Journal of Mechanics Engineering and Automation 11 (2021) 37-45
doi: 10.17265/2159-5275/2021.02.002

DAVID PUBLISHING

Assessment of Potentially Attractive Tasks to Collaborative Robotics Application: A Case Study Based on Electronics Industry

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Abstract: The use of robotics in the electronics industry has been of great importance to raise productivity and quality levels. When compared to the classic industrial robots, the collaborative ones present themselves as a trend, bringing greater flexibility, improving ergonomics, shortening implementation time and degree of configurability. However, the correct definition of their use, when compared to industrial robots, still needs more understanding and discussion so as not to become an intuitive process. The objective of this work is to present a methodology based on a time and motion study to define the tasks which have the greatest potential to be automated and to be implemented with simplicity. To validate this methodology, two consecutive stations of a packaging assembly line of smartphones were considered. The obtained results show feasibility and applicability in the tested solution, allowing it to be applied in other situations.

Key words: Collaborative robots, automation, methodology.

1. Introduction

The adoption of automated systems by industries constitutes as one of the main strategies to increase their productivity. In the case of electronics manufacturing, traditionally marked by intensive use of labor, two main factors are considered: high complexity of activities and shorter life cycle between the development and its obsolescence in the productive process [1].

Traditionally, the classic automated manufacturing systems are rigid and require large batches production to be economically justifiable. Consequently, in situations where the demand is fragmented, that is, smaller batches where the exchanges are more frequent, in most cases it precludes the implementation of automation [2, 3]. In these systems, robots traditionally are used with safety cages—cloistered—in rigid operations of simple and repetitive tasks, presenting limitations in new uses (reconfigurations) [4].

Unlike industrial robots, the collaborative robots or COBOTs aim to operate in more dynamic environments through interaction with operators, varieties of tasks and more frequent changes. The introduction of collaborative robots can create a number of benefits for industrial operations by allowing the robot to work in the open environment without physical protection, and it is possible to combine elements of manual operations with the robot activities, eliminating from the operator tasks which are heavy and do not aggregate value [5].

Supported by computer vision systems and

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equipped with sensitive sensors, this new treatment allows the work of the robot in collaboration with the human being [6]. In this context, it is possible to eliminate ergonomically critical tasks at workplaces, which was not previously possible, and to implement faster and more appropriately reach the return of investment.

The collaboration between the robots and the human being has been announced as promising to face the challenges in the present scenario, allowing the use of cognitive capacities of the human being, their versatility and flexibility. While robots demonstrate their excellence in performing repetitive tasks with a high degree of repetitiveness and replacing heavy and ergonomically inadequate tasks [7]. Because of this hybrid system, it is possible to achieve more reconfigurable systems which allow more agile adaptations in environments of permanent changes, as well as in the manufacture of customized products [8].

However, because it is still a recent technology, companies still need more knowledge about the applications and the potential of implementation, promoting initiatives based solely on the experience and intuition of the staff involved [9]. The objective of this work is to evaluate solutions involving the use of collaborative robots through appropriate methodology. This will be done through a case study at a smartphone manufacturing company located in Jaguariúna SP, Brazil.

A brief overview of traditional industrial robots and collaborative robots will be presented in Section 2. In Section 3, a methodology will be proposed to define the potential activities for automation that will be validated through the case study present in Section 4. Finally, the conclusions will be addressed in Section 5.

2. Overview—Industrial Robots versus Collaborative Robots

A convergence of factors has contributed to the increased use of robots in the industrial environment. Prices for hardware and software are expected to fall more than 20 percent in the next decade. At the same time, as the robot will become more accessible and easier to program, a large number of smaller companies will be able to deploy and integrate automated systems using robots in their manufacturing. Advances in vision systems, sensors, robotic grippers systems, and information technology will enable these systems to become smarter, more networked, and immensely more useful for a wide variety of applications. Because of this scenario, an exponential growth of the installed base of the robots from the current approximate 2 million units to 4 million by 2025 is expected [10].

The speed at which it will occur will depend on the industrial segments as well as the economic and social conditions of the countries. Taking into consideration the industrial segments, the automotive sector, electrical and electronic equipment and machinery in general will account for about 75%. Table 1 gives a summary of this growth observed during the period between 2014 and 2016, with emphasis on the electronics industry [11].

