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Matlab Simulator of a 6 DOF Stanford Manipulator and its Validation Using Analytical Method and Roboanalyzer

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Abstract: This paper represents the generation of a STANFORD 6 DOF manipulator end-effector matrix using a MATLAB code. The end effector matrix of the manipulator is also calculated by analytical method. Roboanalyzer software is used to support the results generated by the MATLAB code and analytical method. The homogenous transformation matrix is of the order 4×4 that gives us the end effectors or tool frames position and orientation with respect to the fixed base frame. D-H parameters are used for the frame assignment to each link. Forward kinematics is implemented in MATLAB, analytical method and Roboanalyzer software and the results are compared which are found to be equal.
Keywords: 6-DOF STANFORD Manipulator, MATLAB, Roboanalyzer Software, DH Parameters, Forward Kinematics

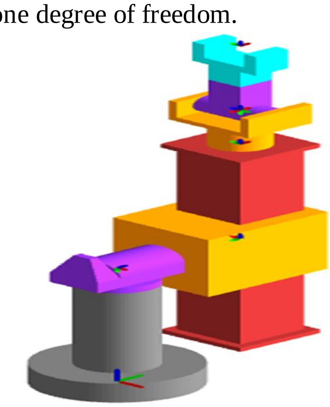
I. INTRODUCTION

A robot is designed to accomplish a particular task in an application and to achieve this, it is required to have the position and control of the tool or end effector in a robotic manipulator. Different tools or end-effectors are attached to the manipulator depending on the task to be executed. The tool or end-effector follows a planned trajectory to carry out the task in the 3D workspace and thereby the position and control of each link and joint is required. A kinematic model is formulated to analyze the motion behavior of the manipulator. The kinematics model deal with the spatial position of links and joints without considering the forces or moments that cause the motion. The forward kinematics studies the effect of the entire set of joint variables on the position and orientation of the tool. Denavit and Hartenberg (1955) proposed that four parameters are required to assign frames to each link of a manipulator and these DH parameters have become the most common standard method for describing the robot kinematics.
The aim of this paper is to compare the results obtained from MATLAB and Roboanalyzer software and predict the position of the end-effector matrix of a STANFORD 6 degree of freedom robot.

II. STANFORD MANIPULATOR AND MANIPULATOR KINEMATICS

A. Robot Description

The robot is a 6 degree of freedom robot arm manipulator as shown in the figure. It has one prismatic joint and five revolute joints giving a configuration of RRPRRR. The last three revolute joints constitute a wrist and the first three, an arm. It has total 7 links including the base link. The arm accomplishes the task of reaching the desired position and the wrist helps in the orientation of the tool. All the joints are actuated by DC motors and has only one degree of freedom.



B. *Forward Kinematics*

Forward kinematics gives the position and orientation of the end-effector matrix for an n-degree of freedom manipulator with respect to a base frame. Here the joint variables are known and the manipulator under consideration is a 6-degree of freedom Stanford manipulator.

In revolute joints, the angles between the links are the joint variables. In prismatic joints, the link extension and contraction are the joint variables.

The overall transformation matrix describes the position of end-effector or tool-frame with respect to the fixed base frame. For this purpose, frames are assigned to each link starting from the base frame. Thus a manipulator having n links will have n+1 frames with the reference base frame named as {0}. A transformation matrix relating two frames attached to two adjacent links is obtained and an overall description of the tool-frame is obtained by combining the individual transformation matrices.

DH notation describes the assignment of frames to each link in a kinematic chain and defines a manipulator in terms of four joint link parameters. The four parameters are link length, link twist, joint distance and joint angle.

C. *Links and Joints Convention*

A robot manipulator having n DOF is modeled as a manipulator having n joints, as one joint has only one degree of freedom unlike a ball socket joint that has two degrees of freedom. It is an open kinematic chain of rigid links connected to each other by revolute or prismatic joints to allow relative motion between the two links. It can be concluded that an n DOF manipulator has n joints and n+1 links. The links are numbered from 0 to n and the joints from 1 to n. Thus joint i connects link i-1 and link i. Thus to move link i, we need to actuate joint i.

