MEMS MEASUREMENT USING A PLASTIC AND METAL ARM INTEGRATED INTO A MECHATRONIC SYSTEM

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Abstract – The paper is related with microfabrication, IoT and 3D printing. Globally, there is an ongoing concern for microfabrication, especially for its manufacturing methods / processes. Industry 4.0 is an important term and refers to the digitization of all industrial processes and their transformation into smart, efficient and autonomous processes through detection, connectivity, big data analysis and control. An important component of Industry 4.0 is 3D printing. Along with Additive Manufacturing (AM), we can use the name Rapid Manufacturing (RM) or Rapid Prototyping (RP). Other less common names are digital manufacturing / fabrication, layered manufacturing or DMF (Desktop Manufacturing).

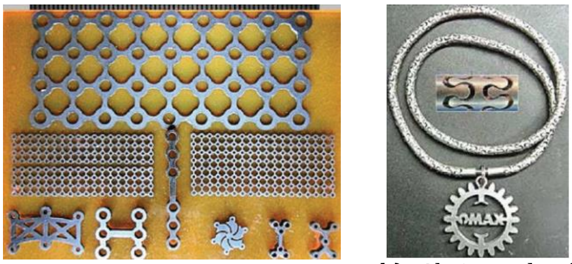
Keywords: MEMS, Measurements, 3D print, Metal, Plastic, Degrees of freedom.

1. Introduction

MEMS systems represent the natural evolution of millimeter systems by resizing them to values close to or below 1 mm.

Globally, there is an ongoing concern for microfabrication [1], especially for its manufacturing methods / processes. Microfabrication [2] refers to the production of parts or the characteristics of parts with at least two dimensions in the submillimeter range. The size of the part can go up to a few millimeters, while the characteristics of the part are largely in the range of micrometers.

In order to further highlight the micro and nano domain, mechanical microfabrication and microforming a few techniques were selected for description. An example is presented in Figure 1.



a) Titanium and stainless steel orthopedic parts

b) Chain made of a solid titanium tube (outer diameter is 0.64 mm)

Figure 1: Examples of abrasive parts micro processed with water jet [3]

The world is constantly changing in terms of technologies and how human interact with them in order to find and implement solutions for a better life.

Industry 4.0 [4][5][6][7] refers to the digitization of all industrial processes and their transformation into intelligent, efficient and autonomous processes through detection, connectivity, big data analysis and control.

Figure 2: Ecosystem of Industry 4.0
Source: www.xenrc.com [8]

An important component of Industry 4.0 is 3D [9][10][11] printing. Along with AM (Additive Manufacturing), we can use the name Rapid Manufacturing (RM) or Rapid Prototyping (RP). Other less common names are digital manufacturing / fabrication, layered manufacturing or DMF (Desktop Manufacturing).

We live in a connected world where billions of computers, tablets, smartphones, buildings, portable objects, medical devices, game consoles, and other smart items are constantly purchasing, processing, and providing information.

IoT [12][13][14][15] is a global communications network infrastructure that connects physical and virtual entities around us, taking advantage of massive data capture and communication capabilities.

Today's industry has facilitated the emergence of collaborative robots, called cobots, especially due to the need for a common work environment in which humans and cobots carry out complex activities.

The cobot is a robot designed for physical interaction with humans in a common workspace.

Cobots are specially created to work with people, not just for them. Instead of being in a cage, they work in a cooperative environment and help with complex tasks that cannot be fully automated. For example, they can hand over components to the people they work with, who will perform more precise assemblies or quality control tasks.

