Acta Universitatis Sapientiae
Electrical and Mechanical Engineering, 5 (2013) 85-96

Characterization Methods of a 2 DOF Micro Positioning Compliant Mechanism

Daniel LATEŞ[1], Simona NOVEANU[2], Vencel CSIBI[3]

Technical University of Cluj-Napoca,
Department of Mechatronics and Machine Dynamics,
Cluj-Napoca, Romania,
[1]e-mail: daniellates@yahoo.fr
[2]e-mail: simona.noveanu@mdm.utcluj.ro
[3]e-mail: csibiven@yahoo.com

Manuscript received October 15 , 2014; revised December 15, 2014.

Abstract: This paper presents a micro positioning plain mechanism with two degrees of freedom. The mechanism is compliant with rectangular joints for profile sections. The actuation of the mechanism is performed using two piezoelectric actuators. The limit positions of the final effector mechanism are determined by two experimental methods. The first method is an optical method that uses a CNC and CMM Aberlink program. The second method uses the same CNC probing, but the equipment is completed with the Aberlink 3D program and a testing head. At the end of the paper the comparison of the results obtained by the above methods are analyzed.

Keywords: compliant mechanisms for positioning, displacement, CNC, Aberlink CMM, Aberlink 3D.

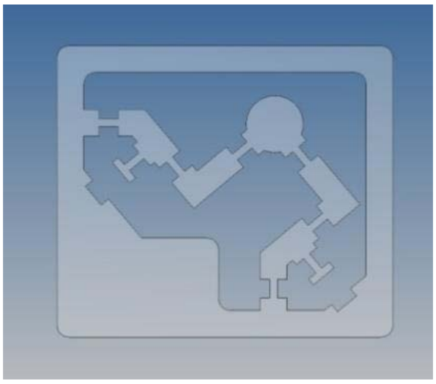
1. Introduction

Plan positioning mechanisms have been studied in different variants [9], [15], [16]. For micro and nano positioning systems made with joints and/or flexible elements having limited motions but suitable for miniaturization are used [1], [2], [7], [8]. Their actuation is effected by the use of unconventional actuators [5], [6], [17], [18].

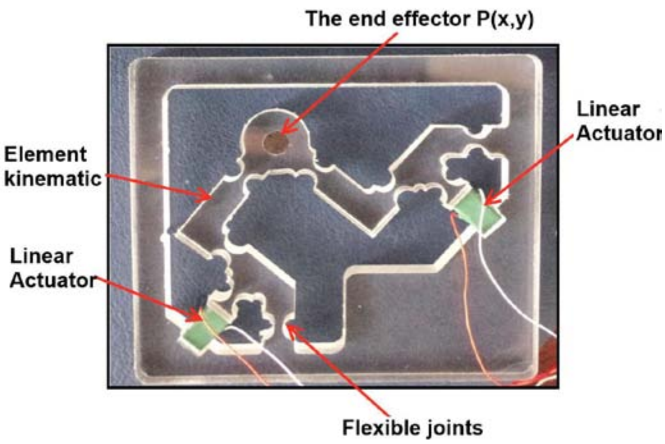
This paper presents the design of a positioning mechanism with flexible joints created of one single piece. The characterization of the compliant mechanism is performed by a piezoelectric drive activated through two methods: the first is optical using a CNC and CMM Aberlink program; the second method uses the palpation and is assisted by the same CNC with the 3D Aberlink program.

2. Design and implementation of the micro positioning mechanism

The compliant micro positioning mechanism is actuated by two linear piezoelectric actuators each capable of a 9,1 μm maximum stroke. The structure constituent elements are represented in *Fig. 1*, [3], [4]. The projections on axes *x, y* of the motions of the *"P"*- end effector are calculated separately for each actuator and finally totalized. The 3D model of the micro positioning system design is shown in *Fig. 1*.



a) 3D Model



b) Model made practical

Figure 1: Description of structure.

Finite element analysis is performed for 1, 3, 5, 7 and 9 μm stroke values admitting the following constants of the mechanism constituting material: Poisson's ratio $\nu = 0{,}39$ and Young's modulus $E = 0{,}39\,\text{MPa}$.

