Assisted Multi Objectives Research Optimization of the Arm Type Robot's Forces

Adrian D. Olaru, Serban A. Olaru, Niculae C. Mihai, and Natalia M. Smidova

Abstract— **Multi objectives optimization in Robotics is one of the most difficult problem to be solved. In the paper will be shown the matrix form of the resistive and active forces and the proper algorithm to establish the best case between all studied cases. The mathematical matrix form of the active forces equations was transposed to the virtual LabVIEW instrumentation with the goals to obtain some characteristics of the active forces in each joints of the robot variation vs. time in the case when were changed some functional or constructive parameters. By using proper algorithm was choose the best solution between the studied cases for down movements of the robot's arm. The applied method, the algorithm and the proper virtual instrumentation solve one small part of the complex problems of the optimisation in robotics.**

Index Terms—**Assisted research, multi objective optimization, virtual instrumentation, robot's joints forces.**

I. Introduction

The optimizing of the force variation vs. time in Robotics is one of the most important problem to be solved. Without the assisted research isn't possible to study the dynamic behavior because will be necessary to show the variation of the forces and moments vs. time to identify and establishing the better solution of the movements, or dimensions of the bodies and the relative velocities. In the paper authors [1]-[17] by using the special software RoboAnalyzer, Robotech, V-Rep, RoKiSim, Ros,show some characteristics and solve direct and inverse kinematics problem and also the direct and inverse dynamic problem, but without show the mathematical matrix model and how could be influenced the force variation by different velocity characteristics or to obtain the minimum variation of the forces. Robotect [5] and V-REP [6] are robotics learning and simulation software. A user could simulate robot manipulators and mobile robots in various environments by introducing virtual sensors and actuators. RoKiSim [7] and RoboDK, Webots [8] are a development environment which focuses on modeling, programming, and simulation of robots. In the papers [18]-[37] are shown some applications, simulation, and visualization based on the Gazebo [15] simulator. The proper assisted research was made by using the proper virtual LabVIEW instrumentation. In the literature about the research of the robot's forces don't show the mathematical matrix model, don't show how will be the variation of these forces when will be changed the successive or simultaneously movements of the robot's bodies. In the last research [38]-[47] we solved some problem from the dynamic behavior of the robots.

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II. The Forces Mathematical Matrix Model

The mathematical model of the robot's forces analyze contents the following matrix equations, see Fig.1:

$$(P)^0 = [z_u]\{(F)^0 -/+[m_u](a_{gi,0})^0\} \qquad (1)$$

$$[z_u] = \begin{vmatrix} \dots & \dots & \dots \\ \dots & z_{i,j} & \dots \\ \dots & \dots & \dots \end{vmatrix} \; z_{i,j} = \begin{pmatrix} -1 - oposite\ graph \\ 1 - same\ sens\ graph \\ 0 - do't\ touch\ graph \end{pmatrix} \qquad (2)$$

$$(F^0) = \begin{pmatrix} [D_1^0](F_1^1) \\ [D_2^0](F_2^2) \\ [D_3^0](F_3^3) \\ [D_4^0](F_4^4) \\ \dots\dots \end{pmatrix} \qquad (3)$$

$$[D_4^0] = [D_1^0][D_2^1][D_3^2][D_4^3]$$

$$[D_i^j] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & c & -s \\ 0 & s & c \end{bmatrix} or \begin{bmatrix} c & 0 & -s \\ 0 & 1 & 0 \\ s & 0 & c \end{bmatrix} or \begin{bmatrix} c & -s & 0 \\ s & c & 0 \\ 0 & 0 & 1 \end{bmatrix} \qquad (4)$$

$$[F_1^1] = \begin{bmatrix} 0 \\ 0 \\ -m_1 g \end{bmatrix}$$

$$[m_u] = \begin{bmatrix} m_1\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} & 0 & 0\dots \\ 0 & m_2\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} & 0\dots \\ 0 & 0 & \dots \end{bmatrix} \qquad (5)$$

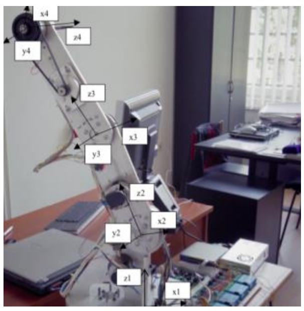


Fig. 1. Arm type studied robot.

$$(a_{gi,0})^0 = \begin{pmatrix} [D_1^0](a_{g1,0}^1) \\ [D_2^0](a_{g2,0}^2) \\ [D_3^0](a_{g3,0}^3) \\ [D_4^0](a_{g4,0}^4) \\ \dots \end{pmatrix} \qquad (6)$$

where: $(P)^0$- is the active force matrix reduced to the base; $[z_u]$- unitary joints-bodies matrix; (F^0)- resistive force matrix reduced to the base; (F_i^i)- resistive force matrix reduced to the proper cartesian system; $[D_i^j]$- transfer matrix from the *i* cartesian system to *j* cartesian system; $[m_u]$- mass matrix, or where m_i was multiply by unitary matrix for the space.

