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THE FEATURE OF THE AUTONOMOUS ROBOT FOR CLEANING THE FLOOR IN THE BATHROOM

This article is a new robotic arm for cleaning the floor in the toilet with an increased radius of action of the robotic arm type SCARA. The most common current trends in production include short production cycles, low volumes and a wide variety of orders that can be solved with the help of the SCARA robot. With the advent of the COVID-19 virus in the world, the term "cleaning and disinfection" has become one of the most important tools for preventing the population from becoming infected with the virus. The research focuses on the research and implementation of SCARA-type robots and describes the possibilities of using a SCARA-type robot. This article describes the selection and deployment of a SCARA robot in industrial automation. This research project describes the simulation of a new SCARA-type robotic arm with a long reach and sliding mechanism, we have developed a new multi-joint robotic arm for working in confined spaces with an autonomous toilet floor cleaning system.

Key words: Automation, SCARA robot, forward kinematics, inverse kinematics.

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Жуынатын бөлме еденін тазалауға арналған автономды роботтың ерекшелігі

Ұзартылған SCARA типті робот қолымен дәретхана еденін тазартатын жаңа роботтың көрсету қазіргі жағдайда өте маңызды мәселелердың шешімі болып табылады. өндіріске әсер ететін заманауи тенденцияларға қысқа тауарлық циклдар, шағын көлемдер және SCARA роботының көмегімен шешуге болатын тапсырыстардың үлкен алуандығы жатады. Әлемде COVID-19 вирусының пайда болуымен "тазалау және дезинфекция" термині халықтың вирусты жұқтыруының алдын алудың маңызды құралдарының біріне айналды. Соған орай, осы ғылыми жұмыста біз дәретхана еденін тазартатын өзін-өзі басқару жүйесі барә ішкі құрылымы жағынан жаңа көп буынды роботты ұсынылды. SCARA роботтары өздерінің қаттылығы мен жоғары дәлдігіне байланысты салада ең көп қолданылатын роботтардың бірі болып табылады. Жобалау процесі қосылым конструкциясын, сілтеме конструкциясын, контроллер конструкциясын және механикалық таңдауды қамтиды. Ғылыми жұмыс SCARA типті роботын зерттеуге және орындалу процессіне бағытталған және SCARA типті роботын пайдалану мүмкіндіктерін сипаттайды. Бұл мақалада өнеркәсіптік автоматтандыруда SCARA типті роботын таңдау және орналастыру жұмысы туралы айтылады. Жұмыс құрылымында роботтың конструкциясын модельдеу, кинематика, кинематикалық валидация қарастырылған. Кинематикалық валидация арқылы буындардың бұрылу бұрышың, жылдамдығының және үдеудің мәні алынған.

Түйін сөздер: Автоматтандыру, SCARA робот, алға кинематика, кері кинематика.

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Особенность автономного робота для уборки пола в ванной комнате

В данной статье представлена новая роботизированная рука типа SCARA для уборки пола в туалете с увеличенным радиусом действия. К наиболее распространенным современным тенденциям в производстве относятся короткие циклы продукции, малые объемы и большое разнообразие заказов, которые можно решить с помощью робота SCARA. С появлением в мире вируса COVID-19 термин "очистка и дезинфекция" стал одним из важнейших инструментов предотвращения заражения населения вирусом. В этом исследовательском проекте описывается моделирование нового робота-манипулятора типа SCARA с большим вылетом и раздвижным механизмом. Роботы SCARA являются одними из наиболее широко используемых роботов в промышленности благодаря присущей им жесткости и высокой точности. Процесс проектирования включал проектирование соединения, проектирование звеньев, проектирование контроллера, а также выбор механических и электрических компонентов. Исследование посвящено изучению и внедрению роботов типа SCARA и описывает возможности использования робота типа SCARA. В данной статье описана работа по выбору и внедрению робота типа SCARA в промышленную автоматизацию. Мы разработали новый многошарнирный робот-манипулятор для работы в ограниченном пространстве с автономной системой уборки пола в туалете.
Ключевые слова: Автоматизация, робот SCARA, прямая кинематика, обратная кинематика.

1 Introduction

It has been at least two decades since conventional robotic manipulators became a common production tool in industries ranging from automotive to pharmaceuticals [1]. In many ways, the proven benefits of using robotic manipulators for manufacturing in various industries have motivated scientists and researchers to try to expand the use of it in many different areas. To apply robotics in all areas, scientists had to invent several other types of robots, different from conventional manipulators. New types of robots can be divided into two groups: redundant manipulators and mobile robots. These two groups of robots have greater mobility, allowing them to perform tasks that conventional manipulators cannot. Many engineers have expanded the work with the added mobility of new robots to make them work in tight spaces [1]. In the course of work, the limitations for robotic arms are usually dependent on the working environment, they are changeable. Engineers had to invent different methods to allow robots to automatically cope with various constraints. And an autonomous robot is one that is equipped with those methods that allow it to automatically cope with various environmental constraints while performing the desired task [1].

