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ANALYSIS OF WORKSPACE MODULAR SERIAL MANIPULATOR

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ABSTRACT: In determining the size and shape of an unknown serial kinematic structure is possible through use of direct kinematics of a number of supporting software products [4]. The article deals with using of computational program MathCAD to obtain cloud of points representing the workspace. To obtain the precise form is necessary to cut a work space. For this purpose, was used by Excel. Select the appropriate cloud of points you can get the desired form and size of the workspace of any serial manipulator.
KEYWORDS: workspace, serial manipulator, rotation module, curvature module

❖ INTRODUCTION

For effective production, [6] is appropriate to consider the manipulator with 5DOF least, to achieve any point in space and its orientation in at least two axes. The analysis of the workspace was chosen a serial kinematic chain with 5DOF. This serial kinematic chain (hereinafter called as a manipulator, (Fig. 1) consists of five basic modules with rotary angle of curvature of 60°, more precisely described in [1,2]. Swiveling of curved rotary modules manipulator moves in the space of unknown rotating element. This element should be described by dimensional and shape characteristics. To describe these characteristics, it is necessary to use mathematical knowledge in the form of matrices and using the D-H principle deployment of coordinate systems [3].
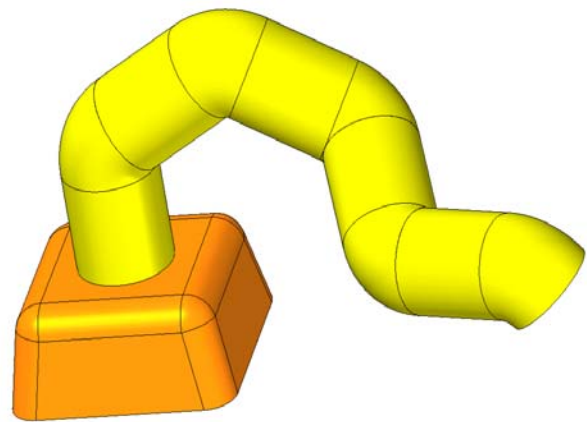

Figure 1. Serial manipulator with 5DOF and 60° curvature of module (3D model)

❖ KINEMATIC ANALYSIS

The beginning of all coordinate systems used in kinematic analysis is always in place of movement. Modules are numbered from the base, the first stationary part has the number "0 ", other motion modules are indexed from 1 to n is a sequence of indexes upwards. Moving units are also numbered from the base, and the i-th rotation unit connecting i-1 and i-th module. Axis "z_{i-1}" is the axis of rotation movement of the i-th unit. Positive direction of the axis is directed preferably to the positive quadrant of the basic coordinate system. Axes "x_i" is perpendicular to the axis "z_{i-1}" and "z_i". So axes z_{i-1} and „z_i„ are concurrent, the positive direction of axes „x" is the requirement that the rotation around the axis x_{i+1} pass axes „z" from a lower to the higher index. Axes „z_n" of last, fifth coordinate system we conduct the end point of the last module the best parallel to the axis of the previous coordinate system, or should it be placed in a distinguished direction, ie parallel with the process of connecting terminal head. Axes „x_n„ last of the coordinate system we conduct the end point of the last module always so cut the axis of the previous coordinate system. In the case referred to is appropriate to place it in the end the last module. Positive direction of the axis is directed into the workspace.
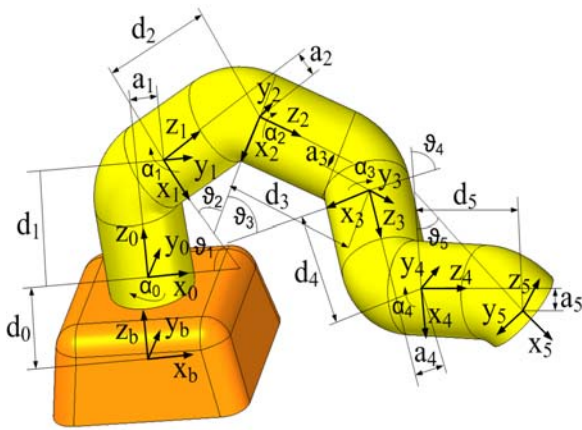
Figure 2. Kinematic diagram of the 3D model of the manipulator

