METHODOLOGY FOR COBOTS IMPLEMENTATION INTO THE ASSEMBLY APPLICATIONS

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The affordability and ease of programming of collaborative robots (cobots) is a critical factor in increasing their widespread use in many automated processes (assembly processes included). Therefore, the task of this article is to offer a suitable methodological approach to the design of a collaborative application concerning the necessary flexibility wherever a significant change or reconfiguration of the physical production environment is not required. The final solution is tested on the example of a collaborative assembly application on a manufactured object, taking into account the division of tasks between the operator and the collaborative robot. The simulation and initial testing results proved not only the feasibility and suitability of the methodology but also a significant shortening of the assembly cycle and the ability to automate the selected assembly operation.

KEYWORDS

Cobots, Assembly Process, Automation, Human-Robot Interaction

1 INTRODUCTION

At present, new innovative requirements are emerging from various fields, both in the industrial and non-industrial spheres, which are diametrically moving away from the needs of classical automation [Vargas 2019, Trojanova 2021]. We should note that conventional industrial robots can no longer respond to these requirements, and collaborative robotics seems to be the right way to succeed in the market. Thus, there are strong voices, proposals, and opinions from many quarters, and the common denominator is the reference to a considerable newly created innovative space for collaborative robotics [Vargas et al 2019]. These views are accepted worldwide, and their accuracy is documented by many studies, e.g. [Vysocky and Novak 2016; Marvel et al 2020 or Cini et al 2021]. The manual and often very monotonous assembly activities of a person at the conveyor belt displace the ubiquitous growing trend of cobots implementation.

Their advantage is, e.g., also adequate mobility in confined spaces or directly working on the desk next to the operator. The critical difference is the deployment in the selected assembly application because some tasks are not even suitable for human cooperation, even if the cobot will implement them. Cobots can perform both collaborative tasks and tasks of a standard industrial robot. This allows small and medium-sized companies to step into automation of existing work environments at affordable investments. The difference between a classic industrial robot and a collaborative robot may not be evident at first glance (Figure 1).

Well, e.g., we can differentiate it according to the deployment method in the application, the technique, and complexity of programming, or the chronology of the implementation of the assigned task. Emphasis on the safety of an automated assembly workplace is a necessary prerequisite for the successful implementation of such systems, not to mention the area of collaborative robotics. Since this area is characterized by human-robot contact, it is necessary to know the norms and standards that determine the conditions and rules of such cooperation. The specification ISO / TS 15066 and standard 10218-1, 2 address this issue.

The fair pressure values at quasi-static contact are approximately in the range of 110 to 220N / cm^2, and the allowable force at this contact is between 65 - 210N, depending on the human site. The values are well documented from car incidence and experiment measurements. However, specific values of temporary contact force are not available due to the varying sensory pain in each person [Virgala et al 2021].

Collaborative robot, MOTOMAN HC 10 — Industrial robot, MOTOMAN SIA 10D

Figure 1. The difference between a cobot and classic industrial one

Compliance with standards is a must for any risk assessment and in case of an accident, risk assessment and each device used in the system will be examined for compliance with Machine Directive [Yaskawa 2021]. The design of the collaborative assembly workplace can be derived from the previous experience and knowledge, other similar applications as well as available technologies, or based on framework orientation points:

- Understand how a cobot differs from a traditional industrial one.
- Understand applications that are suitable for implementing a cobot.
- Understand that although cobots are primarily characterized by simple and intuitive programming, more complex programming is usually needed.

2 METHODICAL APPROACH

Automation processes and activities, in general, are responsible for the reasons that contribute to the development of many (and different) methodologies or procedures for collaborative application design [Quenehen 2021]. At the same time, the common denominator of each of them is that they were previously performed either entirely without the participation of a cobot, or by quite manually, or it is a wholly new process or activity (Figure 2). It should also be noted that there is probably no universal methodological approach to implementing cobot in a selected automated activity to be used in every application or process.

The solution seems to be implementing gradual and clear methodological steps, which will divide the extensive and complex problem of the methodological approach of collaborative application design into a series of smaller and manageable parts. These steps are defined by the degree of "collaboration" of the selected (assembly) activity, the degree of implementation of sophisticated sensor technology, or considerations of the defined workspace within the production hall (concerning application and operator safety).