Countries that adopt more aggressive policies with the more intensive use of robots will realize the significant increase in productivity relative to the costs of dedicated labor as shown in Fig. 1. For South Korea, for example, a productivity increase is projected

Table 1 Number of robots sold by industry segments.

Segmento	Year			Growth (%)
	2014	2015	2016	
Automotive	94,000	98,000	103,000	9.57
Electronics	43,000	65,000	91,000	111.63
Machinery	21,000	29,000	29,000	38.10
Chemical-plastic	17,000	20,000	20,000	17.65

Source: Ref. [11].

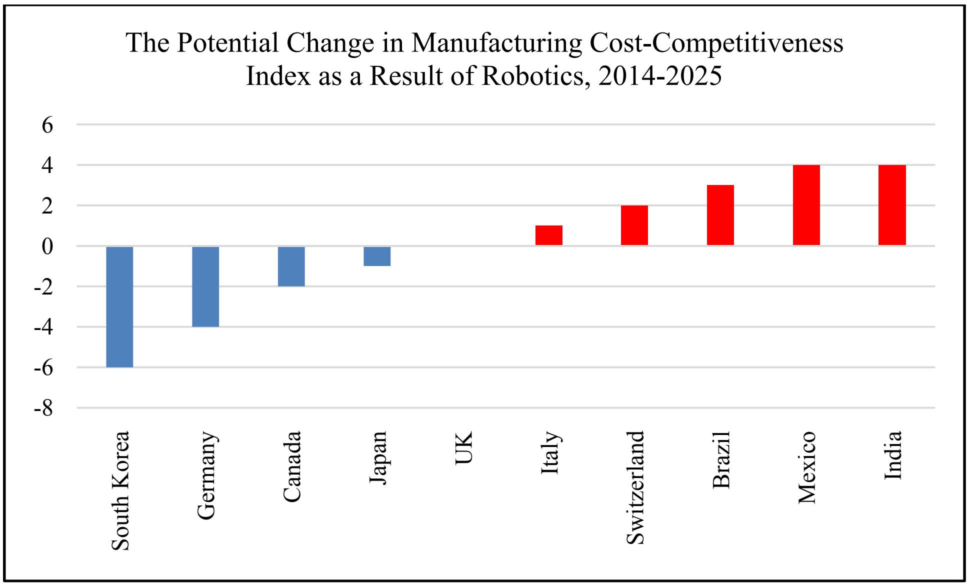

Fig. 1 Gains or losses in productivity relative to the projected US market to 2025.

Source: Ref. [10].

