# MECHATRONIC SYSTEM USED IN THE LABORATORY FOR COMPLEX ANALYSIS APPLIED AND USED IN INDUSTRY
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# *SISTEM MECATRONIC UTILIZAT IN LABORATOR PENTRU ANALIZE COMPLEXE APLICATE ȘI UTILIZATE ÎN INDUSTRIE*

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## ABSTRACT
*Equipment and methods for microfabrication and micro measurements are under constant development. There are a multitude of possibilities to connect and control equipment for control and measurements adapted with the development of Industry 4.0. Using the terms Internet of Things, 3D printing, virtual reality, augmented reality, collaborative robots, microfabrication, etc. and related applications are common in daily research and innovation activity. This paper presents the construction of a mechatronic system and the measurement procedures used in the working mode. Experimental results and their interpretation as well as the final conclusions of this paper are presented. The mechatronic system is intended for use in the main fields such as automotive, aeronautics, robotics, agriculture and others.*

## REZUMAT
*Echipamentele și metodele pentru microfabricație și micromăsurări sunt în continuă dezvoltare. Există o multitudine de posibilități de a conecta și de a controla echipamente pentru control și măsurări adaptate o dată cu dezvoltarea Industriei 4.0. Utilizarea termenilor Internet of Things, printare 3D, realitate virtuală, realitate augmentată, roboți colaborativi, microfabricație, etc. și a aplicațiilor aferente sunt comune în activitatea zilnică de cercetare și inovare. Această lucrare prezintă construcția unui sistem mecatronic și procedurile de măsurare utilizate în modul de lucru. Sunt prezentate rezultate experimentale și interpretarea acestora precum și concluziile finale ale acestei lucrări. Sistemul mecatronic este destinat utilizării în principalele domenii, cum ar fi cel auto, aeronautic, agricultură, robotică și altele.*

## INTRODUCTION
In the research activity in the field of mechatronics, a precise method of measurement is necessary in order to carry out conclusive tests. The development of manufacturing processes is correlated with the four identified industrial revolutions: the first industrial revolution took place at the end of the 18$^{th}$ century and the beginning of the 19$^{th}$ century; the second industrial revolution begun at the end of the 19$^{th}$ century; the third industrial revolution begun in the second half of the 20$^{th}$ century; and the fourth industrial revolution begins with the 3$^{rd}$ millennium (*Vinitha K. et al., 2020*).

The mechatronic system presented in this paper is intended for the improvement of mechanical microfabrication (*Brousseau et al., 2010; Razali et al., 2013; Quaglia G. et al., 2020*) techniques, namely: micro-milling, micro-drilling, micro-turning, micro-rectification, micro-polishing, micro-polishing and water jet abrasive micro-machining, etc. Also, the mechatronic system is intended to improve microforming techniques: microforging, microextrusion, microstamping and microhydroforming, microforming (*Xu J. et al., 2021; Raja P. et al., 2021*), etc.

Globally, there is an ongoing concern for microfabrication, especially for its manufacturing methods/processes. One of the most popular microfabrication processes is microforming.

Recently, in Europe, the concept of micro-nano manufacturing technologies (MNMT) was used due to the difficulty to delimit the fields of micro technologies and nano technologies. An example is The Center of Micro/Nano Manufacturing Technology (MNMT-Dublin - https://www.mnmt-dublin.org/) and INCDMTM laboratories (*www.incdmtm.ro*) used in the daily research and innovation activity (*Gheorghe et al., 2022*).

The paper aims to present a mechatronic system *(Ivanov D., 2021)* that is intended for use in the laboratory and in the industrial environment and improves the quality of positioning and measurement in the field of mems correlated with the reduction of working time. The approach to the measurement systems and the procedures used is, lately, built on Industry 4.0 (*Oztemel et al., 2020; Zheng et al., 2021; Ghobakhloo M., 2020*) and IoT (*Kiran D.R., 2017*) concepts in order to control the mechatronic system from distance and watch the measurement process through virtual reality applications, augmented reality (*Tan et al., 2022*) or robots or collaborative robots (*Böckmann et al., 2021; Patange et al., 2022*). An important aspect of various industries' approaches to data use is data protection and cyber security (*Martin et al., 2017*).

## MATERIALS AND METHODS

The mechatronic system is based based on a hexapod platform with controller (*Gauthier et al., 2011*) presented in Figure 1 and uses for measurements a transducer with (Figure 3, position 4) and a renishaw probe (Figure 5, position 2) with a ruby ball stylus.

