficient and reliable picking for all components, which has been pointed out by [1]. Accordingly, recent studies within the industry still mostly report on manual component kitting in the materials supply to assembly [4].

There exist several types of grippers. According to [5], grippers can be based on three different actuating principles: mechanical, vacuum or magnetic, and universal. It

is possible to change grippers between different picks, thus utilising the advantages of the different grippers, even though this can be time consuming and may accordingly reduce the capacity of the picking operation. Another option is to allocate only certain SKUs to robotic picking while other components are still being picked by a human.

The use of robot grippers has been addressed in research. Topics that have been dealt with include vision-supported bin picking [8] and robot agility architecture [6]. [1] and [3] recognise the complexity of picking heterogeneous components in component kitting and study the division of labour between robot and human pickers in this context. The relationship between gripper types and component characteristics has received a fair amount of attention within literature dealing with robot applications in manufacturing settings. [2] suggests design guidelines for various types of grippers that in part consider component characteristics, while [9] point out component characteristics as central when selecting gripper for assembly applications. [7] focus on assembly operations, including picking of components, and propose a methodology for the division of labour between human and robot for such contexts. Materials handling in assembly operations share similarities with component kitting, but the latter also imposes unique requirements with respect to robotic picking. In component kitting, picking and placing of components are central activities which are repeated for all components of a kit and the applicability of knowledge from assembly operations is not obvious. To design processes for component kitting that effectively utilise robotic support, it is of central importance to understand which type of gripper, if any, fits which component characteristics, and which option should be used when multiple options appear feasible. The current paper expands on the research by [7] in a component kitting context, and aims to improve the understanding of the relationship between gripper types and component characteristics in order to improve setup and processing times for component kitting.

This aim is addressed by means of a laboratory experiment where components of varying characteristics are kitted by means of robotic grippers. Here, it is important that the grippers considered in the study can grasp components with characteristics that often appear in kit preparation. Based on the reviewed literature, the two gripper types two-finger servo-electric gripper and a vacuum gripper are focused upon in the paper. This is because 1) they are based on two principally different actuating principles [7], and 2) they have frequently been considered in theoretical studies dealing with robotic kit preparation (e.g. [1], [3]).

The experiment is set up to answer two research questions that both address the relationship between gripper types and component characteristics in kit preparation. As noted above, it is important when dealing with robotic kit preparation to know for which component characteristics different gripper types are suitable to use. A first question is therefore expressed as: *which component characteristics are important for graspability with a two-finger servo-electric gripper and a vacuum gripper, respectively, in components kit preparation?*

When a component can be grasped by several types of grippers, it is necessary to know which gripper type should be used, and whether it is worthwhile from an efficiency standpoint to perform a tool change. A second research question can be expressed as follows: *for components with characteristics that are suitable both for a two-finger servo-electric and a vacuum-gripper, which gripper type should be used?*

The remainder of the paper is structured as follows. Section 2 presents the experimental settings and research method. Section 3 presents the results and an analysis of the results. Finally, section 4 presents a discussion of the paper’s findings and conclusions.

2 Experimental settings

The research questions that were identified as important with respect to the paper’s aim, as presented above, were used as basis for the design of an experiment. As explained in the introduction, the paper considers two gripper types: a two-finger servo-electric gripper and a vacuum gripper.

In terms of components, the component characteristics shown in **Table 1** were derived from previous studies on the topic (e.g. [7]; [5]). Components were selected from a set of automotive components, aiming to establish variability with respect to the component characteristics in **Table 1**. The factor levels in **Table 1** were determined based on the variability with respect to the component characteristics among the selected components. In total, 18 components were selected for the experiment, ranging from bolts and nuts to rear-view mirror caps and bearings. Each component was classified according to the component characteristics in **Table 1**. An overview of the component selection is shown in **Table 2**.

Table 1. *Factor levels among the component characteristics.*

Name	Description	Level 1	Level 2	Level 3
F1: Size	Longest straight line L through the component [mm]	$L < 20$	$20 < L < 70$	$L > 70$
F2: Weight	Weight W of the component [kg]	$W < 0.1$	$0.1 < W < 1$	$W > 1$
F3: Regularity	Refers to whether all components of the same type have the same shape, e.g. metal plates (regular) or wires (irregular)	Irregular	Regular	
F4: Flatness	Refers to the diameter of the largest planar surface D on the component’s surface relative to the diameter of a vacuum gripper d_{vac}	$D < d_{vac}$	$d_{vac} < D < 2d_{vac}$	$D > 2d_{vac}$
F5: Fullness	Refers to whether the component has holes (hollow) or not (full) that can help grasping	Hollow	Full	
F6: Stiffness	Refers to how easily the component deforms when compressed	Deformable	Stiff	

A three-level shelf was created to simulate storage racks in an industrial kit preparation process, and a UR10 robot arm was placed in front of the shelf. The shelf was built in proportion with the UR-10 robot arm, and the components to pick were put into plastic boxes stored on the shelf, see **Figure 1**.

