Method of measuring the surface profile by means of a mechatronic profilograph provided with a parallel control of sensor drives

S A Vasiliev 1,2, A A Fedorov 1, V V Ivantsivskiy 2 and R V Chernukhin 2
1 Chuvash State University named after I. N. Ulyanov, Cheboksary, 428015, Russian Federation
2 Novosibirsk State Technical University, Novosibirsk, 630073, Russian Federation

E-mail: vsa_21@mail.ru

Abstract. The article considers a method for measuring the surface profile by means of a mechatronic profilograph provided with parallel control of sensor drives along a specified trajectory. A description of the developed control system for the mechatronic profilograph with distributed control of its actuators is presented. The given design of the control system makes it possible for the operating unit (laser sensor) of the profilograph to effectively perform the programmed movements. The developed software implements a set of functions necessary for parallel control of the profilograph drives, depending on the specified on-line operating modes. The program allows you to set parameters and control instructions for lower-level modules, tabulate data on the movement of the working point along the x, y axes and distances in these coordinates as well as to construct 2D and 3D graphs. The implementation of the method for measuring the surface profile was carried out using a mechatronic profiler provided with parallel control of the sensor drives when profiling along the Fermat spiral. The information and measurement system made it possible to provide information on 2 parameters: the distance between the sensor and the measured surface, as well as the angle of turning determined by the angle sensor from the zero point. A graph of the measurement of the corrugated sheet surface with a flexure in the cross section downwards in polar coordinates is obtained. The analysis of the obtained data allowed us to determine the corrugated sheet flexure which was 13.8 mm, graph, immediately following the heading. The text should be set to 1 line spacing. The abstract should be centred across the page, indented 17 mm from the left and right page margins and justified. It should not normally exceed 200 words.

1. Introduction
With the development of digital technologies in various practical areas, there is a need to obtain morphological characteristics of different surfaces in a quantitative form. There are various methods and means of measurement, including contact approaches, such as profilometry [1], and non-contact methods using laser measurement technology and mathematical methods of information processing [2-5]. A number of technological parameters of the products surface shape, which include microrelief, undulation and roughness, are critical for various sectors of the economy. For example, in scientific studies of mechanical engineering [6], the morphological characteristics of metal sheets were determined, while in precision agriculture, scientific works were concerned with the measurement of microrelief, ridgeness and lumpiness of the soil [7-8]. In experimental studies [9-11], the well-known...
profilograph designed by Vasiliev S. A., determining the profile of the soil covering along a circle or a spiral, is widely used.

The design of the well-known automated profilographs consists of kinematic pairs of links that are connected to each other in series [12, 13]. The serial design of these profilographs has certain advantages, but does not allow the working point to make complex motions. It can only move along a given trajectory.

It is known that the principle of the parallel design [14, 15] is quite widely used as an operating unit for devices and technical means of measurement in the instrument-making and machine-building industries, in the agro-industrial complex and other sectors of the national economy. A specific advantage of the parallel design is rapid response along with a relatively high speed and rigidity of the structure. The interconnection of the output link and the input link of a mechatronic profilograph will present a certain chain of kinematics, and the above advantages can be obtained only by reducing the kinematic connections in the design of the device.

A number of scientific papers prove the prospects of the spiral approach as a fast method of collecting data in surface topography.

Therefore, it is relevant and effective to use new mechanisms of the distributed design in mechatronic profilograph that combine the advantages of parallel and serial designs, which allow us to obtain increased indicators of mobility, speed and a wide range of measurements of various surfaces profiles.

We have developed a parallel-serial design of the mechatronic profilograph and its control system. Using the main control system the measurements are carried out remotely by the operator by means of a laptop. The control functions for the lower level are located in the central control unit of the profilograph.

2. Methods
In designing the control system of the mechatronic profilograph, there was a task to study the developed control unit for the operating mechanisms such as electric drives of measuring sensors. In addition, to accurately determine the horizontal surface in which the laser sensor moves, the mechatronic profilograph was provided with an accelerometer and a gyroscope. The mechatronic profilograph was equipped with a GPS receiver to establish the coordinates of geo-location for the use in the field of accurate land utilization, and with a compass for orientation, which makes it possible to use the system for manipulating various means of control in on-line mode.

Figure 1 shows the parallel design of the mechatronic profilograph control system including the control unit with separate electric drives giving the mechatronic device two degrees of freedom. The mechatronic profilograph consists of a base, a rack on which an angle sensor is mounted, by means of rolling bearings, a housing with a power supply unit and a control unit placed in it, a fixed support wheel, a satellite communicating with it, a laptop provided with an information measurement system and computer control to coordinate the operation of electric motors during the measurement, as well as a program for processing the data received from sensors and devices, a guide, a carriage, a laser position sensor and electric motors. The housing is mounted on a rack by means of rolling bearings. Fixed support wheel, a satellite and a motor located on the movable housing are used to rotate it. The laptop is connected with the control unit, sensors and electric motors via Bluetooth using built-in Bluetooth radio modules.

The principle feature of the control system is Bluetooth communication which provides data transmission to the control system, the laser sensor, the laptop and the angle encoder. Besides, Bluetooth communication prevents the winding of electrical wires when the profilograph sensor rotates.

Application of a laptop as the main unit for processing the obtained data makes it possible to perform the most resource-consuming tasks, including the automatic control of the profilograph. At the same time, there is every indication for the automatic mode of the mechatronic profilograph operation.
3. Results and discussion

The experiments were carried out on a mechatronic profilograph provided with two operating mechanisms having two measurement sensors (figure 2).

