Low-cost Automation – changing the traditional view on automation strategies using collaborative applications

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Abstract: The labor cost has been one of the main reasons for industry to move some of the production to so called low-cost countries. Research has shown that this issue is more complex than just calculate labor cost as main driver. Organization culture, research and development and technical competence is also important drivers for a successful automation strategy. Another important factor when it comes to automation strategies is what production parameters to consider choosing the right automation. Traditionally five parameters have been considered i.e. Volume, batch sizes, variants, investment cost and labor cost. With new and cheaper solutions for automation these two views on automation and low-cost production need to be considered and changed. This paper will describe three demonstrators using low-cost automation solutions to automate simple tasks in final assembly systems. The stations' investment cost is all below 50,000 euro. The first demonstrators have been set up and tested in a lab environment. The results show a high precision, easiness in programming and high quality. The aim is to test this further in real industrial environment to stress the system and to put it into a tougher environment.

Keywords: Human-centered automation and design; Human operator support; Design, modelling and analysis of HMS

1. INTRODUCTION

In 1995 the analysis company Gartner developed the hype curve where technology and innovation management (TIM) is described. The model explains a general path a technology takes over time, in terms of expectations or visibility of the value of the technology [1]. The model proposes that technologies progress through five stages of innovation and business development; technology trigger, peak of inflated expectations, trough of disillusionment, slope of enlightenment and plateau of productivity. The model depicts the First Law of Technology, stating that "we invariably overestimate the short-term impact of a truly transformational discovery, while underestimating its longer-term effects" (Collins, 2010). The last stage, the plateau can be defined as when the technologies reach the plateau of the curve when approximately thirty percent of the target audience has adopted or is adopting the technology. In the era of the fourth industrial evolution a lot of new technologies has been emerging during the last twenty years. Altogether, 46 different technologies were assessed with respect to the hype cycle model across the reports published from 2003 until 2009 (Gartner, 2016). In the era of industry 4.0 nine areas of emerging technologies were presented [2] in 2017. In order to achieve a good collaborative workstation between humans and robots, several of these technologies is needed early in the design of the stations [3], for example IIoT, Machine Learning and collaborative applications [4, 5]. According to the IFR only 3,4 percent of the industrial robots were robots designed for collaborative applications in 2018. If the technology should reach the plateau e.g. thirty percent, new strategies and a new view of how and when to automate is needed.

It is not only the technology itself that is the needed in order to succeed with collaborative applications. The operator 4.0 [6] need to be able to cooperate with robots to a higher extend than before. Skills, knowledge and design for human robot teams is needed. There has been several suggestions about human-robot collaborations [7] but this is still not so many implementations due to safety etc.

Low-cost automation is a new strategy that needs to be considered in future assembly systems. Small robots designed for collaborative applications is often cheaper than traditional industrial robot applications if a well-documented and grounded work is done before. The physical level of automation is usually high in the beginning of the product flow e.g. Body in White (BiW) stamping operations, welding cells (also defined as early assembly tasks [8]) while at the end of the product flow there is still a lot of manual tasks e.g. material handling, kitting and final assembly [9].Some of the reasons are the same as for the outsourcing parameters e.g.

high volume, long product life-cycle (if it is taken under consideration that car manufacturer often use the same platform for a divers numbers of car brands). If instead the products are more complex, with small series of items and meeting a rapidly changing demand or short lead times it is more likely that the production will stay closer to costumer in order to not disturb their total throughput time, which may damage their reputation and reliability toward their customers[10]. Companies are becoming more aware that there are other performance criteria that needs to be considered next to low costs of wages e.g. total cost of operations, total life cycle costs, productivity, reliability, flexibility [11] and quality had to be taken into account [12]. From a lower system level there are a broad spectrum of assembly systems with varying degrees of automation that exist in traditionally high-cost countries. Today e.g. manual assembly, semi-automatic assembly or automatic assembly [13]. Since the level of automation is very low at the end of the product flow there is also a great potential for automation. In order to fully reach the automation potential, new strategies for automation is therefore needed.

