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Kılavuz çekme makinası kinematik analizi ve Simmechanics ile simülasyonu

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Kılavuz Çekme Makinası Kinematik Analizi ve Simmechanics ile Simülasyonu

Araştırma Makalesi / Research Article

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ÖZ

Bu çalışmada, 4 serbestlik dereceli kılavuz çekme makinesinin tasarımı, kinematic analizi ve simülasyonu gerçekleştirilmiştir. Tasarım için Solidworks kullanılmıştır. Cihazın Solidworks montajı Simmechanics modülüne transfer edilip MATLAB blokları haline getirilmiştir. Manuel olarak çözümlenmiş olan kinematic analizin sonuçları Mfunction ile sisteme tanıtılıp uç işlevci pozisyonuna bağlı olarak sistemin hareketi kontrol edilmiştir. Kılavuz çekme makinası tasarımı bilgisayar kontrollüdür ve otomasyonla desteklenin montaj hatları için uygun bir çözümdür.

Anahtar Kelimeler: Kılavuz çekme makinesi, Simmechanics simulasyon, kinematik analiz.

Kinematic Analysis of Tapping Machine and Simulation with Simmechanics

ABSTRACT

In this study, the design, kinematic analysis and simulation of a 4-degree-of-freedom tapping machine were performed. Solidworks software was used. The design was transferred to the Simmechanics module and transformed into MATLAB blocks. The results of kinematic analysis were introduced to the system with Mfunctions, and the movement of the system was controlled depending on the position input. The tapping machine design is computer controlled and is a suitable solution for tapping on automation supported assembly lines.

Keywords: Tapping machine, Simmechanics simulation, kinematic analysis.

1. INTRODUCTION

In recent years, developments in machine technology have rapidly increased the tendency to design and use automation oriented machines.

The tapping machine is a manipulator that performs tapping in the manufacturing industry and assembly lines with the automation system. In its design, kinematic and inverse kinematic calculation systems were adhered to. Movement ability was realized with coordinate information. In the design, the limbs connected with more than one joint increased the mobility. The movement of the joints is provided by servomotors. The design of the tapping machine was based on the functional functions of industrial robots.

The history of industrial automation is characterized by periods of rapid change in popular methods. The periods of change in automation techniques depend on the world economy. Industrial robots were described as unique devices in the 1960s. With CAD-CAM systems, automation in manufacturing processes has been re-characterized as well. Comprehensive developments in CAD-CAM systems directly influence and even manage industrial automation [1] In the 2000s, about 78% of robot use in America included welding and material loading robots. Within the development process, 10% of robot automation has been directed towards industrial applications [2]. The experience gained in rough operations such as handling, loading, and welding leads the way in the transition to precision operations. The technological innovations and developments that are experienced rapidly in the industrial robot industry attract the attention of researchers. The tapping process is a process that must be shown sensitivity in the manufacturing sector.

The tapping process is a process that is used extensively to open screws in holes [3]. The taps have threads in the desired form around them and are comprised of one or more cutters. Their profiles differ as they may be cylindrical or conical [4,5]. According to the Turkish Standards Institute, a tap is defined as a cutter with screw threads on it that is used for cutting screws in holes that are drilled in materials such as metal and plastics via drilling bits or are brought to a specific point through turning [4,5,6].

Tapping is basically the performance of drilling operations. The screw is cut by combining the tool's rotational and advancing movements. It can be done by different methods, some of which are drilling machines, machining centers, lathe centers equipped with rotary

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heads, conventional turning, and manually [7]. Current developments in robotics allow the use of manipulators with automatic control during tapping.

Different principles can be taken as basis for robot manipulator control. Control by show and teach method, offline programming, and control by artificial neural network underlie them. The methods may be preferred according to needs. The kinematic and inverse kinematic equations need to be solved in order to use the programming logic in control of the manipulator. Coordinate information that is to be achieved constitutes the movement of the end effector. The angle changes in joints of the end effector which must be attained can be determined by the DenavitHartenberg principle, which is one of the basic principles of kinematics.

