Development of Control System for Robotic Surface Tracking

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***Abstract*—This paper describes the development of an industrial robot manipulator control system for 3D scanning of surfaces prior to robotic plasma processing and cutting of products with complex shape. Preliminary 3D scanning of the surface by a robot manipulator is needed to create a 3D model of a product in order to automatically generate a program for moving the robot to ensure robotic precise plasma processing or cutting of the product. The new algorithm of synthesis of the robot manipulator motion-controlling system by dynamics and perturbations compensation method has been developed. The scheme of 3D scanning on the basis of an industrial robot manipulator has been identified.**

***Index Terms* — robot manipulator, algorithm of motion control, analytical synthesis, 3D scanning, plasma processing.**

I. Introduction

At present, the application of robots in the area of manufacturing is fast growing [1, 2]. A modern robot manipulator can be considered as a mean of setting spatial position and orientation of an arbitrary tool with high precision and accuracy. With the addition of a distance sensor or a vision system element (camera or projector), the robot manipulator can provide an excellent system of surface scanning. Currently, industrial robot based 3D-scanners are used in quality control systems, automatic packing lines, and assembly systems [2-6]. The application of robot based scanners has been steadily expanding, especially in medical volumetry [7, 8].

Robots are currently used in manufacturing processes such as plasma cutting, plasma surface treatment in the form of plasma spraying of powder or wire coatings [9, 10]. The plasma processing requires accurate setting of a number of parameters during the entire processing time. These parameters include the distance from the plasma system nozzle to the surface of a workpiece, the nozzle movement speed, the angle between the plasma jet and the surface being treated etc. [9]. Exceeding these parameters beyond the permissible limits can lead not only to defective products, but also to an accident (a short circuit). In cases when the robot program is generated according to a given geometrical model of a processed workpiece or part, very often deviation of the shape of the real object from the model leads to the violation of process parameters with all its undesirable consequences. This problem is particularly acute in the case of objects with complex shape, when small relative errors of geometric parameters and object positioning leads to large deviations of the distances between the tools mounted on the manipulator and the object surface. The optimum solution to these problems is pre-scanning the surface of an object.

To implement 3D scanning of an object using a robotic arm, it is necessary to solve the problem of controlling the motion of a robotic arm and planning its trajectory. Number of research publications have addressed this issue recently [11–15]. The challenge to build a robot around trajectories has been investigated in this thesis report [11] where an integrated force/torque sensor (the flexible controller) has been shown to solve this problem. However, according to [11] the problem requires more study because the navigation of the robot and the motion of the arms should slow down or stop to avoid moving obstacles, and these two tasks should be synchronized, but the dynamic and precision of trajectory following of the robot base and arms are different. Therefore some new strategies to achieve manipulation during navigation should be proposed.

In another research [12], the motion control problem in operational space has been explored using the resolved motion rate controller RMRC (kinematic control) plus the intrinsic joint velocity PI controller of the industrial robots are used. The solutions of the overall closed–loop system have been proved to have uniformly ultimately boundedness (UUB). The researchers [12] carried out some experiments in a PA10-7CE robot arm and tested the same hierarchical structure in different operation modes. They showed that the operation in torque mode is more affected by mechanical vibrations, perhaps due to friction and to the discretization of the controllers [12].

In the reported research work [13], the motion planning method for the control of the robot arm's movement at the established speed through the settled points had been selected. The trajectory was divided into segments of equal length and the time constants were

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obtained after the research of the electromechanical and electrical time constant of the used motors. The author of paper [13] concluded that it is necessary to improve the trajectory planning algorithm to reduce the robot arm end-point deviations from the desired trajectory. In paper [14] a new adaptive tracking control method for uncertain flexible joint robots has been designed.

Controllers designed by authors of the paper [14] can make the position tracking error arbitrarily small, while keeping all the closed signals globally/semi-globally uniformly ultimately bounded. However, as mentioned in paper [14], there are still remaining problems to be investigated, such as how to design an adaptive tracking controller for the flexible joint robots in random vibration environment.