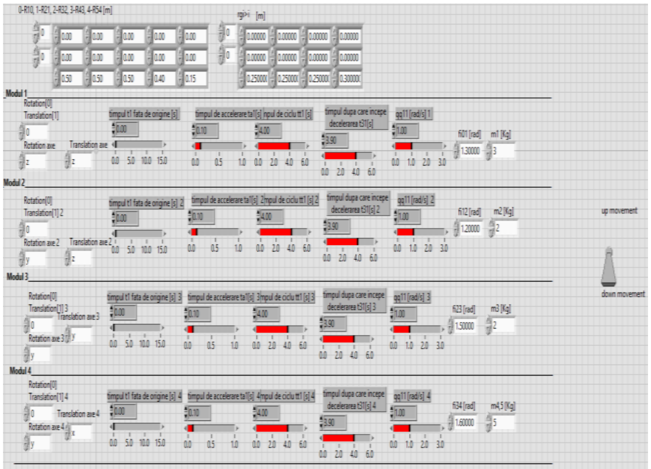


Fig. 2. The front panel of the LabVIEW *VI* to determine the active forces.

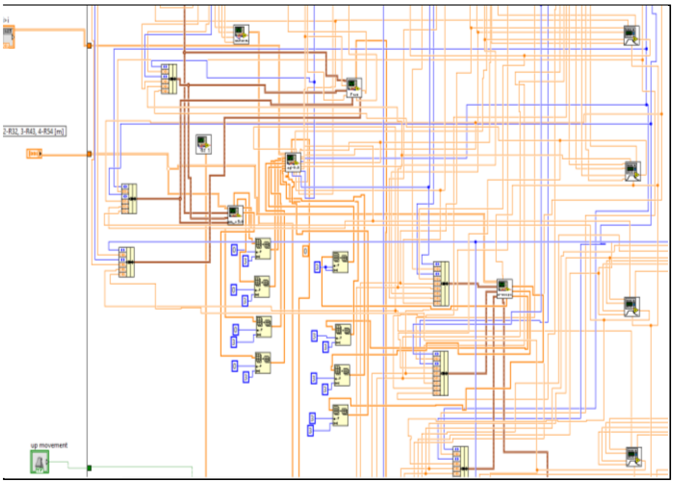


Fig. 3. The block schema of the active forces *VI*-s.

III. The Virtual Used LabVIEW Instrumentation

The *VI*-s to determine the active forces of one arm type robot contents the followings, Figs. 2-9: joint's velocity for the trapezoidal velocity characteristics; the time from the origin time, acceleration time, time of a cycle, time after begin the deceleration, joint's mass, table with position vectors of each robot's joints and weight centre of mass. The module of output data contents the characteristics of forces in all joints by *ox*, *oy* and *oz* axes and also the force module of vector in the space with the angle variation to the base plane. All these characteristics are versus time. Virtual LabVIEW instrument for the active force was constructed by using the mathematical matrix model of the forces, relation (1). We can see inside of the block diagram of the virtual instrument some other sub*VI*-s (subroutine) to calculate the absolute velocities and accelerations, the matrix of the resistive forces (fig.), the matrices of mass, the matrix of incidences bodies-joints (*G*) and joints- bodies (*Z*), relation (2), the matrix to transfer all vectors between Cartesian systems to the base, relations (3),(4), the 6x6 matrix with three dimensions to generate all needed transfer.

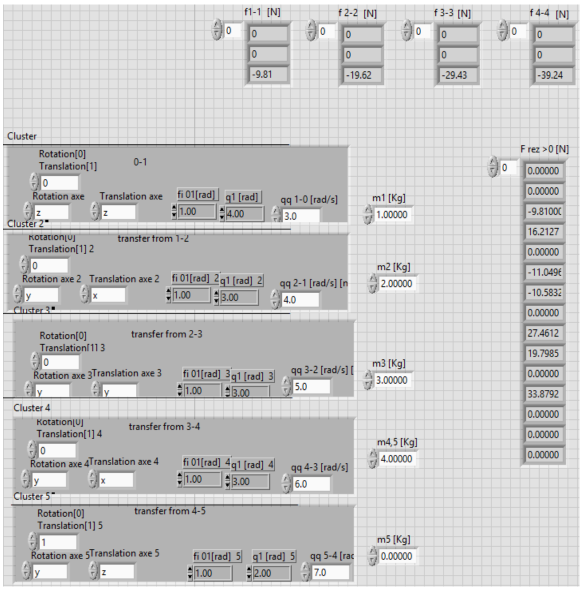


Fig. 4. The front panel of the sub*VI*-s to determine the resistive force.

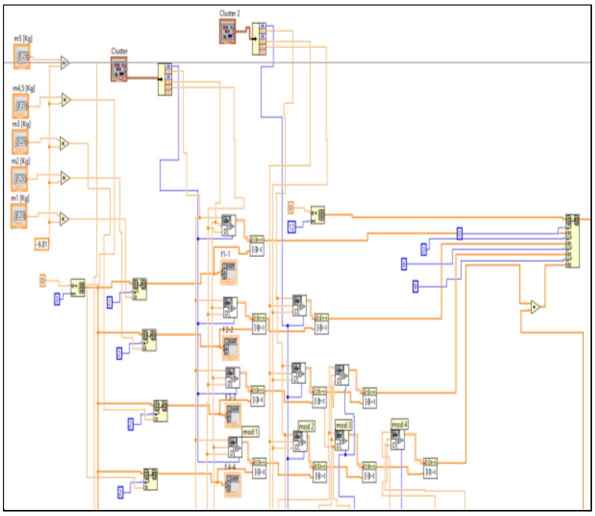


Fig. 5. The block schema of the sub*VI*-s to determine the resistive force.