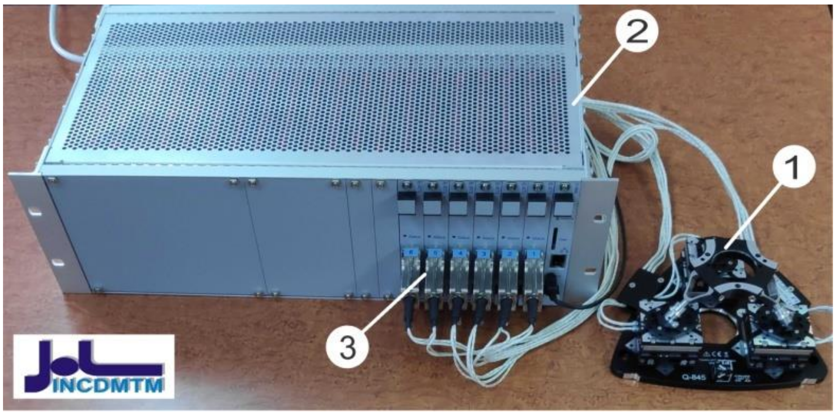


**Fig. 1 - Mechatronic system used in the laboratory for complex analysis applied in industry**

*1-Motion platform with six degrees of freedom; 2- Kinematic controller; 3-Connection plugs for controller and motion platform*

The main characteristics motion platform are: ±7 mm travel range in X and Y, and ±5 mm in Z; ±7° rotation range in θX, θY, and ±8° in θZ; 10 N load capacity, center mounted.

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The Renishaw probe have a 10 cm feeler and it has a force of 0.07–0.08 N.

The transducer has 10 mm measurement range and 1 µm resolution.

For analysis and interpretation regarding the microgeometry topography of the structures surfaces (*Garcia et al., 2020*) for the measured parts analysed in presented paper is used Atomic Force Microscope from INCDMTM CERTIM Laboratory and presented in Figure 2. The movement accuracy is at the nanometer level and allows the system to amplify the displacement > 2000 times.


**Fig. 2 - AFM Microscope, NTEGRA Probe NanoLaboratory NT – MDT**

*1 – base unit; 2 – measurement head; 3 – vibrations isolation system; 4 – optical system visualization*

Following the scanning of 50 × 50 µm surfaces, different topographic parameters could be analysed (roughness, surface asymmetry, flattening coefficient), which provide information related to the surface quality of the measured part. In this way it was possible to characterize in detail the structure of the surfaces.

The determined topographic parameters (roughness-Ra, maximum height-$h_{max}$, height in 10 points-Rz, asymmetry of the surface-Ssk, flattening coefficient-Ska) following the AFM study provide information related to the analysed surfaces.

The asymmetry index Rsk evaluates the degree of asymmetry of a distribution and characterizes, together with the flattening index Ska, the shape of the distribution (illustrated as a histogram). The Ssk asymmetry index is negative or positive as the survey distribution is asymmetric to the left or to the right, respectively. A symmetrical distribution, such as the normal distribution, has zero asymmetry.

The flattening coefficient Ska is part of the indices of appreciation of the shape of a distribution. A high flattening index shows a distribution with large "tails" (far from average categories are present), while a low flattening index shows a distribution in which fewer far from average categories are present. In the case of a distribution close to the normal distribution, the flattening coefficient is around 3. Based on this result, the excess E is defined as the difference between the flattening coefficient and three. For E> 0, the distribution is called leptokurtic (the height of the curve is higher compared to normal), and for E <0, it is called platykurtic (the curve is flattened). If E = 0, the distribution is mesokurtic. Excessively large data sets tend to have a distinct peak near the mean. Low excess data sets tend to have a flat maximum near the average rather than a sharp peak. A uniform distribution would be the extreme case.

The method for measurement with mechatronic system using the transducer and renishaw probe with stylus is using the contact point by positioning the with motion platform and controller. The measurement are made in 4 point and repeated 10 times for each measurement point. The relation used for result determine is:

$$\overline{y} = \frac{\sum_{i=1}^{10} p_i}{10} \text{ [mm]} \quad (1)$$

The measurement procedure for mechatronic system is presented in the next 5 figures and we can see the contact point realized. The measurement can be done in industry like automotive, agriculture, aeronautical etc.