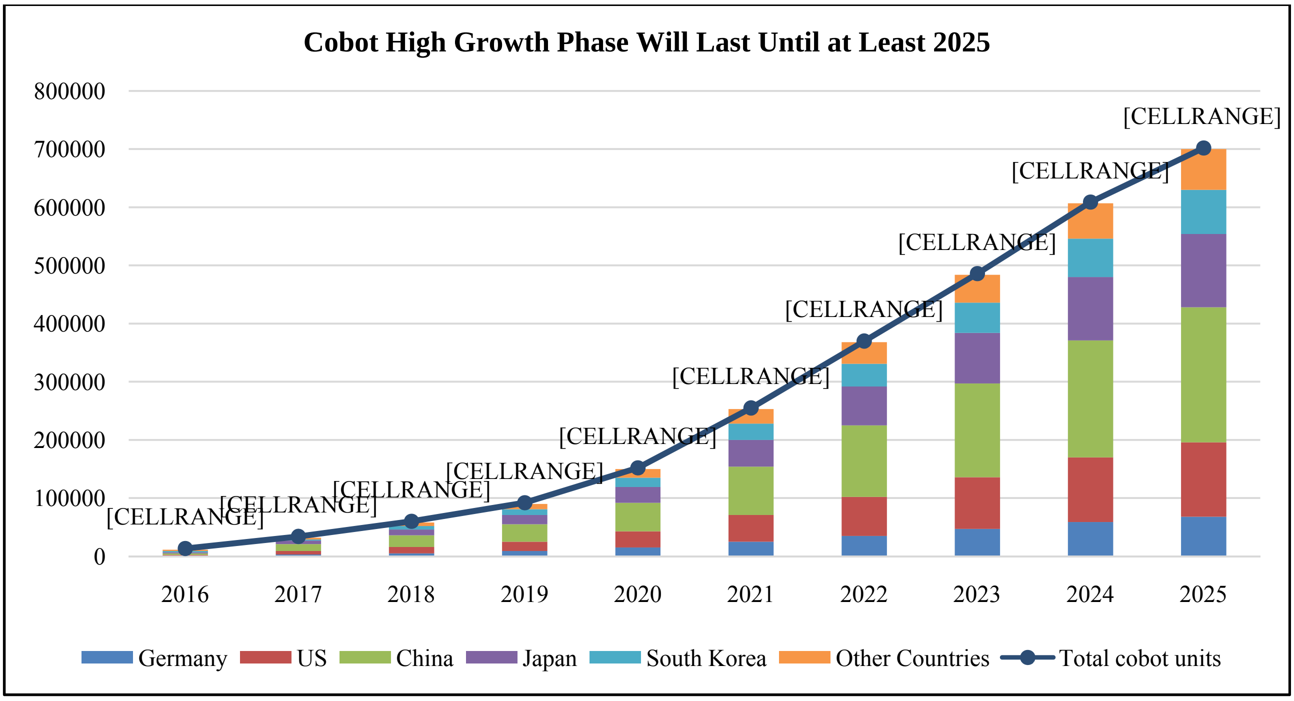

Fig. 2 Perspective of the exponential increase of production of collaborative robots.

Source: Ref. [12].

of about 6% in relation to the cost of labor based on the American market, while countries such as Brazil will have a reduction in labor productivity estimated at around 3% with a projection of 2025 [10].

Finally, the production and sales forecasts for the collaborative robots are very promising before this scenario as detailed in Fig. 2. According to surveys conducted, in the last year there were approximately 20,000 units produced with an average price around $28,000. The forecasts indicate annual reduction from 3 to 5% reaching the value of $17,000 in 2025 and an exponential increase estimated at 700,000 units [12].

3. Methodology

Many studies have been conducted in the field of industrial assemblies. Most of the work is based on fully manual or automatic processes [13]. However, it will be necessary to consider hybrid models combining manual operation with those performed by robots. The procedure adopted in this work will be specific to the process in which it will be applied and validated through the case study and has as reference the studies [14, 15]. The suggested sequence includes mapping the current process, determining the human capacity indicators in relation to the robot and determining the degree of complexity required by the automation. The following is a brief explanation of this model.

3.1 Mapping of the Current Process

The labor time for the application to be validated will be obtained through a traditional time and motion study and methods detected in practice. Subsequently, to validate the robot cycle times, practical simulations will be done in the laboratory using boundary conditions close to the manufacturing environment. For this study, activities in a packaging assembly line will be considered.

3.2 Determination of the Human Performance Indicators in Relation to the Robot

Based on Refs. [16-19], the specially developed criteria will be presented for the application to be validated. This way, for each of the activities considered in the time and motion study, the performance of the human being in relation to the robot will be evaluated. Table 2 exemplifies the criteria which will be used to evaluate the performance of the operator in relation to the robot for each of the tasks. Note, for example, that for criterion (C1) the specification (E1) recommends that activities with short and repetitive cycles (≤ 8 sec) are more appropriate to the robot and, therefore, the performance level of the human being would be 0. Likewise, criterion (C3) demonstrates that cellulosic materials typical of packaging processes (boxes, trays, cushions, etc.) are usually supplied in a flat shape and need to be molded. This shaping process requires skill and force control, being more suitable for the human being and would receive performance grade 1 for the specification (E7).

Based on Refs. [16-19] were developed the criteria that yield the correlation between human and robot performance for the presented case study.

Table 2 Criteria and specifications for measuring the degree of performance of activities.