The Joint Parameters of Stanford Manipulator are listed in table below

Table 1 D-H Parameters of Stanford Manipulator

Sr. No	Joints	a (mm)	α (deg)	d (mm)	Initial Value(JV)	Final Value(JV)
1	Joint 1	0	-90	0.762	0	60
2	Joint 2	0	-90	0.393412	-90	-150
3	Joint 3	0	0	Variable	0.635	0.735
4	Joint 4	0	-90	0.2268	0	60
5	Joint 5	0	-90	0	180	150
6	Joint 6	0	0	0.4318	180	150

Since joint angle and joint variable are the only variables in revolute and prismatic joint respectively we will be taking 4 sets of values for these D-H parameters and finding the end effector for these four sets using forward kinematics

The step-by-step frame assignment for each joint-link of the manipulator is shown below. Frames are first assigned to the intermediate links, links 1 to 5 and then to link 0 and link 6

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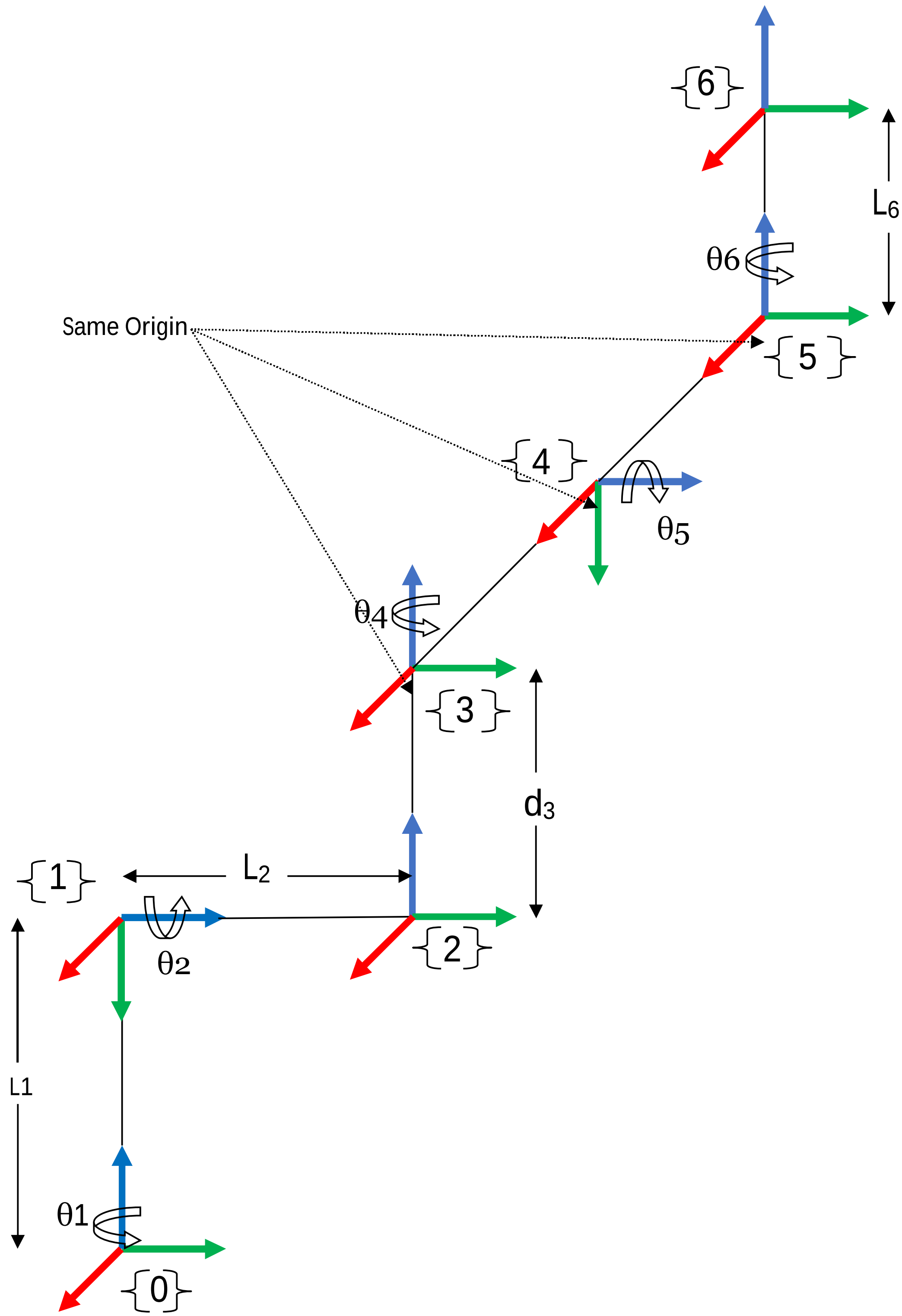

