PRZEGLĄD ELEKTROTECHNICZNY

Ukazuje się od 1919 roku **12'2024**

Organ Stowarzyszenia Elektryków Polskich • Wydawnictwo SIGMA-NOT Sp. z o.o.

1. Paweł STRĄCZYŃSKI, 2. Łukasz GRUSZKA 3. Robert KAZAŁA, 4. Tomasz GRZMIL

Kielce University of Technology (1) (3), Warsaw University of Technology (2)
SORTER Michał Ziomek Spółka Jawna (4)
ORCID: 1: 0000-0002-9116-0266, 2: 0000-0002-1597-927X, 3: 0000-0002-3859-7274

doi:10.15199/48.2024.12.01

Energy consumption analysis for a 6-axis industrial robot in the packing process

***Abstract**. Electrically powered handling robots are increasingly used in packaging systems. One of the ways to improve the energy efficiency of such systems is to use the trajectory of robots movement determined taking into account energy consumption. The article presents an analysis of the influence of the position of the robot base on electricity consumption for a 6-axis robot used in the packaging process. The research was carried out on a real object. The research took into account the energy consumption of individual robot joints, taking into account the current limitations resulting from the applied drive control algorithm. The presented results and the analysis carried out allow for the planning of movement trajectories allowing for the reduction of energy consumption in robotic systems.*

Streszczenie.** W systemach pakowania coraz częściej stosuje się roboty manipulacyjne zasilane elektrycznie. Jednym ze sposobów poprawy efektywności energetycznej tego typu systemów jest wykorzystanie trajektorii ruchu robotów wyznaczonej z uwzględnieniem zużycia energii. W artykule przedstawiono analizę wpływu położenia podstawy robota na zużycie energii elektrycznej dla 6-osiowego robota wykorzystywanego w procesie pakowania. Badania przeprowadzono na obiekcie rzeczywistym. W badaniach uwzględniono zużycie energii poszczególnych przegubów robota z uwzględnieniem aktualnych ograniczeń wynikających z zastosowanego algorytmu sterowania napędem. Przedstawione wyniki oraz przeprowadzona analiza pozwalające na planowanie trajektorii ruchu pozwalających na zmniejszenie zużycia energii w systemach zrobotyzowanych.* ***(Analiza zużycia energii dla 6-osiowego robota przemysłowego w procesie pakowania)

Keywords: : industrial robot, energy consumption, robot path planning
Słowa kluczowe: robot przemysłowy, zużycie energii, planowanie ścieżki robota

Introduction

The number of industrial robots in production plants is constantly growing [1]. Robot manufacturers are faced with newer and newer challenges. Robotization of the industry should not only increase the efficiency of production, but also reduce production costs. An important issue, especially where industrial robots perform a large part of the work during the production of the product, is to limit energy consumption [2, 3]. The task of the robot is therefore not only to perform the given work within a specified time, but to do it in an optimal way from an energetic point of view [4, 5, 6, 7, 8, 9]. Analysis of electricity consumption for different types of movements allows to estimate the scale of the problem. The key influence will have such factors as:

- dynamic parameters of movement,
- path planning,
- energy recovery.

While energy recovery is not exclusively related to the construction of the power supply system, the already planned path of the gripper end or the generated trajectory of movement of the robot joints can be optimized in terms of minimizing energy consumption in a way that often does not require hardware interference for already existing solutions.

The aim of the study is to analyze the potential Energy benefits of modifying the geometric path for the gripper tip in the considered packaging process.

Optimization of the energy consumption of an industrial robot in the analyzed process is a very complex problem and in simple terms it will come down to setting the extreme (minimum) for the target function dependent on three factors:

- speed (movement dynamics),
- acceleration (movement dynamics),
- displacement (path of movement).

Due to the complexity of the kinematic chain of the 6-axis manipulator, parameter relationships for individual joints are very important. The research can be divided into two stages:

- study of the impact of dynamic parameters on energy consumption - clearly established trajectory and variable dynamics of movement,

(1) $$E=min\left(v_1(s), \dots, v_6(s), a_1(s), \dots, a_6(s) \right),$$

- examining the impact of path optimisation - constant dynamic parameters and different paths of access to a specific position.

(2) $$E=min\left(v_1(s), \dots, v_6(s) \right).$$

taking into account the current limitation:

(3) $$\left[i_1, i_2, i_3, i_4, i_5, i_6\right] \le \left[I_{n1}+I_{n2}+I_{n3}+I_{n4}+I_{n5}+I_{n6}\right].$$

The study presents the impact of path optimization on energy consumption.