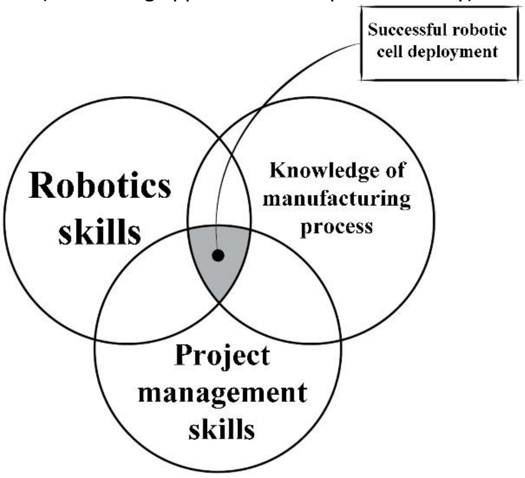

Figure 2. Possible methodical approach for cobot implementation [Bouchard 2016]

A suitable solution and facilitation of cobot implementation is the application of the principles of the so-called "lean robotics." This principle is perceived as a systematic approach to implementing a collaborative application and begins with the initial design through its integration up the automated operation itself. The basic principle of lean production is that deploying the proposed (assembly, in our case), the automated workplace is as early and straightforward as possible [Dyadyura 2021]. With this in mind, we consider it necessary to focus on the following key factors:

- Initial planning of a collaborative (assembly) application.
- Automated operating conditions and operator safety.
- Workplace layout.
- Selection of peripheral devices.
- Decomposition of the (assembly) process into programmable sections.
- Appropriate assembly algorithm.
- Determination of individual sequential handling operations (cobot vs. operator).
- Installation of devices in the automated workplace.
- Training of personnel for operation and maintenance.

When designing the assembly process, it is necessary to consider that only specific assembly tasks can be performed efficiently by the cobot, primarily due to its technical limitations. Therefore, part of experiments is also to identify which assembly cycle tasks are more recommended for the cobot and the operator by considering the aforementioned key factors [Bozek 2021]. Based on the analyzed facts, the tasks were divided according to the description below and their duration:

- Concentration of individual parts of the assembly object in a shared working space.
- Assembly scenario and general assembly technology methodologies.
- The synergy criterion presupposes the efficient use of cobot and operator.
- Criterion considers the specification of assembly activities against the assembly object.
- A criterion that considers the sequence of processes between the cobot and the person to create the minor possible time gaps between individual assembly operations.
- Assembly time.
- Criterion taking into account the optimal complementarity of the cobot and human during the process.

Although the focus of these critical factors determines the deployment of the cobot in a small automated workplace, their impact is significant on the entire company or even the whole plant [Tichy et al 2021]. Therefore, the presented approach provides more significant potential and shows instructions on how to deploy the cobot application faster and more efficiently (Figure 3) by eliminating activities without added value (actions that do not directly participate in the implementation - assembly of the product).

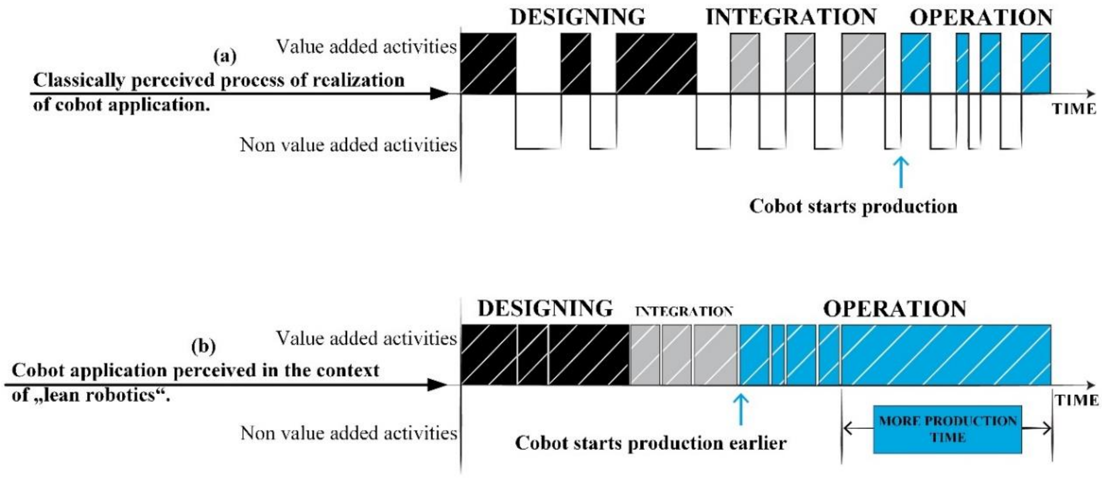

Figure 3. Assembly sequence of the product [edited from Bouchard 2016]

3 EXPERIMENTS AND RESULTS

While designing an assembly process, it is firstly necessary to consider that only certain assembly tasks can be performed efficiently by a robot due to inherent technical limitations. Operator tasks focus on implementing preparatory activities, screwing, or inserting individual parts of the assembly object (limit switch XCKJ – Schneider Electric). On the other hand, the cobot's operation is directed towards feeding tasks, which simplifies the operator's work and speeds up assembly time.