III. METHDOLOGY

MATLAB code for finding out the end effector transformation matrix is prepared. We have taken four cases, for all these cases we have found end effector matrices via code. Roboanalyzer is used for demonstrating same four cases and the end effector transformation matrices are found through Roboanalyzer. The end effector transformation matrices by the Roboanalyzer are then compared to the one found by MATLAB simulator. Further analytical approach was also taken into account, and the end effector transformation matrices for the considered cases were found and the results were compared to the one obtained by MATLAB.

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This was done to validate simulator by the two methods, Roboanalyzer and analytical method.

IV. FORMATION OF MATHEMATICAL MODEL USING MATLAB

The simulation results as presented are for the forward kinematic analysis of the STANFORD Robot as modelled using the (D-H) concept. Simulations were conducted using MATLAB coding on an Intel (R) CORE i5-2450M CPU @ 2.50GHz, 4.00GB Memory (RAM), 64bit Operating System. The MATLAB coding was used to do mathematical iterations of the serial link manipulator. The variables θ1, θ2, θ3, and θ4 respectively represent the joint axes 1 through 4. Kinematics equations from the overall transformation matrix were developed using the MATLAB R 14.0b . A code has been developed to generate the forward kinematics equations and calculate the robot Manipulator position and orientation in terms of joint angles and its output is compared with Robot software (which is the simulate program supplied with the robot system) for four sets of joint parameters. The result of end-effecter‟s position from MATLAB iteration was then compared with experimental result generated from inbuilt Robo Analyzer software. For different keyboard values entered on the Robo Analyzer software, the corresponding joint angles, simulation and experimental positions for the end-effecter are presented.

V. INPUT SET OF D-H VALUES

Table 2 SET1

Joint No	Joint Type	Joint Offset (b) m	Joint Angle (theta) deg	Link Length (a) m	Twist Angle (alpha) deg	Initial Value (JV) deg or m	Final Value (JV) deg or m
1	Revolute	0.762	Variable	0	-90	0	0
2	Revolute	0.393412	Variable	0	-90	-90	-90
3	Prismatic	Variable	-90	0	0	.635	.635
4	Revolute	0.2268	Variable	0	-90	0	0
5	Revolute	0	Variable	0	-90	180	180
6	Revolute	0.4318	Variable	0	0	180	180

Table 3 SET2

Joint No	Joint Type	Joint Offset (b) m	Joint Angle (theta) deg	Link Length (a) m	Twist Angle (alpha) deg	Initial Value (JV) deg or m	Final Value (JV) deg or m
1	Revolute	0.762	Variable	0	-90	20	20
2	Revolute	0.393412	Variable	0	-90	-110	-110
3	Prismatic	Variable	-90	0	0	.660	.660
4	Revolute	0.2268	Variable	0	-90	20	20
5	Revolute	0	Variable	0	-90	170	170
6	Revolute	0.4318	Variable	0	0	170	170

Table 4 SET3

Joint No	Joint Type	Joint Offset (b) m	Joint Angle (theta) deg	Link Length (a) m	Twist Angle (alpha) deg	Initial Value (JV) deg or m	Final Value (JV) deg or m
1	Revolute	0.762	Variable	0	-90	40	40
2	Revolute	0.393412	Variable	0	-90	-130	-130
3	Prismatic	Variable	-90	0	0	.700	.700
4	Revolute	0.2268	Variable	0	-90	40	40
5	Revolute	0	Variable	0	-90	160	160
6	Revolute	0.4318	Variable	0	0	160	160

Table 5 SET4

Joint No	Joint Type	Joint Offset (b) m	Joint Angle (theta) deg	Link Length (a) m	Twist Angle (alpha) deg	Initial Value (JV) deg or m	Final Value (JV) deg or m
1	Revolute	0.762	Variable	0	-90	60	60
2	Revolute	0.393412	Variable	0	-90	-150	-150
3	Prismatic	Variable	-90	0	0	0.735	0.735
4	Revolute	0.2268	Variable	0	-90	60	60
5	Revolute	0	Variable	0	-90	150	150
6	Revolute	0.4318	Variable	0	0	150	150

VI. MATLAB OUTPUTS

With the help of the MATLAB code for a 6-DOF STANFORD Manipulator, the end effector position was obtained for four different sets of joint variables (joint angles). The input values for the prismatic joint were also varied and the results were obtained.