Presumption that any two coordinate systems can be described by group of four variables: θ. (angle between axes „x_{i-1}„ and „x_i„in the rotation about an axis „z_{i-1}"), d (normal respectively minimum distance between the axes „x_{i-1}" and „x_i", in the positive direction in the axis direction „z_{i-1}"), and (normal respectively. minimum distance between the axes„z_{i-1}" and „z_i", in the positive direction in the axis direction „x_i"), α (angle between axes „z_{i-1}" and „z_i" in the rotation about an axis„x_i"). A pair of translational shifts and two angles of rotation, then the variable characterizing the rotation of the modules currently called the generalized variable „q_i", while the index "i" characterizes sequence a member of the kinematic chain. Fig. 2 shows a representation of kinematic diagram of a serial manipulator with 5DOF.

Transformation of coordinates of two coordinate systems located neighboring to each other by D-H parameters will be done through the transformation matrix "Ab0", which is a specific form (1).

$$Ab0(q1,q2,q3,q4,q5) := \begin{pmatrix} \cos(q1) & -\sin(q1)\cdot\cos(a) & \sin(q1)\cdot\sin(a) & lx1\cdot\cos(q1) \\ \sin(q1) & \cos(q1)\cdot\cos(a) & -\cos(q1)\cdot\sin(a) & lx1\,\sin(q1) \\ 0 & \sin(a) & \cos(a) & lx2 \\ 0 & 0 & 0 & 1 \end{pmatrix} \;\text{simplify}\rightarrow\; \begin{pmatrix} \cos(q1) & \dfrac{\sin(q1)}{2} & \dfrac{\sqrt{3}\cdot\sin(q1)}{2} & 150\cdot\cos(q1) \\ \sin(q1) & -\dfrac{\cos(q1)}{2} & -\dfrac{\sqrt{3}\cdot\cos(q1)}{2} & 150\cdot\sin(q1) \\ 0 & \dfrac{\sqrt{3}}{2} & -\dfrac{1}{2} & 50\cdot\sqrt{3} \\ 0 & 0 & 0 & 1 \end{pmatrix} \tag{1}$$

Matrix "Ab0" expresses the transformation relationship of the first two coordinate systems as it can be converted by the coordinates of any point of the coordinate system of higher to lower. In the case where it is necessary to recalculate the coordinates of for example from a third coordinate system to the first, it is necessary to multiply the quartet of transformation matrices (2).

$$\mathbf{T}_b^3(\vartheta_1,\vartheta_2,\vartheta_3) = \mathbf{A}_b^0.\mathbf{A}_0^1(\vartheta_1).\mathbf{A}_1^2(\vartheta_2).\mathbf{A}_2^3(\vartheta_3) \tag{2}$$

In this case, the matrix „T3b" In this case, the matrix 'T3b'refers to the overall transformation matrix of three coordinate systems and using it you can convert points from the third module on the coordinates of the base hard module, a mathematical expression (3).

$$\begin{bmatrix} x_b \\ y_b \\ z_b \\ 1 \end{bmatrix} = \mathbf{T}_b^6(\vartheta_1,\vartheta_2,\vartheta_3,) \begin{bmatrix} x_3 \\ y_3 \\ z_3 \\ 1 \end{bmatrix} \tag{3}$$