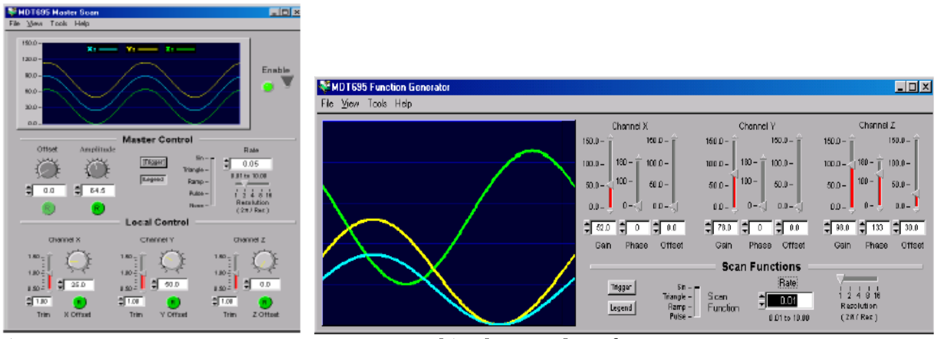
The obtained results are presented in Table 1.

Table 1.

Test nr.	*Actuator 1* (*Left*)	*Actuator 2* (*Right*)	*Force on actuator* (*N*)	*Displacement of the actuator* (μm)	*FEM Analysis Displacement of endpoint "P"* (μm)		
					x	*Y*	*comp*
1.	x	-	0,038	1	1,3	0,4	1,4
2.	x	-	0,116	3	4,0	1,5	4,1
3.	x	-	0,194	5	6,5	2,6	7,0
4.	x	-	0,272	7	8,7	3,9	9,6
5.	x	-	0,350	9	12	4,8	13
6.	-	x	0,07	1	0,5	0,8	0,9
7.	-	x	0,210	3	1,5	2,4	2,9
8.	-	x	0,350	5	2,6	4,1	4,8
9.	-	x	0,490	7	3,7	5,7	6,8
10.	-	x	0,650	9	4,9	7,6	9,1

3. The control of the micro positioning mechanism

Micro positioning mechanism control is achieved through an MDT693A controller that has the ability to interact and control through a Master Scan screen. Here the desired settings can be made for controlling the motions of the actuators. *Fig. 2a* presents the arrangement of the buttons. *Fig. 2b*, shows the function generator window [12].



a) Master Scan screen b) The window function generator

Figure 2: MDT693A controller Interface.

4. The characterization of the micro positioning mechanism

The characterization of the mechanism is performed using the following two investigative methods:

- measurements on a stand using the Aberlink CNC and CMM software (method 1);
- measurements on a CNC machine using the 3D Aberlink program (method 2).

4.1 The realization of the measurement on stand Aberlink with CNC and CMM software (method 1)

The measurements using the experimental stand were realized with the help of an image acquisition camera designed for this type of machine and a special program called "Aberlink color CMM Camera". With this equipment small or dedicated parts can be measured, acquiring two-coordinate data (2D). The use of this method provides high-resolution and non-contact control. The camera disposes of light setting, edge detection and optical scanning tools, which are fully programmable, having the possibility to use also the tactile method within the program, [10].

The infrastructural characteristics of this method are:

- Fully compatible with Aberlink's easy-to-use measurement software;
- Swap between touch probe and CMM camera in seconds;
- Use touch and vision technology within the same inspection program;
- Unique duel light ring with UV LED's to back light parts on the CMM;
- High speed optical scanning - up to 5000 points/second;
- High precision edge detection for feature inspection;
- Thread measurement - min/max/mean pitch, left/right angles, effective diameter;
- Screen overlays - XY/angular crosshairs, align to mouse, align to edge;
- Large stand-off for measuring over tall features;
- Fully programmable digital zoom (no need to change lens);
- Directional overhead lights and back light for profile and surface feature inspection;
- Telecentric lens measures accurately even when the feature is out of focus [10].

Fig. 3 shows the stand built for these types of measurements. The main components that act in the main experiment are also detailed.

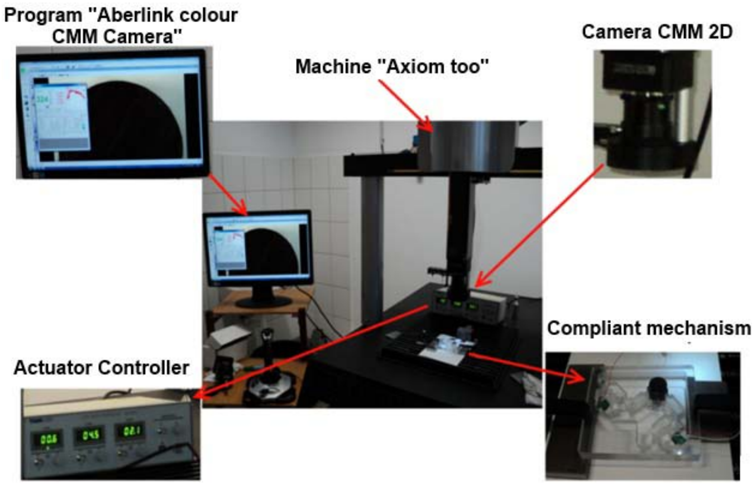


Figure 3: CMM 2D camera measurement stand.