In paper [15] a robot model of surface tracking motion is proposed on the basis of the six-axis wrist force sensor measuring. The robot force control algorithm has been designed and experiments have been carried out. It was demonstrated that to obtain accurate form of six-axis force acting on the sensor and achieve further precise control of robot gripper ends, the actual operation of the contact surface equation must be combined in solution.

Obviously, the selection and programming of the object trajectories, including speeds and accelerations, is a rather difficult task to achieve [11-15]. The fact that the robot manipulator is a multilink coupled inertia mechanical system with actuators being limited in power and moment should be taken in account. As a rule, each kinematic pair of the manipulator (joint) has its own drive, a positioning transducer and a microprocessor control system of the drive. As a whole, we get a servo system of this pair process position, which has its own dynamic characteristics. At a higher level, coordinated work of the positioning systems of all joints is being implemented. Usually, to facilitate software development at this stage, along with others, the motion of the tool in a preset direction in the Cartesian reference system, regardless of the type of movement of pairs of actuators is foreseen. The Kawasaki RS10L robot can serve as an illustration, where rotational pairs are used, but the motion of the tool in a preset direction is foreseen

Our motivation in this research study is the development of an intelligent robotic system for plasma processing of complex shapes based on preliminary 3D scanning of the treated surface by the robot manipulator. In this study we address both the above-described scientific problem, as well as the practical challenges which authors met with the use of Kawasaki industrial robot (Kawasaki Robotics, Japan) for plasma surface treatment [10, 16, 17].

The purposes of this study are to design a new algorithm of synthesis of the robot manipulator motion-controlling system and to develop a 3D scan system scheme based on contactless distance sensors installed on an industrial robot manipulator.

II. Experimental

The research has been carried out at a pilot production site established in the East Kazakhstan State Technical University with an industrial complex for plasma processing of materials on the basis of Kawasaki RS-010LA, an industrial robot, (Kawasaki Robotics, Japan).

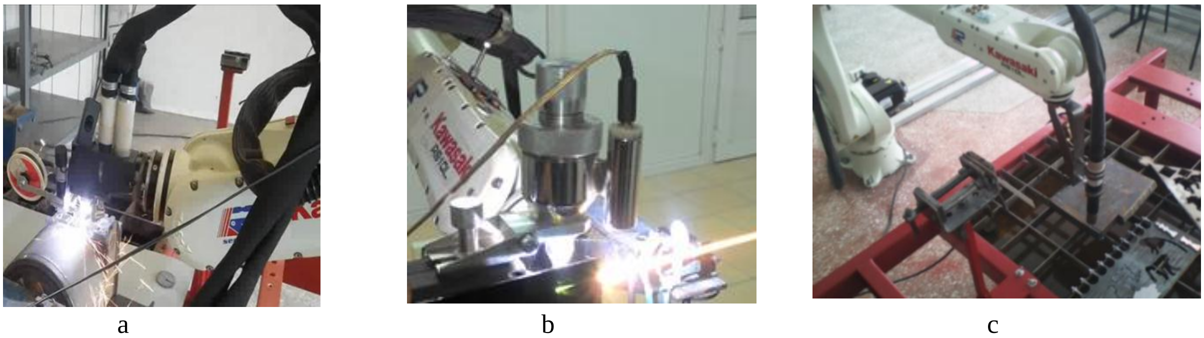
The robot consists of movable parts with six degrees of mobility for moving the equipment installed therein according to a predetermined trajectory. The robot's arm is equipped either with a device for air plasma cutting ("UPR") produced by "NPPTekhnotron" Ltd. (Russia) to work on plasma cutting, or "MPN-004" microplasmatron produced by E.O. Paton Institute of Electric Welding (Ukraine) for microplasma spraying of wire or powder coatings.

Fig. 1 shows the robotic processes of microplasma spraying of wire "Fig.1a" or powder "Fig. 1b" and the robot with a device for plasma metal cutting "Fig 1c".

The KawasakiRS-010LA robot manipulator characteristics are as follows:

positioning accuracy – 0.06 mm;
maximal linear speed - 13100 mm/s;
engagement zone - 1925 mm;
working load capacity - 10 kg.