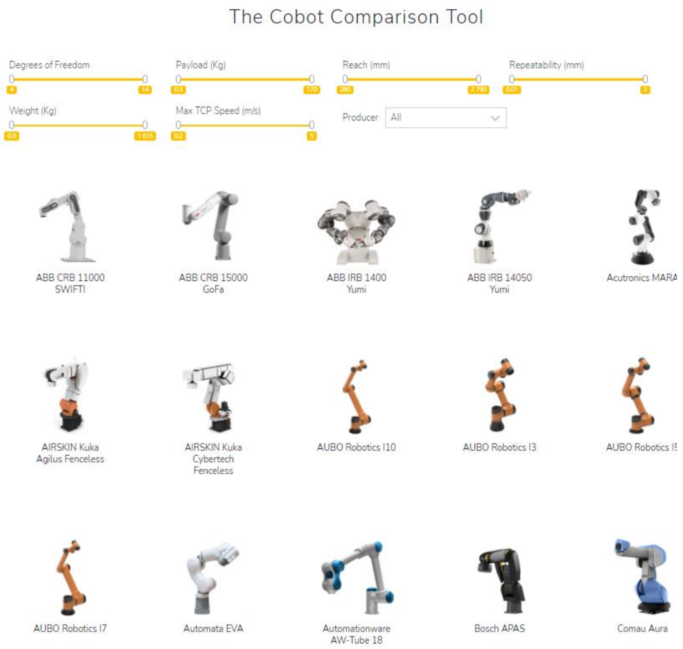


Figure 3: Cobots – tool for comparing cobots [16]

2. Description of MEMS Mechatronic System and Tests Performed With it

The paper describes the design and realization, in its own conception, of an intelligent integrated mechatronic system designed for MEMS constructions. The design and realization of the system has two directions in which parts are tested and analysed using an arm made of metal powder such as a plastic arm. The tests performed were completed by comparing the results obtained with the two arms.

2.1. Description of the MEMS Mechatronic System

Looking at the current state of the art in the field of MEMS and NEMS, the author of this paper designed and developed a smart integrated mechatronic system for MEMS & NEMS constructions used in manufacturing processes and ultra-precise measurements. The structure of the smart integrated mechatronic system for ultra-accurate measurements is shown in Figure 4.

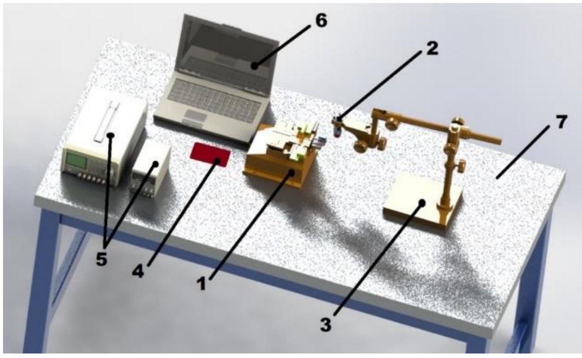


Figure 4: The structure of the smart integrated system for high-precision measurements

Legend:

(1) measuring and positioning subassembly
(2) digital microscope;
(3) digital microscope support holder;
(4) electronic board for measuring microrobot control;
(5) power supplies;
(6) PC data acquisition and subassembly measurement and positioning control;
(7) anti-vibration laboratory table.

The purpose of the smart integrated mechatronic system for high-precision measurements is too high-precision measure parts with submillimeter dimensions so that they can be used in MEMS and NEMS manufacturing processes. In order to be able to observe the measurement process, a digital microscope (part 2 of figure 4) is used positioned above the measuring part with the help of the microscope holder (part 3 of figure 4). In order to acquire the obtained data, a PC is used (reference 6 from figure 4) which stores and analysis the recorded data but also allows the visualization of the part measurement process through a specialized software installed for the digital microscope. The power supplies (part 5 of figure 4) and the electronic board (part 4 of figure 4) are used to control the measuring microrobots in the measuring and positioning subassembly (part 1 of figure 4). The measuring and positioning subassembly is shown in Figure 5).

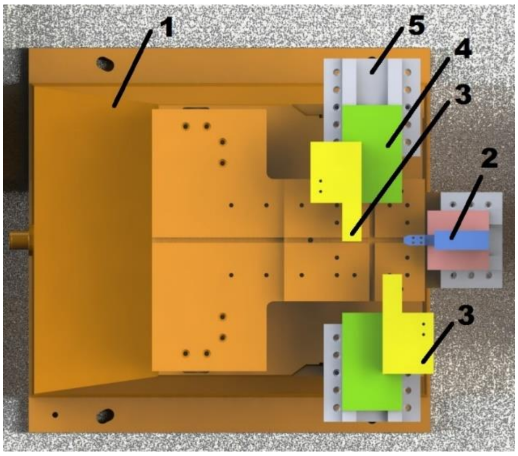


Figure 5: Measuring and positioning subassembly

Legend:
(1) Robotic positioning system HEXAPOD F-206, with 6 degrees of freedom
(2) Measuring robot with metal arm;
(3) Measuring robot with plastic arm;
(4) Upper positioning plate measuring robots;
(5) Bottom plate for positioning measuring robots