In complex nonlinear and coupled systems, the robot manipulator cannot be efficiently controlled by the conventional position-integral-derivative (PID) controller. In order to enhance the effectiveness of the conventional PID controller for nonlinear indeterminate systems, the gains of the PID controller must be conservatively set. The PID controller process must adapt to parameter changes [8]. In this study, kinematic and inverse kinematic equations were derived from the DenavitHartenberg principle. MATLAB simulation was performed by PID control for the derived equations.

In a research by Donya et al., a framework for neural networks (NN) based consensus control is proposed for multiple robotic manipulators systems (MRMS) under leader–follower communication topology.Two situations, that is, fixed and switching communication topologies, are studied by using adaptive and robust control principles, respectively. Radial basis function (RBF), NN estimator, and observers are developed for system uncertainty and the leader manipulator′s control torque is provided online [9].

In “Computationally efficient and robust kinematic calibration methodologies and their application to industrial robots” by Messay et al., efficiency calculation and robust kinematic calibration algorithms were studied for industrial robots with partial measurements. This involves finding the Cartesian coordinates of the calibration points and applying some calibration techniques to some reference points that require radial measurement from the calibration points. The method needs neither orientation methods nor explicit information about where the reference axis is located. Contrary to similar studies, the original Denavit-Hartenberg kinematic model is simplified when both methods are used. The simplified DH(-) model has not only proven to be robust and effective in calibrating industrial manipulators but it is also favored from a computational efficiency viewpoint since it consists of comparatively fewer error parameters [10].

2. DESIGN OF TAPPING MACHINE

The tapping machine design has a structure that can perform the tapping function functionally. With the addition of automation system to the design, tapping ceased to manual job. With this machine, in addition to standard tapping operations, screws can also be cut in the angled holes. Angled tapping function was added with a servo motor added immediately after the end effector.

The tapping machine was designed as a manipulator with three degrees of freedom until the wrist and having three axes. Two more movements were obtained in the design by adding a servo motor and a hydraulic motor to the wrist. Three servo motors positioned from the principal axis to the wrist were used to position the wrist and make it follow the desired trajectory. With the servo motor in the wrist, the axis shift of the end effectorwas blocked so that the trajectory was followed without any error and oscillation. Thanks to the hydraulic motor placed on the end effector, the tap head was made rotational.

Figures 1 and 2 show the working space suitable for the tapping machine. Due to the geometric constraints for the first limb in this working space, the θ2 angle must not exceed 90° (Figure 3). If this limit is exceeded, the end effector and upper limbs hit the table placed on the floor. The working space was abided by to avoid damage that might occur in the machine. In the second limb, the angle θ3 must be between -90° and 160° (Figure 3). Thus, the collision of the first limb with the tail part of the second limb, which is its balance element, is prevented. With these boundaries kept, it can be understood from the figure within what maximum limits the machine will move.

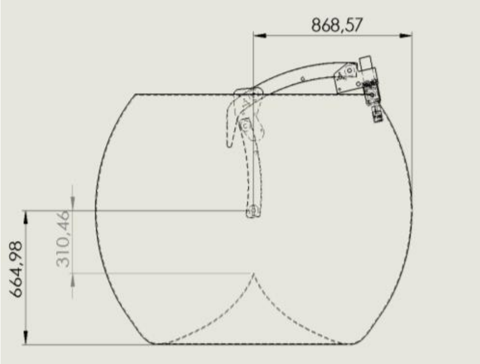

Figure 1 Basic measures for the tapping machine.

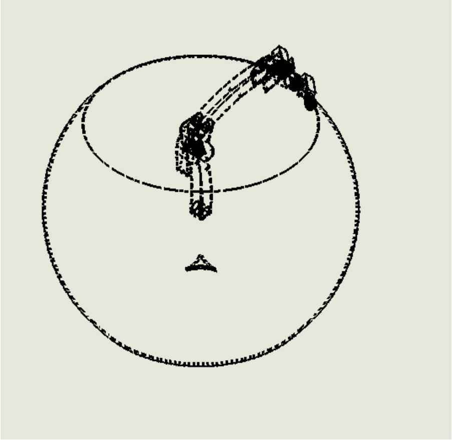

Figure 2 Working space boundaries obtained for the tapping machine.

