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Evaluating Cobots For Final Assembly

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Abstract

Collaborative robots becomes more and more common in lab environment and soon also in industry. In order to create resource- and volume flexibility, dynamic and smart automation could be seen as an answer. This paper has investigated the collaborative robots UR3 and UR5 for O-ring assembly and final assembly, compared to the current state which is performed manually. The methodology Dynamo++ was used for measurement and analysis in terms of LoA (cognitive and physical), cycle-time and quality. Furthermore, automation strategy, safety and easiness of programming was investigated. Results show that collaborative robots have great potential in the middle product volume area. A lot of time, layout space and money could be saved with these solutions. However, standards and safety has to be investigated further in order to reach its fully potential.

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Keywords: UR3;UR5, Collaborative Robots, Final assembly; LoA; Levels of Automation, Co-bots

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1. Introduction

Physical automation is still not common in final assembly systems. Case studies in over twenty cases measuring over 2000 tasks in Swedish industry shows that over 90% of the task are performed by humans [1-3]. This depends on varies aspects. Product Volume and Product variants might be the most common way of determine when or when not to automate [4], Return of investments and ramp-up time are two other aspects. It is hard to motivate an investment of a robot cell if the volume is too small, so middle volume products are still assembled by humans. Collaborative robots or ``cobots" are intended for direct interaction with a human worker, handling a shared payload and the benefits may be expected in ergonomics, in productivity and in the interface of computers and information systems to those many activities which continue to make good use of uniquely human skills [5]. But this idea is not new. Twenty years ago, the first cobot was presented [6], this cobot was the simplest one with one joint and two control moves. Robots and especially cobots have had a tremendous evolution the last ten years. The technology should be easy for the user to understand intuitive to use, they are conducive to learning and respond reliably. This means that flexible solutions in all four areas (cyber-physical, hardware-software) are necessary. Collaborative manufacturing has emerged as the norm of manufacturing in a distributed environment [7]. There are different solutions; light-weight robots (such as universal robots), cameras, gestures etc. [8, 9]. Among many other factors, flexibility, timeliness, and adaptability are identified in this research as the major characteristics to bring dynamism to collaborative manufacturing [7]. Therefore, companies must obtain deeper knowledge about new production solutions and be willing to evaluate them with reference to their own production in order to create a long-term sustainable system [10]. An enabler to achieve flexible and changeable systems is the ability to upgrade or downgrade the level of automation [11]. Most system design tools focused solely on the physical system [12] towards a more flexible assembly [13] but all resources contributed to flexibility. However, it is common that designers automate every subsystem which leads to an economic benefit for that subsystem but leaves the operator to manage the rest [14]. Taken the perspective and history from the third paradigm it is clear that this debate is still going on, but in this paradigm with a more advanced technology. Still the important questions of automation strategies, standards of

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systems and the flexibility of humans remains. At shop-floor user level the shop-floor decision support system need to have capability to be individualized [15]. The aim of this paper is to evaluate collaborative robot solutions in terms of strategy, safety, easiness of programming and cycle time. This will be done within an industrial case study.

2. Automation strategies

When top management initiates automation, often with the aim to reduce manufacturing cost, the decision on automation tends to be the only concern, i.e. automation is the manufacturing strategy [15]. The common strategy among industry has been to automate high volume products with low product variant, but in order to stay competitive companies have to come up with solutions to also automate small or middle volume products. Several development trends towards highly automated production and shop floor workplaces were seen during the 1980's and early 1990's. At that time the predominant task allocation strategy was "left-over allocation". Since the late 1990's trends are changing, much due to obvious shortcomings of automation to fulfil cost and flexibility expectations. Instead of having big robot cells that are static the trend is towards collaborative robots, small and flexible units. Flexibility and changeability of assembly processes require a close linkage between the worker and the automated assembly system [16]. Both humans and robots have crucial advantages regarding industrial assembly processes [17]. While robots ace at repetitive and monotonous assembly steps, humans are still the most flexible resource within the system [1]. The ability to handle unexpected and unplanned tasks are also prior to the humans [18]. Combining these advantages by means of direct human-robot cooperation seems to be interesting for producing companies but has not been realized in industry yet [17].Traditionally levels of automations is often divided into three different levels i.e. manual, semi-automatic and automatic. In order to get a more detailed measure of the manual part of the assembly tasks, levels of automation should be divided into seven levels [19]. Furthermore, cognitive automations should also be considered in every task [1]. A matrix defining and measuring both physical and cognitive automation has been developed and validated for over ten years in over ten Swedish companies, illustrated in figure 1. This matrix is used to determine the current and future state of the automation strategies within the case study.