Kawasaki robots are controlled by AS software system.



a b c

Figure 1. Robotic pilot production site processes of microplasma spraying of wire (a); microplasma spraying of powder (b); plasma cutting of metal (c)

III. Results and Discussion

A. Development of a Robot Control System

The dynamics of the robot tool in a given direction can be represented by a linear ordinary differential equation of second order of general form (1) or in a vector-matrix form (2), convenient for the synthesis of the control algorithm as follows:

$$\dot{x}_{01} = a_1 x_{01} + a_2 x_{02} + u - f_{x1},$$
$$\dot{x}_{02} = x_{01} - f_{x2}, \qquad (1)$$
$$y_0 = c_1 x_{01} + c_2 x_{02} - f_y,$$

$$\dot{\mathbf{x}}_0 = \mathbf{A}\mathbf{x}_0 + \mathbf{B}u - \mathbf{f}_x, \quad y_0 = \mathbf{C}\mathbf{x}_0 - \mathbf{f}_y, \quad \begin{bmatrix} \mathbf{A} & \mathbf{B} \\ \mathbf{C} & 0 \end{bmatrix} = \begin{bmatrix} a_1 & a_2 & 1 \\ 1 & 0 & 0 \\ c_1 & c_2 & 0 \end{bmatrix} \qquad (2)$$

where $\mathbf{x}_0 = [x_{01} \quad x_{02}]^{\mathrm{T}} \in \Re^2$ – state variables; $u \in \Re^1$ – manipulated value; $y_0 \in \Re^1$ – output variable; $f_y \in \Re^1$ – perturbation on output variable; $\mathbf{f}_x = [f_{x1} \quad f_{x2}]^{\mathrm{T}} \in \Re^2$ – perturbations on state variables. Matrixes $\mathbf{A} \in \Re^{2\times 2}$, $\mathbf{B} \in \Re^{2\times 1}$, $\mathbf{C} \in \Re^{1\times 2}$ are said to be given, $c_2 \neq 0$. Available to be controlled are: y_0, x_0.

To solve the problem of controlling the robot we used a method of compensation for the object dynamics and disturbances which has several advantages noted in the papers [18, 19]. This is an analytical method that in a single algorithm provides both the correction of the own dynamics of the control object and the processing of external influences with zero static error. The source data here is set in the form of filter-standards of a closed system, that is convenient for practical applications. The object control algorithm (2) by this method is obtained as follows (3)

$$\dot{\mathbf{x}}_\phi = \mathbf{R}_1 \mathbf{x}_\phi + \mathbf{\Phi}_2 \varepsilon, \quad u = \mathbf{R}_3 \mathbf{x}_\phi + \mathbf{N}_1 \cdot \tilde{\mathbf{x}}_o + \mathbf{P}\varepsilon,$$
$$\tilde{\mathbf{x}}_0 = \mathbf{x}_0 - \mathbf{x}_\phi, \quad \varepsilon = y - y_0, \qquad (3)$$

The processes in a closed control system are represented by the expressions offered bellow (4):

$$\dot{\mathbf{x}}_\varphi = \mathbf{\Phi}_1 \mathbf{x}_\varphi - \mathbf{\Phi}_2 \mathbf{C}\tilde{\mathbf{x}}_0 + \mathbf{\Phi}_2 (y - f_y), \quad \dot{\tilde{\mathbf{x}}}_0 = \mathbf{\Phi}_{r1} \tilde{\mathbf{x}}_0 + \mathbf{f}_x,$$
$$\varepsilon = -\mathbf{\Phi}_3 \mathbf{x}_\varphi - \mathbf{C}\tilde{\mathbf{x}}_0 + y - f_y, \qquad (4)$$
$$u = \mathbf{N}\mathbf{x}_\varphi + (\mathbf{N}_1 - \mathbf{P}\mathbf{C})\tilde{\mathbf{x}}_0 + \mathbf{P}(y - f_y),$$