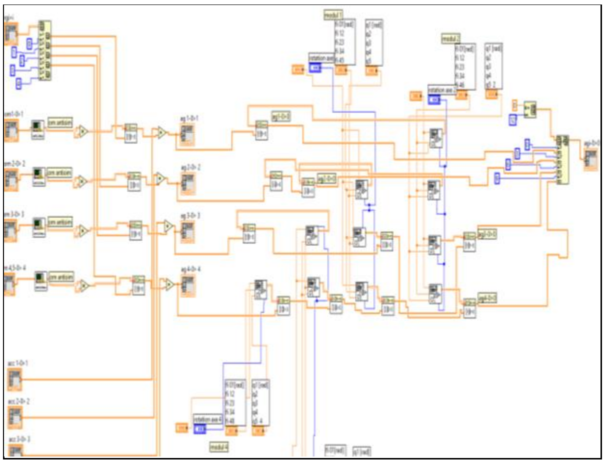


Fig. 6. The block schema of the sub*VI*-s to determine the accelerations of the center of mass.

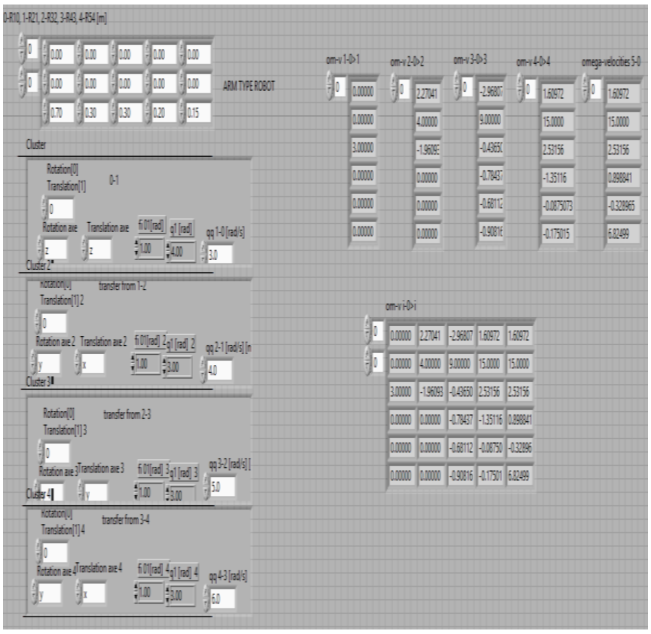


Fig. 7. The front panel of the sub*VI*-s to determine the dual vectors of the linear and angular absolute velocities in all robot's joints.

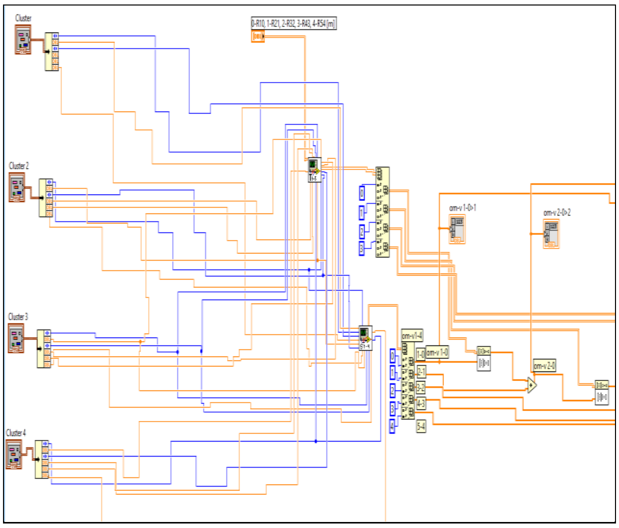


Fig. 8. Part of the block schema of the sub*VI*-s to determine the dual vectors of the linear and angular absolute velocities in all robot's joints.

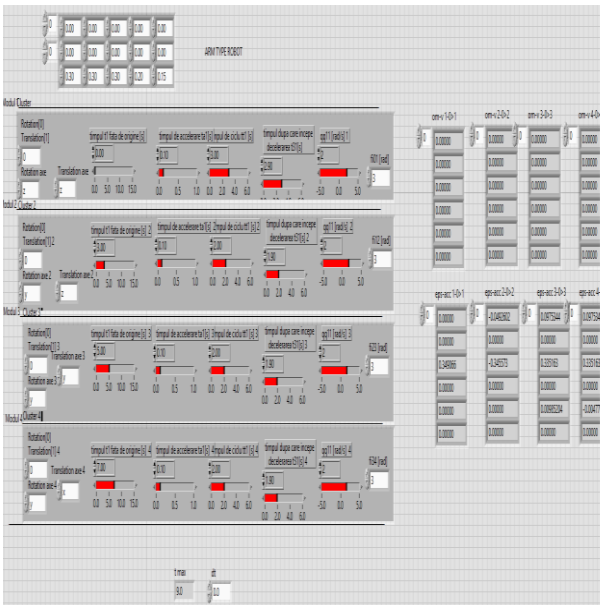


Fig. 9. The front panel of the sub*VI*-s to determine the dual vectors of the linear and angular absolute accelerations in all robot's joints.