Criterion		Specification		Weight
		E1	Better (≤ 8 sec)	0
C1	Cycle time	E2	Equal (9 and 15 sec)	0.5
		E3	Worse (> 15 sec)	1
		E4	Better (≤ 1 kg)	1
C2	Product weight	E5	Equal (1-8 kg)	0.5
		E6	Worse (> 8 kg)	0
C3	Cellulose material shape	E7	Yes	1
		E8	No	0
		E9	Better than robot	1
C4	Quality of the process	E10	Equal the robot	0.5
		E11	Worse than robot	0
		E12	Lower than 13	1
C5	*(Ergonomic evaluation)	E13	Equal to 13	0.5
		E14	Greater than 13	0

* This ergonomic evaluation was proposed by the studied company, using its own methodology, considering aspects such as lateral movements, top-down or bottom-up movements and using the hand as a tool. It is also considered the frequency in which these movements occur in each of the activities and cycle time [20].

Once the criteria have been fulfilled and their respective weights have been qualified by the responsible technical team, the operator performance indexes will be calculated for each of the criteria according to Eq. (1). When the performance index of the human being and the robot, respectively, is, $f_{O,K} = f_{R,K} = 0.5$, it would not matter which activity is used (manual or automatic). In this case, it should not be included for the calculation of the global capacity index to avoid having the result diluted [19].

The global capacity index for the human being, for each of their activities (i), would be an average of all the criteria (k) with their respective weights according to Eq. (2). For the robot the global index will be calculated according to Eq. (3) [19]:

$$f_{pO,ke} = p_k f_{O,ke} \qquad \epsilon\{0; \dots; 1\} \tag{1}$$

$$C_{O,i} = \frac{\sum f_{pO,ke}}{k} \qquad \epsilon\{0; \dots; 1\} \tag{2}$$

$$C_{R,i} = \frac{\sum f_{pR,ke}}{k} = 1 - C_{O,i} \qquad \epsilon\{0; \dots; 1\} \tag{3}$$

3.3 Determination of the Degree of Complexity Required by Automation

Likewise, for each of the activities, criteria and specifications were developed to assess the degree of complexity for the introduction of automation, as suggested in Table 3.

In an analogous way, Eqs. (1)-(3) will have the capacity indexes computed for simple tasks to be automated $C_{AS,i}$ and the complex $C_{AC,i}$ according to Eqs. (4)-(6), [19].

$$f_{pAS,ke} = p_k f_{AS,ke} \qquad \epsilon\{0; \dots; 1) \tag{4}$$

$$C_{AS,i} = \frac{\sum f_{pAS,ke}}{k} \qquad \epsilon\{0; \dots; 1\} \tag{5}$$

$$C_{AC,i} = \frac{\sum f_{pAC,ke}}{k} = 1 - C_{AS,i} \qquad \epsilon\{0; \dots; 1\} \tag{6}$$

Once the calculations of the indicators are finalized, a summary table will allow selecting the activities with the highest potentials to be automated, lower values of $C_{O,i}$ at the same time correlating with simpler activities to be automated, smaller values of $C_{AS,i}$ (ideal scenario).

4. Case Study—Validation

To exercise the proposed methodology two stations in sequence of a packaging assembly line will be considered. The individual activities within the stations are sequential, dependent and performed by a single operator. Table 4 summarizes the activities and respective cycle times obtained in the manufacturing process.

Once the mapping of the activities was accomplished, the next step was to attribute to each of the activities the weight of each of the criteria defined specifically for the packaging process according to Table 1. Then, the performance indexes were calculated to the human being and the robot according to Eqs. (2) and (3). Similarly, the complexity indexes for automation were calculated considering Table 2 and Eqs. (5) and (6). The summarized results are shown in Table 5.

Table 3 Evaluation of the degree of complexity for task automation.

Criterion		Specification			Weight
CA1	Strength control process?	EA1	No	Easy	0
		EA2	Yes	Hard	1
CA2	Pieces in different shapes?	EA3	No	Easy	0
		EA4	Yes	Hard	1
CA3	Parts mechanically indexed?	EA5	Yes	Easy	0
		EA6	No	Hard	1
CA4	Same sequence and cycle time?	EA7	Yes	Easy	0
		EA8	No	Hard	1
CA5	Required integration with other systems?	EA9	No	Easy	0
		EA10	Yes	Hard	1

Table 4 Summary table of the activities in the assembly stations.