This paper aims to describe new way of thinking when it comes to automation strategies and low-cost automation in stations with collaborative applications. Two cases will be analysed and demonstrated in order to show how low-cost automation solution can be designed.

2. AUTOMATION STRATEGIES

Traditional automation strategies are often considering four different parameters 1) Product Volume 2) Batch size 3) Number of variants 4) Demand on flexibility, illustrated in figure 1 [9] adopted from [14].

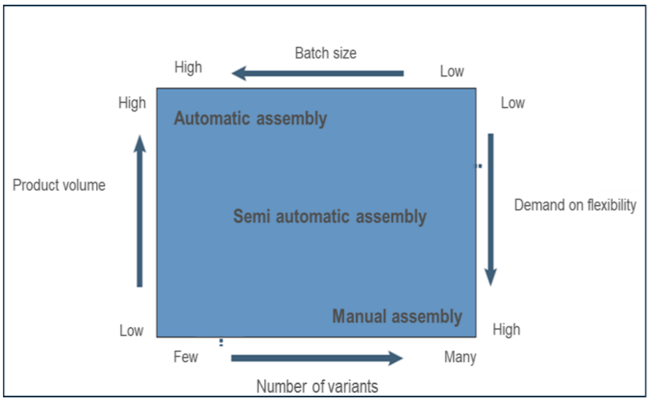

Fig.1. Four parameters in traditional automation strategies

These parameters can also be translated into the system paradigm that has been evolving. Usually there are three systems that are mentioned as the evolving paradigm i.e. DML/S, FMS and RMS [15]. In the Dedicated Manufacturing line/systems (DML/S), focus is on *high volume* production for *a specific part* with cost effectiveness as the main driver. In the second one, Flexible manufacturing systems (FMS), a *high variety* and *low volume* i.e. customisation. When the number of variants increases it puts higher demand on *operational flexibility which* traditionally meant manual or semi-automatic solutions. In the last system, reconfigurable manufacturing system (RMS), the aim is to quickly adjust production capacity and functionality in response to market requirements. In 1996 when RMS systems were introduced a thrive for more reliable machines, innovative control systems and smart sensors were on way to improve the system efficiency during its entire lifecycle e.g., system configuration [16]. This is the focus in industry 4.0 i.e. communication, digitalisation and cyber-physical systems [3].

Traditionally, the choice of a curtain automation strategy was believed to be a compromise between efficiency and flexibility [17] i.e. if human functions are to be replaced by technology and automation, efficiency will (hopefully) increase, but there is a cost in terms of loss of flexibility. According to [18] the top three most crucial parameters for investing in automation solutions today are investment costs, operating cost and flexibility. In line with this, results from a Delphi study with 108 Swedish companies shows that their major concern with automation is to not get enough return on investment of the automation solutions [19]. The investments in industrial robots continuous to increase and between 2016 and 2017 there were an increase of 14 percent. The robots designed for collaborative applications have increased from 2.4 percent (2017) to 3.4 percent (2018) of the total amount of invested industrial robots. Hence, there are still considerations when to invest in automation. A study conducted in Sweden between 2018 and 2019 with 68 companies shows that the three most critical parameters for implementation of automation (and foremost collaborative applications) were:

1. Safety aspects and lack of good and simple guidelines for designing safe collaborative workplaces.

2. Lack of technologies and knowledge of designing interaction between man and robot and between the robot applications and the shop-floor IT

3. The product is not designed for automation but for manual work which makes it difficult to automate the final assembly of the components.

In order to determine what station to automate and what task to automate a function and resource allocation is needed [20] [21] in order to divide the tasks between operators and robots. In order to do this, it is important to see the robot and the operator as resources that can perform the same task. In order to understand and analyse the task allocation it is common to use the current assembly instructions.