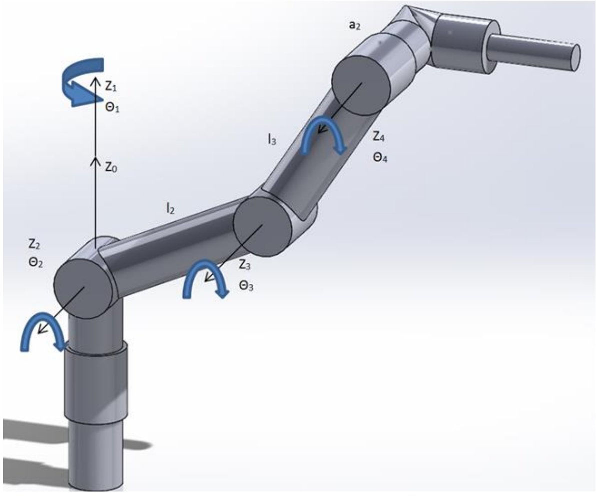

Figure 3. Positioning, rotation angles, and parametric measurements of the axes for the tapping machine.

Tapping is a two-dimensional straight line in terms of the path it is to follow. A robot arm with two joints is sufficient to follow such a line. However, the mobility of two-jointed manipulator is planary. To remove the design from the planarity, a rotary joint was placed at the bottom of the main body. The tapping machine turned into an anthropomorphic structure. Thus, a design having a capacity to operate in two parallel bands based on the need was obtained. Figure 3 shows the joints that were rotated and the ways they were rotated.

The positioning of the end effector is completely provided by the first three joints, which are expressed by the angles θ1, θ2, and θ3. With the help of the joint expressed by Θ4, oscillations and axis deviations of the end effector are prevented during movement. Thus, the trajectory is followed with fewer errors.

Figure 4 shows the mechanical structure of the tapping machine. The three bar mechanisms on the upper arm ensure that the end effector always works in a perpendicular way to the working space. If an angled operation is required, the desired angle can be applied to the end effector via the fourth servo motor.

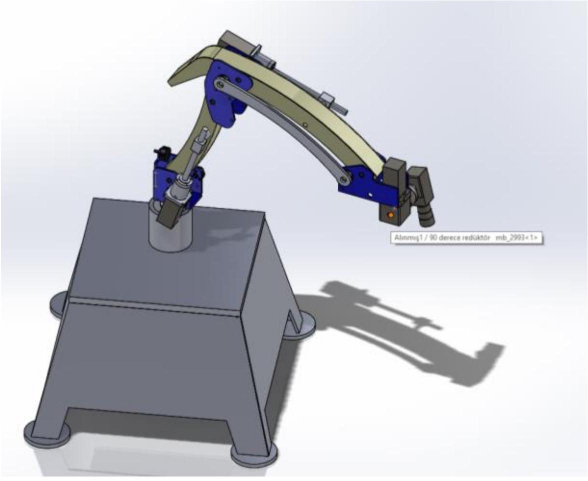

Figure 4 The tapping machine.

3. DYNAMIC ANALYSES FOR THE TAPPING MACHINE

The method of analysis in which the motions and behavioral characteristics of the mechanisms, the tendency of velocity, and the effect of force on motion are analyzed is expressed as dynamic analysis (Figure 5).

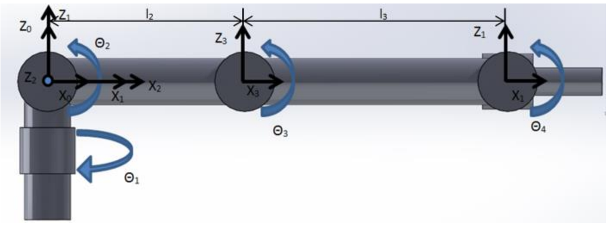

Figure 5. Variable angle values to be used in kinematic analysis (Figure shows the position where the equipment angle values of the device are zero).

In the robotics this becomes more specialized. In this study, the basic principles of robotics were provided, and the mechanical structure of the manipulator was analyzed by Denavit-Hartenberg parameters. Axis sets were placed according to this principle, and the variable parameters of the axes were determined. On the basis of this principle, the mathematical model needed to obtain the position by looking at the angle through forward (direct) kinematic equations was reached. With the inverse kinematic equations, the mathematical model needed to obtain the angle by looking at the angle was showed.