Fig. 4 presents a screen capture obtained during the measurement. The end effector appears black colored due to the contrast (between rear view and track measured) needed for performing the measurements. After the measurement area is delimited, (2 mm from the outer edge of the end effector, in this case), the program allows 342 points of measurement in which it computes the motion from the displacement between the scanned images.

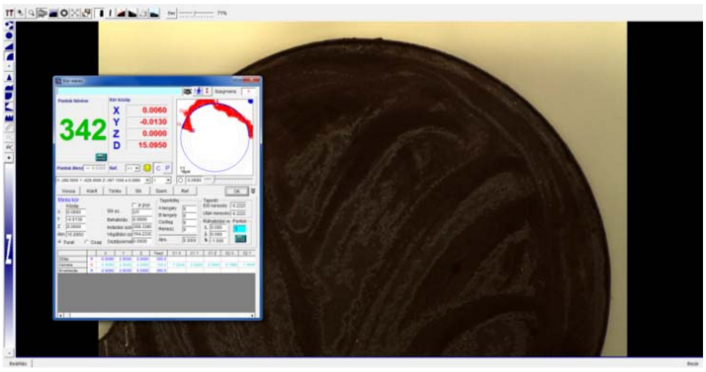


Figure 4: Computing of the displacement.

Fig. 5 shows the measurement points detected by the program after scanning and calculating the motions from the area of interest. The radial lines that start from the circumference of the blue semicircle represent the motions of the measuring points scored by the program. Quite large deviations between the measurement points appear.

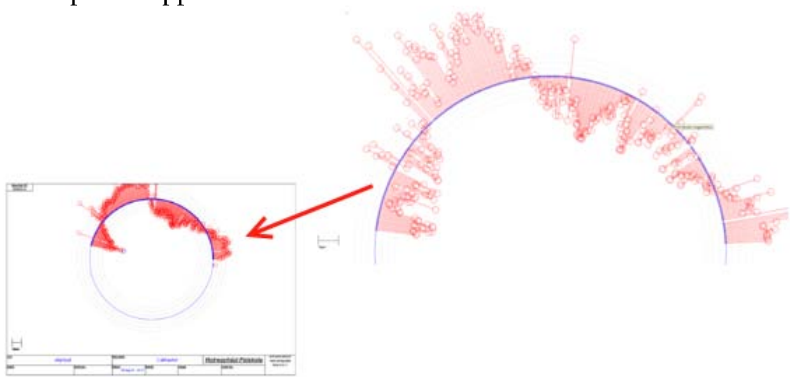


Figure 5: Displacement points made by the mechanism.

4.2 The measuring stand with CNC and Aberlink 3D (Method 2)

For this set of measurements the CNC machine from AXIOM and the 3D Aberlink program was used. Aberlink 3D is an innovative software package for manual designing, CNC and CMMs. This program is one of the favorites for producers of measurement devices. Aberlink provides a complex and easy explorable interface for the user [11].

The characteristics of the second method are the followings:

- Reliable high accuracy 3D inspection;
- Aberlink’s easy-to-use measurement software (now standard on many OEM systems);
- Individual locks and fine adjust hand wheels on each axis;
- Suitable for the workshop environment;
- Anti-vibration protection from local machine tools as standard;
- Temperature compensation and other correction options for workshop environments.

Fig. 6 shows the main acting elements of the experimental stand during the measurements. Before starting the measuring process the machine must be calibrated. This procedure uses particular specimens. The 3D Aberlink software starts while the reference specimens are inserted on the *x*, *y* and *z* directions for the compliant mechanism.

Initially 6 measuring points situated on the circumference of the end effector were chosen. After a few attempts, 20 other measurement points are added in order to obtain the best possible measurement accuracy. The measuring points are placed manually, and then the machine memorizes them automatically. After the palpation process is complete in each of the 20 points situated on the circumference of the end effector, the program automatically calculates the center of the circle that defines the area of interest.

