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INFLUENTIAL ASPECTS TO ROBOTIC CELL ENERGETIC EFFICIENCY: OVERVIEW

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Abstract

This paper focuses on the input parameters that affect the resulting efficiency of a robotic workplace for industrial use. The aim of the investigation was to find which parameters most significantly affect cycle time and electricity consumption, and which way of movement is the most suitable for robotic operation. By finding the most suitable parameters, we obtain the information on how to build the most efficient robotic workplace. The investigation focused mainly on the energy consumption and layout of the robotic work cells components that significantly affect the cycle time and potentially save electric energy.

Keywords

Industrial robot, Cycle time, Energy consumption, Robotic workplace

INTRODUCTION

Today, the business environment is highly competitive, and the manufacturing industry faces new challenges for the products that are innovative and produced in a shortest period of time. Development processes of such products become more complex, since the products become more intricate, versatile, and inherently complicated [1]. With the trends of mass customisation, flexible robotic applications are becoming more popular. Even if conventional robotic automation of manipulation processes seems to be solved on a high level, advanced operations still need a lot of effort to be achieved [2]. Although robotic applications have been used for many decades, their development process is difficult to generalize. Much attention is paid to interactive methods for programming robots on site [3], which, however, can only be used in relatively simple tasks.

Simulation-based offline programming methods are much more suitable for more complex scenarios. Offline programming is therefore becoming increasingly popular owing to its potential to speed up the commissioning phase and reduce on-site workloads. However, offline programming is often performed imprecisely, and requires lengthy modifications either in the program code or in the physical work cell [4]. After all, more complicated solutions still require serious online and offline engineering efforts [5]. In flexible robotic solutions, the lack of accurate enough information further complicates cell development.

The robotic work cell life cycle consists of several stages, from the initial design, through the process planning and commissioning, through to operation, and up to modernization. The process of work cell development involves a pre-operation phase and a number of relevant experts, including manufacturers, process planners or designers. The phases of the working cells development are traditionally managed separately by different workers. There are many planning tools for different aspects of robotic applications that aim to address different phases of the work cell life cycle. However, they do not provide sufficient feedback support, and their interoperability is limited. There is also no comprehensive methodology for the complete cell development. Therefore, in many cases, the implementation of robotic work cells becomes a series of poorly considered improvements and modifications, because the development process is not well chosen or is based on a poorly defined scenario [2].

With this trend, the consumption of energy by industrial robots has attracted many research interests. In general, about 8 % of the electricity in automotive industry is consumed by industrial robots. Therefore, the correct application of the industrial robot can save a large amount of energy [6]. There are two main ways to save electricity. The apparent way to save energy is when the robot is moving. For this case, several methods have been proposed to plan energy-optimal routes. However, industrial robots can save energy even when not moving. Unlike modern electronic devices, there is a lack of efficient and programmable options to shut down robots in idle phases [7].

As with other production systems, the layout design phase is a basic requirement to determine the performance of a production system. Since the path that the robot arm takes to complete a task affects the cycle time of the entire system, initial layout planning is of key importance. Design of the production system layout will have a huge impact on production performance [8]. This is because most of the production performance parameters are highly dependent on the layout design. Good layout design will reduce uptime and increase productivity. Optimization techniques are needed to aid the design process in achieving the optimal layout design. The main criterion for the design of the layout solution is minimization of the layout area. Common layout criteria for a production system can include proximity between components to reduce the distance between objects [9].

OBJECT POSITIONING

Simulation tools can offer enough information to optimize production line design, process implementation, increase productivity and product quality. As most errors are found during the design and planning phases, simulation support engineers intend to minimize design and design errors in order to reduce machine set-up and start-up times, thereby reducing high costs for additional production changes [10]. Because of complexity, diversity, and different goals processes, it is hard to develop a generic method for automatic implementation of the simulation model. There is no approach that offers a solution that is generally applicable to a fully automatic implementation of process simulation models. The investigation proved that, within the specified constraints and restrictions, automatic model generation represents possible [11]. Typical areas of application are production planning and manufacturing.