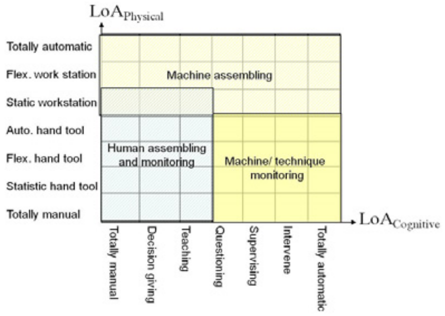

Fig. 1. LoA matrix [20]

3. Standards regarding collaborative robots

There are several drawbacks that prevent collaborative robots from being widely introduced to production environments [21]. Even if the technical challenges of designing and deploying such systems have been overcome, the operators' safety will always be the primary factor for achieving an acceptance. The existing applications separate the human from the robots' working areas in order for the operators´ safety to be ensured. There are numerous of standards regarding robots. ISO 10218-1, ISO 10218-2 are more general standards regarding robot-cell design. The first part of this ISO standard is regarding the robot itself, and the second part is regarding robot system and integration. New ways of determine the safety in a collaborative environment needs to be developed, it could for example be connected to the persons skill-level or what activities that the human and robot will perform side-by-side [22]. These kind of standards exist to ensure and evaluate the safety working with collaborative robots. There is a new published standard, ISO/TS 15066:2016 (Robots and robotic devices - Collaborative Robots), that specifies safety requirements for collaborative industrial robot systems and the work environment. It also supplements the requirements and guidance on collaborative industrial robot operation given in ISO 10218 1 and ISO 10218 2. In practice there could be different solutions within standard requirements but with a resulting difference in the safety level. For example, multiple small robots could be more appropriate than a large and heavy robot. It is a fact that the kinetic energy of a small/lighter robot is less than the large and heavy one when both robots are moving with the same speed, and therefore less harmful to a human if a collision occurs. Also, fenceless separation monitoring requires a lot of clearance between the human and the robot in order for the supervision system to be effective [21]. Although not directly related to safety, there is another robot standard that could be mentioned - ISO 9283 was developed in 1998. This standard consists of performance criteria and related test methods when manipulating industrial robots. In our case we are using an UR 5 and an UR 3 which are not tested in accordance with ISO 9283 by the manufacturer. But an UR 10 robot has been tested with interesting results by a third part [23].Standards will be necessary to be developed before the collaborative robots will be fully accepted within industry. More cases and early demos will hopefully lead the way towards these standards. In the case study in this paper three UR robots are used (one UR 5 and two UR3, illustrated in figure 2). These robots are approved within ISO 15066 and therefore considered safely to explore within the lab and within industry as a second step.

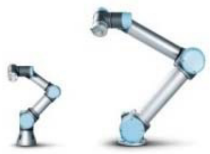

Fig. 2. UR 3 and UR 5 from Universal robots [24]

4. Company description

CEJN is world-leading company producing quick connection couplings. CEJN AB is a middle sized company, founded in 1955 and has been a family-owned business ever since. CEJN AB has five production sites around the world with the main factory in Skövde, Sweden. The product that has been used for this case is the coupling part of a quick connection for oil applications (Fig. 3).

Fig. 3. Coupling from CEJN AB

It is a relatively complex product and CEJN wants to test other automation solutions to assemble this product that is normally chosen.

4.1. Automation strategies at CEJN AB

CEJN AB: s vision when it comes to automation strategies is to increase automation to meet the growing demand and to remain competitive at the global market. Traditionally high volume products has been automated with high automation. The challenge ahead is to be able to automate parts of the low and medium volumes available. The solution is to build flexible flows with low downtime, which can handle multiple product families. The future solution could be to use robots that collaborate with humans i.e. co-bots.

Automation of final assembly is also suitable in the case of relatively simple pick and place operations. As is well suited to be performed by a robot. Manual assembly of for example O-rings and springs have remained manual operations because they are less demanding ergonomic, but they are more complex to automate. This also means greater flexibility in the manual assembly and that large variations in the products in terms of size managed. Flexibility is also great in terms of batch size when the size of the stations are limited.

5. Case study – Current state

The methodologies used in the case study are DFA^2 analysis [25] were the product were evaluated, both in terms of automation friendliness i.e. how easy is the product to automate and if there were and components that could be taken away or integrated with each other. The result is a DFA^2-index that determine the current state and the potential for automation. The analysis is done both on product and component level. The other method used is DYNAMO++, which measure and analysis the levels of automation in a production system [26]. The method also determine what tasks that are suitable for the collaborative robot. Levels of Automation is defined as;" the allocation of physical and cognitive tasks between resources (humans and technology), described as discrete steps from 1 (totally manual) to 7 (totally automatic), forming a 7 by 7 LoA matrix containing 49 possible types of solutions". Furthermore, Physical automation is defined as: "technical solutions helping the operator to assembly the products e.g. WITH WHAT to assemble", and Cognitive automation is defined as: "technical solutions helping the operator e.g. HOW to assemble (Levels 1-4) and situation control (Levels 5-7)" [9].