With knowledge from the study, the robot programmer can more effectively plan the movements of the gripper tip between the points of work. The analysis of the results can also be used for further research related to the preparation of trajectory generator algorithms in terms of minimizing energy consumption.

Presentation of the analyzed packaging process

When undertaking the task of finding the optimal movement of the robot based on any quality criterion, it is necessary to take into account the limitations imposed by

the process in which the robot performs the work. Understanding the automated process is extremely important to ensure adequate efficiency. The packaging process is a typical example of a pick&place task. This type of task is to move the item from the pick-up point to the point of deposition. Characteristically, the passage between points 1 and 2 and 4 and 5 (Fig. 1) follows a straight path - removing / inserting the product into the box.
In the case of the packaging process, the main constraints for a given task are:

- maximum permissible cycle time,
- maximum speed in individual robot movements (in the sections carried out in the task space, this speed is determined by the speed of the TCP point, in the movements carried out in the joint space, the maximum speed is relative to the speed of individual axes),
- limitations of working space related to the presence of other machines and devices in the working field of the manipulator.

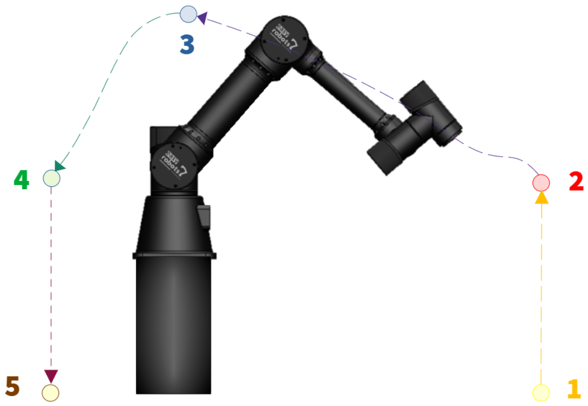

Fig.1 Robot trajectory in a pick & place process: 1) product collection point, 2) above the pickup point, 3) intermediate point, 3) above the put-away point, 4) product put-away point

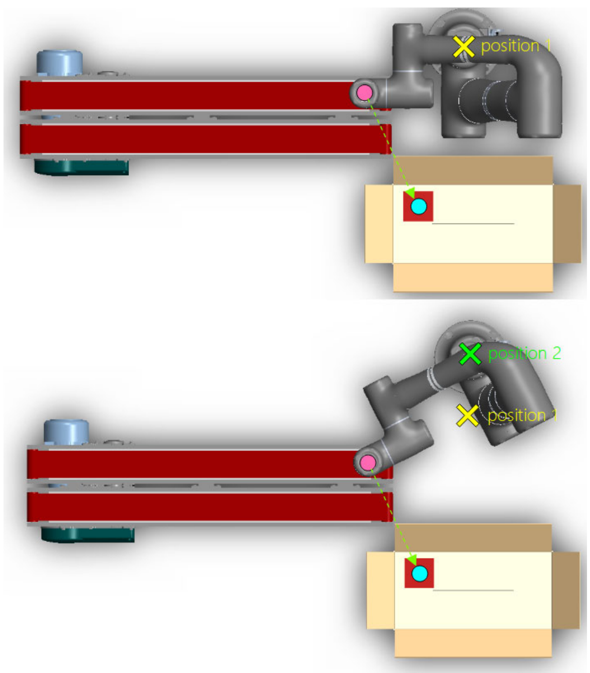

Fig.2 Example positions of the robot base

Knowing the cycle time, it is necessary to choose the dynamic parameters of the movement so that the task is completed before or at the set time. Information on the permitted working area will allow the required restrictions to be imposed on the trajectory generator so that the paths of the gripper tip are planned in an obstacle-free space. An additional parameter that can be taken into account is the position of the robot's base and analysis of the influence of the position on the trajectory of movement and energy consumption. Examples of the robot base positions are shown in in Figure 2.

Parameters and limitations resulting from the use of a real robotic arm

Additional limitations of kinematics and motion dynamics are imposed by the use of a real robotic arm. The dynamics here will be limited by the inertia of individual joints and the current efficiency of servo drives. The ES5 robotic arm has a drive system that includes six miControl servo drivers, respectively E55 for 1-3 joints and E65 for 4-6 joints. Selected parameters of servo drivers are presented in Table 1, while the parameters of the servo power supply are shown in Table 2.

