

SHORT LITERATURE REVIEW ON THE KINEMATICS AND DYNAMICS OF THE INDUSTRIAL ROBOTS

Mariana RATIU¹

¹University of Oradea, e-mail: mratiu@uoradea.ro

Abstract—This paper is the result of a short literature review on the kinematics and dynamics of the industrial robots, a first study conducted in a wider research that will be further developed in the field of the trajectory generating mechanisms of the industrial robots. After an introduction about the importance of the robots in the industrial processes and about the necessity to streamline and optimize the robot's motion, are presented some recent approaches related to the kinematic and dynamic analysis, the optimization of the robot's motion, and modeling of the trajectory generating mechanism of the industrial robots.

Keywords—industrial robots, kinematics, dynamics, optimization, modeling

I. INTRODUCTION

IN the context of increasingly stringent need to reduce costs and increase productivity, it was passed to the extensive use of the industrial robots in automated production processes.

The main problem that arises is the overall efficiency of the robotic system in the production process. A key issue for efficiency is the optimality of the entire set of the robot motion within the industrial applications.

Another key issue is their low stiffness and the bad achievable workpiece quality, making that the industrial robots to be still rarely utilized for machining applications in industry compared to the Computer Numerically Controlled (CNC) machines. In these conditions, the researchers propose milling strategies and robot settings to improve geometrical accuracy as well as surface quality for machining with industrial robots [1].

In the last few years, for increasing the productivity and ensure a suitable quality level, have been developed and implemented innovative, flexible automated assembly and processing systems, with programmable manipulators and modern feeders. To optimize the usage of rotating feeders in a robotic work cell was proposed and experimentally implemented a proper path planning technique for a generic manipulator, that consists in two algorithms: one algorithm for prediction of moving part position, and another one for circular conveyor tracking.

Thereby the robot can pick-up parts "on the fly" from the circular feeder without the need of stopping its rotation [2].

The optimization of the robot motion is also justified by the need of reducing the energy consumption, especially now, when there is a particular emphasis on the need to develop new products and production processes, clean, green, environmentally friendly. The results of some studies show that the energy consumed by industrial robots represents about 8% of all electricity consumed in the production process, and these results led to the development of numerous studies regarding reducing the energy consumption of the industrial robots. Following such studies, it was demonstrated that the optimization of the trajectory by the smoothing the robot motion / by rounding the trajectory, leads to reduced energy consumption [3]. There are others experimental studies that show that the planned smooth trajectories provide superior feasible time-optimal for robot motion [4].

After that, in a study, it was measured the amount of the energy consumed for the motion of an industrial robot, and the result was presented under the form of a colored map around the robot. From this map we can see very clear that keeping the robot motion as close as is possible to its center of gravity, the energy consumption is reduced [5].

So, the optimization of the robot's motion is very important, and many researchers are working for search the optimal trajectories of the robots motion.

II. KINEMATICS AND DYNAMICS OF THE INDUSTRIAL ROBOTS

The kinematic analysis of the industrial robots can be performed by direct and inverse kinematics. While the direct kinematic analysis is well known, and the Denavit-Hartenberg convention is widely used, the calculation of inverse kinematics is complex and time-consuming because of the non-existence of a unique solution.

The most commonly used methods for solving inverse kinematics are:

- 1) *the analytical approaches*: the inverse transformation method; the geometrical method; the Pieper method;
- 2) *the numerical approach*: the iteration method;
- 3) *the mixed numerical-analytical approach*, for simplify the solving processes of the inverse kinematics: product-of-exponentials formulas, vector dot product operations, and double quaternions [6].

In a study was demonstrated that the inverse kinematics equations based on the geometrical method are superior to the traditional method, can save unnecessary inverse solution calculation, saves much time and increases the efficiency. The inverse kinematics equations are the basis for the motion planning, and trajectory control of the robots are the foundation for the dynamic analysis [7].