5.1. Current state

To get an overview of the product and the complexity of the flow, a walk through was done and then a mapping of the different stations, illustrated in figure 4.

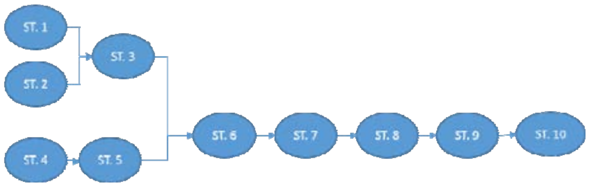

Fig. 4. Current flow

The product that was used for the evaluation had a total amount of 82 tasks divided over 10 stations and 27 components. The flow is a job-shop for station 1-5 i.e. all stations are at different places. Station 6-10 was arranged as a U-cell. The number of different tasks and components differs a lot between the stations.

The results from the DFA^2 analysis shows that the improvement potential for the complete product is almost 70 percent. Most potential lays in creating new and more flexible fixtures and to determine what to be the base-object for the product. The Base-object is the component on which all the other components are assembled on top of or on the side of. If this object is missing it is hard to automate the product. There were a lot of different machines and fixtures within the flow, which also gave lower points at product level. At component-level there were two types of components with a lot of potential; O-rings and open springs, these components are hard to automate and therefore they are interesting for this case.

5.2. The components - O-rings and open springs

O-rings is problematic to automate due to their shape and material, they are also often very slippery. One solution is to invest in advanced machines with high level of automation. In these machines, the O-rings are lined up in rails and are picked by advanced mechanical systems, an example is illustrated in figure 5a. Another solution is to handle this with low level of automation i.e. with some type of simple fixture and the assembly is done by hand, illustrated in figure 5b.

These two solutions are suitable, either for high volume products (5a) or for small volume products (5b), but there is no real suitable solution for middle sized volumes.

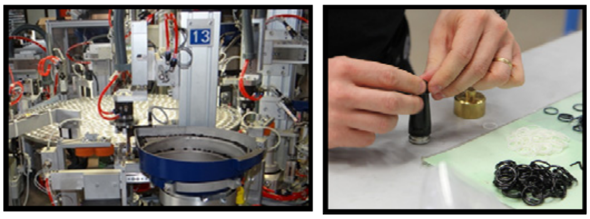

Fig. 5. Automatic solution (a) and manual solution (b) for O-ring assembly

One solution for the middle sized volume is to have two or more parallel stations in countries with low-wages, and still have it manual. One of the goals with this case was therefore to create flexible work stations the costs less than one million SEK (approximately 100’ euro), which usually is counted as the cost for one worker per year.

Springs has another problem, open springs attach themselves to each other which makes the very hard to handle, illustrated in figure 6. These are therefore often left as manual tasks if the volume of the product is too low. If it is high-volume products the spring could be produced directly within the machine.

Fig. 6. Bulk of springs

These tasks are also handled in two ways, either that the spring is made directly in the machine or the assembling is done manually.

5.3. Levels of Automation – current state

The measured Levels of automation for the tasks are illustrated in figure 7.

$\text{LoA}_{\text{Physical}}$								
7								
6								
5				2	2			
4	1							
3	2	1						
2	14	2		5				
1	51	1		1				
	1	2	3	4	5	6	7	$\text{LoA}_{\text{Cognitive}}$

Fig. 7. LoA measurement – current state

The stations with the highest LoA (5:5) is station 1, 4, 7-9, i.e. they are performed with a static machine. For all the tasks, over 90 percent of them are performed manually, which is in line with earlier case studies [26]. About 82 percent of the tasks are performed with own experience which is higher than earlier case studies (usually this number is about 75 percent).

6. Case study – Future solutions

The future solution contains of three flexible assembly units, illustrated in figure 8. This division is based on an analysis of number of components, stations and complexity of the tasks.

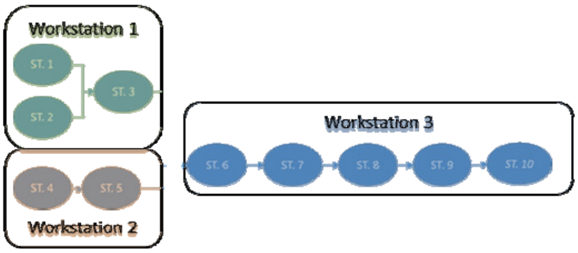

Fig. 8 Future flow

The stations are flexible wagons that easily could be moved and rearranged into u-cells or lines or single stations depending on the demand, illustrated in figure 9.

