



TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 62, Issue I, March, 2019

DESIGN AND MANUFACTURING OF A 6 DEGREE OF FREEDOM ROBOTIC ARM

Florin COVACIU, Daniel FILIP

Abstract: *The paper presents the design and manufacturing process for a 6 degrees of freedom robotic arm. The robotic arm was designed using the Fusion 360 program, after which the components of the robotic arm were manufactured using two CNC machines, namely: a Beaver VC5 milling machine and the Okuma Lb1 lathe. After assembling the robotic arm, tests for functionality were performed by actuating the stepper motors that are attached to the robot arm. The tests performed validated the performances of the robotic system.*

Key words: *robotic arm, CAD model, design, manufacturing, degree of freedom, G-Code*

1. INTRODUCTION

The history of robotics dates back in the ancient world. The modern concept began to be developed with the onset of the Industrial Revolution, which allowed the use of complex mechanics, and the subsequent introduction of electricity. At present, robots are being extensively employed in industries like mechanism design, medical, modeling, control, defense, mechanics, automotive and Artificial Intelligence (AI).

Robots have many different functions such as machine tool load and unload functions, material handling, arc welding, assembly, resistance welding, spraying, painting etc. and they are generally used to perform highly repetitive task, unsafe and unpleasant task. The International Federation of Robotics reports that 72.7% of all industrial robots are used for pick-and-place, welding and assembly [1].

Robotics is a field of modern technology that crosses traditional engineering boundaries. Understanding the complexity of robots and their applications requires knowledge of mechanical engineering, electrical engineering, systems and industrial engineering, computer science and mathematics [2]. Nowadays, the

design of robotic arms is an attractive area of research. A serial manipulator is an open chain configuration in which rigid links are joined by either revolute or prismatic joints. The number of joints in an open chain manipulator is equal to the degree of freedom of the manipulator [3]. The robotic arm design is influenced by a number of variables such as geometry of the manipulator, dynamics involved, the structural characteristics of the linkage system and the actuator characteristics [4].

The kinematics control is an important task for be able to control a serial robot. There are multiple methods to establish the expressions that modeling the kinematic behavior for any mechanical structure, according to dedicated literature [5].

The paper is organized as follow: Section 2 presents designing of the components of the robotic arm. Section 3 presents manufacturing of the parts of the robotic arm, followed by conclusions and references.

2. DESIGNING OF THE COMPONENTS OF THE ROBOTIC ARM

In Fusion 360 we designed a 6 degrees of freedom robotic arm (Figure 1). Fusion 360 is a

complete parametric CAD tool developed by Autodesk (the AutoCAD editors). It is considered by many as a uniting the best tools of cutting-edge programs like Rhino, Inventor, SolidWorks, Vault, and AutoCAD. This tool is complete integration into the cloud, allowing ease of access and collaboration from almost any device connected to the world wide web. It is used across a wide range of industries such as design, and automotive. Autodesk offers a full version of Fusion 360 for free to students, teachers, hobbyists and start-ups who make less than \$ 100k a year [6].

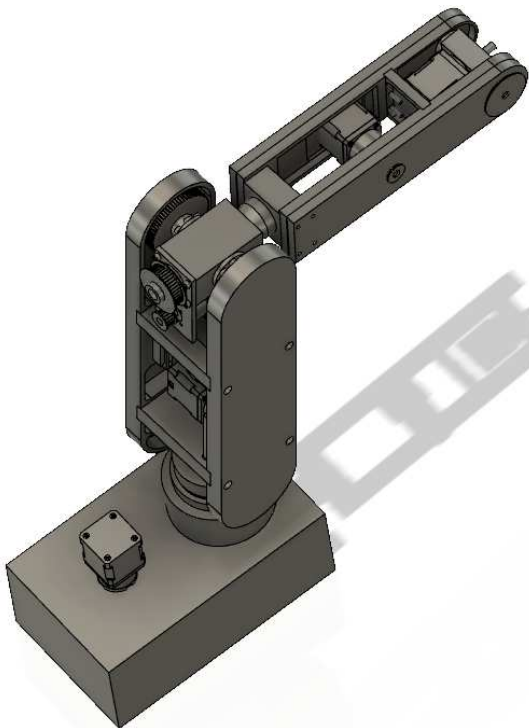


Fig. 1 CAD model

The main components of the robotic arm are:

- The base for the first joint and bearing

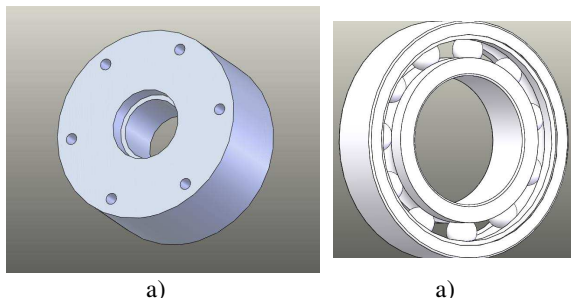


Fig. 2 The base for the first joint and bearing

This base is attached to the base of the whole robot with 6 screws, the middle hole having the role of being a bearing for the shaft of the first joint. We used more types of bearings, depending of the needs that I had every certain part. The biggest one which is represented in figure 2, b is a 6306 deep groove ball bearing. It is used in the center hole of the base of the first joint presented earlier.

- Shaft for the first joint

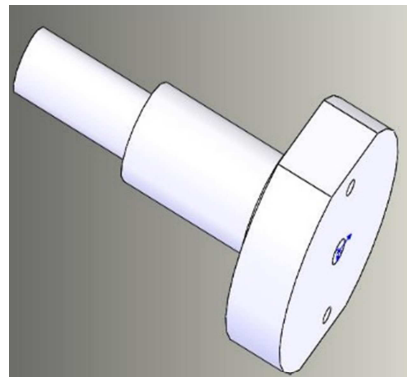


Fig. 3 Shaft for the first joint

The shaft used to rotate the first joint (figure 3). The working principle is simple as follows: on the tip of the shaft a pulley is placed that is connected with a belt to the small pulley on the first joint stepper shaft that will rotate, thus rotating the first joint and the whole robot.

- Shaft for the second joint

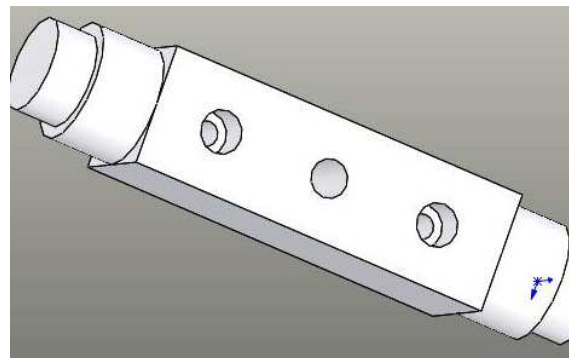


Fig. 4 Shaft for the second joint

This is the second joint shaft (figure 4). On the right tip of the shaft, a pulley is placed, helping the second joint move with the help of the second stepper motor. The middle of it has a

cubical form because it must be fixated with the help of 3 screws on the first joint base, so it doesn't move when the second joint rotates.

- Distance piece for the second joint

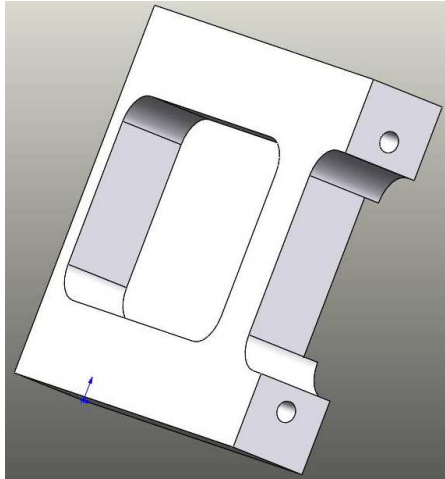


Fig. 5 Distance piece for the second joint

This part is used in two sections of the robot with the role of connecting the two arms that are used to move the first three joints. It has four holes in it for the four screws needed to fix the part on the arm.

- Pulley wheel

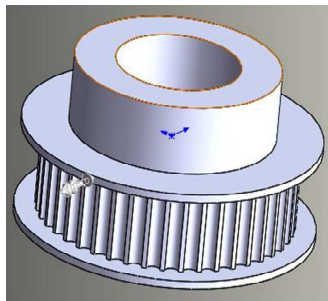


Fig. 6 Pulley wheel

Via pulley wheel can achieve motion transmission by means of a drive belt from a motor to the robot shaft. Drive belts are usually made of leather, cotton, hemp, camel hair, rubber with canvas inserts.