Kinematic Analysis for the Tapping Machine

There are separate vectorial representations for each point of axis and there are matrices defined for each vectorial representation. These matrices are determined by the Denavit Hartenberg principle. Table 1 shows the table of the Denavit Hartenberg parameters defined for the tapping machine [11].

Transformation matrices were formed based on Denavit Hartenberg parameters. l2=571.34 mm and l3=649.97

Table 1. DenavitHartenberg parameters for the tapping machine[11]

Axis	α_{i-1}	a_{i-1}	d_i	θ_i
1	$\frac{\pi}{2}$	0	0	θ_1
2	0	l_2	0	θ_2
3	0	l_3	0	θ_3
4	0	0	0	θ_4

mm, the fixed parameters of the chart, were used in the operations.

Matrices were calculated for four axes. Because the rotational motion of the third and fourth axes was the same, the fourth axis turned out to be excess. For this reason, it is unnecessary to use the transformation matrix of the fourth axis in the position analysis by forward (direct) kinematics. Position was calculated through use of the fifth equation method by considering the first three axes.

$$ {}^{0}_{3}\mathrm{T} = \begin{bmatrix} r_{11} & r_{12} & r_{13} & P_x \\ r_{21} & r_{22} & r_{23} & P_y \\ r_{31} & r_{32} & r_{33} & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix} = {}^{0}_{1}\mathrm{T}\,{}^{1}_{2}\mathrm{T}\,{}^{2}_{3}\mathrm{T} \qquad (1) $$

When the transformation matrices 1, 2, and 3 are written in their places in the equation 1, matrix components 2, 3, and 4 emerge [12]. Here, Px, Py, and Pz represent the position of the end effector, while r_{11},r_{12},r_{13},….,r_{33} represent the rotation matrix components.

$$ P_x = \cos(\theta_1) * (l_3 * \cos(\theta_2 + \theta_3) + l_2 * \cos(\theta_2)) \qquad (2) $$

$$ P_y = \sin(\theta_1) * (l_3 * \cos(\theta_2 + \theta_3) + l_2 * \cos(\theta_2)) \qquad (3) $$

$$ P_z = l_3 * \sin(\theta_2 + \theta_3) + l_2 * \sin(\theta_2) \qquad (4) $$

Position-dependent angle equations for the tapping machine were obtained using the inverse kinematic method. Equation 5 providesthe transformation matrix existing between the basic joint and the axis where the end effector is located. This matrix is shown here symbolically, but it actually represents numerical values. It is required to represent the variables in numerical values.

$$ {}^{B}_{W}\mathrm{T} = \begin{bmatrix} r_{11} & r_{12} & r_{13} & P_x \\ r_{21} & r_{22} & r_{23} & P_y \\ r_{31} & r_{32} & r_{33} & P_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (5) $$

The matrix in equation 5 can also be written in the format seen in equation 6 [13].

$$ {}^{B}_{W}\mathrm{T} = {}^{0}_{1}\mathrm{T}\,{}^{1}_{2}\mathrm{T}\,{}^{2}_{3}\mathrm{T} \qquad (6) $$

$$ {}^{0}_{1}\mathrm{T}^{-1}\,{}^{B}_{W}\mathrm{T} = {}^{1}_{0}\mathrm{T}^{-1}\,{}^{0}_{1}\mathrm{T}\,{}^{1}_{2}\mathrm{T}\,{}^{2}_{3}\mathrm{T} \qquad (7) $$

Using equation 7, the equations θ_1 ,θ_2 , and θ_3 were obtained as follows [14].

$$ \theta_1 = \pi + \mathrm{a}\tan 2(P_y, P_x) \qquad (8) $$

$$ C_3 = \frac{P_x^2+P_y^2+P_z^2-l_3^2-l_2^2}{2l_2l_3} \qquad (9) $$

$$ s_3 = \mp\sqrt{1-c_3^2} \qquad (10) $$

$$ \theta_3 = atan2(s_3; c_3) \qquad (11) $$

$$ s_2 = \frac{(l_2+l_3c_3)P_z-l_3s_3\sqrt{P_x^2+P_y^2}}{P_x^2+P_y^2+P_z^2} \qquad (12) $$

$$ c_2 = \frac{(l_2+l_3c_3)\sqrt{P_x^2+P_y^2}+l_3s_3P_z}{P_x^2+P_y^2+P_z^2} \qquad (13) $$

$$ \theta_2 = atan2(s_2; c_2) \qquad (14) $$

In the tapping machine, θ_4 was externally controlled. For this reason, θ_4 was not included in the calculations. Three bar mechanisms applied in the design of the tapping machine ensure that the end effector is perpendicular to the floor for each angle value of the lower limbs of the system. Therefore,angular input must be externally provided to the end effector for special cases, that is angular operations, with the help of the fourth servo motor.