In Figure 3 is presented the mechatronic system and linear transducer in the active measurement of a cylindrical probe.

In Figure 4 is presented the mechatronic system and linear transducer in the active measurement of a automotive industry probe.

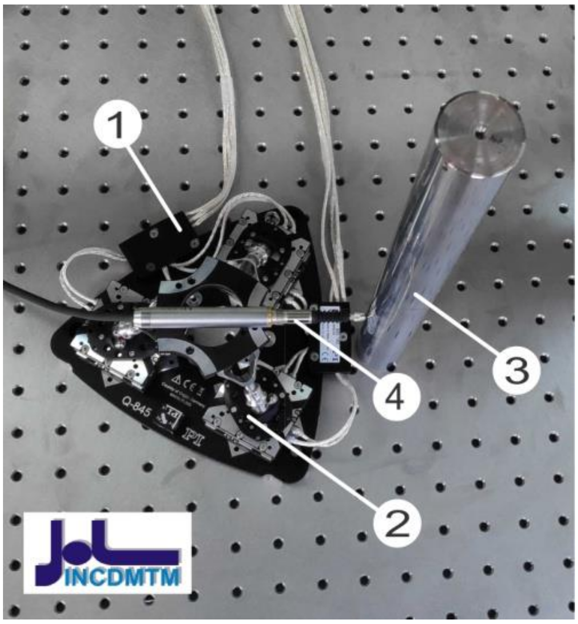



**Fig. 3 - Measurement process with mechatronic system and transducer – view 1**

*1- drive motor for movement and positioning platform;*
*2- movement and positioning platform;*
*3 - measured part; 4- linear transducer*

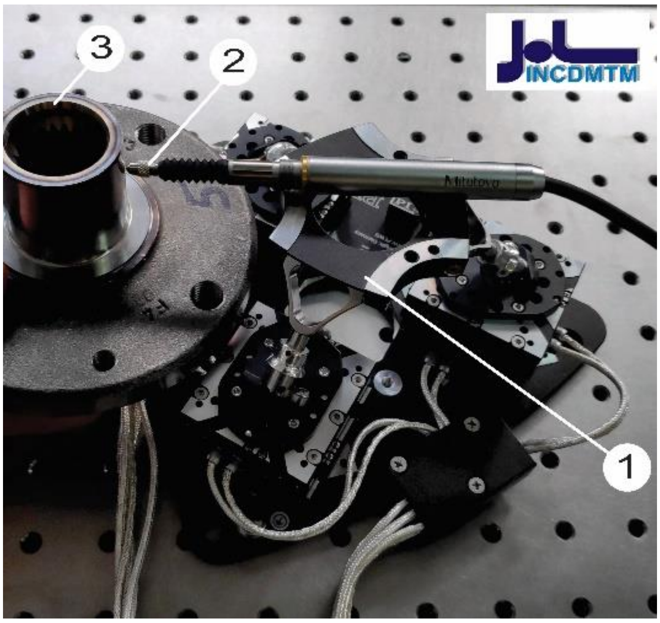



**Fig. 4 - Measurement process with mechatronic system and transducer – view 2**

*1-movement and positioning platform; 2- linear transducer;*
*3-measured part*

In Figure 5 is presented the mechatronic system and stylus probe in the active measurement of a 3D prototyped probe made of plastic material powder.