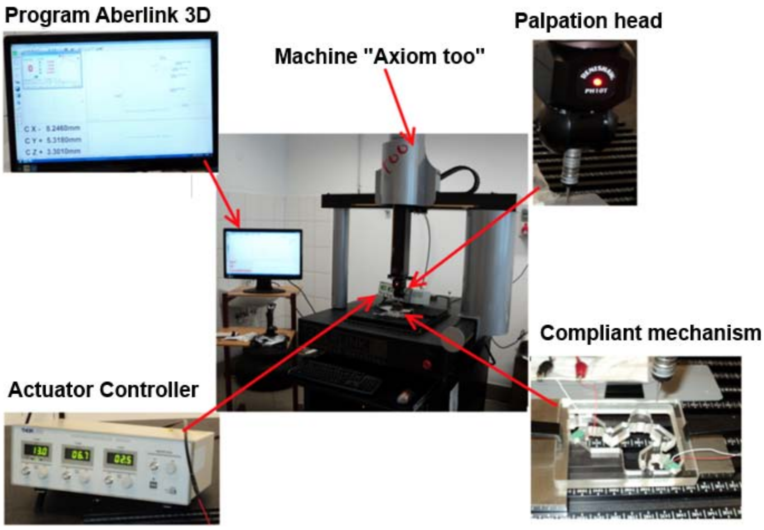


Figure 6: The stand equipped with the specimen.

5. The obtained results and their experimental comparison

5.1. The results

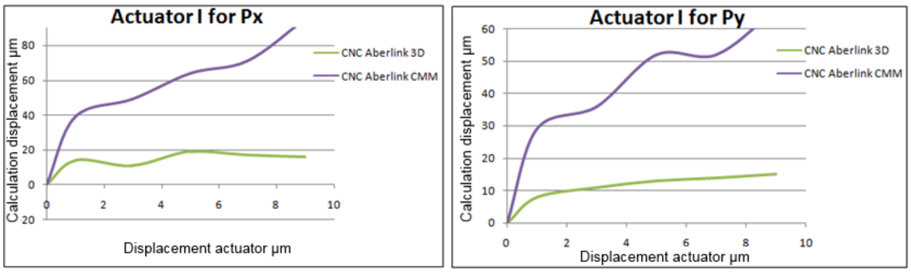
The results obtained through the two experiments performed with the equipment described in the previous chapter are presented in Table 2.

Table 2.

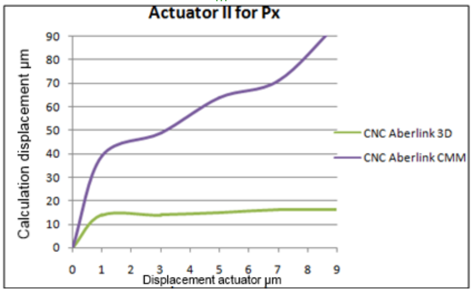
No test	*Actuator 1 (Left)*	*Actuator 2 (Right)*	*Voltage Control Actuator* (*V*)	*Actuator displaceme nt* (*µm*)	*Displacement "P" Method 1* (*µm*)		*Displacement "P" Method 2* (*µm*)	
					x	y	x	y
1.	x	-	13	1	39	29	14	8
2.	x	-	40	3	49	36	11	11
3.	x	-	66	5	64	52	19	13
4.	x	-	93	7	71	52	17	14
5.	x	-	120	9	95	66	16	15
6.	-	x	13	1	39	29	14	13
7.	-	x	40	3	49	36	14	15
8.	-	x	66	5	64	52	15	17
9.	-	x	93	7	71	52	16	18
10.	-	x	120	9	95	66	16	19

5.2. The symmetrical joints micro positioning mechanism with rectangular section (rectangular symmetry)

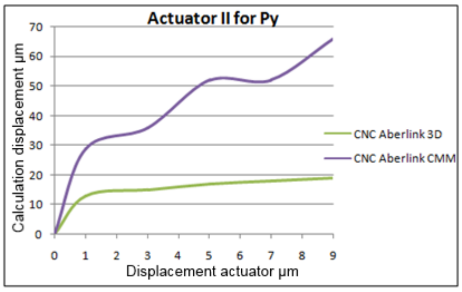
The comparative data are shown in the four graphs presented in *Fig. 7*. Here a smaller measurement error for the *y*-axis can be observed: when the displacement of the actuator reaches 6 microns, the experimenting part has a slight increase, compared to the numerical FEM.