We have used a variety of pulleys, varying in size and number of teeth. The biggest one that I have presented in figure 6 is the pulley used to transmit motion at the second joint. The rest of

the pulleys that I have used are presented in figure 16, after manufacturing them.

- Bolt for the fourth joint

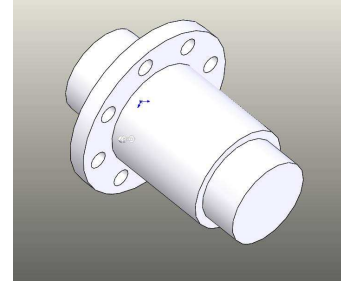


Fig. 7 Bolt for the fourth joint

This is one of the two bolts used for the fourth joint bracket. They are both mounted on the bracket, with one of its tips having a pulley on it while the other one has a bearing. It has eight holes that are used to fix it on the bracket.

- Spindle for the fourth joint

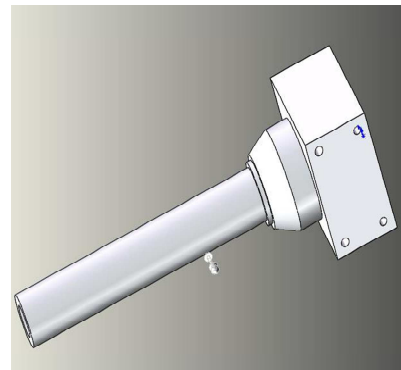


Fig. 8 Spindle for the fourth joint

Shaft for the fourth joint (figure 8). It has the role of rotating the fourth, fifth and sixth joints.

- Arm for the second joint

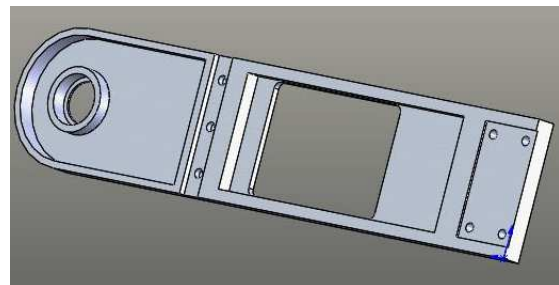


Fig. 9 Arm for the second joint

It is one of the two arms that is used for the last three joints. It has a hole at the end of it where the bracket for the sixth couple is mounted. The three holes that are designed in a vertical line are for a distance piece and the hole in the middle is an opening used for the fifth joint stepper motor.

- Support for the sixth joint

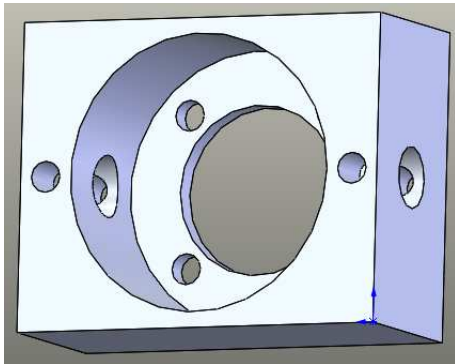


Fig. 10 Support for the sixth joint

Support for the sixth joint, here the last stepper motor that is used to rotate the end effector is mounted, the holes on the sides having the role for fixating the shafts that come in the lateral holes.

- Base for the robot

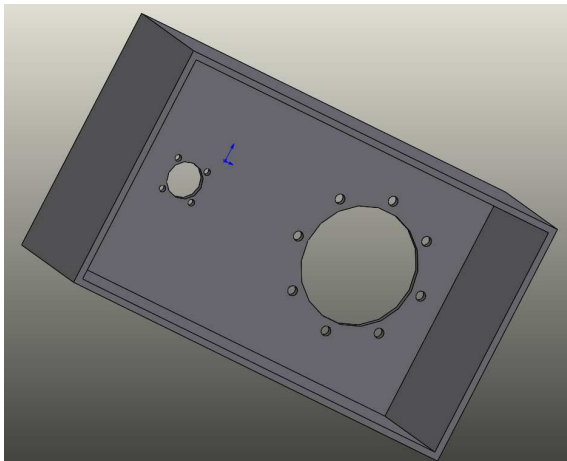


Fig. 11 Base for the robot

The base of the whole robot, the hole on the right is used for the shaft and pulley of the first joint while the whole on the left is used for the first motor. The other holes are used to fix the parts mentioned on the base. The manufactured part will look different. The main reason for this is to

reduce the weight of the whole robot for ease of transportation.