Table 1. Selected parameters of servodrivers

Servodriver	Parameters		
	Up	Max out. curr.	Cont. out. curr.
miControl E55	9-60V	50A	9A (@U_p=60V)
miControl E65	9-60V	15A	4.3A (@U_p=48V)

Table 2. Selected parameters of robot power supply

Power supply	Parameters		
	DC volt.	Curr. range	Over volt. protect.
RSP-3000-48	48V	62.5A	57.6-67.2V

Current limitations are:

(4) $$[i_1, i_2, i_3, i_4, i_5, i_6] \leq [50, 50, 50, 15, 15, 15]\,A$$

(5) $$\sum_{n=1}^{6} i_n \leq 62.5A$$

Measuring station and measurement method

Experimental research was carried out on the test bench shown in the Figure 3. Diagram showing the arrangement of connections of individual robot joints and measurement system is shown in Figure 4.

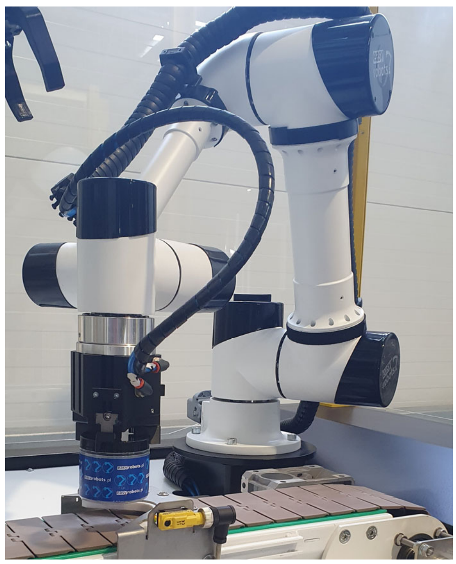

Fig.3 View of the test bench

The robot is equipped with a pneumatic two-finger gripper. Using a gripper, he takes the product from the feeder and then puts it in the box. Measurements of values such as: supply voltage, current, set position and current position for individual drives were read directly from the servo drivers of the robot. For this purpose, a special program has been developed that logs data at a frequency of 50Hz. The data is transmitted synchronously to the robot control computer using the EtherCAT network and saved on the hard disk.

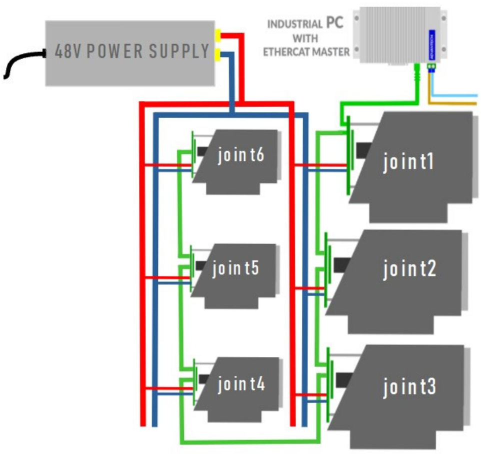

Fig.4 Arrangement of connections of individual robot joints

Study of the influence of the motion path on energy consumption

In order to assess the impact of the trajectory on energy consumption, a particle swarm algorithm (PSO) was used to determine the optimal trajectory to minimize energy consumption. This algorithm is inspired by the behavior of animal populations (flocks of birds). Each individual of the population (a particle of the swarm) has its own position, speed and direction in which it moves. In subsequent iterations of the algorithm, each particle remembers its best solution (local) and the best solution for the entire swarm (global). The task of optimization was to find the optimal position of the robot (its base) in relation to the place of collection and deposition of the workpiece to minimize energy consumption estimated based on the robot dynamics model.

The angular position and speed of individual robot joints measured on the motor of each axis for 8 example trajectories carried out on paths designated for different location of the robot base relative to the defined pick & place task are presented in the figure 5 and 6.

In order to perform the analysis of energy consumption using the optimal position of the robot (and therefore the optimal path), a total energy consumption was determined:

(5) $$E=\int_{0}^{t_k} u(t)\cdot i(t)$$

The changes in the power of individual joints during the robot's movement are presented in Figure 7.

On the graphs, the trajectory for which energy consumption was the lowest is marked in green, and the trajectory for which energy consumption was the highest is marked in blue. Based on the measurement data, the energy consumption for the robot's test duty cycles was determined. The results are presented in the Table 3.