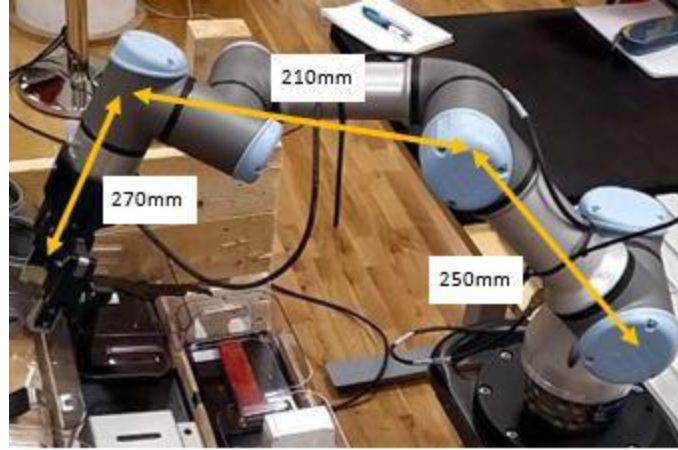


Figure 1. The UR10 robot-arm when picking components from the shelf.

The experiment was carried out in two stages relating to the research questions. In the first stage, grasping attempts were made with the two gripper types for the components shown in **Table 2**.

Table 2. The 18 components considered and their characteristics in terms of the six factors of Table 1.

No.	Description	F1	F2	F3	F4	F5	F6
1	Thick sheet-metal plate	3	3	2	2	1	2
2	Plastic seal	3	1	1	2	1	1
3	Bent metal bracket	2	3	2	2	2	2
4	Angled girder	2	2	2	2	2	2
5	Plastic cabin-interior detail	2	1	2	1	2	2
6	Plastic pipe	3	1	2	3	1	2
7	Screw	1	1	2	1	2	2
8	Towing hook cap	2	1	2	2	1	1
9	Plastic electric connector box	2	1	2	3	2	2
10	Plastic bracket	3	2	2	1	2	2
11	Large bearing	3	3	1	3	2	2
12	Sheet-metal bracket	3	2	1	1	2	2
13	Wide hose half-clamp	2	1	2	2	2	2
14	Bent plastic pipe	2	1	2	2	2	2
15	Bolted plate	1	1	2	3	2	2
16	Hose clamp	3	1	2	3	1	2
17	Sheet-metal cover	3	2	2	3	2	2
18	Rear-view mirror cap	3	1	2	3	1	2

The grasping attempts were made at various resting positions (lying self-supported on a flat surface) of each component. If the component was possible to grasp in at least one resting position, the grasping activity was considered successful and noted as a ‘Success’. If the component could not be grasped in any resting position, the gripping activity was considered unsuccessful and noted as ‘Fail’. Grasping attempts were performed with both grippers for 9 components, while grasping attempts of 4 components were made only with the two-finger gripper, and for 5 components only with the

vacuum gripper. That is, for 9 of the components it was deemed obvious that one of the gripper types could not be used, which were denoted as “Not tested”. The grasping attempts that were performed for each gripper individually were performed in order to clarify the results from the grasping attempts that were made with both grippers.

In the second stage, addressing the second research question, the components suitable to kit with either a two-finger gripper or a vacuum gripper, as determined from the first stage, were compared in terms of the time required to grasp and place components in the kit package with the two different gripper types.

3 Results and analysis

3.1 Suitable gripper type given component characteristics

The outcome of the first stage of the experiment is shown in **Table 3** for each of the two gripper types.

Vacuum-gripper and important component characteristics: Looking at the suitable component characteristics for a vacuum-gripper in **Table 3**, it seems that components that have a large- or medium-sized planar surface, and a low to moderate weight, are suitable. This is represented by, for example, component number 2 (plastic seal), 5 (plastic cabin-interior detail), 6 (plastic pipe), 8 (towing hook cap), 9 (plastic electric connector box), and 13 (wide hose half-clamp). For components with higher weight, similar conditions seem to apply, although it is crucial that there is a planar surface available near the component’s centre of gravity, as with component number 3 (bent metal bracket).

From **Table 3**, the vacuum gripper appears not to be suitable with components of small size or irregular shape, thereby displaying small planar surfaces to grip. This is represented by, for example, component number 7 (screw), 10 (plastic bracket), 12 (sheet-metal bracket), and 14 (bent plastic pipe). Furthermore, with components 1 (thick sheet-metal plate) and 4 (angled girder), which both have planar surfaces for the vacuum-gripper to grip, these cannot be grasped successfully owing to their relatively high weight and the fact that there is no planar surface available near their centre of gravity.

Finger-gripper and important component characteristics: From **Table 3**, it can be seen that the two-finger gripper appear suitable with a multitude of component characteristics. Overall, most components with a thickness smaller than the maximal gap opening of the gripper could be grasped successfully.