Koopmans et al. [12] wrote one of the first articles on the problem of facility device layout. They point out the importance of minimizing available space to reduce the cost and distance of transporting material in the cell. Several years later, Drezner et al. [13] came with the issue of designing a robotic assembly work place, where robots pick parts from bin and assemble them. However, these early optimization methods did not count for all objects on the layout. The heuristic algorithm that uses the spatial representation to solve the problem of robot work cell layout was described by Tay et al. [14]. Cheng [15] performed a robotic work cell simulation using Deneb IGRIP robotic simulation technology. He pointed out that the development of accurate models for the study of robotic work cell simulations is a complex process that requires versatile knowledge in various disciplines. Sim et al. [16] present a genetic algorithm approach to optimize the robot working cell layout by the distance travelled by the robot arm as a means of measuring the degree of optimization. This method is based on the spiral placement method first proposed by Islier [17]. Drira et al. [18] think over problems with static and dynamic arrangement. In a static arrangement, the layout is constant after the design is completed. However, in a dynamic layout, there will be a series of layouts with different arrangements according to the type of operation. Zhang et al [19] design a three-step method and system for automatically optimizing the layout of multiple workstations in a robotic cell to increase robot performance and robotic work cell productivity. In the first step, each robot task is solved separately. The preferred area that can ensure the best performance of the robot in terms of kinematics and kinetics is used to determine the best position of each individual robot. In the second step, all tasks of the robot are considered together in order to find the best order of workstations to be placed according to the operational sequence of the robot. In the third step, an optimization method is used, which can provide an ever-better solution for the final adjustment of the deployment of all workstations. The optimization in the third step is performed regarding the robot cycle time or energy consumption. While positioning in the X and Y axes of workplace is important for shortening the work cycle, positioning in the Z axis is significant in the area of energy efficiency of the workplace. This issue was dealt with by Rassõlkin et al. [20], where the main goal of the experiment was to find how the energy consumption of the ABB IRB 1600 robot depended on the position of the product. During the measurement, the robot moved along pre-programmed paths at 10 different heights starting at the robot base, and every other path was 150 mm higher than the previous one. The graph (Fig. 1) shows that the most energy-efficient position of the workpiece is 750 mm above the base of the robot, while the highest energy consumption was measured in the plane of the base robot.

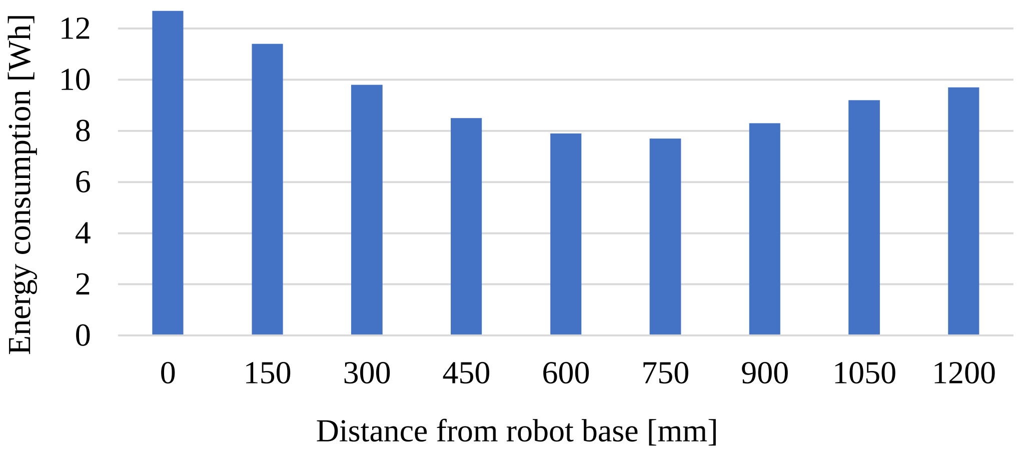

Fig. 1 *Graph of energy consumption depending on the height of the product [20]*

ENERGY CONSUMPTION

In recent decades, rising energy prices and growing environmental awareness have forced engineers and scientists to look for new solutions to reduce energy consumption in production. The appropriate design and operation of automation systems and industrial robots represents a good opportunity to reduce energy consumption in industry, such as energy optimization of operations and by replacing more efficient systems [21]. Energy optimization can be improved by appropriate software settings or by hardware components.