Table 3. Energy consumption for the analyzed robot motion paths

Path	Energy/1000 cycles
Lowest energy consumption	22,67Wh
Highest energy consumption	47,35Wh
Average energy consumption	36,89Wh

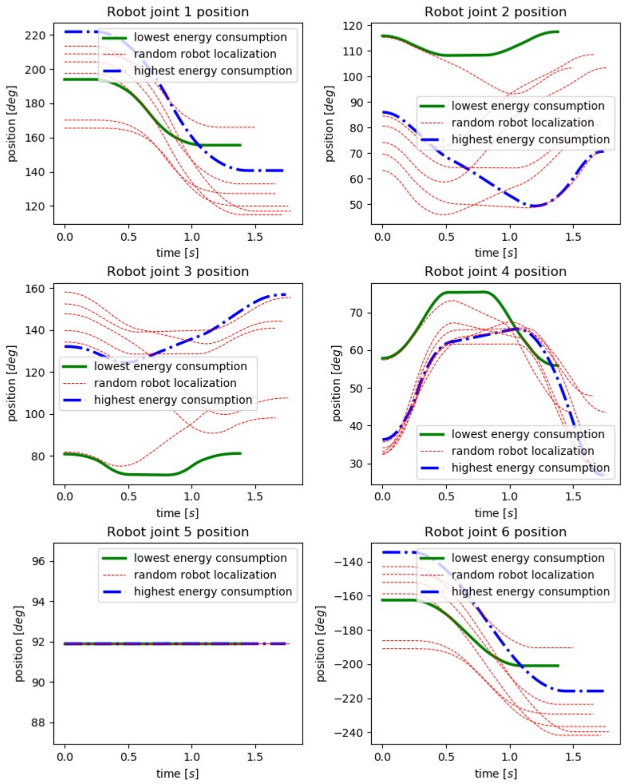

Fig.5 Position waveforms for individual robot joints

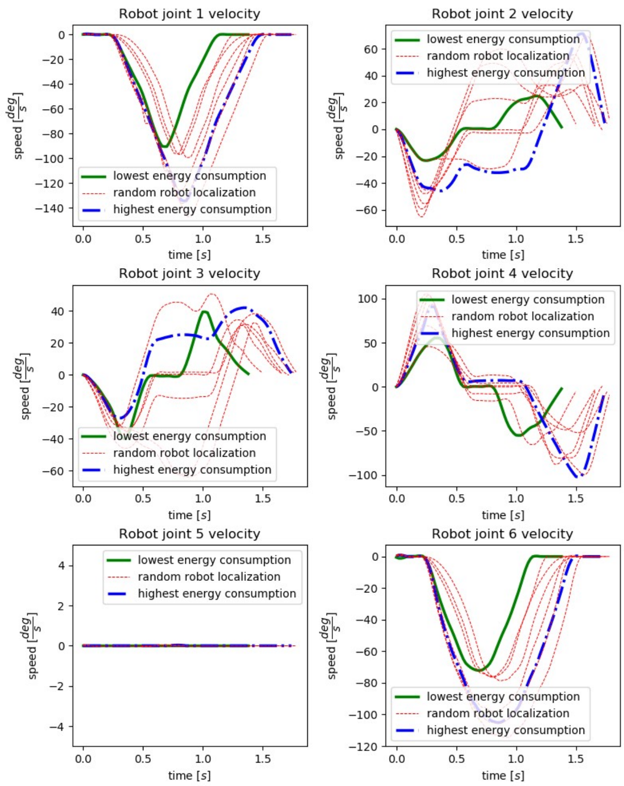

Fig.6 Velocity waveforms for individual robot joints

Based on the analysis of the force moment graph determined using the dynamics model, it could be concluded that the value of the moment of force for the second and third axes, carrying almost the entire mass of the robot, will be of fundamental importance for the energy expenditure in the trajectory. Interestingly, in the case of the task under study, exactly the opposite relationship was observed.