#	Activities	CT (sec)	Station	Total time (s)
A1	Unload full box, load an empty one	9.83		
A2	Stick traceability tag on the box	6.10		
A3	Visual inspections of unit boxes	7.80	1	$\sum_{1}^{5} = 37.87$
A4	Send the full box to the next station	2.12		
A5	Assemble the empty box	12.01		
A6	Scan the box label and each unit	20.63		
A7	Box close and dispose to sealer	5.95		
A8	Pick from sealer and put in line	7.00	2	$\sum_{6}^{10} = 47.93$
A9	Fold and insert cushion 1 in box	7.18		
A10	Fold and insert cushion 2 in box	7.18		

* It is necessary to work less than 55 sec in order to achieve the takt time.

Table 5 Performance indicators versus automation complexity.

Activities	$C_{O,i}$	$C_{R,i}$	$C_{AS,i}$	$C_{AC,i}$
A_1	1.00	0.00	0.2	0.8
A_2	0.40	0.60	0.6	0.4
A_3	0.50	0.50	0.4	0.6
A_4	0.67	0.33	0.0	1.0
A_5	0.60	0.40	0.2	0.8
A_6	0.25*	0.75	0.4*	0.6
A_7	0.50	0.50	0.4	0.6
A_8	0.00*	1.00	0.0*	1.0
A_9	0.60	0.40	0.6	0.4
A_{10}	0.60	0.40	0.6	0.4

* The highest potential to be automated.

To better understand the activities with higher potential for automation, it is necessary to draw a correlation graph $C_{O,i}$ versus $C_{AS,i}$. This scenario will be ideal when both tend to zero. As can be seen in the graph of Fig. 3, the activities A_6 and A_8 represent the highest potential to be automated. A_2, A_3, A_5, A_7, A_9 and A_{10} show some balance suggesting that they can be hybrid, i.e. manual or automatic. Finally, A_1 and A_4 are activities which tend to remain as manual.

Considering the potential of the activities, the sequence of the process with its precedence relations and the balance of the activities, it was possible to consider activities A_6, A_7 and A_8 for the robot station. Fig. 4 shows details of the robotic gripper designed to perform these operations. The gripper consists of a vacuum-driven scanning system and suction cups necessary to carry out the movement, loading and unloading the boxes. This project considered the universal type, that is, capable of attending any type of product without the need of a setup.

In order to have the three activities transferred to the robot, a readjustment of the production arrangement was necessary. First, the robot capacity in terms of reach was analyzed, load in (kg) and precision to perform the three activities proposed in Fig. 3. Then, a virtual robotic simulation was performed to guarantee the attendance to the time for meeting the demand of the process. Finally, station 1 (manual) was balanced again with the inclusion of new activities and revision of some elements of time elapsed from the readjustment of the layout. Table 6 shows in detail the new configuration of the proposed activities followed by the respective time elements which were properly validated. As can be seen in Table 6, the proposed new balancing met the need for the process provided in 55 seconds.