Software Optimization

The software optimization is based on the idea that energy consumption in industrial production equipment results primarily from the control and operation of electric drives in automated production processes. To maximize production (i.e. time minimization), robots and machines are often operated dynamically. This causes high energy losses at high-speed motions as well as redundant energy during slowdown. Also, after many axis movements, they are followed by idle times with a loss of productivity [21].

At present, most of the research on energy saving of industrial robots is focused on improving the trajectory and path planning. Some physical factors such as velocity or acceleration radically influence energy consumption [6]. Gadaleta et al. [22] suggest an energy consumption model by summing the measured energy consumption of the relative components, including electric motors, mechanical components, and the propulsion system. Their result showed that energy can be reduced by selecting appropriate speed and acceleration limits (Fig. 2).

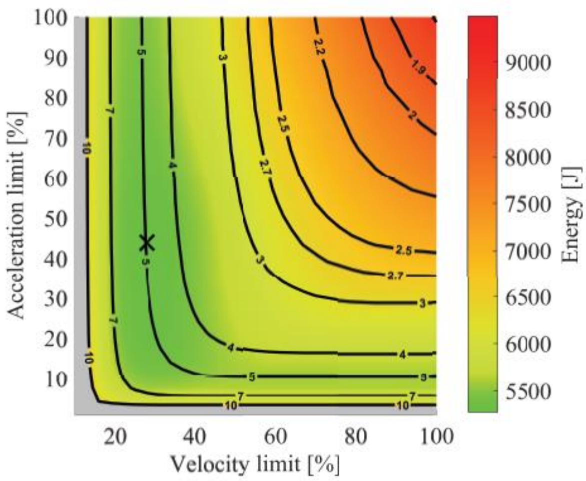

***Fig. 2** Energy consumption (colour map) and motion time (isolines) as function of velocity and acceleration limits* [22]

Mathematical model developed by Bukata et al. [23] consider operation parameters to save energy for a robotic cell. The speeds were reduced and positions of the robot in the robotic cell was optimised. Their experiments showed that energy consumption was reduced by about 20 %. Riazi et al. [23] introduced an algorithm used to minimize acceleration and optimize the sequence of operations without changing the original path. Their experiments showed that energy consumption was reduced by 45 %. Also, Roßmann et al. [24] generated a path movement method by using artificial intelligence. Their simulation proved that energy consumption decreased from 24.5 J to 3.5 J. Rassõlkin et al. [20] discovered that the energy consumed by the Industrial robot in the vertical motion was lower than in the horizontal motion. When moving horizontally (Fig. 3a), it consumed 11.4 Wh, while when moving vertically (Fig. 3b), it consumed only 10.4 Wh. The investigated trajectory was designed in such a way that all six axes of the robotic arm were used during the movement.