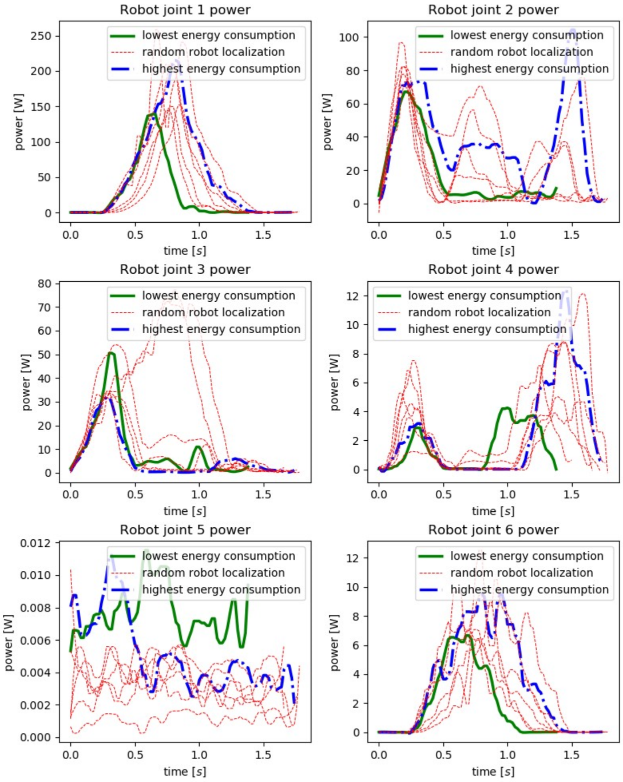

Fig.7 Power waveforms for individual robot joints

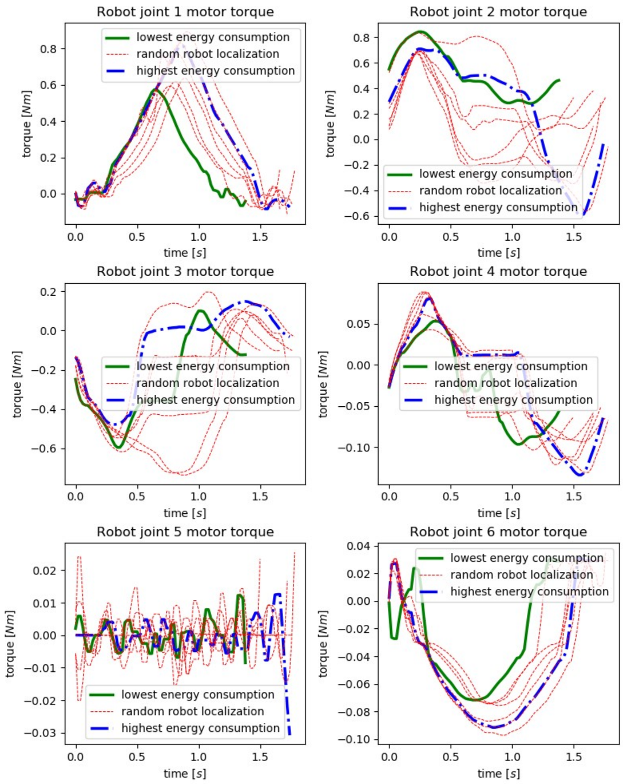

Fig.8 Torque waveforms for individual robot joints

The waveforms of the moments in the trajectory indicated as optimal in terms of energy consumption reach the highest values (Fig. 8), which is transferred proportionally to the current consumed by the drives. However, in trajectories close to the base of the robot (low torque on 2 and 3 axes), the required drive axes (especially 1, 2 and 3) have a longer distance to cover (Fig. 5) to perform the same task. As a result, a higher speed is also achieved on them (Fig.6), which translates proportionally into the voltage generated on the motor. An additional effect of a shorter angular path for the robot axis in the trajectory indicated as energy optimal is a shorter duration of movement. The energy consumption calculated from the measured current and voltage waveforms for the trajectories to be tested is shown in the table 3. The analysis of the presented data shows that the choice of the optimal location of the robot can reduce energy consumption by up to 52.1% and by an average of 38.6%.

Conclusions

In research work on optimizing the energy consumption of industrial robots, the trajectory for a given position of the robot is optimized. The approach presented in the work also takes into account the change of the robot assembly point. Based on the results obtained, it can be concluded that the robot assembly point has a significant impact on Energy consumption and therefore when designing an Energy efficient robotic station, the optimal robot assembly point should be determined, taking into account the minimum energy con sumption as an optimization criterion.

The work was carried out as a part of the project: "Opracowanie technologii systemow automatyzacji i robotyzacji procesow technologicznych sortowania i pakowania z wykorzystaniem manipulatorow i chwytakow" under the action of 1.1 "Projekty B+R przedsiebiorstw, Poddzialania 1.1.1 Badania przemyslowe i prace rozwojowe realizowane przez przedsiebiorstwa" Programu Operacyjnego Inteligentny Rozwoj 2014-2020 based on contract : POIR.01.01.01-00-0566/15 between Sorter Michal Ziomek Spolka Jawna and Narodowe Centrum Badan i Rozwoju.

***Authors**: MSc. Paweł Strączyński, Department of Industrial Electrical Engineering and Automation, Kielce University of Technology, Kielce, E-mail: pstraczynski@tu.kielce.pl; MSc Łukasz Gruszka, Institute of Automatic Control and Robotics , Warsaw University of Technology, Warsaw, E-mail: lukasz.gruszka90@gmail.com; PhD Robert Kazała, Engineering and Automation, Kielce University of Technology, Kielce E-mail: rkazala@tu.kielce.pl; MSc Tomasz Grzmil, SORTER Michał Ziomek Spółka Jawna, t.grzmil@sorter.pl*

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