In (3), (4) denoted: $\mathbf{x}_\phi = [x_{\phi 1} \quad x_{\phi 2}]^{\mathrm{T}} \in \Re^2$, $\mathbf{\Phi}_1 = \begin{bmatrix} \phi_1 & \phi_2 \\ 1 & 0 \end{bmatrix}$, $\mathbf{\Phi}_2 = \begin{bmatrix} -\frac{\phi_2}{c_2} \\ 0 \end{bmatrix}$, $\mathbf{\Phi}_3 = [c_1 \quad c_2]$, $\mathbf{\Phi}_{r1} = \begin{bmatrix} \phi_{r1} & \phi_{r2} \\ 1 & 0 \end{bmatrix}$, $\mathbf{R}_1 = \begin{bmatrix} \phi_1 - \frac{c_1}{c_2}\phi_2 & 0 \\ 1 & 0 \end{bmatrix}$, $\mathbf{P} = -\frac{\phi_2}{c_2}$, $\mathbf{N} = [\phi_1 - a_1 \quad \phi_2 - a_2]$, $\mathbf{R}_3 = \begin{bmatrix} \phi_1 - a_1 - \frac{c_1}{c_2}\phi_2 & -a_2 \end{bmatrix}$, $\mathbf{N}_1 = [\phi_{r1} - a_1 \quad \phi_{r2} - a_2]$,

$y \in \Re^1$ – task for output variable. From (4) it is easy to establish that the static regulation error is zero, a freely selectable pair of coefficients ϕ_1, ϕ_2 that determines the dynamics of the system when working on the effects $y - f_y$, and a pair of coefficients ϕr_1, ϕr_2 that corrects the system's own movements during fx compensation. When assigning each pair of coefficients, it is convenient to represent the transfer functions of the filter standards in the form of Vyshnegradsky (5).

$$W_\phi(s) = \frac{\omega_\phi^2}{s^2 + \varsigma_\phi \omega_\phi s + \omega_\phi^2}, \quad \phi_1 = -\varsigma_\phi \omega_\phi, \ \phi_2 = -\omega_\phi^2,$$
$$W_{r\phi}(s) = \frac{\omega_{r\phi}^2}{s^2 + \varsigma_{r\phi} \omega_{r\phi} s + \omega_{r\phi}^2}, \quad \phi_{r1} = -\varsigma_{r\phi} \omega_{r\phi}, \ \phi_2 = -\omega_\phi^2, \qquad (5)$$

where ω_ϕ, $\omega_{r\phi}$ – natural frequency of the filter-pattern, ζ_ϕ, $\zeta_{r\phi}$ – attenuation coefficient.

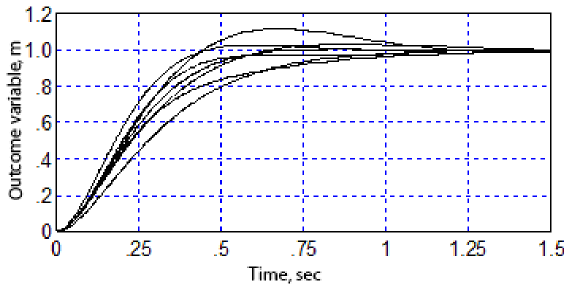
The study of control quality of the obtained system was carried out by the method of robot mathematical modeling , represented by equations (1) and the regulator (3) for the nominal values of the coefficients a_1= - 6.634, a_2= -51.84, c_1 = 0, c_2 = 51.84. These coefficients correspond to the maximum movement speed of the robot tool v_{max} = 4 m/s and dynamic error σ = 20%. When calculating the regulator, the values ω_ϕ, $\omega_{r\phi}$, were taken equal to the object's own frequency, attenuation ζ_ϕ, $\zeta_{r\phi}$ corresponded to the Bessel filter. The equations of the object (1) and the regulator (3) for this example in scalar via (6), (7)

$$\dot{x}_{01} = -6{,}634 x_{01} - 51{,}84 x_{02} + u,$$
$$\dot{x}_{02} = x_{01}, \qquad (6)$$
$$y_0 = 51{,}84 x_{02},$$

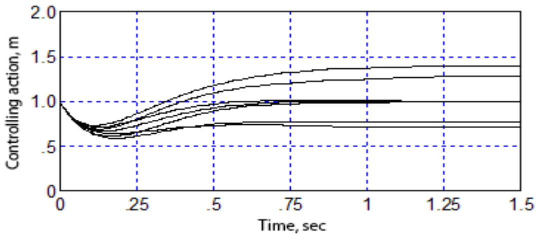
$$\dot{x}_{\phi 1} = -12{,}46 x_{\phi 1} + \varepsilon, \quad \dot{x}_{\phi 2} = x_{\phi 1},$$
$$u = -5{,}83 x_{\phi 1} + 51{,}84 x_{\phi 2} - 5{,}83 \cdot \tilde{x}_{01} + \varepsilon, \qquad (7)$$
$$\tilde{x}_{01} = x_{01} - x_{\phi 1}, \quad \varepsilon = y - y_0.$$