a) b)



c)

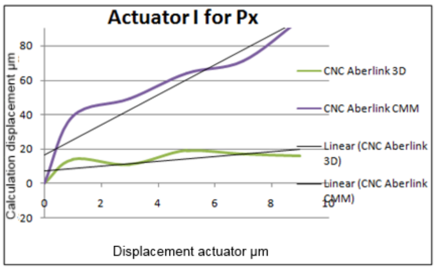


d)

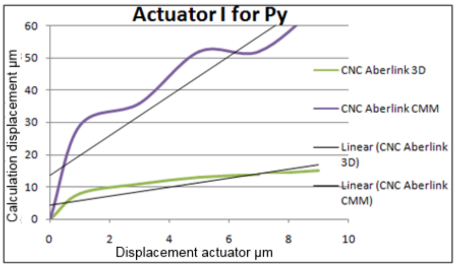
Figure 7: The graph with the results of the "Px" and "Py" end-effectors for actuator no. 1 and 2.

5.3. CNC and CN probe optical linearization method

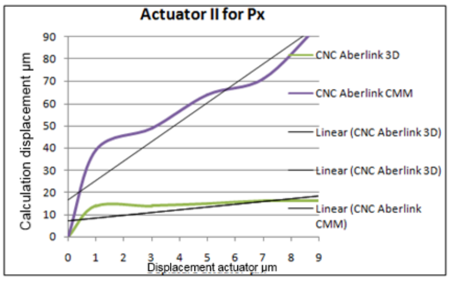
If linearizing the curves, presented in *Fig. 7*, a better operable instrument will be gained. Results of the linearization are shown in *Fig. 8*.



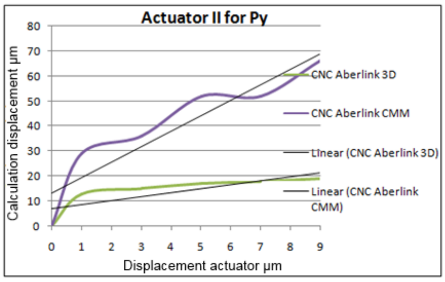
a)



b)



c)



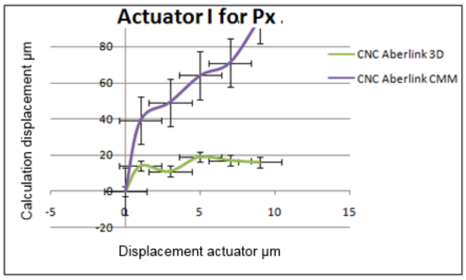
d)

Figure 8: The linearization for the CNC optical and the probe CN methods.

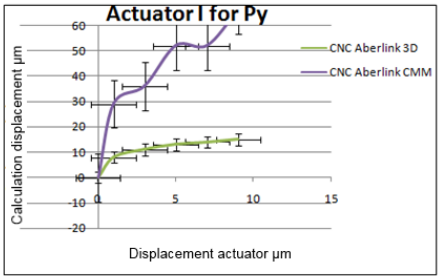
5.4. The errors for the two measurement methods using the error bars with the standard error

As well as knowing the standard error (SE) is the standard deviation of the sampling distribution of a statistic. The term may also be used to refer to an estimate of that standard deviation, derived from a particular sample used to compute the estimate, [13].

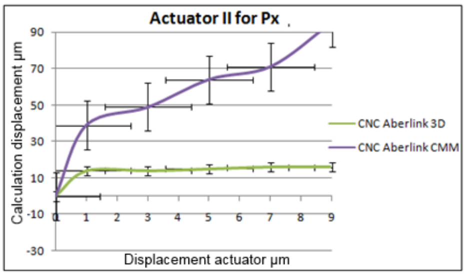
Error bars express potential error amounts that are graphically relative to each data point or data marker in a data series. The error bars displayed were realized using the MS Excel admitting a standard significance level of 95% for both experiments. Standard Error and Standard Deviation are figured on the charts below (*Fig. 9*), [14].