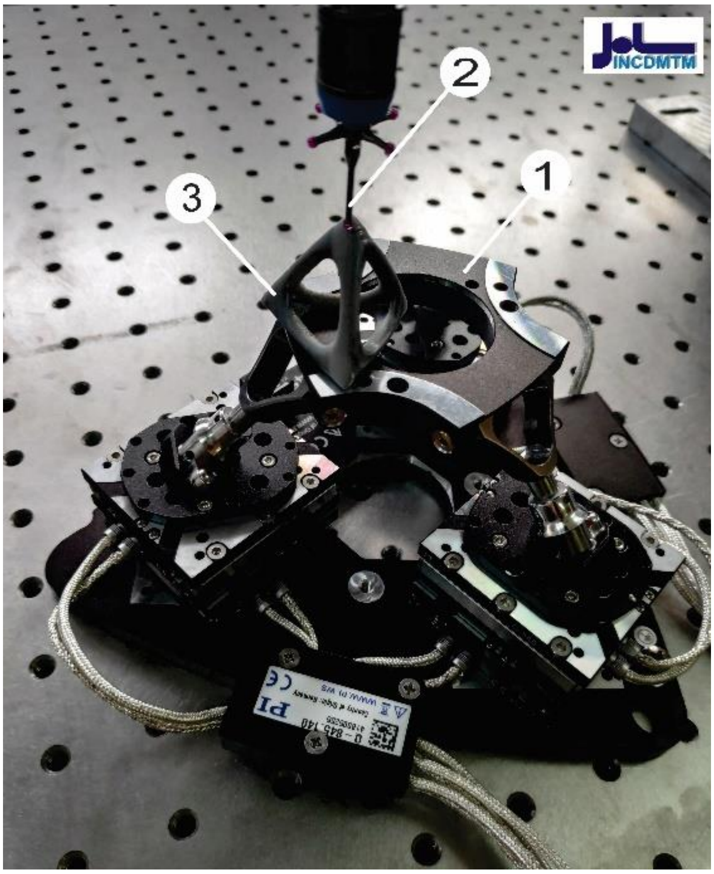



**Fig. 5 - Measurement process with mechatronic system and probe stylus – view 1**
*1-Movement and positioning platform; 2- 3D stylus probe; 3- 3D printed plastic probe for measurement*

In Figure 6 is presented the mechatronic system and stylus probe in the active measurement of a 3D prototyped probe made of metal material powder.

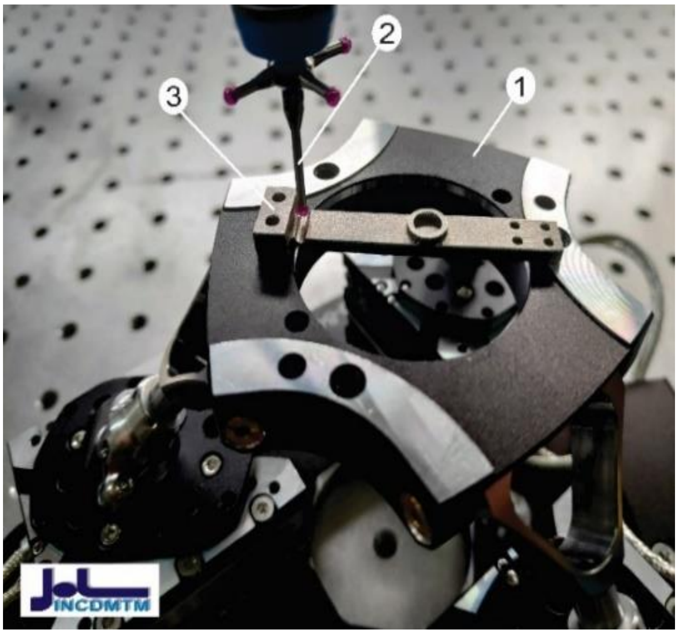



**Fig. 6 - Measurement process with mechatronic system probe stylus – view 2**
*1-Movement and positioning platform; 2- 3D stylus probe; 3- 3D printed metal probe for measurement*

In Figure 7 is presented the mechatronic system and stylus probe in the active measurement of automotive industry probe.

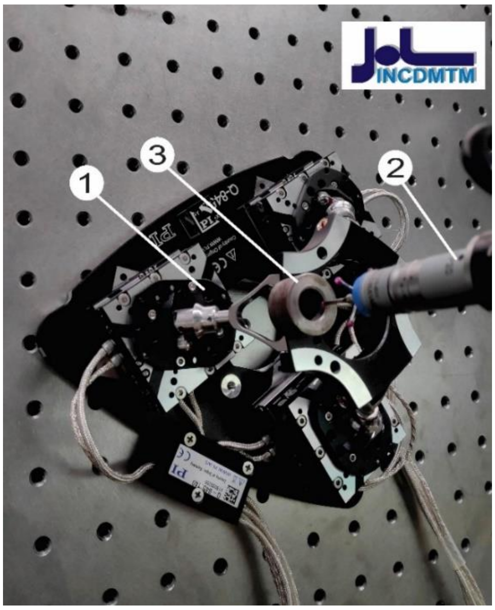
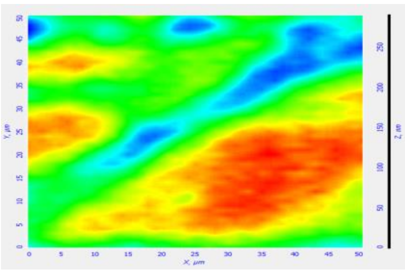