Fig. 2 shows transfer functions of system (6), (7) at the nominal value of the coefficients a_1, a_2, c_2 and their alternate change by 30% of their nominal values. As can be seen, the system is stable and is characterized by a rather low sensitivity to a significant change in the parameters of the control object. This indicates that the system is parametrically robust.

Thus, application of the object's dynamics and perturbations compensation method makes it possible to obtain a control algorithm for the object of a general form analytically by algebraic actions over matrixes. Basic data for calculating the control system are the mathematical model of the controlled object and free parameters of the filters-patterns, provided for practical applications. The algorithm provides zero static error and exposures testing to the filters-patterns. Analysis by the of mathematical modeling method of the robot motion control system developed on the basis of the algorithm proposed in this article allows to conclude that the system provides the defined quality indices and exhibits the properties of parametric and structural robustness.



a



b

Figure 2. Testing of the system for parametric robustness: *a* – outcome variable; *b* – controlling action.

B. Development of the Robotic 3D Scanning System

At present, the most widely used 3D scanning systems is based on 1D distance meter. There are two ways to scan an object – the first method is to move the sensor along the surface of the scanned object and the second way is to move the scanned object. As an example, consider the method proposed by Reyes [20]. In order to scan solid 3D objects, these researchers [20] made use of a very simple method. It consists of taking distance measurements from a solid 3D object that is subjected to a controlled rotation. After each revolution of the object, distance measurements are taken at different heights. In this manner, the outline of the object can be obtained in every revolution by gathering the distance measurements and corresponding rotation degrees. The outline distances are obtained by the difference between a fixed distance and distance measurements.

It should be noted that there is an intermediate method of scanning. In this method both the sensor and the scanned object are mobile. Rahayem and Kjellander used this type of setup for their research [21]. Their setup used a turntable and a motor-driven potter-wheel on which the object is placed upon. This is popular in automated 3-D scanning and significantly reduces the need of the scanner being mobile. If the setup is properly calibrated the scanner only needs to be moved vertically or in an arc alongside the object. Scanning technologies based on 1D distance sensors can be classified as point technology. Point scanning technology is similar to a physical probe in that it uses a single point of reference, repeated many times. This was the slowest approach as it involved lots of physical movement by the sensor (or scanned object). Optical scanning technology provides two other types of scanning methods:

1. Area, which is technically difficult. This group of methods is based on technologies of machine vision.
2. Stripe, which was identified to be faster than point probing as it used a band of many points to pass over the object simultaneously. It was accurate and matched the both requirement of speed and precision

Speaking about the technology of machine vision, we mean primarily the systems of stereo vision. Stereo vision is a technique aimed at extracting depth information of a scene from two camera images [22]. Difference in pixel position in two images produces the depth output. Stereo vision algorithms search for a correspondence between the pixels of the right and left images. In the theory of machine vision, this problem is formulated as the problem of constructing the so-called disparity map [22].

In order to develop a robotic 3D scanning system, we proposed a 3D scanning scheme based on laser distance sensors installed on the Kawasaki RS10L robot manipulator "Fig. 3". In this scheme "Fig. 3", the interrelation of components of the system such as robot manipulator, sensor (3D scanner), E40 controller and PC is clearly represented.