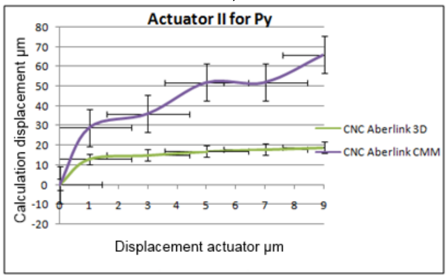
a)



b)



c)



d)

Figure 9: The standard error of the four statistics regarding the positions *x*, *y* of the actuators no. 1 and 2.

6. Conclusion

Regarding the facts and experiments presented above several conclusions can be stated:

The compliant micro-positioning mechanism subject of the study above is able to ensure a greater number positions of required accuracy than classical jointed mechanism. It results in the same simplicity of structure positions characterized by higher accuracy.

The micro-positioning mechanism presented in this paper may be used easily to realize without any difficulties the imposed displacements according to directions *x, y* in the functional plane. This is available due to the work of the compliant joints and the linear piezoelectrical actuators.

Comparing the two experimental methods presented in this paper it can be concluded that palpation method ensures a higher accuracy of displacements due to the direct measuring realized on the periphery of the final effector (a circle).

The advantage of the optical method accompanied by image processing offers the advantage of a larger number of measuring points. In spite of this the measuring errors are larger leading to a bigger value of the dispersion.

From this can be concluded that the optical method is recommended when a short time experiment is needed for rapid data acquisition or estimating the working space of the mechanism. High precision measurements or control are recommended to be realized using the palpation method.

Acknowledgements

This work is supported by the Sectorial Operational Program Human Resources Development HRD / 159 / 1.5 / S / 137516 financed by the European Social Fund and by the Romanian Government.

References

[1] Chao, D., Liu, R., Wu, Y., Shi, L., Zong, G., "Manufacturing error analysis of compliant 3-DOF microrobot", *Front. Mech. Eng. China*, 2006, pp. 299−304.

[2] Huy, H. P.,Chen, I. M., "Optimal Synthesis for Workspace and Manipulability of Parallel Flexure Mechanism", *Proceeding of the 11th World Congress in Mechanism and Machine Science*, August 18-21, 2003, Tianjin, China.

[3] Lateş, D., Noveanu, S., Csibi, V., "Caracterizarea mecanismelor compliante cu două grade de libertate prin metoda preluării de imagine", *Conferinţa a II-a, Naţională multidisciplinară, profesorul Ion D. Lăzărescu*, Alba Iulia, 2014, pp. 105-114.

[4] Lateş, D., Noveanu, S., Zah, M., "Analytical study on compliant joints with asymmetrical profiles", *21th International Conference on Mechanical Engineering* (OGET), Arad, 2013.

[5] Lobontiu, N., Garcia, E., "Mechanics of Microelectromechanical Systems", Kluwer Academic Publishers New York, Boston, Dordrecht, London, Moscow, 2005.

[6] Mătieş, V., Dan, M., Olimpiu, T., Mihai, M., Csibi, V., "Actuatori in Mecatronica", Editura Mediamira, Cluj-Napoca, 2000.

[7] Polit, S., Jingyan, D., "Design of high-bandwidth high-precision flexure-based nanopositioning modules", *Journal of Manufacturing Systems*, Vol. 28, Issues 2–3, July 2009, pp. 71-77.

[8] Tien-Fu, L., Handley D. C., Yuen, K. Y., Craig, E., "A three- DOF compliant micromotion stage with flexure hinges", Industrial Robot: an International Journal, 2004,Vol. 31 Iss: 4, pp. 355-361.

[9] Weiwei, S., Shuang, C., Yaoxin, Z., "Symposium on Robot Control Nonlinear friction compensation of a 2-DOF planar parallel manipulator", *Special Section of Revised Papers from the 8th International IFAC Symposium on Robot Control 8th International IFAC*, Vol. 18, Issue 7, Sept. 2008, pp. 340–346.

[10] http://www.aberlink.com/products/cmm/camera-system/

[11] http://www.aberlink.com/products/cmm/axiom-too-manual/

[12] http://www.thorlabs.de

[13] http://en.wikipedia.org/wiki/Standard_error

[14] http://office.microsoft.com/en-us/excel-help/add-change-or-remove-error-bars-in-a-chart-HP010007462.aspx

[15] http://www.bg.ic.ac.uk/research/e.burdet/parallel.php

[16] http://charm.stanford.edu/ME327/JaredAndSam.

[17] http://www.clubafaceri.ro/22432/motoare-pas-cu-pas-2958446.html

[18] http://webbut.unitbv.ro/Carti%20on-line/BSM/BSM/capitol5.pdf