A. SET 1

0.0000	0.0000	1.0000	1.2936
1.0000	0	-0.0000	0.3934
-0.0000	1.0000	-0.0000	0.7620
0	0	0	1.0000

B. SET 2

-0.2352	-0.2294	0.9445	1.0563
0.9475	-0.2709	0.1701	0.7282
0.2169	0.9349	0.2810	1.1866
0	0	0	1.0000

C. SET 3

-0.5380	-0.1575	0.8281	0.6486
0.7186	-0.5993	0.3528	0.9101
0.4407	0.7849	0.4356	1.5458
0	0	0	1.0000

D. SET 4

-0.7645	0.1746	0.6205	0.1677
0.2919	-0.7645	0.5748	0.8614
0.5748	0.6205	0.5335	1.8253
0	0	0	1.0000

VII. ANALYTICAL RESULTS

The end effector matrix is given by homogeneous transformation matrix

$$\begin{bmatrix} C\theta_i & -S\theta_i C\alpha_i & S\theta_i S\alpha_i & a_i C\theta_i \\ S\theta_i & C\theta_i C\alpha_i & -C\theta_i S\alpha_i & a_i S\theta_i \\ 0 & S\alpha_i & C\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The outputs via analytical method for each set are as shown

SET 1 $\begin{bmatrix} 0 & 0 & 1 & 1.2936 \\ 1 & 0 & 0 & 0.3934 \\ 0 & 1 & 0 & 0.7620 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

SET 2 $\begin{bmatrix} -0.2352 & -0.2294 & 0.9445 & 1.0563 \\ 0.9475 & -0.2709 & 0.1701 & 0.7282 \\ 0.2169 & 0.9349 & 0.2810 & 1.1866 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

SET 3 $\begin{bmatrix} -0.5380 & -0.1575 & 0.8281 & 0.6486 \\ 0.7186 & -0.5993 & 0.3528 & 0.9101 \\ 0.4407 & 0.7849 & 0.4356 & 1.5458 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

SET 4 $\begin{bmatrix} -0.7645 & 0.1746 & 0.6205 & 0.1677 \\ 0.2919 & -0.7645 & 0.5748 & 0.8614 \\ 0.5748 & 0.6205 & 0.5335 & 1.8253 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

VIII. ROBO ANALYZER RESULTS

Keeping the other D-H parameters fixed and by only varying the joint angles and the prismatic joint values, we give four input values to the Roboanalyzer software. The end effector matrix was obtained directly that can be easily compared with the matrix obtained by MATLAB code and analytical method.

A. SET 1

$$\begin{bmatrix} 0 & 0 & 1 & 1.2936 \\ 1 & 0 & 0 & 0.393412 \\ 0 & 1 & 0 & 0.762 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

B. SET 2

$$\begin{bmatrix} -0.235175 & -0.229356 & 0.944505 & 1.056346 \\ 0.947452 & -0.270909 & 0.170123 & 0.728158 \\ 0.216856 & 0.934882 & 0.281015 & 1.186646 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

C. SET 3

$$\begin{bmatrix} -0.537992 & -0.157532 & 0.828099 & 0.648562 \\ 0.718583 & -0.599287 & 0.352838 & 0.910086 \\ 0.440686 & 0.784882 & 0.435611 & 1.545832 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

D. SET 4

$$\begin{bmatrix} -0.764503 & 0.174639 & 0.620513 & 0.167683 \\ 0.291867 & -0.764503 & 0.57476 & 0.861359 \\ 0.57476 & 0.620513 & 0.533494 & 1.825306 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

IX. CONCLUSIONS

The D-H parameter joint angles were varied and the results were obtained by MATLAB. The end effector matrix obtained from MATLAB was compared with that obtained by analytical method and Roboanalyzer software. Other D-H parameters were fixed except the Prismatic joint. Four different input sets were given to the Roboanalyzer software and MATLAB and the corresponding end effector matrix was obtained for each set of values. Analytical method was also used to verify the results obtained by the above two methods. It was observed that the results obtained by the three methods were similar.