**Fig. 7 - Measurement process with mechatronic system probe stylus – view 3**
*1-Movement and positioning platform; 2- 3D stylus probe; 3- Measured part*

## RESULTS

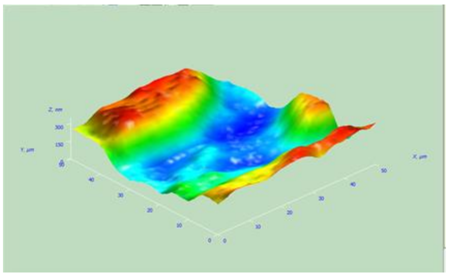
The results for analysis and interpretation on the microgeometry topography of the structures surfaces for the measured parts analysed are presented in Table 1 and Figures 8-10, which present the values of the main topographic parameters determined experimentally and their calculated average value for the measured part.



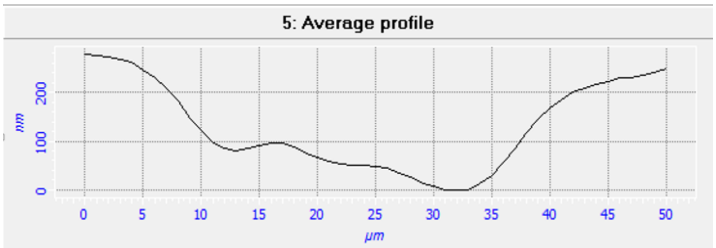
*(a) the scanned 2D surface*

| | |
|---|---|
| Amount of sampling | 2601 |
| Max | 358.251 nm |
| Min | 0 nm |
| Peak-to-peak, Sy | 358.251 nm |
| Ten point height, Sz | 179.681 nm |
| Average | 167.593 nm |
| Average Roughness, Sa | 99.9529 nm |
| Second moment | 201.026 |
| Root Mean Square, Sq | 111.014 nm |
| Surface skewness, Ssk | 0.2145 |
| Coefficient of kurtosis, Ska | -1.44054 |
| Entropy | 6.86163 |
| Redundance | -14.5328 |

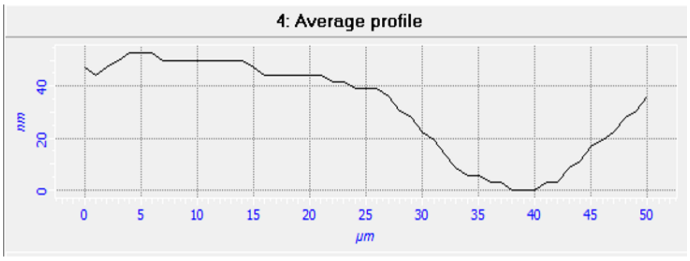
*(b) determined topographical parameters*



*(c) the scanned surface transformed into 3D*

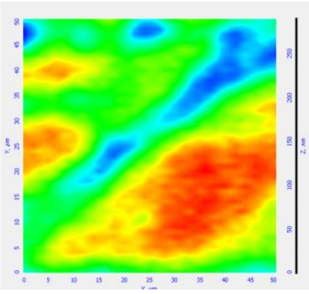



*(d) the average profile in the X direction*




*(e) the average profile in the X direction*

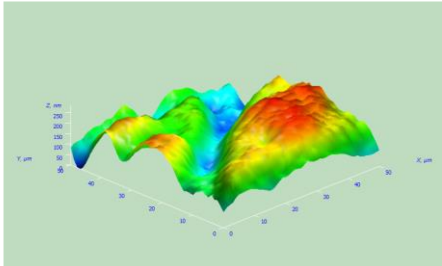
**Fig. 8 - Surface analysis of area 1 on the part measured using AFM**