As shown in **Table 3**, the two-finger gripper was unable to grasp components that had a larger size than the maximum grip opening, and for which it was not possible to enter a hole or cavity, such as with component number 18 (rear-view mirror cap). The two-finger gripper could also not grasp component number 1 (thick sheet-metal plate) due to its high weight and slippery surface generating too little friction to grip the component. Furthermore, as with component number 2 (plastic seal), the component deformed extensively when gripped and was not possible to grip firmly without damaging.

Table 3. *Gripping outcomes for the two gripper types.*

Component no.	Component characteristics						Gripping outcome	
	F1	F2	F3	F4	F5	F6	Vacuum	Two-finger
1	3	3	2	2	1	2	Fail	Fail
2	3	1	1	2	1	1	Success	Fail
3	2	3	2	2	2	2	Success	Success
4	2	2	2	2	2	2	Fail	Success
5	2	1	2	1	2	2	Success	Success
6	3	1	2	3	1	2	Success	Success
7	1	1	2	1	2	2	Fail	Success
8	2	1	2	2	1	1	Success	Success
9	2	1	2	3	2	2	Success	Success
10	3	2	2	1	2	2	Fail	Not tested
11	3	3	1	3	2	2	Fail	Not tested
12	3	2	1	1	2	2	Fail	Not tested
13	2	1	2	2	2	2	Success	Not tested
14	2	1	2	2	2	2	Fail	Not tested
15	1	1	2	3	2	2	Not tested	Success
16	3	1	2	3	1	2	Not tested	Success
17	3	2	2	3	2	2	Not tested	Success
18	3	1	2	3	1	2	Not tested	Fail

3.2 Time requirement for different grippers with the same components

In the second stage of the experiment, addressing the second guiding question, the kitting activity time is considered with respect to components that could be gripped by either a two-finger gripper or a vacuum-gripper. The results are shown in **Table 4**.

Table 4. *Time required for picking the same components with two gripper types.*

Gripper type	Time to grasp [s/component]	Time to place [s/component]	Time to kit [s/component]
Two-finger	3.4 ± 0.25	3.48 ± 0.28	18.4 ± 0.65
Vacuum	1.93 ± 0.1	2.37 ± 0.2	14.2 ± 0.27

As shown in **Table 4**, the vacuum gripper generally requires less time to kit a component when compared with a two-finger gripper. This is because a two-finger gripper often needs some positioning in order to access the gripping points on a component. On the contrary with a vacuum-gripper, as long as there is a gripping point exposed when a component is at rest, there is a straight line towards the gripping point.

4 Discussion and conclusions

The paper has addressed typical issues in designing and planning of robot applications for preparation of component kits. The findings contribute to an understanding of problems related to choice of gripper type in robotic kitting of components, but illuminate also choice between robotic and manual kitting of components. The findings are important as working conditions in picking systems make automation is highly desirable.

In the experiment, two types of grippers were tested: vacuum grippers and servo-electric two-finger grippers. The results show that the two-finger gripper is more versatile with respect to variable component characteristics compared to a vacuum gripper. Two-finger grippers can be used with most of the considered component characteristics, as long as the gap between the fingers is large enough and the component is stiff enough.

Vacuum-grippers are suitable for light components that have planar surfaces larger than the vacuum-gripper's opening. Heavier components with planar surfaces can also be gripped, but the planar surface must then be near the component's centre of gravity.

With components that can be gripped by either a two-finger gripper or a vacuum gripper, the experiment results demonstrated that the vacuum-gripper generally is the faster alternative. This is important during the kit preparation work cycle, as it can be worthwhile to change gripper when the faster alternative is applicable. The time saved from the higher gripping efficiency must, of course, be weighed against the additional time required to perform a tool change.

Accordingly, the results related to the fast vacuum gripper and the flexible two-finger gripper provide input to planning of kit preparation activities. Here, a conscious choice of the sequence by which components are kitted can decrease the time required to prepare kits. However, the kit would need to be structured with separate space for each component in order for the sequence to be freely chosen. With unstructured kits, the assemblers' consumption sequence of components would instead control the sequence.

The components considered in the experiment represent typical components used in assembly of automotive products. The paper shows that all components, in that type of industry, are not feasible for robot picking with the two gripper types considered. In design of kit preparation processes where both manual and robotic picking will be applied, the findings can contribute to better allocation of components between an operator and a robot.

The current paper has presented an experimental analysis of the relationship between gripper types and components in component kitting. The results highlight important aspects of this relationship that are useful for effectively implementing robotic picking in a component kitting context. Future studies should account for the relationship also from a statistical standpoint, potentially by use of a full-factorial experimental approach. Here, the findings of the current paper would constitute a useful starting point.

The experiment show that the orientation of the component is essential for the grippers being able to pick the component. In a future real picking system, there is a need to find ways to control, or to obtain information about, the orientation of components. Possible solutions may include choice of component packages from suppliers, handling

of component packages by robots and their associated grippers, and involvement of operators.

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