Micro-robots for measuring with metal arm (reference 2 in figure 5) and plastic (reference 3 in figure 5) slide with the help of the positioning plate (reference 4 in figure 5) fixed on the hexapod (reference 1 in figure 5) with the help of the fixing plate (part 5 of figure 5). The positioning is done so that the measuring needle is positioned next to the measuring piece.

In Figure 6 is presented the robots used for measurements and we can see all the 3D printed parts.

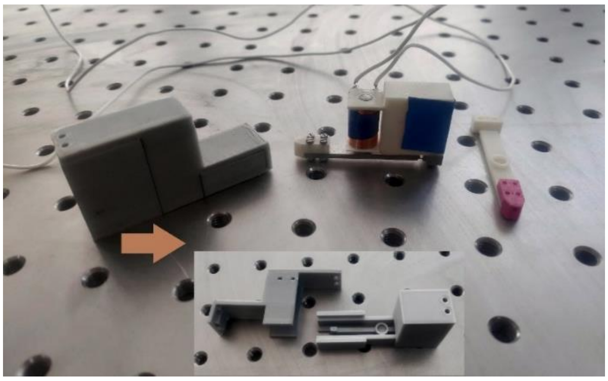


Figure 6: Real measurement robot view with metal arm and plastic arm

Micro-mechanical subsystem has the following characteristics:

- range of movement: X axis: -8..... + 5,7 mm; Y axis: - 5,7..... + 5,7 mm; Z axis: -6,7..... + 6,7 mm; θX axis: - 5,7..... + 5,70; θY axis: - 6,6..... + 6,60; θX axis: - 5,5..... + 5,50;
- actuator resolution: 33 nm;
- minimum increment of displacement X, Y, Z: 0.1 μm (movement on 6 axes);
- minimum increment of displacement θX, θY, θZ: 2 μ rad (0.4 sec arc) (movement on 6 axes);
- bidirectional repeatability X, Y, Z: 0.3 μm; bidirectional repeatability θX, θY, θZ: 3.6 μ rad;
- speed X, Y, Z: 0.003 ..... 10 mm / s;
- maximum load: 2 kg (centered on the mobile platform)
- weight: 5.8 kg
- operating temperature range: -50 ° C ... + 50 ° C.

Figure 7 shows the 3D modeled in SolidWorks and printed upper plate and the lower plate for positioning the robots with metal arm or plastic arm.

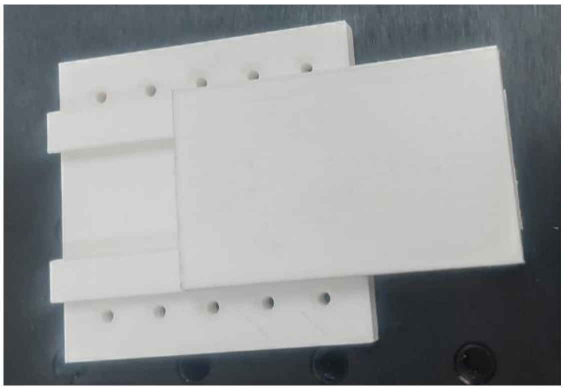


Figure 7: Real view of upper and bottom plate for positioning measuring robots, 3D printed

Figure 8 present the CAD model of the robot with metal arm. The measuring robot with metal arm without housing can be observed to be able to view the coil, the magnet and the measuring needle.