The developed unit for controlling the profilograph drives uses the main 32-bit control chip-STM32F103. In particular, the control unit consists of the VN3SP30 collector motor driver and the TMC2209 stepper motor driver, a set of various chips, an RS42S interface converter, and a set of connectors used for standard digital and analog interfaces. The basic methods for processing the data received from the measuring sensors are programmed in the control unit using the developed program. Algorithms for controlling electric drives are implemented, including the following elements: a PID controller for manipulating the collector motor, a device for processing and calculating data received from the angular encoder, a device for generating control signals when the carriage of the operating link moves along a given trajectory, a PWM signal generator.

In the control unit, the elements of the considered system will be arranged in the following sequence: RF-605 laser distance sensor via the RS-485 interface → motor driver and encoder driver → GPIO lines of the controller. The HC-06 Bluetooth module communicates with the head controller. This module is connected to the UART port of the STM32F103 microcontroller. The Bluetooth counterpart is connected via a USB-UART converter to a free USB port of the laptop.

Using a laptop, the operator selects the required measurement operation or programs it using the profilograph control system software. For example, he can set the parameters of the profilograph laser sensor trajectory; program the graphical interface; generate instructions to control the profilograph laser sensor according to the specified laws of movement; receive and transmit information using Bluetooth connection.

The obtained information is presented by the well-known polar spiral equation for the Fermat spiral, included in the measurement information system:

\[ \rho = \sqrt{a^2 \gamma}, \]  

(1)

where ρ - the radius - vector, m, a - the spiral coefficient, γ - the angle of the radius - vector position from the zero point, deg.

In the Cartesian coordinate system, the Fermat spiral is described by the equations:
where $x$ - the longitudinal coordinate, m; $y$ - the transverse coordinate, m; $z$ - the vertical coordinate - the height of the measured surface irregularities at a given point, m.

\[
\begin{align*}
  x &= \rho \cos \gamma, \\
  y &= \rho \sin \gamma, \\
  z &= z.
\end{align*}
\]  

(2)

The height of the surface irregularities at a given point is determined by the equation:

\[
z = z_{\text{max}} - z',
\]

(3)

where $z_{\text{max}}$ - the maximum distance between the position sensor and the measured surface, m; $z'$ - the actual distance between the position sensor and the measured surface, m.

Experimental studies of the mechatronic profilograph for spiral scanning were conducted in the laboratory of the Mechanical Engineering Faculty of the Chuvash State University named after I. N. Ulyanov. The obtained data on the corrugated sheet surface profile according to the Fermat spiral were tabulated using the MS Excel program. The analysis of the obtained data allowed us to determine the corrugated sheet flexure in the cross section downwards, which was 13.8 mm. The height of the corrugation of the corrugated sheet C-9 was 8.9 mm that satisfies the requirements of product quality control.

4. Conclusion
The designed control system for changing the control signals implements the synthesis laws for changing the generalized coordinates of the mechatronic profilograph. The developed computer software allows the operator to position the laser sensor when setting different movement trajectories and to obtain data on the working point movement along the axes, as well as on the distance to the surface in these coordinates. By reducing the speed of profiling or selecting a movement sensor we can slightly increase the accuracy of measurement by means of the mechatronic profilograph.
Acknowledgment

The article was prepared under the financial support of the Russian Federation President grant no. MD-1198.2020.8.

References

[1] Lushnikov N and Lushnikov P 2017 *J.Transportation Research Procedia* **20** 425-9
[2] Alexander V, Deng H, Islam M and Terry F 2010 Non-contact surface roughness measurement of crankshaft journals using a super-continuum laser *Conf. on Lasers and Electro-Optics* **5** 12-6
[3] Abidin F Z, Hung J and Zahid M N 2019 *IOP Conf. Series: Materials Science and Engineering* **469** 012074
[4] Shih F Y 2010 Image processing and pattern recognition: fundamentals and techniques *Hoboken, NJ Wiley* 537
[5] Lee B Y and Tarng Y S 2001 *Int. J. Machine tools and Manufacture* **41** 1251-63
[6] Stoudt M and Hubbard J B 2015 *J. Acta Materialia* **53** 4293-304
[7] Vasiliev S A, Alekseev V V and Rechnov A V 2015 *J. Agrarian scientific* **9** 11-3
[8] Hockauf R, Grove T and Denkena B 2019 *J. Manufacturing and Materials Processing* **3** 40
[9] Vasiliev S, Kirillov A and Afanasieva I 2018 *Engineering for Rural Development Proc.* **17** 537-42
[10] Vasiliev S A 2016 *Bulletin of Nizhnevolsk agrouniversity complex: science and higher professional education* **3** 220-6
[11] Vasiliev S A 2016 *J. Russian Research Institute of Problems of Melioration* **4** 40-54
[12] Polyakov V M and Nearing M A 2019 *J. Soil Science Society of America* vol 83 pp 327-331
[13] Vasiliev S A, Fedorova A A and Alexandrov R I 2019 *Pat. of the Russian Federation No* 2707907
[14] Merlet J P 2000 Parallel robots. *Academic Publishers* 372
[15] Heylo S V, Glazunov B A and Palochkin S V 2011 Structural synthesis *Kinematic and Power Analysis* **153**