3. MANUFACTURING OF THE PARTS

The machines that were used for the manufacturing of the parts were a lathe Okuma Lb15 (figure 12) and a milling machine Beaver VC5 (figure 13).



Fig. 12 Okuma Lb15

Most machine tool builders source their CNC controls from partners such as Fanuc, Mitsubishi Electric, Siemens, and Heidenhain. Several builders have developed their own CNC controls over the years (including Mazak, Okuma, Haas, and others), but Okuma is unusual among machine tool builders for the degree to which it designs and builds all of its own hardware, software, and machine components. Okuma's CNC control is called the "OSP" series. It offers closed-loop positioning via its absolute position feedback system. The "OSP" name began as an abbreviation for "Okuma Sampling Pathcontrol". In an industry that pushes hard for continual technological innovation, Okuma has often been an innovative leader. For example, it has been among the leaders of development for thermal compensation and collision avoidance. Thermal compensation is designing the machine elements and control to minimize the dimensional distortion that results from the heat generated by machining. This is done both by preventing heat buildup (for example, flowing coolant through machine elements formerly not cooled) and by detecting and compensating for temperature rises when they occur (for example, monitoring temperature with a sensor and using

the sensor's output signal as input to the control logic). Collision avoidance is designing the machine to predict and prevent interference, for example, having the machine "know" the form and location of all fixturing so that it can foresee a crash and stop its own movement before crashing. Recent innovation includes technology to avoid chatter, both by predicting and preventing it and by early automatic detection and correction (via dynamic changes of speeds and feeds) when it does occur [7].



Fig. 13 Beaver VC5

Most CNC milling machines (also called machining centers) are computer controlled vertical mills with the ability to move the spindle vertically along the Z-axis. This extra degree of freedom permits their use in die sinking, engraving applications, and 2.5D surfaces such as relief sculptures. When combined with the use of conical tools or a ball nose cutter, it also significantly improves milling precision without impacting speed, providing a cost-efficient alternative to most flat-surface hand-engraving work. CNC machines can exist in virtually any of the forms of manual machinery, like horizontal mills. The most advanced CNC milling-machines, the multi axis machine, add two more axes in addition to the three normal axes (XYZ). Horizontal milling machines also have a C or Q axis, allowing the horizontally mounted work piece to be rotated, essentially allowing asymmetric and eccentric turning. The fifth axis (B axis) controls the tilt of the tool itself. When all of these axes are used in conjunction with each other, extremely complicated geometries, even organic geometries such as a human head can be made

with relative ease with these machines. But the skill to program such geometries is beyond that of most operators. Therefore, 5-axis milling machines are practically always programmed with CAM [8]. To achieve high productivity in the cutting processes is very important usage modern methods of simulation to avoid loss of used material [9].

The manufactured parts are the following:

- Belt extender



Fig. 14 Belt extender

This is one of the belt extenders that we have used. The principal behind it is that it has four groove holes so that when we use screws to mount it with the motor on the arm, it will move until the belt is extended at a desired length, after which the screws are fully screwed, and the belt is fully extended.

- Belt extender and motor bracket for the fourth joint



Fig. 15 Belt extender and motor bracket for the fourth joint

The manufacturing process was pretty straightforward with the SheetCam program

generating the required G-Code program for the milling machine Beaver VC5.

- Pulleys



Fig. 16 Pulleys

In figure 16 we present all the manufactured pulleys that we have used. We have bought them from a shop and the only manufacturing process we had to do was to broaden the holes in them, so they can fit on the shafts.