❖ SIMULATION OF THE WORKSPACE

Using partial transformation matrices and the total transformation matrix were in the program MathCAD, [7] calculated points manipulator workspace with 5DOF Cloud of points is shown in Fig. 3.
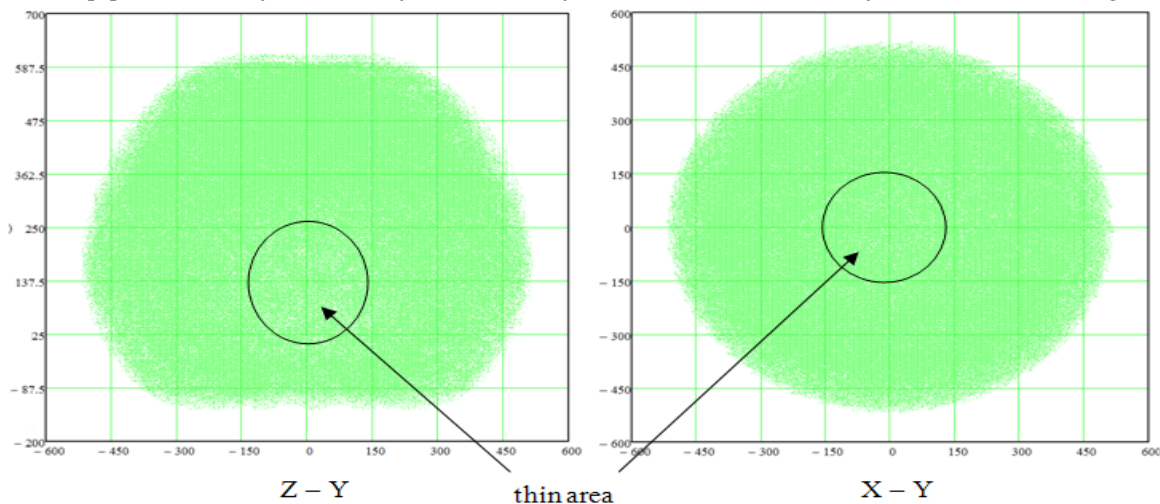

Figure 3. Cloud of points calculated in the program MathCAD

Displayed cloud of points can be identified approximately the workspace The basic form and scope is clear However, in the detailed analysis we find that such a view, we see only clouds envelope points in the middle of this cloud of points is visible loose area, Fig 3. This area is sparse should investigate the best cut workspace. For this purpose, was created a table of values calculated by transferring data from the programming interface to Excel, MathCAD, Fig 4. Subsequently, it was necessary to process the points using simple imaging conditions only those items that meet the condition: point Y   (-9,9). Points which satisfy this condition are shown in the graph. Their number is about 1400. Points which do not comply will appear as a point with coordinates (0,0,0) These points is approximately 63900 The problem is that the type of graph in Excel appears as a larger number than 32000. It follows that the the graph shows approximately 30300 times, point (0,0,0) and approximately 700 times relevant points investigated, forming a cloud of points investigated workspace.

The problem can be solved been selected set of relevant points in 1400 and the number of filtering zero points This way created more cloud points, which is also shown in the table selected corresponding points on Fig 5.

