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Analysis of the Alternative Robotic Palletizing Processes in the Aspect of Electric Energy Consumption

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Abstract: Modern implementations of industrial robots require the use of extensive knowledge and novel concepts. To bring real benefits, robotized processes must be analysed in detail. This paper presents a preliminary study on the analysis of electric energy consumption of an industrial robot in the alternative palletization processes. Firstly, the robotization of manufacturing processes aspect was discussed and advantages of the robotic palletizing process were presented. Secondly, the utilized off-line robot programming environment and a model of the robotic workstation used during the study were described. Conducting analyses based on the alternative arrangement of elements in a pallet layer allowed discussion and the formulation of important conclusions. The research has confirmed the validity of detailed analysis of robotic production processes.

Keywords: Industrial Robot, Palletizing, Off-Line Programming, Electric Energy Consumption

1. Introduction

Large-scale robotization of modern manufacturing processes has become a reality. Today, industrial robots are used not only in factories of large corporations, but more and more often when supporting manufacturing processes in small and medium-sized enterprises [1]. The area of industrial robots utilization in manufacturing processes is very wide [2]. Just like in the case of overall production processes, robotic processes require careful analysis, in order to ensure efficiency and real benefits [3]. The effective use of production robots requires, in fact, proper definition of the robot's work parameters, selection of the equipment used or programming of the robot's paths and work. The appropriate planning of the work to be conducted by the robot allows for a substantial improvement of the real processes [4,5]. In the case of production practice, this problem is usually underestimated and robots are programmed on the basis of the integrator's intuition. The implementation of robots is analysed in terms of their impact on the overall processes [6,7], serialization of robot tasks for specific jobs [8,9], precise determination of robot paths [10,11], or electricity consumption [12,13]. Upon analysing the literature in the above-mentioned areas, it can be observed that the number of publications in recent years increased significantly. This proves the relevance of the issues raised, as well as the timeliness of research in this area [14].

One of the numerous and popular implementations of industrial robots is palletizing process (Figure 1). Consequently, the process is the subject of numerous research and analysis [15,16]. The main benefits of robots utilization in this type of process are [17]:

– *increase of the process speed,*
– *decrease the risk of workers' injuries,*

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- *robot's high payload capacity,*
- *constant time of tasks,*
- *repeatability of pallets quality.*

Figure 1: An example of robotic palletizing workstation [17].

The process of palletizing occurs often at the end of the production line, and is a critical part of the delivery of products to potential customers. It is therefore important to analyse the process in detail in terms of the range of motions and robot paths, effective and auxiliary movements, as well as other aspects of robot use [17]. Improper organization of the robotic palletizing workstation may cause that the last phase of the process, which is palletizing, be a bottleneck in the manufacturing system. Electricity consumption is also an important aspect of palletizing robots utilization, as it is one of the elements that affect the profitability of production. Indeed, the rational use of electricity is one of the key issues in the modern world [18].

In order to indicate the need for insightful planning of industrial robots works (taking into account aspects of electricity consumption), a relevant model of the analysed workstation was developed in an off-line robot programming environment. The utilized tools allowed to conduct research on the considered issue.

2. Experimental Section

2.1. Developed model of robotic packing workstation

Due to the use of a Kawasaki robot in the process under consideration, the K-ROSET environment was used as OLP software to simulate the robot's motion trajectory, analyse cycle times, search for potential collisions and determine robot's electricity consumption. The robot is programmed in the AS language, which is implemented in the form of a set of motion commands, signal handling, gripper control, etc. An emulator of the robot controller has been used in the application, which allows for practically 100% consistency of results. That fact support accurate analysis of complex production tasks [19].

In order to realize the established research, a model of a robotic palletizing station was developed (Figure 2), the main component of which was a Kawasaki ZX165U-B501 industrial robot. The given robot model was selected mainly because of its wide motion range. The robot's specification is shown in Table 1. The robot tool was a vacuum gripper available in the libraries of the off-line robot programming environment used. The gripper was selected so that its working surface corresponds as much as possible with the surface of palletized packages. Additional components of the station included a pallet on which the elements are placed, a conveyor belt from which the elements are received, and palletized boxes (which represents the element being transported).