Therefore, the main idea is the gradual implementation of tasks, one after the other [Gualtieri 2021]. It is due to the operator's presence in the cobot's immediate vicinity when he performs partial assembly operations, which would generally be very difficult to automate with just one robotic system. Furthermore, the assignment of tasks is defined by an assembly cycle, and the operator cannot choose in real-time which task will follow (the so-called static task allocation principle).

Thus, it can be stated that the cobot generally stops or slows down its activity with the incoming staff, and after its departure, it resumes its program activity. The next logical step in implementing our selected assembly activity concerning the above vital factors presented is the selection of a suitable alternative assembly sequence. The weighted decision matrix method should be used as a robust decision tool in cases where the solution emphasizes each of the assessed criteria, usually of unequal weighted significance. The resulting selection combines the overall criteria scores for each alternative, considering each criterion weighted by the criteria. The assembly sequence for task allocation between the cobot and operator is shown in Figure 4.

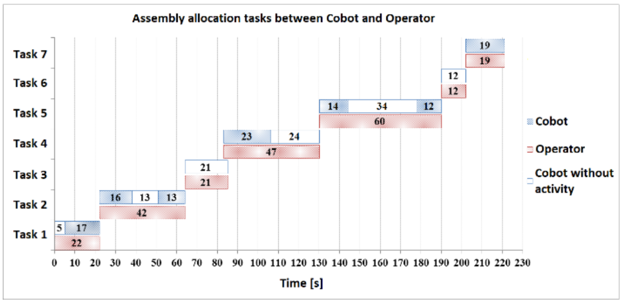

Figure 4. Task allocation for assembly process

From a practical point of view, this concept is experimentally tested via a control module. Its task is to confirm and step through standard buttons that are connected to the safety inputs of the cobot control system (Table 1). The control of the central stop and the switching off of the cobot drives is a matter of course.

Table 1. Description of control module functions

Button	Input	Description of activity
Start	IN 01	Starting of the assembly process
Release	IN 02	Releasing of object´s part
Continue	IN 03	Confirming to the next step
First part	IN 04	Cobot serves a first part of the assembled object
Second part	IN 05	Cobot serves a second part of the assembled object
Packaging	IN 06	Finishing of the assembly process

The corresponding indicates the transition to the next assembly step in the process LED indication. The main element in the algorithm creation and programming of the assembly scenario (concerning the safety factor) is monitoring the state of the input variables, which are controlled by digital inputs. The development an assembly automated workplace with a cobot is based on the penetration of the superiority of the operator on the one hand and the controlled sequence of partial activities on the other hand. The layout of the workplace itself was solved in such a way as to avoid direct contact of the operator with the cobot - the worktable is therefore located in front of the cobot (Figure 5). In the first phases, the design was mainly in a CAD system until the result was tested in motion simulations and virtual reality, while the actual application was built gradually [Holubek 2019].

Figure 5. Layout of the workplace

The operator is a superior element, and it checks the sequence and correctness of the assembly activity. It can intervene, confirm partial tasks, or even stop the whole movement if necessary. The functional program structure is based on the control of function blocks such as *"PSTART"*; *„PWAIT"*; *„IN"*; *„OUT"* which are responsible for the step change of the application algorithm. These relevant blocks are called into the program directly using the programming language *"INFORM"*, whose open architecture allows code modification via C++.

For example, the motion parameters are entered using the "*Teach-In*" method. A characteristic of the programming language is the possibility of adding many control functions, such as "*Wait in*" or more (Figure 6). Built-in and own instructions can be gradually added to the program directly via the editor of the programming unit – pendant.

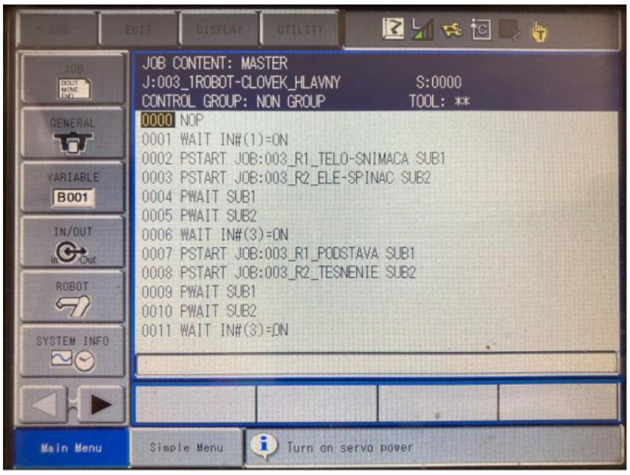

Figure 6. Relevant function blocks

The algorithm process (Figure 7) describes the sequence of tasks that are created based on one main program supplemented by other sub-programs of their own sub-activities, such as the cobot movement command. This ensures transparency and debugging any errors of sub-programs. In addition, main program only continues after the end of the two sub-programs.