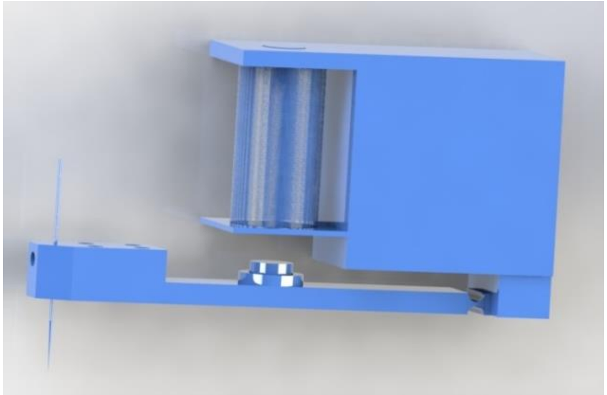
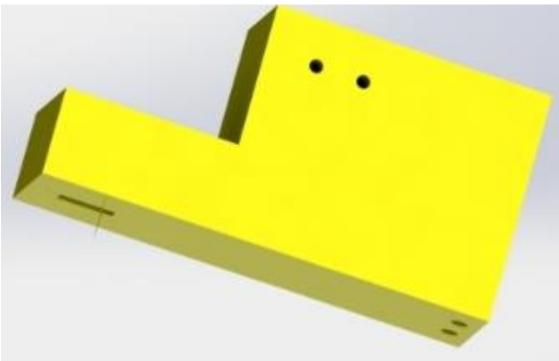


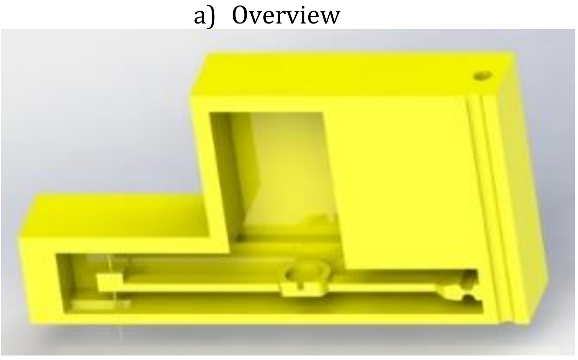
Figure 8: Measuring robot with metal arm

Figure 9 present the CAD model of the robot with plastic arm.

Figure 9.a) shows the overview of the measuring robot with plastic arm and in figure 9.b) can be seen, for example, a section of the measuring robot with plastic arm.



a) Overview



b) Section view

Figure 9: Measuring robot with plastic arm

The measuring needle used is identical in structure of the two measuring robots.

A better view of the subassembly of measurement and digital microscope is presented in Figure 10 and we can notice the role of digital microscope for the measurement process. Along with the microscope, the software that allows the visualization of the movement of the needles mounted on the metal and plastic arms is also very important.

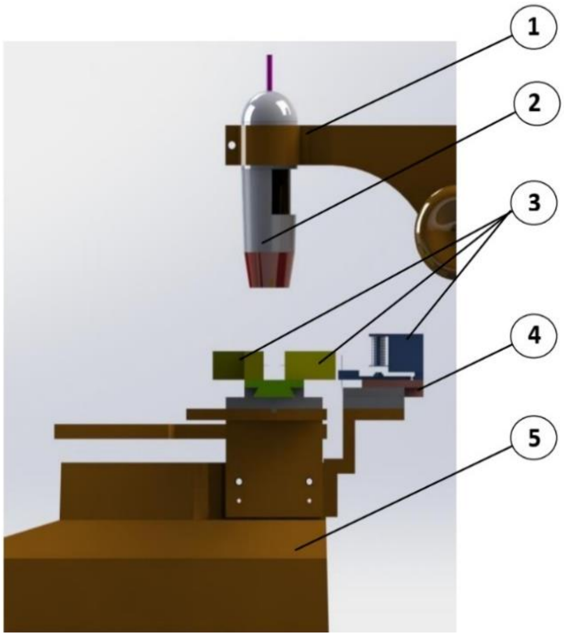


Figure 10: Front view subassembly of measurement and digital microscope

Legend:
(1) Support for mounting the digital microscope
(2) Digital microscope
(3) Measuring robot with metal and plastic arm
(4) Robot positioning plate
(5) Hexapod

The robot assembly for measurement - robot positioning system has for each of the 3 assemblies, 2 degrees of freedom (on X, Y and Z), as we can observe in Figure 11 and Figure 12.