- Arm for the first two joints

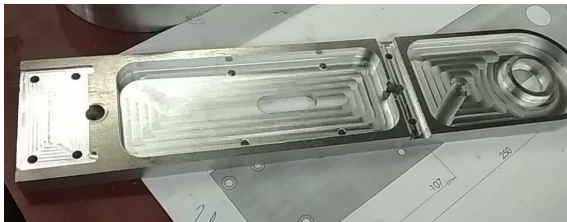


Fig. 17 Arm for the first two joints

In figure 17 we present one of the arms for the first two joints. For the manufacturing part, the arms were pretty hard to do. Two additional parts had to be put on the Beaver milling table because the part was too long and couldn't be fixed on the table for the manufacturing. After putting the additional parts, the SheetCam software was generated a G-Code program or the manufacturing process. This software is a low cost but feature packed CAM package, is suitable for milling, routing, plasma, waterjet, laser and oxy-fuel cutting. Computerized numerical control (CNC) machine tools are commonly used in modern manufacturing practice, to produce a variety of pieces. CAD/CAM software tools are essential for generating creative shapes and toolpaths for the

desired applications e.g. milling, engraving [10]. After the piece was created on the CNC machine, additional changes had to be made to it manually, making this the hardest part to manufacture overall.

- Base for the first joint

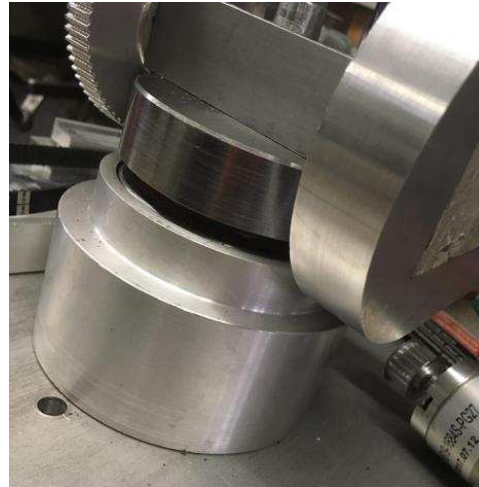


Fig. 18 Base for the first joint

The manufacturing of the base for the first joint was a straightforward process. Here is the mechanical transmission of the base. Besides the increased final product quality, the purpose is to improve robustness and functionality of these accurate displacements systems with respect to the regular current transmission systems [11]. At first the Okuma LB15 was used for the turning parts and then a drill was used for the holes.

- Support plate for motor



Fig. 19 Support plate for motor

The part presented in figure 19 has the role of a distance piece for the second and third stepper motors. The milling was done on the Beaver VC5 mill and a drill was used for the holes.

Assembling the robot

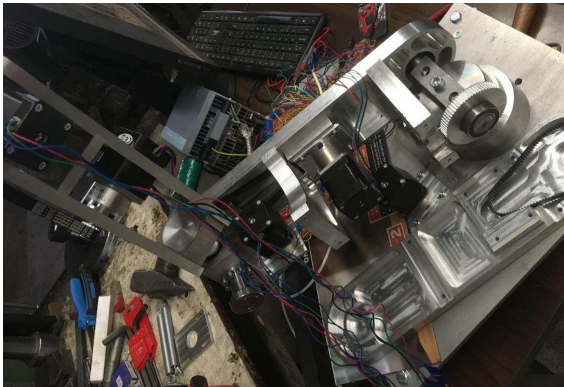


Fig. 20 Assembling the robot

In figure 20 we have presented one of the steps of the assembling process. At this part of the assembling process, the last four stepper motors were mounted on the arms of the robot, with the last arm remaining to be mounted on the assembly. After this part, the assembled structure was mounted on the base of the robot.

Final assembly



Fig. 21 Final assembly

In figure 21 we can see the final assembly of the robotic arm with 6 degree of freedom. For better reliability we can make a numeric analysis to

determine the displacements and stresses for the strength structure using Ansys software [12].

4. CONCLUSIONS

The paper presents design and manufacturing of a 6 degree of freedom robotic arm. The components of this robotic arm were first designed in Fusion 360 program, after which they were manufactured using a milling CNC machine and a lathe. After manufacturing the components, the robotic arm has been assembled and tests have been made for its functionality by actuating the stepper motors. Performed tests have validated the robotic system performances.

ACKNOWLEDGEMENT

This paper was supported by the project „Inter-University Partnership for Excellence in Engineering - PARTING - project coordinated by the Technical University of Cluj-Napoca” contract no. POSDRU/159/1.5/S/137516, project cofounded by the European Social Fund through the Sectorial Operational Program Human Resources 2007-2013, financed by UEFISCDI.