IV. Algorithm for Optimization of the Robot's Forces by Using the Assisted Results

One way to optimize the active robot joint's forces were determined by using one multi objective optimization function. The used algorithm contents the following steps: (i) establish the constructive and functional parameters of the robot that could be studied; (ii) determine some force characteristics by changed some of the constructive or functional parameters, or type of movements; (iii) construct the table with the maximal variation of all these forces; (iv) impose for each type of force one maximal pounder (if all forces are the same impact to the global dynamic behavior of the robot- the values of all pounders will be the same); (v) calculate for each force and cases the pounder values by using the proportion between the minimum value of each force variation and the current variation from minimum to maximum forces and multiply with the maximum pounder values (using the neutrosophic theory) [16], [17]; (vi) calculate separately for up and down movements of the robot's arm and determine the case what the sum of these total pounders have maximal value.

Mathematic we can write this multi objective function (*MOF*) like in relation (7):

$$\begin{aligned} MOF(t_i, tt_i, t_{ai}, t_{di}, l_i, \varphi_i) = \quad (7) \\ \min(rangeP_{1x,y,z}) \cap \min(range|P|_1 \\ \cap \min(range < P_1) \\ \cap \min(rangeP_{2x,y,z} \cap \min(range|P|_2) \\ \cap \min(range < P_2) \\ \cap \min(rangeP_{3x,y,z} \cap \min(range|P|_3) \\ \cap \min(range < P_3) \\ \cap \min(rangeP_{4x,y,z}) \cap \min(range|P|_4) \\ \cap \min(range < P_4) \end{aligned}$$

where: t_i is the time to origin of time [s]; tt_i- the cycle time [s]; t_{ai}- the acceleration time [s]; t_{di}- the time when begin the deceleration [s]; l_i- the length of each body [m]; φ_i- angle position of each body [rad]; $P_{i,x,y,z}$- active forces in each joints [N]; $|P_i|$- module of the active force in each joints, [N]; $< P_i$ - angle in a space of each active force vector, [N].

This *MOF* function have 20 conditions to be simultaneously touch that will be possible by using neutrosophic theory [16], [17], all these conditions will be touch between T (true) and F (false)= $p_i(T) \cup p_j(F)$ where $p_{i,j}$ are the ponders for each criteria and for each cases, otherwise the *MOF* result will be null, because it is impossible that all 20 forces components for each of studied cases to be in the same time minimum.

$$MOF = \max\left(\sum_1^{20} p_i \frac{P_{i,x,y,z,<,min}}{P_{i,x,y,z,<,crt}}\right)_{\text{cases}} \quad (8)$$

where: p_i is the maximal pounder; $P_{i,x,y,z,<,min}$- the minimum value of each of these forces and angles; $P_{i,x,y,z,<,crt}$ - the current value of the forces for each of the studied cases.

The cases that were studied are: 0-0-0-0 all movements are simultaneously; 0-4-4-0 the first and four movements are simultaneously and the second and third will simultaneously, but successive after 4s after the first and fourth; 0-4-8-12 all movements are successive; 0-0.1-0.2-0.3 the movements are successive after the acceleration time of each of them; 0-3.9-

7.9-11.9 the movements are successive after the constant velocity time from the velocity characteristics; 0-0-0-0 l_i=0.8, φ_1=1.4 -all movements are simultaneously, but were changed the length of the first body and the angular position of the first body.

TABLE I: THE MAXIMAL VARIATION OF THE FORCES

case	P1x	P1y	P1z	P1	<P1	P2x	P2y	P2z	P2	>P2
0-0-0-0	9	1.25	1.2	2.5	0.025	8	1.3	1.3	3	0.01
4-0-0-4	8	0.6	1.25	2	0.025	8.2	0.65	1.3	2.5	0.01
0-4-4-0	8.2	1.5	1.3	2.3	0.025	8.2	1.5	1.3	2.8	0.005
0-4-0-4	8.2	1.25	1.8	1.8	0.03	8	1.3	1.55	2.7	0.015
4-0-4-0	8.3	1	1.3	1.2	0.026	8	1	1.3	2.6	0.008
0-4-8-12	8.2	1.2	1.27	2.2	0.025	8.2	1.3	2.2	2.4	0.03
0-4-8-12 l1/0.8	8.2	1.15	1.4	2.2	0.025	8.2	1.3	1.3	2.5	0.023
0-4-8-12 l1/0.8 l2/0.8	8.2	1.1	1.4	2.3	0.025	8.2	1.2	1.3	2.8	0.023
0-4-8-12 l1,l2, fi12/3	9	1	6	5.4	0.047	9	1.25	5.2	4	0.08
0-0.1-0.2-0.3 l1,l2,fi	8	1.28	1.3	2.8	0.028	8	1.3	1.3	3	0.01
0-0-0-0 l1,l2,fi,qq/2	15	1.8	1.75	4.5	0.035	15	2	1.7	5	0.02
0-3.9-7.9-12.9 l1.l2.fi,qq	14.5	2.5	2.2	5	0.04	14.5	2.3	2	5	0.035