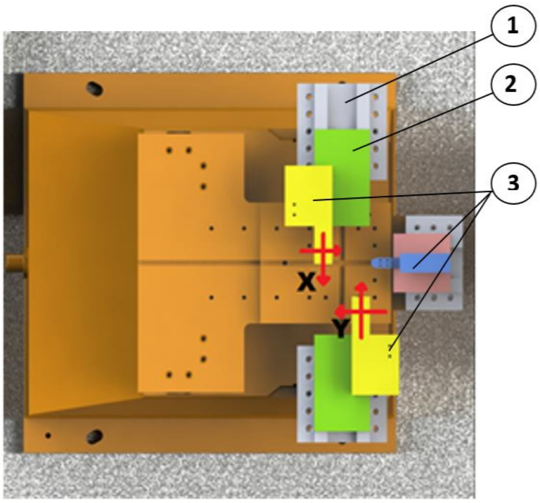


Figure 11: Degrees of freedom for measuring robots with plastic arm (X and Y)

Legend:
(1) Bottom plate for positioning measuring robots;
(2) Upper positioning plate measuring robots;
(3) Measuring robot with plastic arm

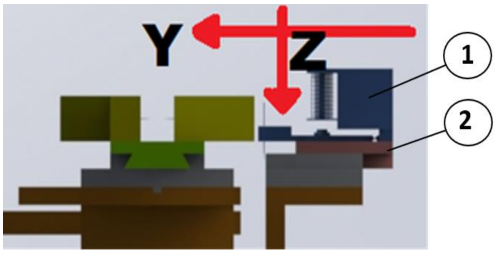


Figure 12: Degrees of freedom for measuring robots with metal arm (Y şi Z)

Legend:

1 - measuring robot with metal arm;

2 - positioning plates

Most parts of the MEMS mechatronic system were designed and realized by 3D printing in INCDMTM laboratories.

2.2 Trials and Tests Carried out in INCDMTM Laboratories with the smart Integrated Mechatronic System Designed for MEMS.

Trials and tests were performed for the measuring robot with metal arm and plastic arm. The purpose of the tests was to determine the travel made by the measuring needle in the current range printed on the integrated system.

Figure 13 shows the preparation of the equipment for measurements and the acquisition of data. As can be seen in Figure 13, the preparation involves using and starting the 2 current sources (position 3 in Figure 13) used to apply the desired voltage via the signal conversion board (position 2 in Figure 13) Mounting the robots with arms made of plastic and metal (position 4 in figure 13) is made on the hexapod (position 1 in figure 13) For an alternative check a portable multimeter is used (position 5 in figure 13).

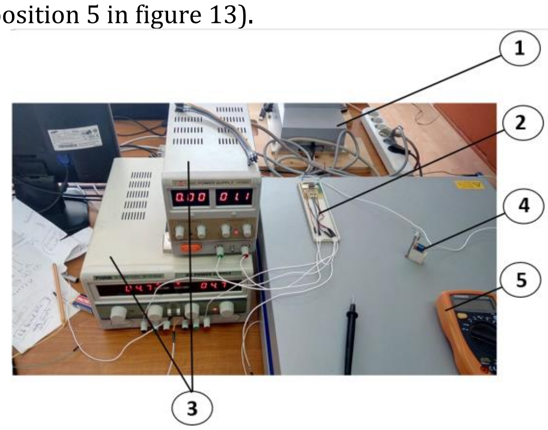


Figure 13: Preparation of equipment for measurement and data acquisition

Legend:

(1) hexapod

(2) signal conversion board;

(3) power sources;

(4) measuring robot

(5) portable multimeter

According to Table 1, for the set of 11 measurements a constantly increasing input voltage from 0 to 5 V was applied correlated with an intensity from 0 to 250 mA. The metal arm used in these tests moved, influenced by the applied voltage, from 0 to 215 μm.

Table 1: Measurements using robot with metal arm

No.	U_{IN} [V]	I_{IN} [mA]	Movement [μm]
0	0,00	0	0
1	0,10	5	13
2	0,60	30	29
3	1,00	50	41
4	1,40	70	62
5	2,00	100	79
6	2,50	125	104
7	3,00	150	123
8	3,40	175	139
9	4,00	200	165
10	4,60	230	184
11	5,00	250	215

According to Table 2, for the set of 11 measurements a constantly increasing input voltage from 0 to 5 V was applied correlated with an intensity from 0 to 250 mA. The plastic arm used in these tests moved, influenced by the applied voltage, from 0 to 549 μm.