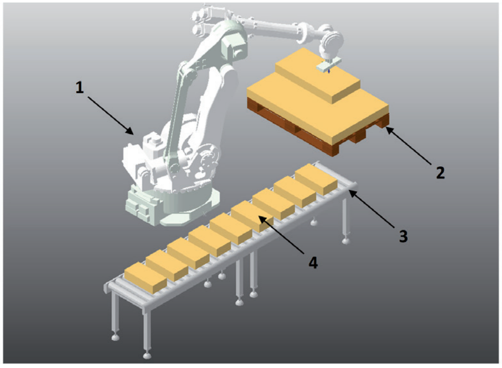

Figure 2: Model of palletizing workstation developed in the K-ROSET software: 1 – industrial robot, 2 – pallet, 3 – conveyor belt, 4 – palletized boxes.

Table 1: Utilized industrial robot specification [20].

Robot specifications	
Parameter	Value
Model:	ZX165U-B501
Type:	articulated robot
Type of tool:	vacuum gripper
Maximum load:	165 kg
Degree of freedom:	6 axes
Repeatability:	±0.03 mm
Maximum speed:	2500 mm/s
Horizontal reach:	2651 mm
Vertical reach:	3415 mm
Driving motor:	brushless AC servo motor
Programming:	AS language (teach/repeat mode)
Power requirements:	200 ÷ 240 V

2.2. Assumptions and conditions of conducted analysis

The analysed process concerned the robotic palletization of cardboard boxes with dimensions of 400 × 200 × 100 mm placed on a standard pallet with dimensions of 1200 × 800 mm. In order to real production conditions and analyse alternative scenarios of robot's movement – it was assumed that the robot place 5 layers of packages on a pallet, while packages can be arranged in three different configurations (Figure 3):

1. *Arranging packages according to the layout 1.*
2. *Arranging packages according to the layout 2.*
3. *Arranging packages according to the layout 3.*

The order of placing boxes on the pallet layer was presented in the Figure 3 by means of appropriate box numbers. In each of the configurations, boxes were stacked to avoid collisions with items previously stacked on a pallet.

During the development of the robot program, both motion instructions and gripper instructions were used. The commands contained in the robot program included movements with joint and linear interpolation. The robot's operation was simulated with the speed set to 80%. Due to the complexity of the robot program and the significant number of robot instructions a suitable script was developed in the Matlab environment (Figure 4).

```
% LAYER 2
    trans = 100;
    dist = 200;
    fprintf(';--- LAYER: 2 ---\n')

    for j = 1:12
    fprintf('JAPPRO #TP_T,%g\n',100)
    fprintf('CLAMP 1\n')
    fprintf('LMOVE #TP_T\n')
    fprintf('JAPPRO #TP_T,%g\n',100)

    fprintf('JAPPRO #TP%g,%g\n',j,dist)
    fprintf('LAPPRO #TP%g,%g\n',j,trans)
    fprintf('CLAMP -1\n')
    fprintf('JAPPRO #TP%g,%g\n',j,dist)
    end
```

Figure 4: The code snippet taken from script utilized in the process of robot program generation.

In order to estimate the robot's electricity consumption, the "Power Consumption" plug-in was used (Figure 5). Mentioned module allows analysing energy aspects, such as determining the average current for each axis of the robot during the execution of instructions included in the program and determine total electric energy consumption in a given process. In turn, to analyse the times of individual movements of the robot, a module named "Cycle Time" was utilized. The aspect of gripper operation and the effect of peripheral devices was not taken into account according of utilized software limitations.