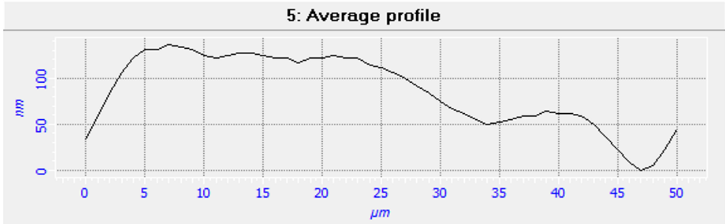
(a) the scanned 2D surface

| | |
|---|---|
| Amount of sampling | 2601 |
| Max | 288.823 nm |
| Min | 0 nm |
| Peak-to-peak, Sy | 288.823 nm |
| Ten point height, Sz | 148.855 nm |
| Average | 169.075 nm |
| Average Roughness, Sa | 55.8775 nm |
| Second moment | 181.65 |
| Root Mean Square, Sq | 66.4111 nm |
| Surface skewness, Ssk | -0.279015 |
| Coefficient of kurtosis, Ska | -0.847434 |
| Entropy | 6.45144 |
| Redundance | -16.6243 |

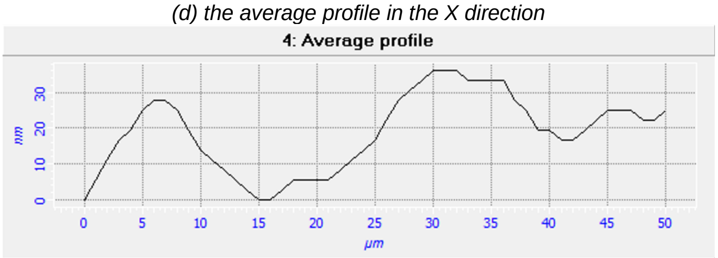
(b) determined topographical parameters



(c) the scanned surface transformed into 3D

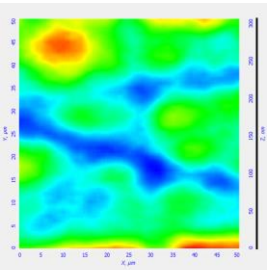



(d) the average profile in the X direction




(e) the average profile in the X direction

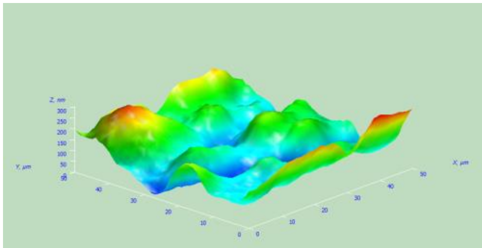
**Fig. 9 - Surface analysis of area 2 on the part measured using AFM**



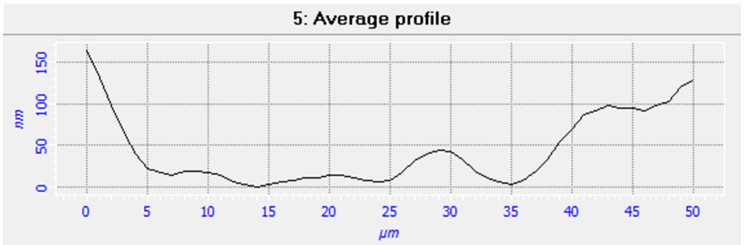
(a) the scanned 2D surface

| | |
|---|---|
| Amount of sampling | 2601 |
| Max | 305.486 nm |
| Min | 0 nm |
| Peak-to-peak, Sy | 305.486 nm |
| Ten point height, Sz | 151.632 nm |
| Average | 117.3 nm |
| Average Roughness, Sa | 46.8714 nm |
| Second moment | 131.17 |
| Root Mean Square, Sq | 58.7044 nm |
| Surface skewness, Ssk | 0.664095 |
| Coefficient of kurtosis, Ska | -0.0103481 |
| Entropy | 6.31535 |
| Redundance | -15.4212 |

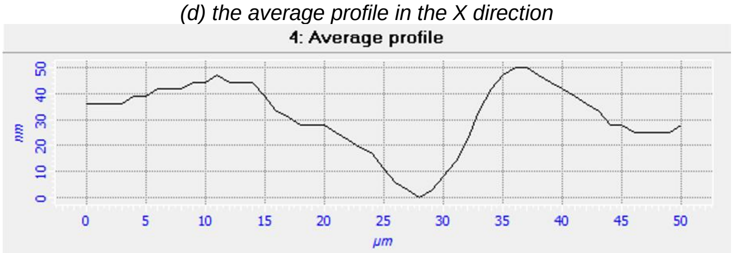
(b) determined topographical parameters



(c) the scanned surface transformed into 3D




(d) the average profile in the X direction




(e) the average profile in the X direction

**Fig. 10 - Surface analysis of area 3 on the part measured using AFM**

Table 1 presents the results of the surface analysis of measured piece.