Table 2: Measurements using robot with plastic arm

No.	U_{IN} [V]	I_{IN} [mA]	Movement [μm]
0	0,00	0	0
1	0,10	5	34
2	0,60	30	78
3	1,00	50	106
4	1,40	70	159
5	2,00	100	203
6	2,50	125	267
7	3,00	150	316
8	3,40	175	355
9	4,00	200	419
10	4,60	230	468
11	5,00	250	549

According to Table 3, for the set of 10 measurements performed on a 0.5 mm hold with the 2 types of arms designed, the results obtained are similar, which shows that although the metal arm has a higher stroke in the gap, the quality of the results obtained in tests is similar. The repeatability obtained by the tests is compliant.

Table 3: Measurements for the gauge of 0,5 mm

No / measurement	Micro-Robot with metal arm [μm]	Micro-Robot with plastic arm [μm]
1	496	500
2	503	496
3	500	496
4	502	498
5	504	503
6	503	505
7	500	505
8	495	497
9	497	500
10	501	502

Figure 14 graphically shows the movement of the arms made of metal and plastic in tests to measure a gauge of 0.5 mm. It can be seen that the range obtained in the tests is between 495 μm and 503 μm for the metal arm and 496 μm and 505 μm for the plastic arm.

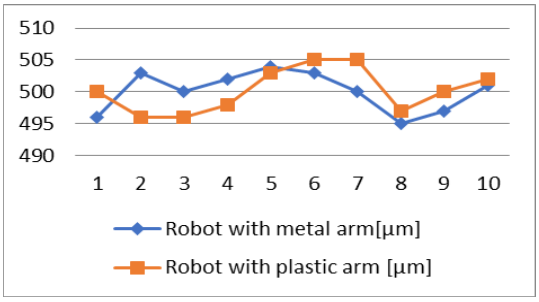


Figure 14: Comparative graph for the metal and plastic arm microrobot, measuring a piece of 500 μm

According to Table 4, for the set of 10 measurements performed on a 1 mm hold with the 2 types of designed arms the results obtained are similar, which shows that although the metal arm has a higher stroke in the gap, the quality of the test results is similar.

Table 4: Measurements for the gauge of de 1 mm

No / measurement	Micro-Robot with metal arm [μm]	Micro-Robot with plastic arm [μm]
1	1008	998
2	1002	1000
3	1001	1005
4	998	1004
5	996	996
6	997	998
7	997	1000
8	1000	999
9	1001	1004
10	1000	1002

Figure 15 shows graphically the movement of the arms made of metal and plastic in tests to measure a gauge of 1 mm. It can be seen that the range obtained in the tests is between 996 μm and 1008 μm for the metal arm and 996 μm and 1005 μm for the plastic arm.

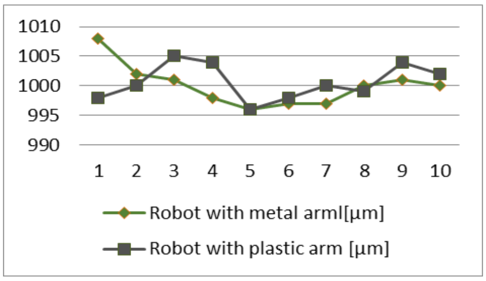


Figure 15: Comparative graph for the metal and plastic arm microrobot, measuring a 1 mm gauge

In this paper we present only some of the tests performed in the laboratory with the MEMS mechatronic system.

Future work will focus on adapting the system and creating applications that can be used in mechatronics, medicine, metrology and more.

3. Conclusions

In conclusion, for a voltage between 0 V and 5 V the measuring robots with metal and plastic arm move linearly with the mention that the range is longer for the robot with plastic arm.

Acknowledgements

Design Execution and testing the metal and plastic arm of the robot together with the upper and bottom plate measuring of the mechatronic system was an extremely delicate process due to its innovative character and precision of execution. For this reason, we 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.

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