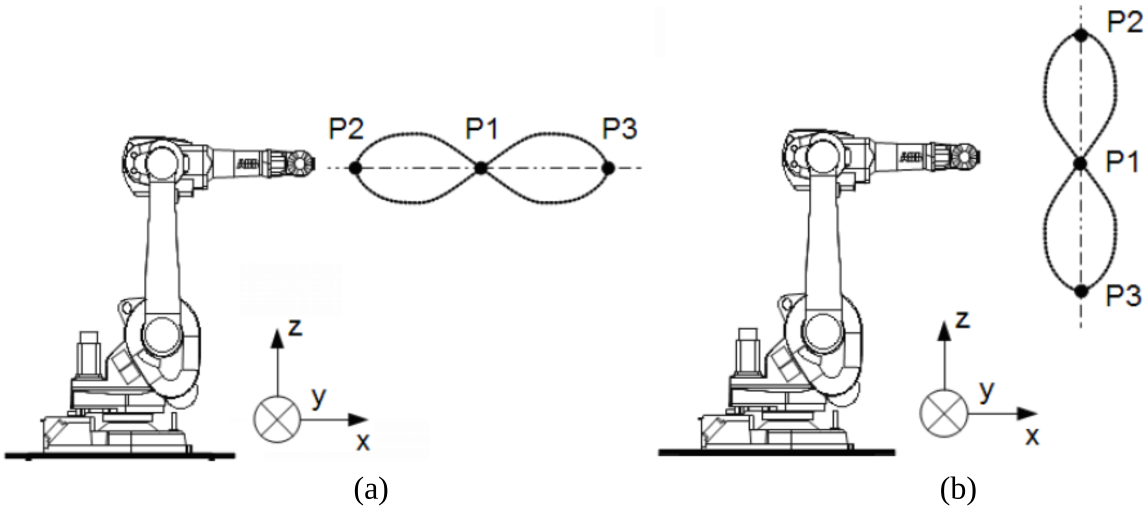

Fig. 3 *Investigated trajectory – (a) horizontal movement (b) vertical movement* [20]

A review of the literature shows that energy consumption has been optimized by taking into account one or more relevant factors, such as jerking, acceleration, or speed. Most of the factors mentioned were considered to be connected with energy consumption and controllable parameters.

Hardware optimization

Hardware optimization offers the implementation of new types of driving systems, as well as energy recovery and distribution strategies. These enable a new approach to reducing energy consumption, and thus reduce impact on the environment. By choosing the right automation system for a given application, you can decrease energy consumption while maintaining productivity [21].

Li et al. [25] compared serial and parallel configurations of a similar workspace manipulator and payload. The parallel configuration was shown to be more energy efficient on average in horizontal motion, consuming only 26 % of the energy of the serial manipulator. However, it is less energy-efficient when moving vertically. Lee et al. [26] simulated a robotic system based on a parallel mechanism with excess control, which showed the possibilities of reducing the loss of electrical power by 26.1 %. Also, Ruiz et al. [27] made a comparison between planar, parallel, 3 revolute joints and non-redundant manipulator and their redundant kinematically modified versions. Energy consumption was reduced in modified versions. KUKA robots support the PROFIenergy profile, which enables one to control energy consumption by sending commands via the PROFINET network. This allows for deeper power saving modes for robots, such as bus shutdown or hibernation, which saves 50 kWh or 0.6 % per year [23, 28]. According to Meike et al. [28], decreasing time delay when breaks of industrial robot are released by 2 seconds, it can save up to 300 kWh per robot a year. Kapoor et al. [29] introduced KERS (Kinetic Energy Recovery Systems) to obtain energy from robot regenerative braking.

DISCUSSION

The standard procedure for designing work cells contains only a reachability parameter in the offline simulation, which is commonly upgraded by shortening cycle times after the real objects are placed in the robotic work cell. It is due to the inaccuracy of placing devices and shape of objects that are not 100 % matching the simulation. Additionally, communication between devices can increase cycle time in work cells with many devices. The simulation software cannot detect this communication problem. Some off-line simulation programs (e.g. Process Simulate or RobotStudio) contain energy consumption plugins, but they are only for informative purposes and they are not very accurate. To obtain real values of energy consumption, we need an external device to measure real energy consumption.

Using a method of mixing the parameters of positioning and energy consumption, not only objects reachability before a real work cell is built, can improve efficiency of robotic work cells, which has a great impact on lowering the energy needed and shortened cycle times. Thus, work cells are more productive, less expensive to operate, and more environmentally friendly.

CONCLUSION

The expected benefit of this paper is to show the possibilities of designing a work cell for industry using different input parameters for the design phase. Designing with additional parameters appears to be more beneficial than the standard design method. Not only to save money spent during working time, but also to save nature from wasting unnecessary energy which could not be needed for the manufacturing process.

Future research: Today, when big companies need to produce more new products in a shorter time, they do not have time or investment to search the optimal energy-saving and shortest cycle time options. The authors want to focus their research on developing a methodology suitable for designing robotic workstations not only with a parameter of reachability but also energy consumption and efficiency to reduce energy consumption, shorten cycle time and increase productivity.

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