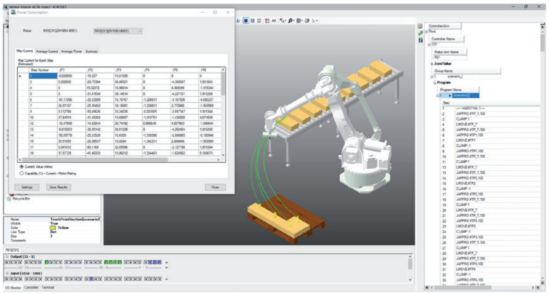

Figure 5: Analysis of electric energy consumption during robot simulation.

By means of the presented tools and based on the assumptions made appropriate research were conducted.

The following parameters were analysed:

– pts_{Li} – *sum of the robot's supporting movements times during placing boxes on a single layer in a given configuration (i – represents layer number),*

– pte_{Li} – *sum of the robot's effective movements times during placing boxes on a single layer in a given configuration (i – represents layer number),*

– $pt_{Li} = (pts_{Li} + pte_{Li})$ – *sum of the robot's movements times during placing boxes on a single layer in a given configuration (i – represents*

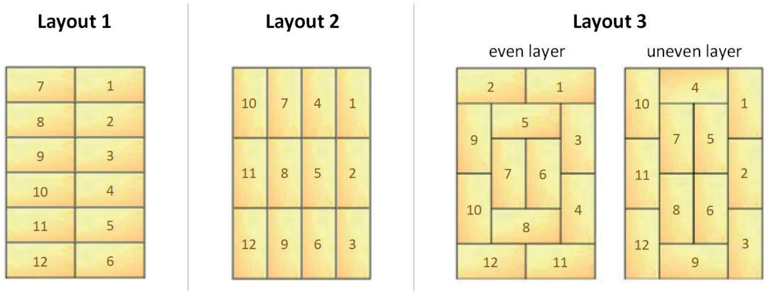

Figure 3: Arrangement of boxes on a layer – the numbers represent the order of placing boxes on the pallet layer (own study based on [21]).

layer number),

– *Σpts_{Li}, Σpte_{Li}, Σpt_{Li} – total times of concerned movements of the robot,*

– *ct_j – total operating time of robot's gripper (j – represents pallet configuration number),*

– *EC_{TOTALj} – robot's total electric energy consumption (j – represents pallet configuration number).*

3. Results and Discussion

The conducted studies were aimed at determining the times of individual movements of the robot and determining the electric energy consumption of the robot – both during the placement of a single layer and the whole pallet. The results of the carried analyses are summarized in Table 2.

Analyzing the results, it should be noted that the values of supporting and effective movement times were similar for each layer in each configuration (Figure 6). As a consequence, the time required to complete one layer of the pallet averaged 56.92 [s]. The shortest time to complete a whole pallet was characterized by configuration 1 (layout 1), and the difference between the configuration with the longest pallet loading time (configuration 3 – layout 3) was insignificant and amounted to 0.23 [s].

In turn, analysing the operating time of the robot vacuum gripper, it should be noted that the times for each configuration are similar (Figure 7). The gripper was active the longest when stacking packages in configuration 1, and the difference between configuration 2 was only 1.14 [s]. However, saving each second for successive pallets will result in savings in the consumption of compressed air. This fact, in turn, will translate into robot's operating costs.

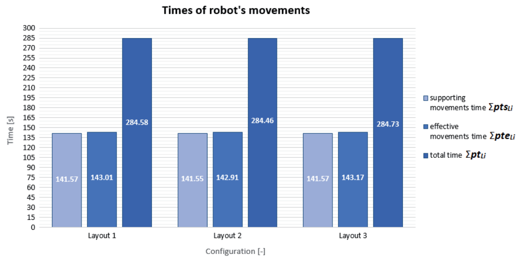

Figure 6: Times of robot's movement.