Hence, if a collaborative application will be used, the order of the tasks might need to change to avoid critical situations, this can be simulated in order to find the critical tasks [22]

[23] and to avoid collisions [24, 25]. Another concept that can be used in order to understand ad determine the interaction between the operator and the automation is to use the 'Level of Automation over time' concept [26]. It is important that the task and resource allocation is done before a technical solution is chosen. A flexible production system composed by human-robot collaboration workstations to have three components were as the first is that task level synchronization is required for human-robot cooperation and collaboration [27]. If collaborative applications are required, further analysis of the different levels of interaction [28] i.e. co-existing, synchronization, cooperation and collaboration., human-robot teams and safety functions is needed. Other parameters like reachability, payload, graspability and placing is also important to consider.

For humans and robots to work together collaboratively, new parameters must be considered in order to obtain acceptable, successful solutions. Results from the Swedish study shows that the most common reasons to consider collaborative applications is to improve (or more even) quality, decrease or take away ergonomic issues and resource/routing flexibility i.e. to be able to move the robot between stations when needed. If this is compared to a study made by Fraunhofer in Stuttgart, the top three answers were increase operation efficiency, innovation and to improve ergonomics [28], Quality (6) and Flexibility (8) was among top 10.

Four "new" parameters illustrated in figure 2 need to be considered when designing production station with low-cost automation intended for collaborative applications.

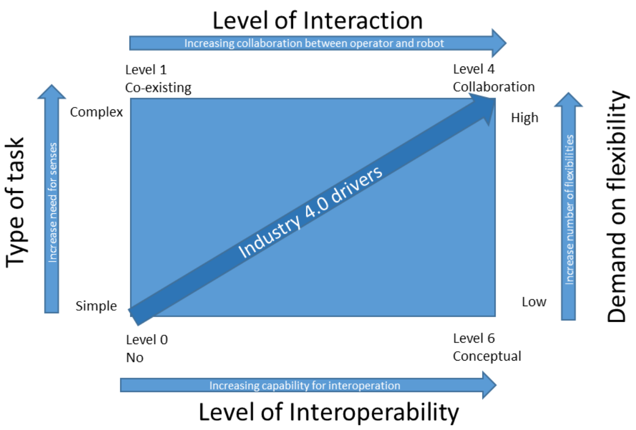

Fig.2. Four parameters in new automation strategies

Level of Interaction [28] – This is an important factor to consider, most implementations that has been made is done at the two lower levels of interaction i.e. co-existing or synchronising tasks. The two higher levels i.e. cooperation and collaboration need a lot of safety systems and also a higher level of interoperability.

Type of task – instead of looking at product volume the companies can look at what type of task that can be performed as collaborative tasks. If it is a simple pick-and-place task or load-unload task the robot could handle many different variants and thereby also a higher volume. One area that we think the robot applications will increase is internal logistics with material handling and kitting. The task is also more complex if the human senses is needed to be replaced or automated, seeing (vision), feeling (sensors), hearing etc.

Level of Interoperability [29] – is the ability of two or more systems or elements to exchange information and to use the information that has been exchanged [30]. When implementing robots for collaborative applications the system needs to communicate with other systems such as ERP, MES the operator etc. IIoT can be used in order to create a more dynamic and adoptable system [31, 32].

Need for flexibility – it is important to define what type of flexibility the applications should solve and how often it is needed. Over fifty different types of flexibilities has been defined [33]. In RMS routing flexibility is one of the important parameters and is still today. Mobility or the ability to change quickly between products [34], not only by changing the material but to change the place of the robot will be an important parameter in the future.