Achieve further improvement mirrored been selected points, as shown in Fig 6. By having all the basic modules, which make up investigate manipulator is rotating, while rotation is not limited, it is clear that it is possible to regulate all points with the opposite sign values "X" while leaving the values of "Z". This modification get additional points contributing to the improvement of a thickening cloud of points in the plane cuts the work area.
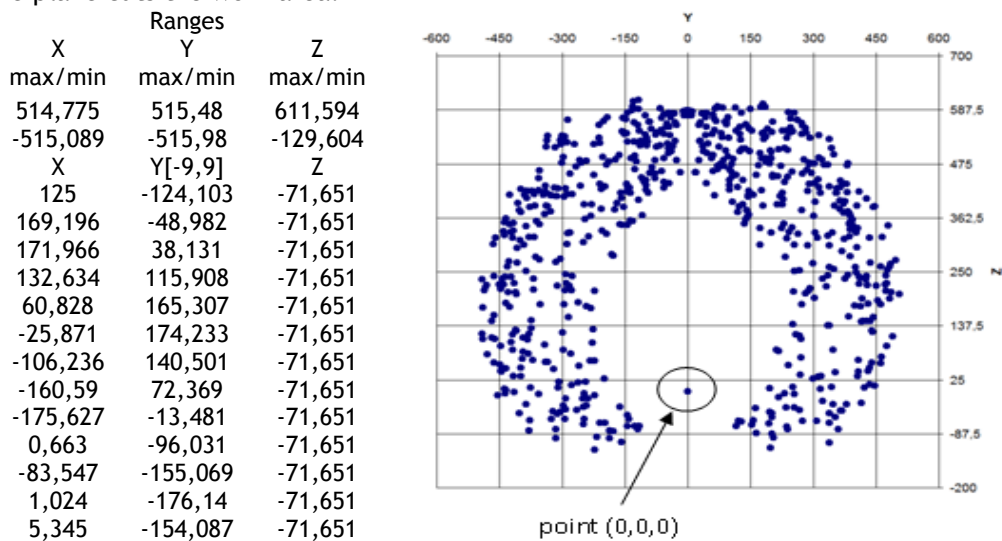
Ranges		
X	Y	Z
max/min	max/min	max/min
514,775	515,48	611,594
-515,089	-515,98	-129,604
X	Y[-9,9]	Z
125	-124,103	-71,651
169,196	-48,982	-71,651
171,966	38,131	-71,651
132,634	115,908	-71,651
60,828	165,307	-71,651
-25,871	174,233	-71,651
-106,236	140,501	-71,651
-160,59	72,369	-71,651
-175,627	-13,481	-71,651
0,663	-96,031	-71,651
-83,547	-155,069	-71,651
1,024	-176,14	-71,651
5,345	-154,087	-71,651

Figure 4. Initial values of cloud points (over 65500 points, 700 shown)

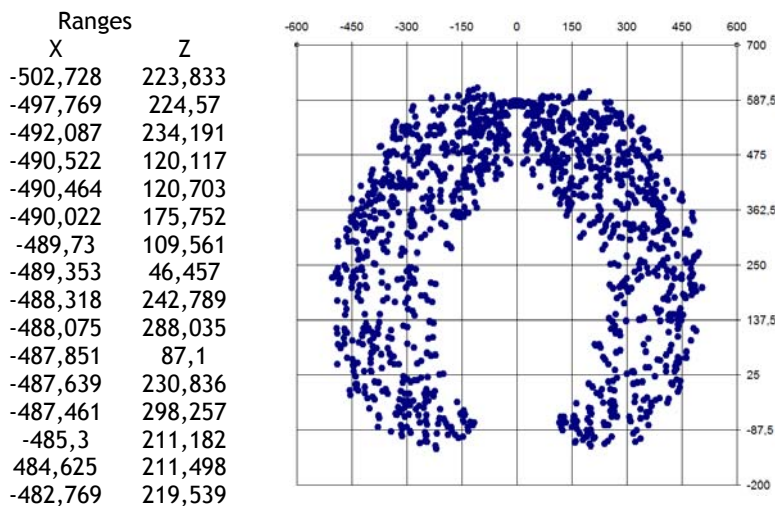| Ranges	
X	Z
-502,728	223,833
-497,769	224,57
-492,087	234,191
-490,522	120,117
-490,464	120,703
-490,022	175,752
-489,73	109,561
-489,353	46,457
-488,318	242,789
-488,075	288,035
-487,851	87,1
-487,639	230,836
-487,461	298,257
-485,3	211,182
484,625	211,498
-482,769	219,539

Figure 5. Initial values of cloud points (more than 1400 points)

Obtained clarification and simplification resulted to an increase in perfection of cut workspace homogeneous kinematic structure of serial 5DOF. Very interesting test of the accuracy of solution for analysis of point clouds and the subsequent acquisition of workspace overlay graph cloud of points obtained in the program MathCAD, while clouds of points cut, processed and selected in Excel.