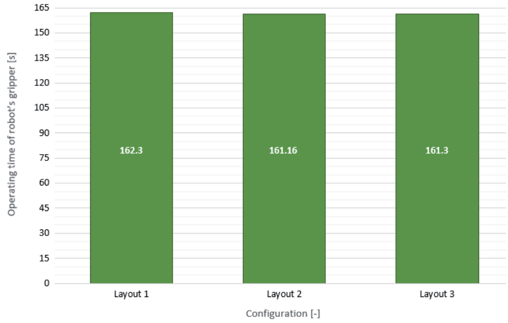

Figure 7: Total operating time of robot's gripper.

Table 2: Results of the conducted analyses.

Configuration (j)	*Layer number (i) [–]*	*Single layer*			*Pallet*				
		pts_{Li} [s]	*pte_{Li} [s]*	*pt_{Li} [s]*	*Σpts_L [s]*	*Σpte_{Li} [s]*	*Σpt_{Li} [s]*	*ct_j [s]*	*EC_{TOTALj} [Wh]*
1	1	27.54	28.86	56.40	141.57	143.01	**284.58**	162.30	**161.55**
	2	28.54	28.74	57.28					
	3	28.54	28.58	57.12					
	4	28.54	28.42	56.96					
	5	28.40	28.42	56.81					
2	1	27.54	28.86	56.40	141.55	142.91	**284.46**	161.16	**173.52**
	2	28.61	28.70	57.31					
	3	28.58	28.51	57.09					
	4	28.42	28.48	56.90					
	5	28.41	28.35	56.76					
3	1	27.58	28.83	56.42	141.55	143.17	**284.73**	161.30	**169.88**
	2	28.67	28.70	57.38					
	3	28.45	28.61	57.06					
	4	28.42	28.58	56.99					
	5	28.45	28.45	56.89					

Analysing the results, it should be noted that the alternative order of elements palletizing results in a variety of energy consumption values (Figure 8). Moreover, a slight difference between the values for the loading time of whole pallet does not mean the same results in terms of electricity consumption. This is because the research showed that the most favourable configuration in terms of the execution time of the pallet loading is characterized by the least favourable electric energy consumption. Consequently, the difference between the most and least favourable configuration was as much as 11.97 [Wh]. This difference becomes significant in the case of loading more pallets (it will steadily increase). For example – with the number of 10 pallets reaching 119.7 [Wh] and with the number of 100 pallets, as much as 1197 [Wh].

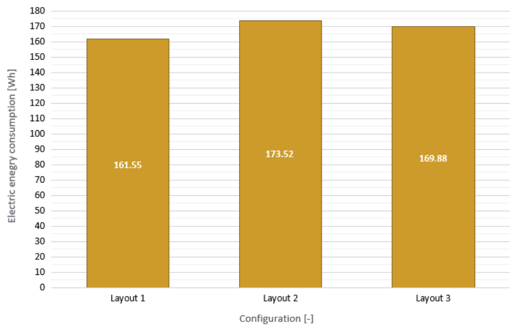

Figure 8: Electric energy consumption of the robot.

Summarizing the study, it should be noted that the shortest pallet loading time is not equivalent to the lowest electric energy consumption. This fact is probably due to the range of movements of the robot in configuration 2. During the simulation of the robot's operation, it was possible to observe a significant movement of the axis 6 of the robot (on which the gripper is installed). This movement was related to the need for proper orientation of boxes on the pallet. Therefore, in order to optimize the presented problem, it would be necessary to analyse in detail the ranges of motion of individual axes of the robot and minimize their angular displacement.

4. Conclusions

The increasingly widespread use of industrial robots for a variety of manufacturing processes has become a reality. Nowadays, it is not enough just to implement a robot. Each of the robotized processes requires extensive knowledge and the implementation of many analyses. This publication analyses the electric energy consumption of an industrial robot in the palletizing process. The conducted research has proven the validity of careful analysis and planning of robotic processes. Indeed, proper planning of the robot's movement can bring many benefits – both for a given process and for the production processes as a whole. The research presented in the paper should be continued, and should include issues of in-depth analysis of the process under consideration, minimizing the movements of the robot's joints and carrying out its optimization using elements of multi-criteria analysis.

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