3. DEMONSTRATING LOW COST SOLUTIONS

Two industrial cases have been investigated. These cases are within final assembly and both are sub-assembly stations. One of the products is currently assembled at the subcontractor and the other is assembled in the factory but away from the final assembly. The main reason for considering automation is to decrease ergonomic issues and to create resource flexibility. According to the "old" automation parameters the batch sizes is low. In Case A the batch is one end-product which can be up to eight sub modules in case B they assemble five boxes in one batch, both these can be considered low batch sizes. Furthermore, it can be many different variants since the products are costume made. The volume can also be considered low volume size it is at the end of the product flow. The sum of the old parameters show that manual assembly is the best alternative. The aim was therefore to invest in low cost automation were the hardware investment is low and the programming is easy so that the ramp-up of the change will be as short as possible. For Case A this meant to have an investment cost under 10 000 euros and for case B we aimed for an investment cost on the hardware under 5000 euros. The pilot tests are small tests with around 3 hours production. The layout and size of the station is aiming to be able to fit in two euro palls e.g. the area of the stations are maximum 1600*2400 mm. The first initial tests have been performed in a test-lab environment with the aim of moving it out to a factory test environment for further tests. Since the end-product is mass customised the assembly stations need to have high flexibility to handle this. The type of tasks performed by the robots are easy pick-and-place tasks in both cases but with additional screwing tasks in case B.

Case A: Sub assembly of switches for dashboard

This first product has 83 different switches assembled in modules of four. Today the operators manually pick switches using pick-to light system and places them in the modules by hand. Three different manipulators have been tested but since it is an easy pick-and-place task, there is no need for highly complex manipulators. The weight of the components is also low, under 100 grams so there is no need for big robots. The robots used in the low-cost case is two different robots from Dobot, illustrated in figure 3. The DOBOT M1 is a Scada robot designed for industrial use and is used at the end of the line because of force needed to assemble the switches. A Dobot magician is used on a rail to pick the different switches and place them on a conveyer belt to transport the switches to the scada robot. This is a low level of interaction since the operators is only filling up the material racks and picks up the finished modules, this is planed to also be done automatic with an AGC in the future. The racks for the material are 3D printed used for all the different switches and the modules, illustrated in figure 3. Small sensors are attached to these racks, so the system knows when to change the rack. The communication between the robots is done through an Arduino. There is a need for a rather low level of interoperability, probably level 2, syntactic is enough as a first step i.e. standard APIs for communication between robots and IIOT platform Thingworx that will be handling the communication with the order system