P3x	P3y	P3z	P3	<P3	P4x	P4y	P4z	P4	<P4
9	1.3	0.2	4.2	0.04	6	1.3	1.25	4.5	0.03
9	0.6	1.6	3.5	0.026	6	0.6	1.8	3.5	0.03
8	1.5	2.2	4.5	0.037	6	1.5	2	3.8	0.035
8.3	1.2	1.65	4.3	0.045	6	1.2	2.2	3.8	0.033
8	1	1.2	4.3	0.045	6	1	1.8	3.5	0.03
9	1.2	2	4	0.044	6	1.2	2.3	3.5	0.04
8.4	1.2	2	4.4	0.055	6	1.2	2.3	3.5	0.04
8.5	1.2	2.4	4	0.035	5.5	1.2	2.4	3.3	0.04
10.5	1.2	6	5	0.05	11.5	1.2	7.8	4.5	0.085
8.5	1.33	0.25	4.4	0.035	6	1.33	1	4	0.03
17.5	1.7	1.5	7	0.07	11	1.8	3	7	0.06
12	2.4	4.2	7	0.095	11	2.2	5.5	7	0.08

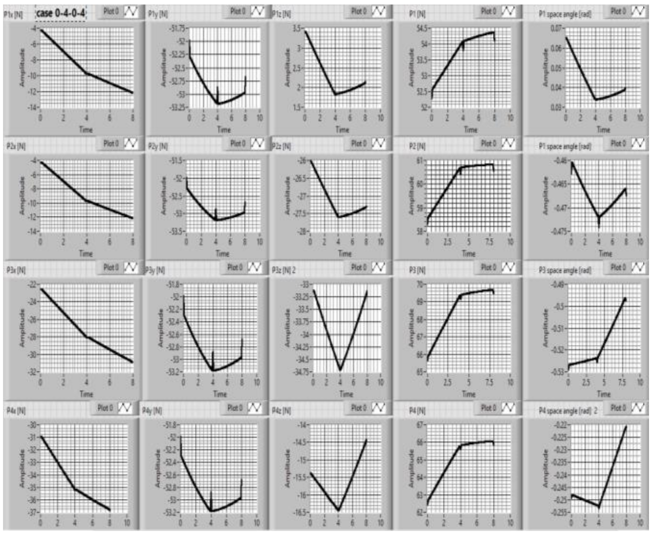
TABLE II: THE POUNDERS CALCULATED USING THE TABLE 1

case	P1x	P1y	P1z	P1	<P1	P2x	P2y	P2z	P2	>P2
0-0-0-0	88.8889	48	100	48	100	100	50	100	83.33333	100
4-0-0-4	**100**	**100**	**96**	**60**	**100**	**97.56098**	**100**	**100**	**100**	**100**
0-4-4-0	97.56098	40	92.30769	52.17391	100	97.56098	43.33333	100	89.28571	200
0-4-04	97.56098	48	66.66667	66.66667	83.33333	100	50	83.87097	92.59259	66.66667
4-0-4-0	96.38554	60	92.30769	100	96.15385	100	65	100	96.15385	125
0-4-8-12	97.56098	50	94.48819	54.54545	100	97.56098	50	59.09091	104.1667	33.33333
0-4-8-12 l1/0.8	97.56098	52.17391	85.71429	54.54545	100	97.56098	50	100	100	43.47826
0-4-8-12 l1/0.8 l2/0.8	97.56098	54.54545	85.71429	52.17391	100	97.56098	54.16667	100	89.28571	43.47826
0-4-8-12 l1,l2, fi12/3	88.88889	60	20	22.22222	53.19149	88.88889	52	25	62.5	12.5
0-0.1-0.2-0.3 l1,l2,fi	100	46.875	92.30769	42.85714	89.28571	100	50	100	83.33333	100
0-0-0-0 l1,l2,fi,qq/2	53.33333	33.33333	68.57143	26.66667	71.42857	53.33333	32.5	76.47059	50	50
0-3.9-7.9-12.9 l1.l2.fi,qq	55.17241	24	54.54545	24	62.5	55.17241	28.26087	65	50	28.57143