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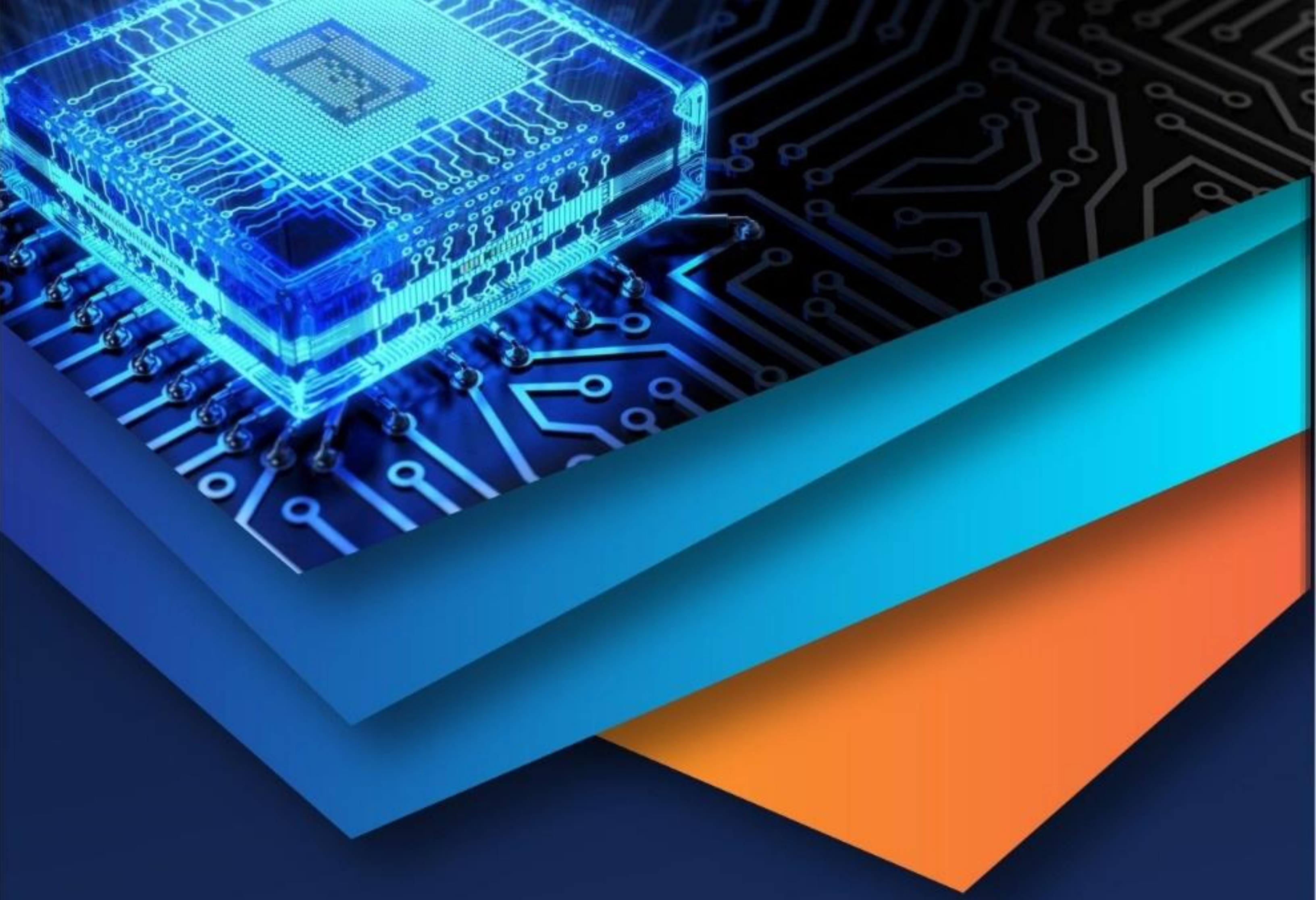

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