By using for inverse kinematics analysis of an artificial intelligence technique, like fuzzy logic, neural network or adaptive and hybrid artificial intelligent techniques, like ANFIS (Adaptive Neuro-Fuzzy Intelligent System), is obtained an advantage of fast computation. Manjaree [8] developed more comparative studies for inverse kinematic analysis, by using the ANFIS method, geometrical/analytical approach and experimental validation, for 2-DOF (degree-of-freedom), 3-DOF and 5-DOF planar robotic systems, one of them considering wrist in motion.

For the study of the inverse kinematics of redundant manipulator, there are mainly used three methods: algebraic method, geometrical method, and numerical iteration method, each of them with their disadvantages. Problems like workspace obstacle avoidance, safety, energy consumption, and stability are not always considered and discussed. In a concrete study about a 6-degree-of-freedom redundant manipulator, to ensure the motion safety and reduce the energy consumption, an improved particle swarm optimization (PSO) algorithm is adopted to optimize the trajectory of the boom system. Also, is demonstrated the performance and the superiority of the improved strategy in comparison with the traditional method [9].

The PSO algorithm with Lyapunov stability conditions was used in another study for tracking control of the complex trajectories, performance and robustness of a robot arm for limb rehabilitation, that can be easily adapted to different other subjects by considering model parameter uncertainties [10].

The dynamics study the forces required to cause the motion. There are several parallel algorithms to calculate the dynamics of the industrial robots and several approaches to accelerate calculations [11].

III. THE OPTIMIZATION OF THE ROBOTS MOTION

Currently, in many industrial applications, the robot motion is still optimized manually, and this is expensive and predisposing to errors. Therefore, in recent years, the researchers are working on search algorithms for automatic calculation of the optimal trajectories of the robot motion. This approach has proved to be quite complicated, because of several factors, such as

redundant kinematics, collision avoidance, ambiguous possibilities for performing the tasks, etc. [12]

Alatartsev [13], starting from the premise that many types of tasks allow a certain freedom of execution, develops studies for searching a much more efficient task sequencing. He proposes a new and efficient heuristic to solve such problems, focused on optimizing Euclidean distance only, showing its applicability.

In trying to solve the problem of integrated task sequencing and path planning in Remote Laser Welding, Kovacs [14] introduces a new model, in fact, an extension of the well-known Travelling Salesman Problem with Neighbourhoods and Durative visits (TSP-ND). He demonstrates through extensive computational experiments that the novel approach solves efficiently industrially relevant problems, and it achieves a substantial improvement in cycle time.

It is generally assumed that the robot has to follow exactly the end-effector path and its motion law, and via-points should be strictly visited, without any deviation [15], to obtain an optimized trajectory. In opposite with this conviction, Alatartsev demonstrates, in another study, [16], about the trajectory optimization problem for the effective tasks performed by industrial robots, that relaxing the path, the motion law is also followed strictly, and this can lead to a significant trajectory cost reduction.

Studying the multiple approaches that exist to find a suitable robot trajectory in a given environment, and their advantages and disadvantages, some researchers propose [17] a novel approach to deform the trajectories while keeping their local shape similar. This novel approach is based on the discrete Laplace–Beltrami operator, well-known in the computer graphics community, but not yet exploited for robotics problems.

For trajectory planning of an industrial robot in the presence of fixed and oscillating obstacles, in a research were used two intelligent optimization algorithms: non-dominated sorting genetic algorithm (NSGA-II) and multi-objective differential evolution (MODE). The results concluded that MODE technique is the best one for the multicriteria optimization problem if the user wants a best optimal solution trade-off very quickly. Also, NSGA-II technique is the best for the multicriteria optimization problem, if the user wants a number of solution trade-offs for his choice [18].

The redundant robots present some advantages compared to conventional, non-redundant manipulators, like an increased workspace and a remarkable adaptability to specific tasks.

A redundant robot has the potential to avoid the singularities and the collisions while operating in cluttered work environments. While a six-degree-of-freedom manipulator can reach a given position and orientation in only a finite number of ways, through the addition of a seventh joint, it can allow an infinity of ways and can avoid the obstacles and influence the proper choice [19].