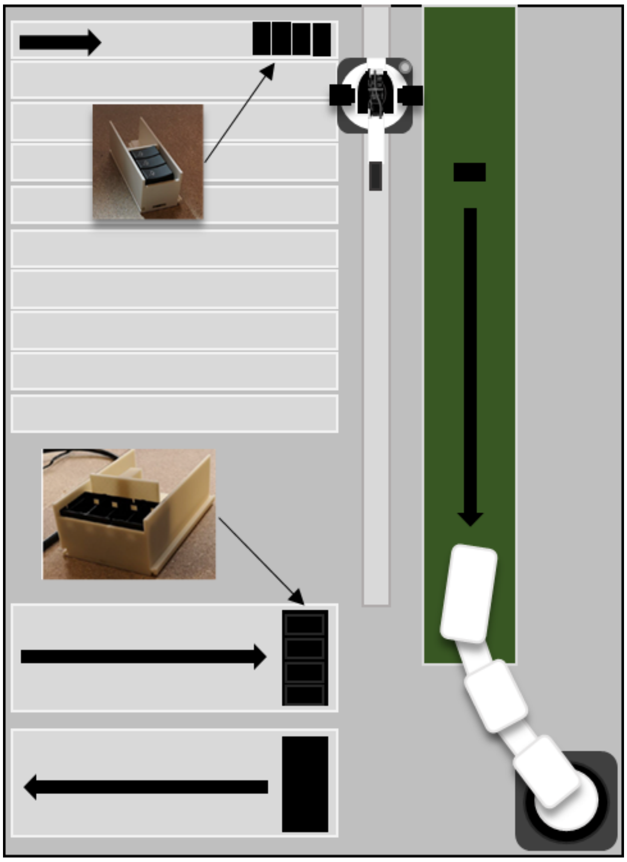

Fig. 3. Low-cost solution for case A

Case B: Sub-assembly of fuse boxes

The second product have 14 different variants of midi fuses that can be assembled into the fuse box. The fusebox consist of two bigger and approximately ten smaller (depending on the variant), each fuse is the attached with two bolts. Connected to three of the fuses there is also a cabling assembled. Today the assembling is done mainly manual except for tightening and cutting the cable ties. The weight of the components is under 100 g and no special force is needed. Therefore, the robots used in this low-cost alternative are two Dobot magician, for picking and placing the different fuses and to do the first tightening of the screws of the fuses. This station is designed as a co-existing station i.e. the lowest level of interaction which means that the operator and the robots are working side by side but not at the same station and not at the same time. The operator is doing the last assembly with the cabling and the tightening and cutting the cable ties. The operator will also do the last fastening of the bolts with a pneumatic or electric screwdriver. The material racks is 3D-printed both for the fuses and the bolts in the same way as in case A.

The communication between the robots will be the same as in case A. The communication between operator and the conveyer for the fuse boxes will be done with sensors and an Arduino as well. Safety will also be higher between the conveyers and the operators; risk assessments is needed in order to determine what is needed as safeguards etc.

The communication between the station and the order system will be communicated through the IIoT platform, thingworx.

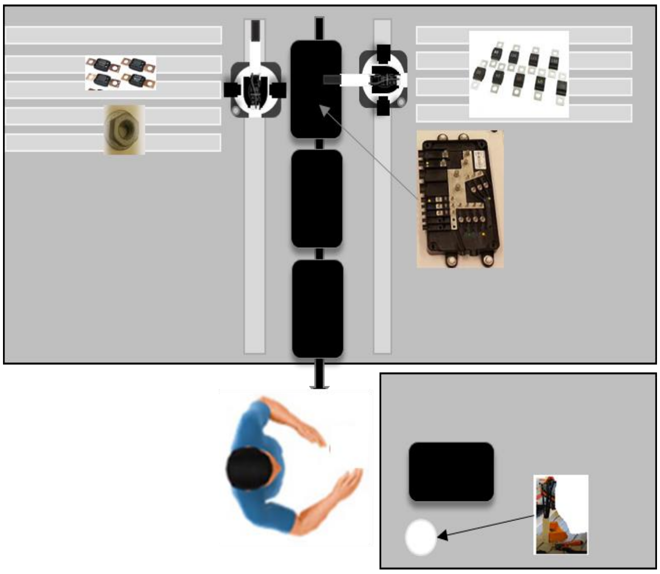

Fig. 3. Low-cost solution for case B

4. DISCUSSION AND CONCLUSION

This paper has discussed the need for new parameters to consider when designing systems with collaborative robot applications. Reconfigurable manufacturing systems are still needed and have great potential in final assembly. With new enabling technologies such as collaborative applications, IIoT, smart sensors and machine learning, new solutions will come. This paper has showed two different examples of low-cost automation with collaborative robot applications that can be used for final assembly in high-cost countries. Since new technologies are available on the market and the investment cost has decreased and probably will continue to decrease, new strategies for automation is necessary. Investment cost and return on investment should not be considered as the most crucial parameter in automation projects. Parameters such as ease of use, safety and operational flexibility is more important to consider in future automation solutions. Furthermore, new strategies for both product and production design for adjusting to automation will become vital in the future. If the product is design for automation it is easier to automate the production as well. Solutions for automate material handling, kitting and final assembly is still under development even though the evolution is going faster.

Safety equipment needed for the implementation has not been considered in these cases. Furthermore, a full risk assessment and CE-marking of the solutions have not been done since that solutions has been tested in lab-environment in the first step. This will be needed if to implement these solutions in a real production environment. This will be even more important to consider when low-cost solutions will appear.

Areas such as internal logistics and kit-preparation also needs to be considered in order to create high level of flexibility and reconfigurability in the systems.

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