**Table 1**

**The average of the selected parameters for 3 measured areas**

| Analysed zone | Ra (nm) | $h_{max}$ (nm) | Ssk | Ska |
|---|---|---|---|---|
| Area 1 | 99.95 | 358.25 | 0.21 | -1.44 |
| Area 2 | 55.87 | 288.82 | -0.27 | -0.84 |
| Area 3 | 46.87 | 305.48 | 0.66 | -0.01 |
| **Average calculated value** | **67.56** | **317.52** | **0.20** | **-0.76** |

The results of measurement tests are presented in Table 2.

**Table 2**

**Measurement 4 points 10 times**

| Number of measurement | Point 1 [μm] | Point 2 [μm] | Point 3 [μm] | Point 4 [μm] |
|---|---|---|---|---|
| **1** | 596 | 700 | 801 | 898 |
| **2** | 603 | 696 | 802 | 900 |
| **3** | 600 | 696 | 801 | 905 |
| **4** | 602 | 698 | 798 | 904 |
| **5** | 604 | 703 | 796 | 896 |
| **6** | 603 | 705 | 797 | 898 |
| **7** | 600 | 705 | 797 | 900 |
| **8** | 595 | 697 | 800 | 899 |
| **9** | 597 | 700 | 801 | 904 |
| **10** | 601 | 702 | 800 | 902 |
| $\overline{y}=\frac{\sum_{i=1}^{10} p_i}{10}$ | 600.10 | 700.20 | 799.30 | 900.60 |

According to Table 2, for the set of 10 measurements performed on 4 contact points, there is a similar variation for repetability. For point 1, there is a variation between 595 μm and 604 μm resulting $\overline{y}=\mathbf{600.10}\,\overline{y}$ μm. For point 2, there is a variation between 696 μm and 705 μm resulting $\overline{y}=\mathbf{700.20}\,\overline{y}$ μm. For point 3, there is a variation between 796 μm and 802 μm resulting $\overline{y}=\mathbf{799.30}\,\overline{y}$ μm. For point 4, there is a variation between 896 μm and 902 μm resulting $\overline{y}=\mathbf{799.30}\,\overline{y}$ μm.

## CONCLUSIONS

In conclusion, considering all the measurements and analysis presented and prepared as a result of the experimental research carried out in the metrologically certified laboratories of the National Institute for Research-Development in Mechatronics and Measurement Technique in Bucharest, the mechatronic system is validated for metrological and industrial use in technical fields of automotive, agricultural, aeronautics, robotics etc. and in all manufacturing industries.

Future research and concept development, starting from the presented mechatronic system, are highlighted below:

- Research on the development of a virtual application for mechatronic system;
- Research for improved protection of the human operator;
- Research to improve the speed and stability of the mechatronic system;
- Research on the mapping of the workspace so that we can accurately identify, at any time, the position of the analysed parts at a defined time.

## ACKNOWLEDGEMENT

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The author is grateful to INCDMTM Bucharest. Design Execution and testing parts was an extremely delicate process due to its innovative character and precision of execution. For this reason, was preferred to make them on specialized 3D printing equipment, existing in the CERMISO center from INCDMTM Bucharest. In this sense, an EP - M250 Shining 3D equipment was used for 3D metal printing and a JCR 1000 Dual Sicnova equipment for 3D plastic printing. Access to these modern technologies has greatly facilitated the process of adapting the elements mentioned above to the executed mechatronic system, eliminating costs and additional time generated by the classic casting technology.

**REFERENCES**

[1] Akhtar Razul Razali, Yi Qin, (2013). A Review on Micro-manufacturing. Micro-forming and their Key Issues. *Procedia Engineering*, Vol. 53, pp. 665-672, ISSN 1877-7058. https://doi.org/10.1016/j.proeng.2013.02.086.

[2] Böckmann, Sönke, Igor Titov, and Martina Gerken, (2021). Extraction of Soil Solution into a Microfluidic Chip. *AgriEngineering*, Vol.3, no. 4. pp. 783-796. https://doi.org/10.3390/agriengineering3040049

[3] Brousseau, E. B., Dimov, S. S., & Pham, D. T., (2010). Some recent advances in multi-material micro- and nano-manufacturing. *International Journal of Advanced Manufacturing Technology*, Vol. 47(1-4), pp.161-180. doi:10.1007/s00170-009-2214-5.

