Application machining robots in processing operations

S Guergov, N G Nikolova and G Stefanov
Technical University - Sofia, FIT, FA, 8 Kl. Ohridski Blvd., 1000 Sofia, Bulgaria
sguergov@tu-sofia.bg, ninan@tu-sofia.bg, gommes@abv.bg

Abstract - An approach for the realization of various technological operations (drilling, milling, boring, grinding, etc.) on the basis of a specially designed execution technological system and an industrial robot has been developed. In the end effector of it, instead of a complex and large-sized tool turret, the workpiece is established. The method of producing geometrical surfaces of the workpiece is through the following formative motions: the feed motions are performed by the robot and the primary cutting motions by the tools, which are clamping in the turrets of the technological modules.

Keywords — machining robots, machine tools, industrial robots, processing operations.

1. Introduction
Created to be auxiliary, the idea of using robots to perform specific technological operations such as welding, assembly, coating, etc. is enforced [1,2,3].

This possibility is further enhanced by the rapid development of computer equipment, which creates prerequisites for the synchronization of the motions of the end effector, the kinematic and the dynamic capabilities of the robots when performing complex motions and even to perform some single technological operations, such as milling, drilling, polishing, grinding, deburring, sheet cutting, etc. [4,5].

Using a single robot as a technological one should not mean that only the robot holds the tool. Many applications work better when the robot holds the workpiece, bringing it to a stationary tool. This increases flexibility by allowing the robot to perform many different operations [6].

2. Formulation the problem
There are two approaches of using a single robot to perform multi-operational machining operations:

1) using a complicated end effector (analogous to a tool turret) to locate the cutting tools ‘figure 1’;
2) using a universal gripper for clamping the workpiece and the working motions to be performed by separate executive technology modules/machines ‘figure 2’.

The advantage of the second approach is the reduction or elimination of the number of bases of the workpiece. This reduces errors, as well as the cycle time needed to process the workpiece.

During multi-operation machining, through using various tools (such as lathe tools, milling cutters, drills, grinding wheels, etc.), it requires a multifunctional end effector analogous to the DST-tool turret [7] ‘figure 1’. The figure shows that the use of such end effector will greatly increase the requirements for the robot in terms of load capacity, stability, dynamic characteristics, etc.

For the above reasons, the second approach is preferred, with the following formatting movements being performed to obtain the geometric surfaces of the workpiece: the feed motions are performed by the robot and the primary cutting motions by the tools, which are clamping in the turrets of the technological modules.
The decision to use industrial robot and specialized technological modules through optimal control in on-line mode with the ability to maintain the set quality of the workpiece is distinguished by significantly lower value of inputs, higher flexibility with possibilities for dynamic technological reconfiguration when performing various technological operations.

This article aims to develop the hardware and software environment of a robotic system for performing various technological operations (drilling, milling, boring, grinding, etc.) on the basis of a specially designed execution technological system and robot (in this case M430i-A/4FH) ‘figure 3’.

3. Operating environment
The executive technological system ‘figure 4’ includes: three working positions providing rotary motion, in which tools such as drills, milling machines, grinding discs, countersinks, grooves, etc. can be established; one position (turning knife) for turning and grinding operations and one rotating high-speed position with rotary motion (up to 30000 min\(^{-1}\)) for finishing operations, etc.

The specialized software package of FANUC Roboguide, which has very good hardware and software compatibility, flexibility and versatility, is used for software and information security of the entire system.

The package has a rich library consisting of a wide variety of robot models, static objects, obstacles, conveyors, metal cutters and more. It allows instructions to be generated for managing peripherals devices, defining states for logical structures execution, and communication with sensors, etc. Furthermore, its software compatibility creates preconditions for integrating external CAD models (e.g. through Solid Works) and optimizing constructive and technological solutions (e.g. through MATLAB).

The custom software application enables possibility for detailed modelling of the work environment, creating and simulating work movements, computer animation which supports validation and verification of the generated process, calibration of the virtual environment to the actual technology, communication with the robot control system, etc.
Figure 4. Executive technology system

Figure 5 shows the general architecture of the entire system, which includes the user software, interface and the elements of the multifunctional robotic technological system.

Figure 5. System architecture

The sequence for realizing the workflow is as follows:
- creating a virtual model ‘figure 6b’ of the working scene ‘figure 6a’ in Roboguide environment;
- performing a procedure to calibrate the virtual model;
• determining the geometric elements and processing modes of the workpiece from the technological documentation;
• analysis of trajectory movements, creation of logical control structures, while taking into account the forces arising from cutting processes;
• defining process variables;
• training of job positions ‘figure 7’;
• simulation and testing ‘figure 6c’;
• adjustments making;
• workflow in a real environment ‘figure 6d’.

![Image](image_url)

**Figure 6.** Workflow logic

![Image](image_url)

**User coordinate system**

- $V(s)_1$, $V(s)_2$, $V(s)_3$, $V(s)_4$ - processing feed rate
- $V(tr)_1$, $V(tr)_2$, $V(tr)_3$, $V(tr)_4$ - moving speed of the robot end effector on the trajectory (speed of positioning motions)

**Figure 7.** Trajectory and motions of the robot end effector

For machining the workpiece ‘figure 2’, which has holes, bevels, chamfers, grooves, surfaces etc., different technological operations (drilling, milling, etc.) are required, as well as control programs for workpiece production are developed, various auxiliary subroutines for activation and adjusting movements of the gripper and a main program that determines the sequence of execution of the technological operations.

In ‘figure 8’ (as an example) is given the control program as well as a fragment of the machined surface by radial channels milling.
Figure 8. Control program for milling of radial channels

Conclusions
For machining the workpiece ‘figure 2’, which has holes, bevels, chamfers, grooves, surfaces etc., different technological operations (drilling, milling, etc.) are required, as well as control programs for workpiece production are developed, various auxiliary subroutines for activation and adjusting movements of the gripper and a main program that determines the sequence of execution of the technological operations.

In ‘figure 8’ (as an example) is given the control program as well as a fragment of the machined surface by radial channels milling.

This solution to use a technology robot and specialized modules, optimized on-line control with the ability to maintain the defined quality of the workpiece, has a significantly lower investments value, more flexibility with opportunities for dynamic technological reconfiguration when performing various technological operations.

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