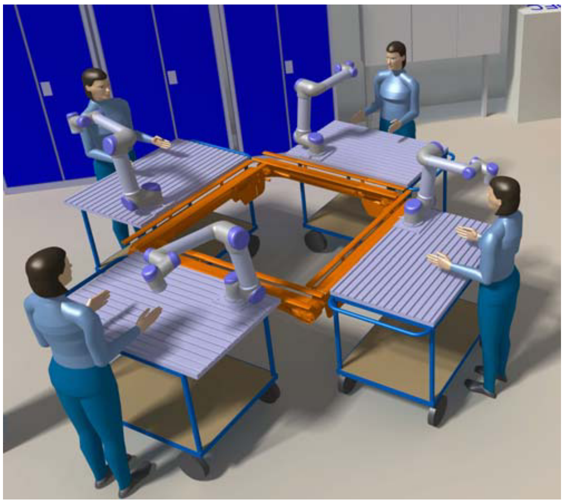

Fig. 9 Future flow

The transportation between them is a conveyer belt, which makes the transportation automatic, if standing together. There are two different pallets, one for the components at station 1 and one for the rest of the product starting at staion 2. By having the components kitted and the product at one pallet the DFA^2 analysis was improved by approximately thirty percent.

6.1. The components – Future solutions

All three works stations had one or more hard issues to handle. One of the most important things to improve based on the DFA2 analysis was the fixtures and base-object. The Base-object is created in Station 2 and has a top approach i.e. all the components are assembled on top of the first component. This station also creates the fixture on which the product is transported. Station 2 did not have any O-rings to assemble, but they had an open spring, in order for this to be assembled with the future solution a change in the design of the base-component is needed. In order to test the station this task was done manually to start with.

Station 1 is a sub-assembly station for station 3, which contains of both O-ring assembly and open springs. This station had the most improvement potential of the three stations in terms of DFA^2-index and time. The solution for the O-ring assembly was to try a combination of two off-the-shelf solutions in terms of Schunk's O-ring gripper and one UR5 robot, illustrated in figure 10.

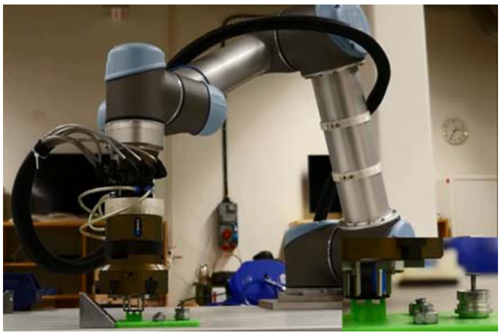

Fig. 10. UR5 assembling O-rings

The gripper was very complex, in terms of many fingers, to be able to handle the O-ring but the evaluation was very positive. The cycle-time was almost the same for the robot and the human when testing but the gain is the flexibility of the worker when having the robot. In terms of handling the springs and the other components not being O-rings, a magnet was used as a gripper. The components were kitted and the gripper had three different kind of magnets for gripping different components. This design saved tool-change which also decreased the total cycle time. At station three, there were a lot of different machines and the robot is planned to be used mainly for pick and place operations.

6.2. Levels of Automation – Future state

One of the most important issues was to avoid the ironies of automation i.e. left-over automation [27], as much as possible and also to reduce the space of the stations so that one operator could manage all the ten stations. The current state analysis resulted in three collaborative robots, two UR3 and one UR5 that was used for the evaluation. The robots are performing tasks at Station 1 and station 3. At station 1 the UR5 is used for O-ring assembly and UR3 is used for assembling and screwing and in station 3 it is used mainly for loading and unloading machines.

The 82 tasks from the current state were increased both physical and cognitive, illustrated in figure 11. Over half of the tasks could be performed with co-bots (LoA=6:6).

$LoA_{Physical}$								
7								
6					51			
5					9			
4			2					
3								
2		1			5			
1		1	9	2	2			
	1	2	3	4	5	6	7	$LoA_{Cognitive}$

Fig. 11. LoA measurement – Future state

The solutions has not yet been evaluated regarding safety for industrial operators since it has not been tested in real industrial environment. The current state analysis shows great potential in saving time and money if investing in these solutions. One important thing was to adapt the product and the components for automated assembly, which is the first step towards an industrial implementation. The budget for the three stations was below one million Swedish crowns, which was one of the goals with the project.

7. Conclusions

The safety issue is off-course one of the things that has to be tested and evaluated before these kind of solution could be installed full-time in industry. Despite this there lays a great potential in collaborative robots. This paper has shown that it is not a black-and-white decision any more when handling middle sized volumes. It is possible to invest in small dynamic and flexible works stations for the cost of one human worker. We believe that the future holds a lot of small dynamic cells that could be re-programmed from one day to another if needed and that the mobility and flexibility that these solutions holds is necessary to create a sustainable work environment of the future.

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