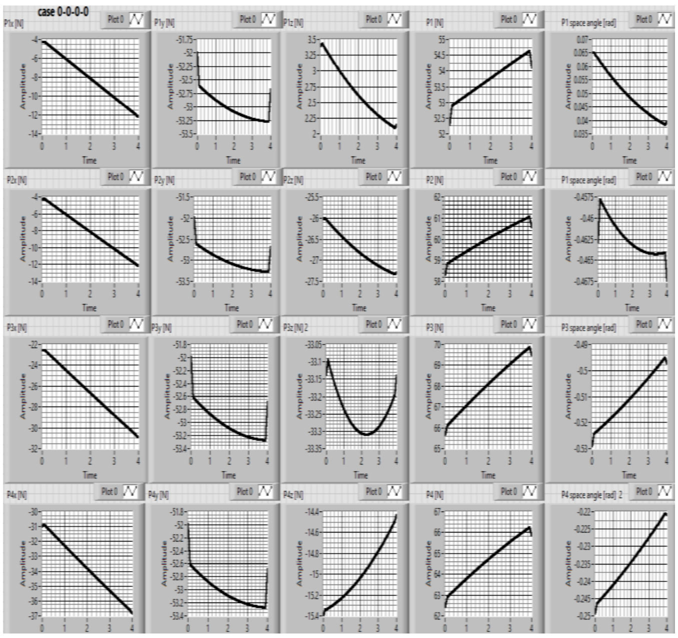
P3x	P3y	P3z	P3	<P3	P4x	P4y	P4z	P4	<P4	
88.88889	46.15385	100	83.33333	65	91.66667	46.15385	80	73.33333	100	1592.7521
88.88889	**100**	**12.5**	**100**	**100**	**91.66667**	**100**	**55.55556**	**94.28571**	**100**	**1796.4578**
100	40	9.090909	77.77778	70.27027	91.66667	40	50	86.84211	85.71429	1563.5846
96.38554	50	12.12121	81.39535	57.77778	91.66667	50	45.45455	86.84211	90.90909	1417.9102
100	60	16.66667	81.39535	57.77778	91.66667	60	55.55556	94.28571	100	1648.3487
88.88889	50	10	87.5	59.09091	91.66667	50	43.47826	94.28571	75	1390.6569
95.2381	50	10	79.54545	47.27273	91.66667	50	43.47826	94.28571	75	1417.5208
94.11765	50	8.333333	87.5	74.28571	100	50	41.66667	100	75	1455.3896
76.19048	50	3.333333	70	52	47.82609	50	12.82051	73.33333	35.29412	955.9893
94.11765	45.11278	80	79.54545	74.28571	91.66667	45.11278	100	82.5	100	1596.9999
45.71429	35.29412	13.33333	50	37.14286	50	33.33333	33.33333	47.14286	50	910.9314
66.66667	25	4.761905	50	27.36842	50	27.27273	18.18182	47.14286	37.5	801.1170

V. ANALYZE OF THE MULTI OBJECTIVE FUNCTION

This paper tries to develop one general assisted methodology of the dynamic behavior in the real domain of the articulated didactical arm type robot by analyze the active forces in each robot's joints, Figs. 10(a)-(k).



(a)



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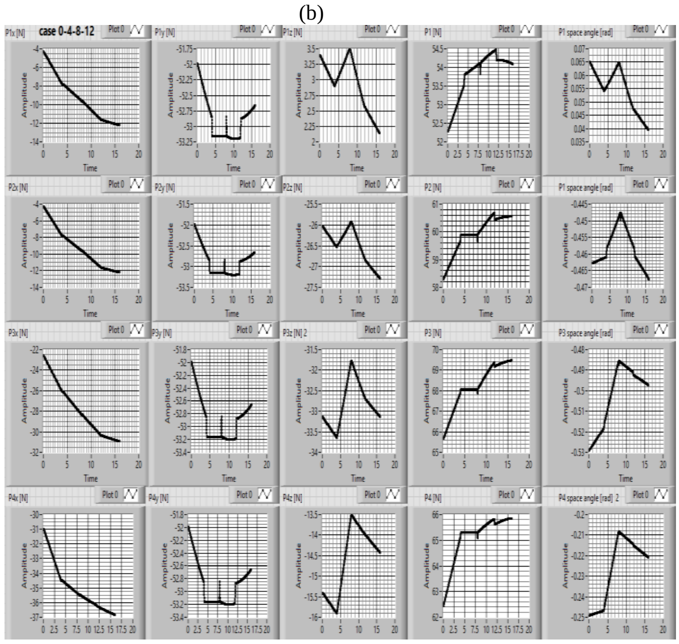
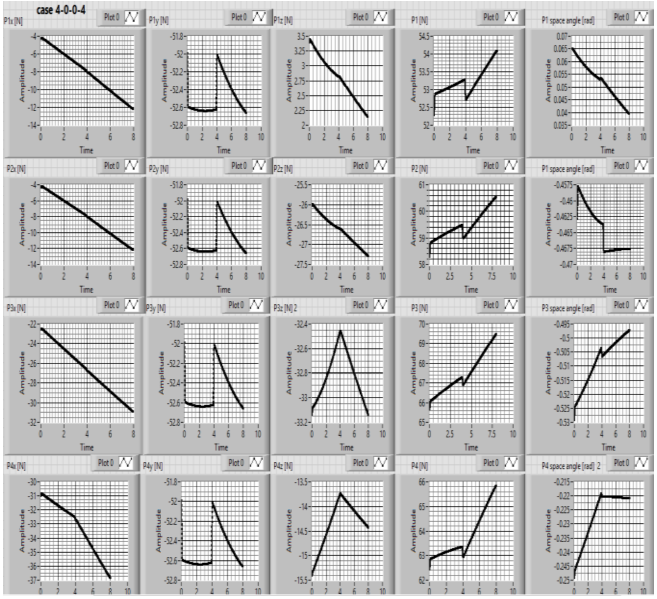
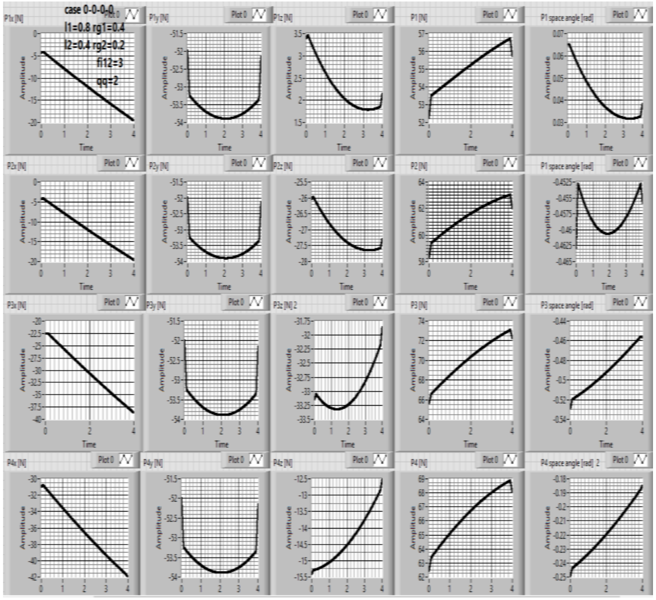