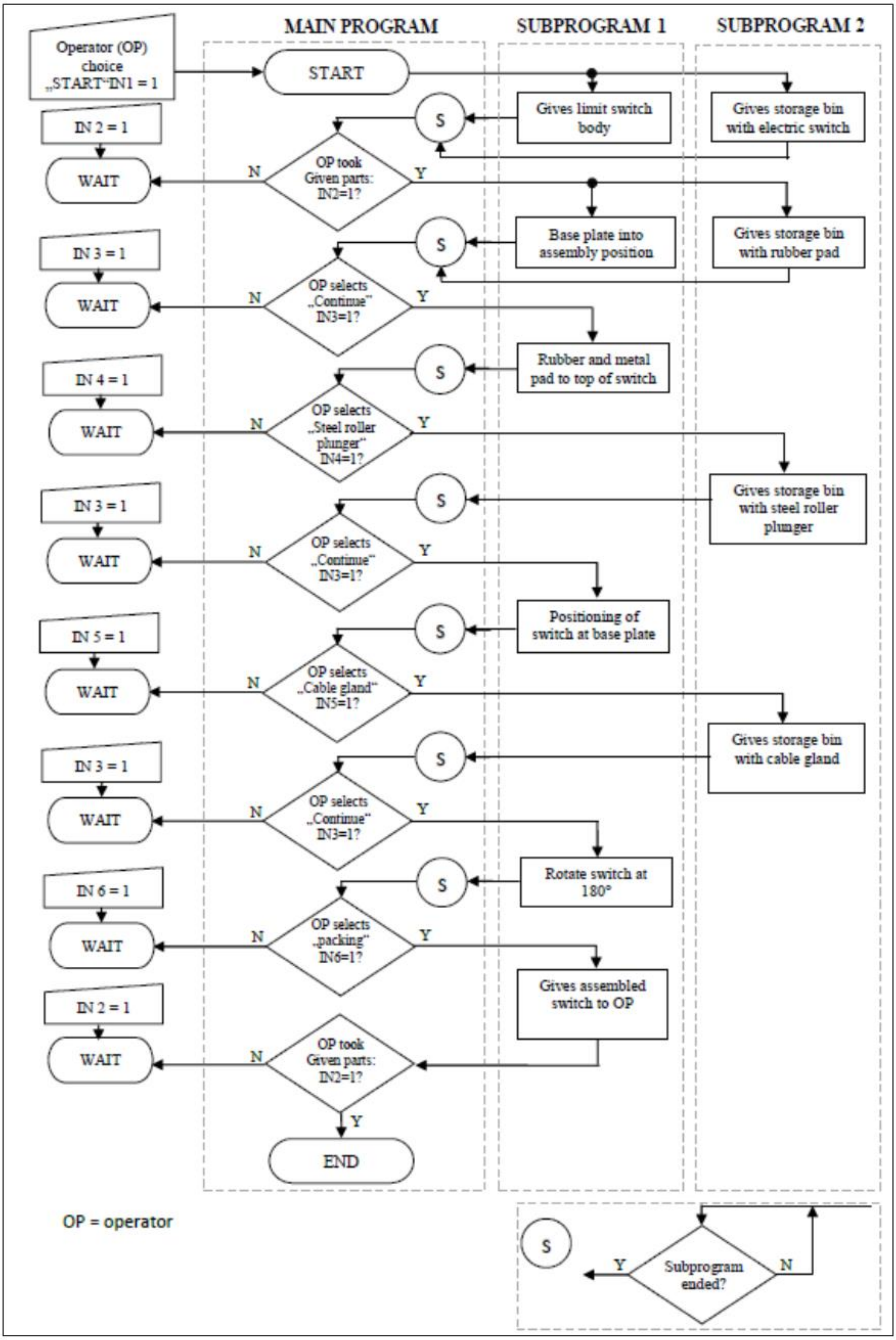

Figure 7. Algorithm for the assembly process

4 CONCLUSIONS

The article investigates the possibilities of a methodological approach for designing a workplace with a cobot emphasizing assembly activities. Critical factors that affect the design, implementation, and deployment of the investigated solution in automated operation were specified. The experimental (assembly) application was monitored by a superior operator and controlled by a safety sensor for security reasons. The presented solution is placed on the factor that cobot should perform light monotonous operations, and operator engages in demanding activities in automation, or that whose require the thinking and deduction.

Therefore, some applications are better left to cobots and more complex value-added tasks to the operator. The article also includes an algorithm for the assembly process. The characteristic feature is that it always continues only after completing individual subprograms and the operator's approval. Future activities assume the deployment of this practical solution into the actual automated operations. Another exciting factor would be to equip the workplace with an autonomous 3D camera system and ensure assembly facilities' supply and removal.

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