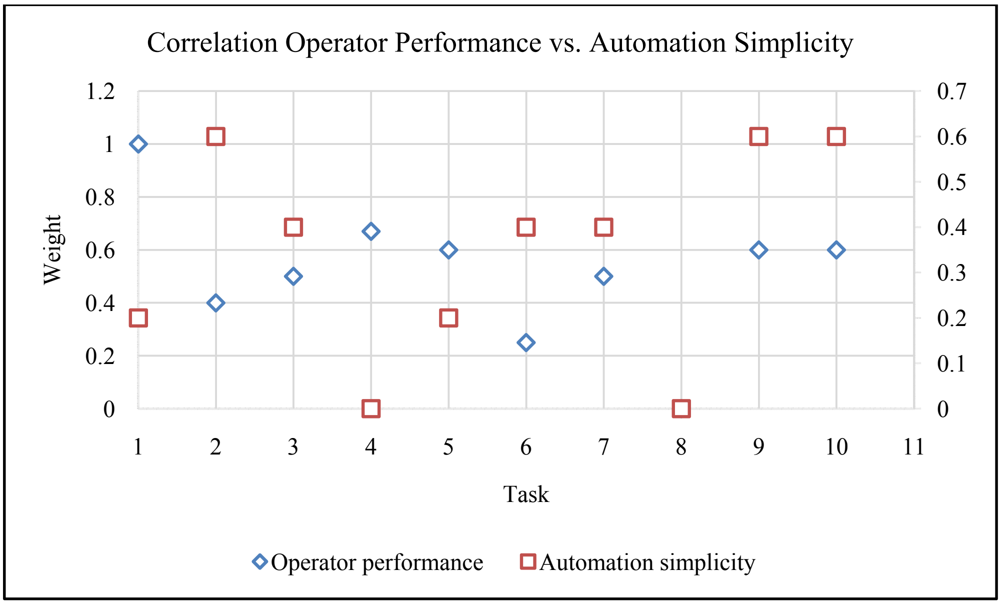

Fig. 3 Correlation between operator performance and automation simplicity.

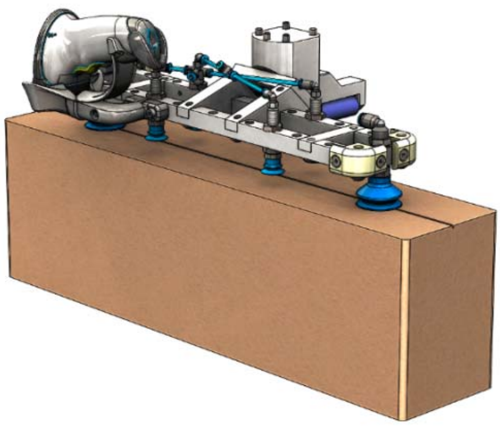

Fig. 4 Representation of the robotic gripper.

Table 6 Balancing of stations (St) activities and new cycle times after automation.

#	Activities	CT (seg)	Station	Total time (s)
A1	Unload a full box and load an empty one	8.50		
A2	Stick traceability tag on the box	6.10		
A3	Visual inspections of unit boxes	7.80		
A4	Send the full box to the next station	1.50	Manual	$\sum_{1-5}^{9-10} = 44.91$
A5	Assemble the empty box	9.00		
A9	Fold and insert the cellulosic cushion 1 into the carton	6.00		
A10	Fold and insert the cellulosic cushion 2 into the carton	6.00		
A6	Scan the box label and individual units	15.00 (r)		
A7	Close the box and dispose it to the sealer	5.95 (m)	Hybrid	$\sum_{6}^{8} = 40.95$
A8	Remove from the sealer and dispense to the conveyor	20.00 (r)		

* It is necessary to work less than 55 seconds in order to achieve the takt time. (r) = robot, (m) = manual.

Fig. 5 Sequence of robot activities: scan, dispose in the sealing machine, remove and stack.

5. Final Considerations

The electronics industry still uses a large part of its labor-intensive processes and represents great potential for the use of automation despite the challenging scenario (very rapid changes and complex operations).

The prospects of the production volumes of robots are very promising, which will allow the reduction of costs and more intense use in the industrial sector. This speed will depend on the type of industry, trade barriers and the cost of labor in different countries. However, productivity gains in the adoption of advanced robotics are undeniable.

The methodology presented, when considering two sequential stations of manual activities, allows greater freedom to choose the activities which will be automated, considering the human performance potential and the complexity degree of automation.

As a practical result of this methodology it is possible to raise the level of productivity and quality, transferring to the robot activities which are non-ergonomic and require more repetitiveness. At the same time, the activities transferred to the robot are not specific and complex, which translates into shorter development and implementation times and future opportunities in its reconfiguration for new products and processes. In this study, it was restricted to evaluate only one study of the packaging process. Therefore, the criteria defined for the assessment of both the operator performance and the automation complexity were defined and evaluated for this specific process. As proposals for future work it is suggested:

- Applying this methodology to other processes and establishing a comparative study;
- Establishing a study of safety standards involving collaborative robotics;
- Considering also automation of complex tasks;
- Evaluating situations where there is possibility of time elements that involve the displacement of the robot in autonomous vehicles.

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