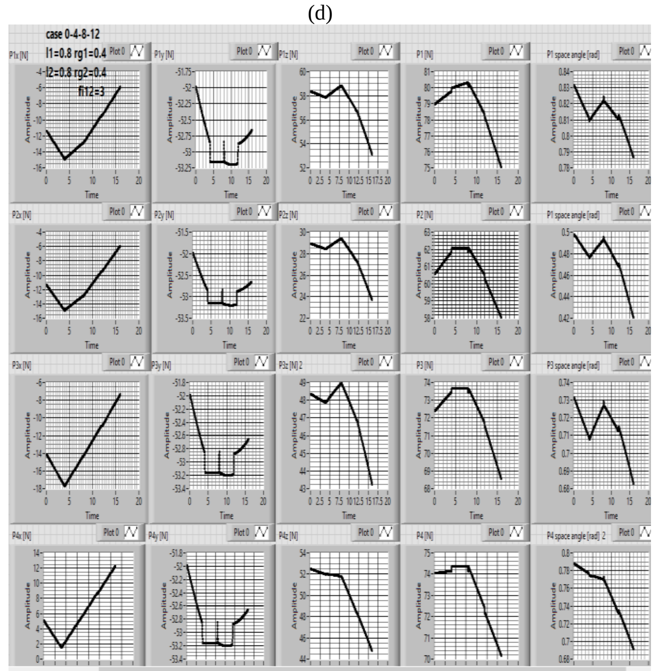
(c)


case 4-0-0-4

(d)


case 0-0-0-0
l1=0.8 rg1=0.4
l2=0.4 rg2=0.2
fi12=3
qq=2

(g)


case 0-4-8-12
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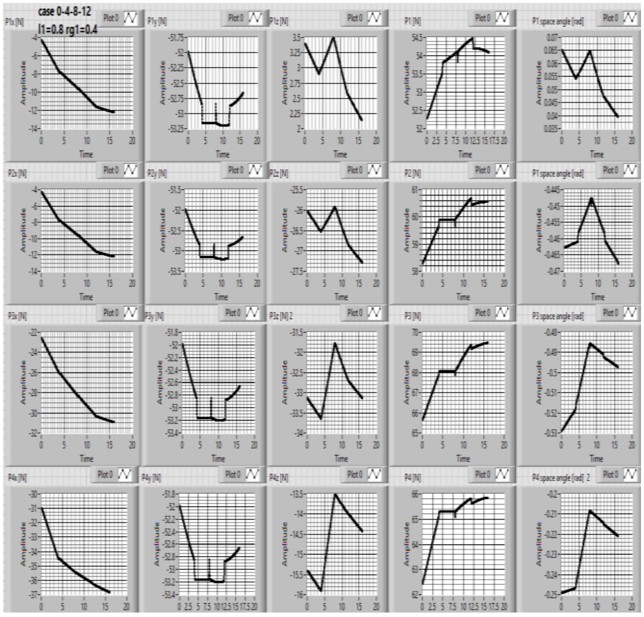
l2=0.8 rg2=0.4
fi12=3

(e)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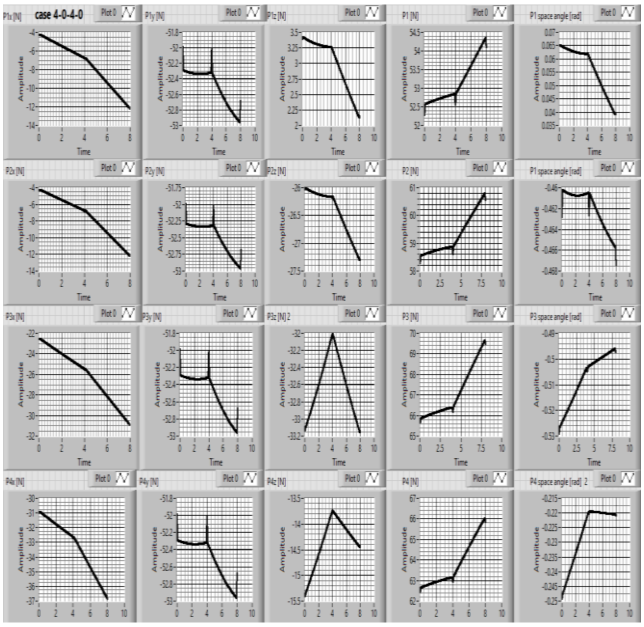
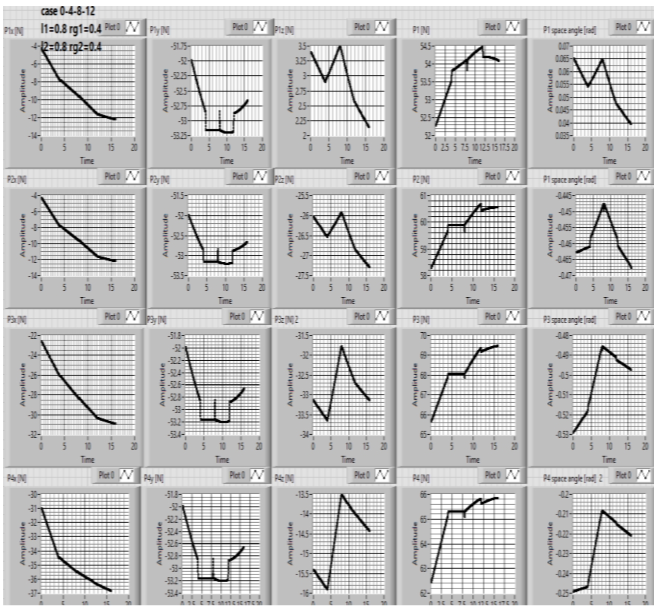
l1=0.8 rg1=0.4