Tapping machine is a mechanical system with an automation direction. The position equations are obtained through solution of a set of mathematical equations. There are angular positions where equation solutions reach infinite values. These positions are called singular points and are determined by singular point analysis. There is a method to follow to avoid these points. If the determinant of the Jacobian matrix is equal to zero, singularity emerges. The solution of this equation gives information to the designer about the points to be avoided [15].

$$ \begin{vmatrix} (-l_3s1c23 - l_2s1c2) & (-l_3c1s23 - l_2c1s2) & -l_3c1s23 \\ (l_3c1c23 + l_2c1c2) & (-l_3s1s23 - l_2s1s2) & -l_3s1s23 \\ 0 & (l_3c23 + l_2c2) & l_3c23 \\ (-l_3s1c23 - l_2s1c2) & (-l_3c1s23 - l_2c1s2) & -l_3c1s23 \\ (l_3c1c23 + l_2c1c2) & (-l_3s1s23 - l_2s1s2) & -l_3s1s23 \end{vmatrix} \qquad (15) $$

$$ \det(J) = -l_2l_3s3(l_2c2 + l_3c23) \qquad (16) $$

In order to avoid the singular point, the following results were obtained by equalizing the determinant to zero:

Since l_2 and l_3 can never be zero, either of the following has to be true here: s3=0 or $l_2c2 + l_3c23 = 0$. Considering these principles, θ_3=0 and θ_3=π must not occur. In addition, P_x=P_y=0 values must be avoided. The geometry of the manipulator does not allow this, either.

There are angle values that should not be reached technically. These values were completely determined by the geometric properties of the manipulator. The working ranges of θ_2 and θ_3 based on geometric constraints are as follows:

Θ_1 =0~360° θ_2=0 ~ 89° and θ_3= -90° ~ -160° (17)

4. SIMULATION OF THE TAPPING MACHINE BY MATLAB SIMMECHANICS

In this section, the obtained equations were simulated through MATLAB Simmechanics module to analyze what kind of problems could be encountered at the specific points reached by the robot arm.

Simmechanics is a Simulink-based software in which the environmental analysis and research of the controller system is carrited out in an interdisciplinary way. Simmechanics enables intuitive and efficient dynamic analysis and meaningful modeling of multi-limbed mechanical systems. All work is done in simulink environment [16].

First, a solid model was created by making necessary simplifications in SolidWorks. Then the solid model was transferred onto MatLab through Simmechanics Link. Here, the mechanical structure of the mechanical system was obtained. Figure 6 shows the scheme of the mechanical system obtained in Simmechanics.

As shown in Figure 6, the robot consists of serially connected limbs and joints. In the figure, Revolute 1, Revolute 2, and Revolute 3 refer to each rotational joint. The part between the two revolutes refers to the limbs. Notmuch work was done on the limbs as the limbs would be actuated from the joint points. The main work was done on the joints as the control of the servo motors placed in the joints constituted the basis of the movement of the system.

Figure 6. The schematic structure of the mechanical system obtained in Matlab Simmehanics module.

Each rotational joint was provided with a joint actuator, and the limb was given a rotational movement. A sensor was connected to the rotational joint as an output. Thus, feedback from the movement given became possible. Figure 7 presents the control scheme and angle values of the manipulator based on position input.

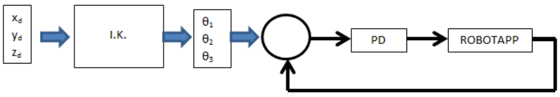

Figure 7. The control scheme and angle values of the manipülatör (X_d=desired x position, I.K=inverse kinematics).