[4] Garcia, R. (2020). Nanomechanical mapping of soft materials with the atomic force microscope: Methods, theory and applications. *Chemical Society Reviews*, Vol. 49(16), pp.5850-5884. doi:10.1039/d0cs00318b.

[5] Gauthier, M., (2011). Microhandling strategies and microassembly in submerged medium. *Robotic microassembly*, pp. 189-224. doi:10.1002/9780470634417.ch5.

[6] Gheorghe, G; Sorin-Ionut, B; Ilie, I; Veronica, D; (2022) Is Romania Ready for the Development of Smart Industry 4.0?. *Innovations in mechatronics engineering*. pp. 293-304. doi 10.1007/978-3-030-78170-5_26

[7] Ghobakhloo, M., (2020). Industry 4.0, digitization, and opportunities for sustainability. *Journal of Cleaner Production*, Vol. 252, doi:10.1016/j.jclepro.2019.119869.

[8] Ivanov, D., Tang, C. S., Dolgui, A., Battini, D., & Das, A., (2021). Researchers' perspectives on industry 4.0: Multi-disciplinary analysis and opportunities for operations management. *International Journal of Production Research*, Vol. 59(7), pp. 2055-2078. doi:10.1080/00207543.2020.1798035.

[9] Kiran D.R. (2019). Internet of Things. Production Planning and Control. pp. 495-513, ISBN 9780128183649. https://doi.org/10.1016/B978-0-12-818364-9.00035-4.

[10] Martin E., Thomas D., Hristo A., (2017). The Evolution of the V-Model: From VDI 2206 to a System Engineering Based Approach for Developing Cybertronic Systems. *14th IFIP International Conference on Product Lifecycle Management (PLM)*. pp. 382-393, ff10.1007/978-3-319-72905-3_34ff. ffhal-01764166f

[11] Oztemel, E., & Gursev, S., (2020). Literature review of industry 4.0 and related technologies. *Journal of Intelligent Manufacturing*, Vol. 31(1), pp. 127-182. doi:10.1007/s10845-018-1433-8.

[12] Patange, Abhishek & R, Jegadeeshwaran & Bajaj, Naman & Khairnar, Apoorva & Gavade, N., (2022). Application of Machine Learning for Tool Condition Monitoring in Turning. *Sound & Vibration*. Vol. 56, pp. 127–145. 10.32604/sv.2022.014910.

[13] Pradeep Raja, C., & Ramesh, T., (2021). Influence of size effects and its key issues during microforming and its associated processes – A review. *Engineering Science and Technology, an International Journal*, Vol. 24(2), pp. 556-570. doi:10.1016/j.jestch.2020.08.007.

[14] Quaglia, Giuseppe, Carmen Visconte, Leonardo Sabatino Scimmi, Matteo Melchiorre, Paride Cavallone, and Stefano Pastorelli, (2020). Design of a UGV Powered by Solar Energy for Precision Agriculture. *Robotics* 9, Vol. 1: 13. https://doi.org/10.3390/robotics9010013

[15] Tan, Yi, Wenyu Xu, Shenghan Li, and Keyu Chen, (2022). Augmented and Virtual Reality (AR/VR) for Education and Training in the AEC Industry: A Systematic Review of Research and Applications. *Buildings*. Vol. 12(10), 1529. https://doi.org/10.3390/buildings12101529

[16] Vinitha, K., Ambrose Prabhu, R., Bhaskar, R., & Hariharan, R., (2020). Review on industrial mathematics and materials at industry 1.0 to industry 4.0. *Materials Today: Proceedings*, Vol. 33, pp. 3956-3960. doi:10.1016/j.matpr.2020.06.331.

[17] Xu, J., Wang, X., Wang, C., Yuan, L., Chen, W., Bao, J., . . . Guo, B., (2021). A review on Micro/Nanoforming to fabricate 3D metallic structures. *Advanced Materials*, Vol. 33(6). doi:10.1002/adma.202000893.

[18] Zheng, T., Ardolino, M., Bacchetti, A., & Perona, M., (2021). The applications of industry 4.0 technologies in manufacturing context: A systematic literature review. *International Journal of Production Research*, Vol. 59(6). pp. 1922-1954, doi:10.1080/00207543.2020.1824085.

[19] https://incdmtm.ro/?lang=en

[20] https://www.mnmt-dublin.org/