(h)


case 4-0-4-0

(f)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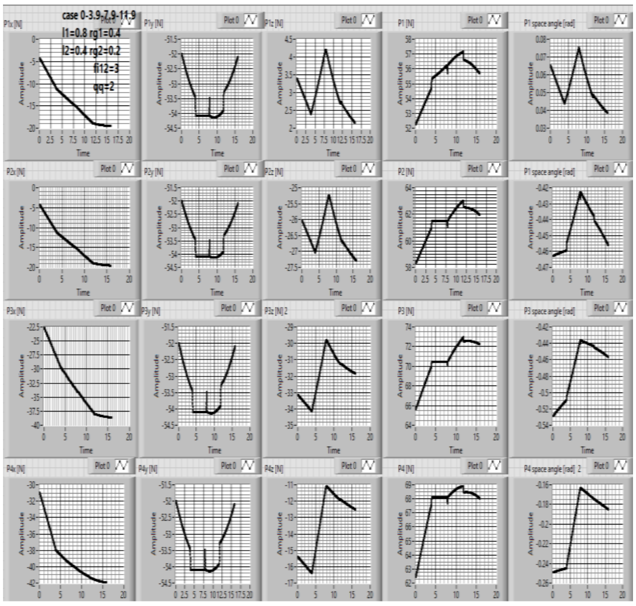
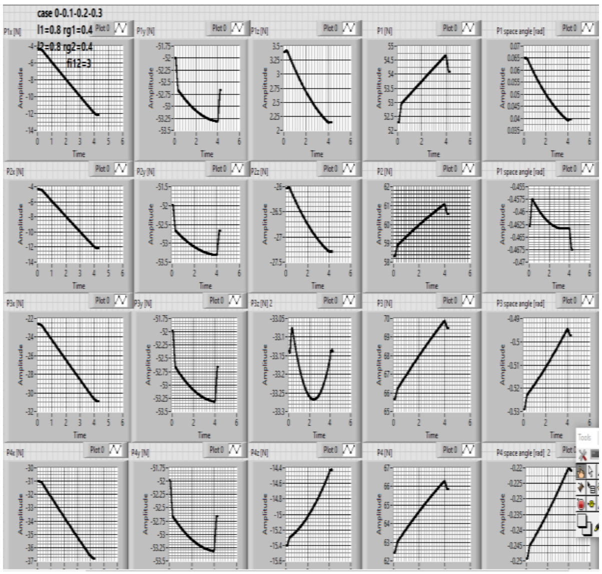
l2=0.8 rg2=0.4

(i)



(j)



(k)

Fig. 10(a)-(k). The variation of the robot's joints forces vs. time and also the variation of the space angle vs. time in different cases of the movements: simultaneously, successive, or combination of them.

The best solution to be assured the minimum variation of the forces and also the position of vector in the space was the case 4-0-0-4 that mince the successive movements of first and fourth robot's body, 4s after the movements of the second and third bodies.

In the paper were solved the following problems: the theoretical and the experimental assisted research of the active forces in robot's joints by using the matrix form of the mathematical model; the research was made by using the proper theoretical LabVIEW *VI*-s; the optimization of the dynamic behavior with the virtual proper *VI*-s was made by applying the proper algorithm and the neutrosophic theory; the choice of the optimal case between the studied cases open the way to choose the optimal movements of the robot's arm, simultaneously, successive or combine between them.

The actual research in the world does not approach the assisted virtual instrumentation for the optimization of the dynamic behavior parameters that were studied in this research.

VI. Conclusion

The results shown in the paper, the researched active forces in some different cases of the robot's joints movements, the applied method, algorithm, multi objective function (*MOF*) and the proper LabVIEW *VI*-s can be used in many other research in the robotics field and will be used in the next research to optimize the moments.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

AO conducted the research and all mathematical model, algorithm and wrote the paper; SO analyzed the data and the English grammar; NM assured the experimental stand; NS work in the research of actual stage. All authors had approved the final version.

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