6. REFERRING

- [1] World Robotics. Int. Fed. Robot., Frankfurt, Germany, 2013.
- [2] Pandilov, Z., Dukovski, V., Comparison of the characteristics between serial and parallel robots, Acta Technica Corviniensis - Bulletin of Engineering, Jan-Mar2014, Vol. 7 Issue 1, p143-160. 18p.
- [3] Murray, R., Li, Z., Sastry, S., Mathematical Introduction to Robotic Manipulation, vol. 29. 1994, ISBN-13: 978-0849379819.
- [4] Vertutt, J., Liegeois, A., General design criteria for manipulators, Mechanism and Machine Theory, Volume 16, Issue 1, 1981, Pages 65-70, doi.org/10.1016/0094-114X(81)90052-5.
- [5] Schonstein, C., Kinematic control functions for a serial robot structure based on the time derivative jacobian matrix, Acta Tehnica Napocensis, Series: Applied Mathematics and Mechanics, vol. 61, Issue II, ISSN

- 1221-5872, pag. 253-660, 2018, Cluj-Napoca, România
- [6] ***,all3dp.com/1/autodesk-fusion-360-free-download-full-version/
- [7] ***,en.wikipedia.org/wiki/OkumaCorporation
- [8] ***, en.wikipedia.org/wiki/Milling_(machining)
- [9] Koukach, D., Pop. G., Preja, D., Machining process modeling, Acta Tehnica Napocensis, Series: Applied Mathematics and Mechanics, vol. 54, Issue IV, ISSN 1221-5872, pag. 659-668, 2011, Cluj-Napoca, România
- [10] Matei, C., Steopan, A., Blebea, I., Cam in the cnc machining process, Acta Tehnica Napocensis, Series: Applied Mathematics and Mechanics, vol. 55, Issue IV, ISSN 1221-5872, pag. 203-206, 2012, Cluj-Napoca, România,
- [11] Sucală, M., Veja, A., Mechanical transmissions for accurate displacements, Acta Tehnica Napocensis, Series: Applied Mathematics and Mechanics, vol. 54, Issue I, ISSN 1221-5872, pag. 43-48, 2011, Cluj-Napoca, România,
- [12] SIMION M., BOTEAN, A., BEJAN M., Numerical analysis of state of stresses and deformations of an industrial serial robot 5r, Acta Tehnica Napocensis, Series: Applied Mathematics and Mechanics, vol. 54, Issue IV, ISSN 1221-5872, pag. 675-680, 2011, Cluj-Napoca, România
- [13] Raghaven, M., Roth, B., Kinematic analysis of the 6R manipulator of general geometry. In: Proc fifth int symp on robotics research; 1990. pages: 263–9. ISBN:0-262-13253-2.
- [14] Chen, Y., Leitmann, G., Robust control for rigid serial manipulators: A general setting. In American Control Conference (Vol. 2, pp. 912–916). IEEE. ISBN: 0-7803-4530-4.

PROIECTAREA ȘI FABRICAREA UNUI BRAȚ ROBOTIC CU 6 GRADE DE LIBERTATE

Rezumat: Lucrarea prezintă proiectarea și procesul de fabricație pentru un braț robotic cu 6 grade de libertate. Brațul robotic a fost proiectat cu ajutorul programului Fusion 360, după care componentele brațului robotic au fost fabricate cu ajutorul a două mașini unelte cu comandă numerică și anume, o mașină de frezat model Beaver VC5 și un strung model Okuma Lb1. După asamblarea brațului robotic s-au făcut teste pentru funcționalitate prin acționarea motoarelor pas cu pas care sunt atașate brațului robotului. Prin testele efectuate s-au validat performanțele sistemului robotic.

Florin COVACIU, Dr. Ing., Lecturer, Technical University of Cluj-Napoca, Department of Design Engineering and Robotics, Florin.Covaciu@muri.utcluj.ro, Phone: 0755566491, B-dul Muncii 103-105, Cluj-Napoca, ROMANIA

Daniel FILIP, Dr. Ing., Lecturer, Technical University of Cluj-Napoca, Management and Economical Engineering, daniel.filip@mis.utcluj.ro, Phone: 0749042915, B-dul Muncii 103-105, Cluj-Napoca, ROMANIA