Control information of rotational joints is preferred as angular position, angular velocity, and angular acceleration. As showed in Figure 8, the angular mobility of the system was characterized by use of sub-functions.

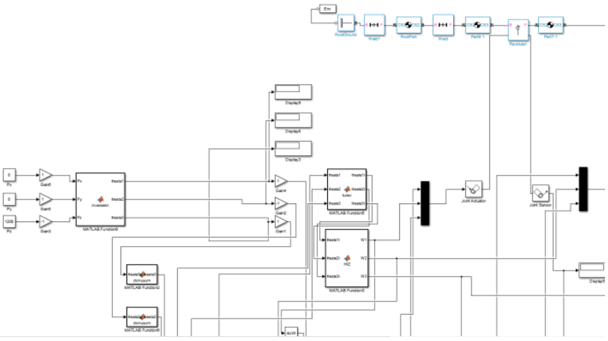

Figure 8. Matlab functions feeding the actuator.

Figure 9 presents the entire manipulator system. Thanks to this system, the end effector of the manipulator in which the position values were given as input reached the desired position, and the resultant value was obtained correctly with the help of the displays. The movement was given based on time. The orbit equation limiting when it should be in what position was also taken into account in this block diagram.

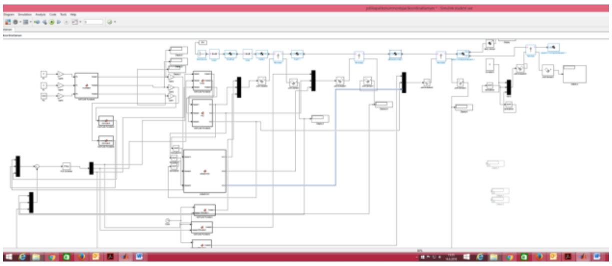

Figure 9. Block diagram for the general simulation of the tapping manipulator.

After the simulation block diagram was constructed, tests were performed for different position coordinates, and the operation tests were performed. Working space values were determined. In Figure 10, images for the positions Px = 549.3mm, Py = 460.9mm, and Pz = -325.1mm within different periods of time during simulation are displayed.

Figure 10. Images for the positions Px = 549.3mm, Py = 460.9mm, and Pz = -325.1mm within different periods of time during simulation.

Figure 11 provides the time-dependent graph of angular position change for each joint. According to the data obtained from it, the correct angle values were seen to have been reached for the desired position.

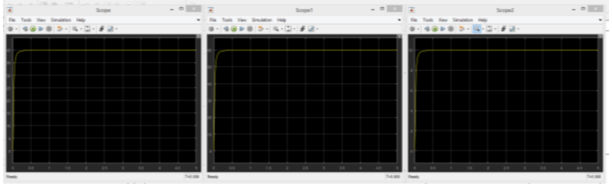

Figure 11. Angular position-time graphs of the first and second joints.

5. CONCLUSION

In this study, tapping machine, which mostly had a manual control, was equipped with computer controlled structure with the help of servo motors. The kinematic equations solved based on the Denavit Hartenberg principle were simulated via Simmechanics. The passive system of the tapping machine was modeled by use of SolidWorks software and exported to SimMechanics.

SimMechanics module was found to be a very practical analysis tool for mechanism control in machine manufacturing with its standby blocks and MFunction blocks. The treatment of the system as a passive system and the determination of its movement characteristics were fruitful for analyzing the compatibility of the system with new orbits. Thanks to PD, errors emerging in the system were compensated. As the operations to be performed in the tapping machine would not produce intense and complex dynamic effects and tapping would be performed at a constant speed, the need for acceleration analysis reduced. For this reason, the use of PD was sufficient for the system design.

In this study, tapping operation was subjected to automation. Automation has many advantages in mass production. The largest contribution of the device is to successfully carry out small tolerance tapping. Another advantage is the reduction in errors due to human factor in mass production. In the experiments, it has been observed that the device reduces labor costs. With the optimum design of the tapping machine, the simulation became effective. Simulation of the device focuses on unobtrusive details at the design stage. Thus the most ideal design has been achieved.

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COMPLIANCE WITH ETHICAL STANDARDS

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Conflict of Interest: The authors declare that they have no conflict of interest.

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