Assuming the accuracy of solutions and the election of a single magnification should be the graphic representation of the match and give a clear idea of the necessity or uselessness analyze workspace unknown kinematic motion structures not only views on a plane Cartesian space, but also in the section of this space [9]. As seen in Fig 7, workspaces and analyzed in a second program to match exactly in the spot where they were in Fig. 3 places with little cloud of points should not manipulator workspace, thus the end effector can not work in this area.

| Ranges		Mirrored points	
X	Z	X	Z
-502,728	223,833	502,728	223,833
-497,769	224,57	497,769	224,57
-492,087	234,191	492,087	234,191
-490,522	120,117	490,522	120,117
-490,464	120,703	490,464	120,703
-490,022	175,752	490,022	175,752
-489,73	109,561	489,73	109,561
-489,353	46,457	489,353	46,457
-488,318	242,789	488,318	242,789
-488,075	288,035	488,075	288,035
-487,851	87,1	487,851	87,1
-487,639	230,836	487,639	230,836
-487,461	298,257	487,461	298,257
-485,3	211,182	485,3	211,182
-484,625	211,498	484,625	211,498
-482,769	219,539	482,769	219,539
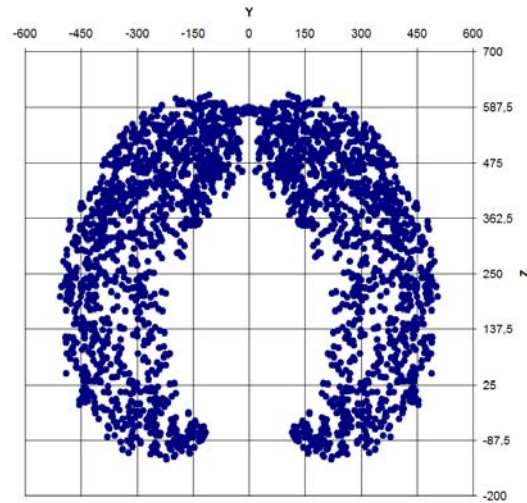
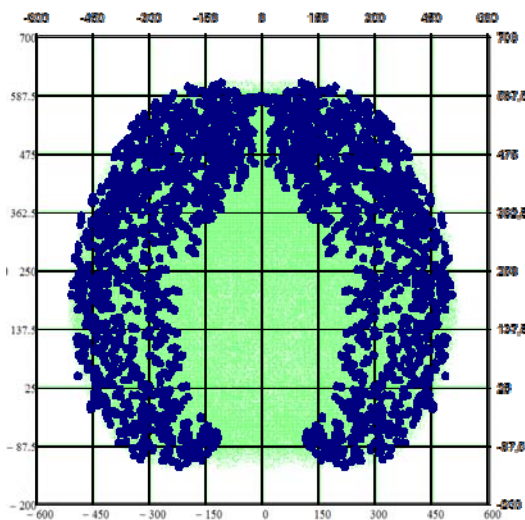Figure 6. Initial values of cloud a mirror points (more than 2800 points).

Figure 7. Displacement points clouds obtained from the MathCAD and Excel

❖ CONCLUSION

Kinematic analysis of cloud points was found manipulator workspace with 5DOF., which consists of five items of rotary motion modules with 60 ° curvature. This cloud of points represents most probable the work area because it was obtained by analyzing a large number of random points, namely around 2800. Cut cloud of points which represent the rotational workspace showed a cavity in the middle of the workspace where the end effector can be achieved [10]. For the most advanced examination work area would be best to generate 3D body with specialized software to work with the clouds of points. Further to the analysis work area is necessary to implement a functional prototype also consider the potential risks [5], which may Act in motion kinematic structures arise. After an analysis can be stated that this principle is beneficial in automated handling systems and the application of the relevant cases [8].

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