The system can scan an object based on the measurement of the distance from the surface of an object in a discrete set of points forming a network with the specified geometric parameters imposed on the surface of the object. A 3D-model of the scanned object is built using interpolation procedures of grid points. Thus, the creation of a system of 3D-scanning requires the construction of a data collection system involved in the formation of tasks for the robot manipulator. The system consists of consecutive moving according to scanning points, at each point performing actions necessary for scanning, and also storing the results of the measurements at the points of scanning in the memory. As precision distance sensors usually have a limited operation range, and some of them require orientation of the axis of the sensor in a direction perpendicular to the area of an object subjected to scanning, it is necessary to implement a complete system consisting of "rough" and "fine" scanning subsystems. The system of "rough" scanning, that uses position sensors with a wide range of measurable distances and is insensitive to the orientation relative to the surface. The "rough" scan results are used for setting "fine" scanning sensors in the operating position. This is to make sure that emergency situations are prevented during the process of scanning. Thus, in order to implement the scanning system we must develop the hardware and software for the data collection system briefly described above. The system development should include research on testing the algorithms of setting the distance sensors in the operating position and the study of the system performance characteristics in test situations with known geometry.

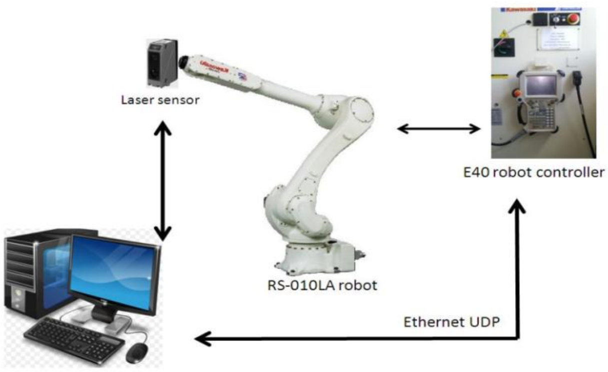


Figure 3. Scheme of the 3D-scanning system based on laser sensors installed on the manipulator of the industrial robot Kawasaki RS10LA.

The main difference between our current research of robotic 3D scanning from the methods described in previous researchers work [3-8] is that we propose to program the robot by a 3D-model of the object to be processed. This 3D-model is obtained by scanning the object using an industrial robot as a key component of the scanning system.

The basic idea of our method is the development of a combined system for scanning with the split of scan process into two phases: a rough scan phase and a refining phase. For rough scanning a vision system, that uses a single camera mounted on the manipulator and a fixed structured light projector, is used.

During the rough scan phase, photography of an “illuminated” object from several points of space is performed (with the known orientation of the principal optical axis of the camera). Using the images obtained in the shooting process, the software of the scanning system produces a segmentation of the object surface and builds an approximate 3D model of the object.

According to the segmentation results, a set of reference points is selected on the surface with known spatial coordinates. This will enable us to accurately construct the 3D model of the object.

After selecting the reference points, the software generates the program of the manipulator. The program defines how the manipulator successively passes the reference points, performing surface scanning at each of the points.

The vision system is built on the original algorithm. It implements three stages processing of the image obtained by the camera:

1) building a function module of the intensity gradient;

2) construction of a set of lines of this function level.

The structuring of the system of level lines radically simplifies the task of finding correlation between the lines obtained in the processing of the two photos taken at different camera positions;

3) calculation of the spatial coordinates of the scene points, whose images lie on these lines.

C. Theoretical Foundation of 3D Scanning by Robot - Manipulator

Data is collected in two coordinate systems. One is the Cartesian coordinates of end effector and the second is Euler’s angles e.g. rotational angles about X, Y, Z axis which relates to the tool orientation. Fig. 4 presents the robot’s coordinate system.

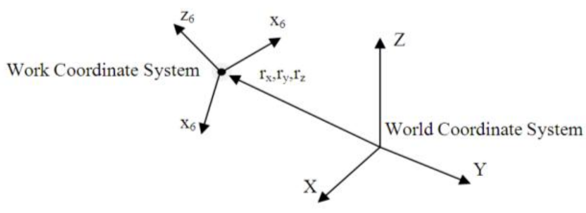


Figure 4. Robot coordinate system

Work coordinate system homogeneous system vector $(X, Y, Z, 1)$ defines world coordinate system homogeneous vector $(X, Y, Z, 1)$ by mean of transform (8)

$$\begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} = [A] \times \begin{bmatrix} x_n \\ y_n \\ z_n \\ 1 \end{bmatrix} \quad (8)$$