In this context, the redundant robots have become industrially important, and the researchers develop and present studies about it. In one of these studies is

presented a method that uses, in addition to standard optimization techniques, a joint space decomposition, and inverse kinematics analyze to obtain minimum-time B-spline joint trajectories along prescribed task space paths for kinematically redundant robots [20].

For increasing the flexibility and maneuverability, sometimes are used snake robots, that have a mechanism with the high degree of freedom, which impedes their control, but facilitates their motion on uneven surfaces. There are many studies that search the best algorithms for control the joints motion of the snake robot [21].

The most used optimization criteria are the minimum time trajectory planning, minimum jerk trajectory planning, minimum energy consumed or minimum actuator effort, or hybrid criteria, for example, minimum time and energy, where a trade-off is made between the path duration and the mechanical energy of actuators.

In a recent paper, it is presented a study on the working times of the industrial robots while taking into account the corresponding economic impacts. For calculate the time needed for an industrial robot to perform a task, are compared, two methodologies based on optimization and simulation procedures. The optimization methodology is based on the kinematics and the dynamics of industrial robots. The simulation methodology is based on a robotic simulation program called GRASP. The results show the opportunity costs of non-using the methodology with optimized time trajectories [22].

IV. MODELING OF THE TRAJECTORY-GENERATING MECHANISM OF THE INDUSTRIAL ROBOTS

To today's challenges induced by globalization, competition worldwide, along with other technology design and processing, computer technology and information processing, and computer-aided design, modeling and simulation play a central role [23].

For the industrial robots, the trajectory generating mechanism is a part of the guiding device having the role of achieving change position manipulated object. The trajectory generating mechanism of the industrial robots plays in the handling operation the same role it plays the shoulder, arm and forearm of the human operator, so that is also called "arm".

In recent decades, together with physical prototypes, the modern virtual prototyping techniques continue to advance and become more powerful. The motion of any mechanical assembly can be modeled, evaluated and optimized in two or three dimensions. Results can be recorded using animation tools and can be played at any time after that. The two main types of motion simulation are kinematics and dynamics of motion [24].

The simulation tools are the foundation for the design of the robots, for their application in complex environments, and the development of new control strategies and algorithms [25].

The dynamic model of a robot is useful and necessary for its motion simulation, so no need to build a real model. A valid model representing kinematic and

dynamic properties of a robot helps to understand the mutual relations between the torques applied to each joint and the result of the robot motion [26]. Based on the dynamic model of a robot, it can be realized divers robotic driving models [27].

During the last years, more researchers have made studies within the field of robotics simulation and most of the commercial robotics companies have developed complex simulation software packages for their products. For example, ROBOLAB is a Matlab toolbox for off-line robot simulation; ROBO is a package for a Mitsubishi Movemaster RV-M1 robot; RPSim - a portable and open-source package for Fanuc M-6iB robot series [28]. Other methods presented in the literature for kinematic and dynamic simulation is based on PRO/E, ADAMS, and ANSYS, VC++, DUM in CATIA [29].

The ADAMS software application is a family of interactive motion simulation used to analyze the behavior of the complex mechanical systems. With it, Gou did the modeling and simulated the motion of a robot used in a welding process and verified the validity of the inverse kinematics equations based on the geometrical method [7].

To improve the robot dynamic behavior and reduce the end-effector position errors, was developed in the ADAMS multibody simulation environment a reliable robot dynamic model by simply starting from the robot definition done through CAD model and the catalogs investigation. In this study was analyzed the influence of the joint compliance behavior and actuator rotational inertia effects on end-effector position accuracy [30].

V. CONCLUSION

After a short literature review on the kinematics and dynamics of the industrial robots, we can conclude that there are an important number of researchers who develop different theoretical and experimental studies and have different approaches in the field of optimization and modeling of the industrial robots. This work will be further thorough and developed to find the best approach for modeling and to optimize an industrial robot in ADAMS software application.

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