According to Fig. 4, the homogeneous transformation matrix A can be described by the formula (9)

$$A = \begin{bmatrix} \mathrm{l_x} & \mathrm{m_x} & \mathrm{n_x} & \mathrm{r_x} \\ \mathrm{l_y} & \mathrm{m_y} & \mathrm{n_y} & \mathrm{r_y} \\ \mathrm{l_z} & \mathrm{m_z} & \mathrm{n_z} & \mathrm{r_z} \\ 0 & 0 & 0 & 1 \end{bmatrix}, \quad (9)$$

where $\mathrm{l_x} = \cos(\alpha_2) \cdot \cos(\alpha_3)$

$\mathrm{l_y} = \sin(\alpha_1) \cdot \sin(\alpha_2) \cdot \cos(\alpha_3) + \cos(\alpha_1) \cdot \sin(\alpha_3)$

$\mathrm{l_z} = \sin(\alpha_1) \cdot \sin(\alpha_3) - \cos(\alpha_1) \cdot \sin(\alpha_2) \cdot \cos(\alpha_3)$

$\mathrm{r_x}, \mathrm{r_y}, \mathrm{r_z}$ - coordinates of work coordinates system origin

$\alpha_{1,}, \alpha_2, \alpha_3$ – rotational angels about X, Y, Z axis respectively

Initially the laser device measures the distance along z_n axis. Then to build the 3D image of the scanned object in our case we need only last column from the result matrix (8). The robot working frame (including the laser measurement head) moves along the given path during 3D scanning. The path and the trajectory planning for this application is an important and interesting research and development topic.

D. Application System Concept

For the given application the data synchronization was achieved by the application of a supplementary software. The PC is connected to the Robot Controller via RS232 serial interface (Fig. 3). In this case it is possible to operate the process of measurement using PC software via user interface, or automatically via specialized software application. The sequence of events for system is briefly described below:

- Sending the robot to the position according to the planned trajectory;
- Send request for measurement to sensor;
- Getting the results of distance measurement;
- Read current coordinates of manipulator;
- Transfer received data the data-base
- Waiting for the next request/ stop

E. Advantages of the Use of Laser Sensor

There are at least two main advantages in using the laser instead of any other signal as follows:

1) Laser provides concentrated narrow beam with very low deviation. It allows measuring distance to very tiny objects, such as the depth of very narrow holes. This is not achievable by ultrasonic or radio beams.

2) Laser beam is monochromatic. This simplifies measurement processing significantly. Laser has a high intensity which is nearly not diffusing, so it is not as much attenuated by environment as other mediums. Therefore it allows performing a long distance measurement

There are four most common measuring principles implemented in laser range finders and laser scanners. These include Time of Flight method, Triangulation Method, Interferometer Method and Phase Shift Method [23]. Our choice in this study has been the Triangulation Method, as it is the most precise in relatively short distances. Binocular triangulation laser sensors intended for use in automation systems and non-contact measurement of various geometries such as: thickness, straightness, internal and external diameters, scanning of the shape of complex shapes, and determination of the position of objects. In addition, the sensor is able to connect positioning signals from machines for the implementation of 3D scanning systems. Due to the two sensors symmetrically positioned relative to the laser beam, the binocular sensor is able to work with a deeper relief without loss of signal.

The segmentation algorithm of the point cloud obtained at the stage of rough scanning of the surface has been designed by us and described in our paper [24].

IV. Conclusion

The new algorithm of synthesis of the robot manipulator motion-controlling system by dynamics and perturbations compensation method has been designed. The obtained control algorithm can be applied to automate a wide class of industrial facilities.

A 3D scanning system scheme based on laser triangulation distance sensors installed on the manipulator of the industrial robot Kawasaki RS10L has been developed. This system is based on exiting technology and equipment. It offers solution to the current issues of robotic plasma processing of complex shape workpieces.

The results of the research are of significance for a wide range of researchers developing control algorithms for production sites with mechatronic systems and for researchers developing robotic 3D scanning systems.

Conflict of Interest

The authors declare no conflict of interest

Author Contributions

Assel T. Kussaiyn-Murat and Albina T. Kadyroldina conducted the research; Alexander L. Krasavin and Gennady K. Shadrin developed the mathematical models and analyzed the data; Darya L. Alontseva and Elaheh Ghassemieh wrote the paper; all authors had approved the final version.

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