Autonomous robots must be able to efficiently use and synchronize their limited physical and computational exchequer to operate in a dynamic environment. In each field of activity of progressive complexity, it becomes necessary to impose explicit restrictions on the control of planning, perception and action in order to exclude unexpected interactions between behaviors [2]. Autonomous robots must plan when to act, how to find errors and recover from them, how to deal with conflicting goals when performing complex tasks in any dynamic environment. Following this, robots must precisely coordinate all of their limited dynamic and computational resources [2]. In order to improve the comprehensibility of the system and ensure that the robots perform their tasks, explicit constraints are needed that impose structure on the control of planning, perception, and action as tasks and environments become more complex. Any methodology should be to develop robotic systems consisting of sets of behaviors, which can be independent objects that control actions. Running systems consist of sets of local behaviors that can run without additional awareness of the environment. The main problem is that as the number of additional tasks increases, so does the ratio of complexity between behaviors, which can reach such an extent that it becomes difficult to predict the overall behavior of the control system [2].

The robot arm's arm can move within the three main x, y, and z axes associated with base motion, vertical direction, and horizontal direction. Manipulators are available in various configurations: rectangular, cylindrical, spherical, rotating and horizontally articulated. A robot with a horizontal rotating configuration, the Selective Compliance Articulated Robot Arm (SCARA) has four degrees of freedom, in which the two or three horizontal servo-controlled joints are the wrist, elbow, and shoulder [3]. Most importantly, the last vertical axle is pneumatically controlled. Each working task can be set as pickup, non-contact task (ceiling mounting) and contact task (stuff sorting). SCARA, developed in Japan, is suitable for inserting small parts on assembly lines, such as inserting electronic components [3].

SCARA robots have become popular on packaging and assembly lines with three rotating and one prismatic degrees of freedom [4]. Hiroshi Makino first introduced this type of robot in 1979. Commercial SCARA robots are develop in a variety of sizes, line speeds and payload capacities, thus, the control systems of such robots are intended for general industrial applications [4].

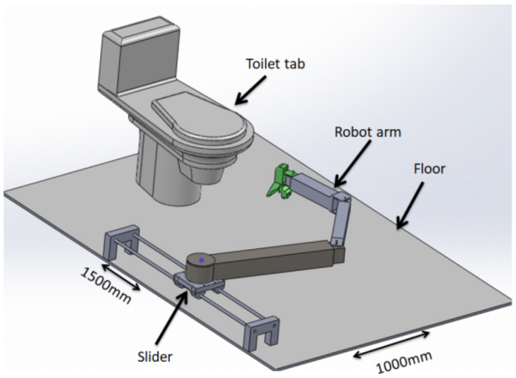
2 Robot design

The workplace and the task set determine the design of the robot. The robot you are designing has several significant parts to learn; the resulting robot can work only in the analyzed and predetermined workplace. The dimensions of the area obtained in this study, i.e. the bath, should be 1000 mm wide and 1500 mm deep. The toilets considered in the study were obtained in accordance with the standards of Western European countries, i.e. the dimensions of the public toilet were 850 mm wide and 1500 mm deep [5].

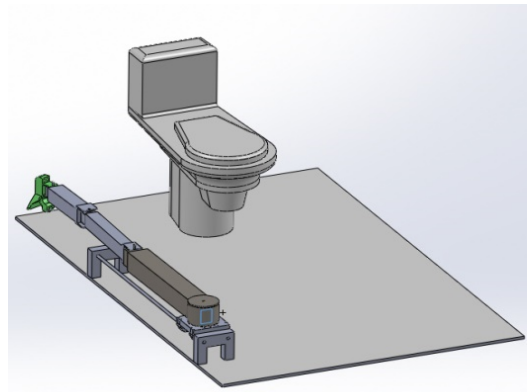
Firstly, the manipulator performing the task must be accessible at any point in the given workspace without dead zones and must be sufficiently compact. Therefore, with this in this study, we proposed a multi-joint arm, which is similar to the structure of the SCARA robot [5]. As shown in Figure 1, the robot arm is aligned along the slide rail after the cleaning process. In general, in such a limited working space, there are individual advantages due to the flexible structure of the continuum arms. The main thing in this task is to have a strong connection with the robot in the hands of a heavy control device [5].

3 Robot arm design

The studied manipulator has the following designs: the manipulator consists of four joints and three links. The robot arm has a particular advantage because the robot is designed to rotate only on the Z axis. The design of the manipulator has been simplified as much as possible



a)



b)

Figure 1: a) The mode of operation of the robot; b) Robot standby mode.

in order to reduce the cost and production time. For the accuracy of work, stepper motors were used to drive the robotic arm [5]. This robotic arm has a total of four stepper motors. A feature of the robot arm is that the robot arm rotates only along the Z axis. Therefore, the design creates a significant dynamic load on the basic drive of the robot. Following these, the dimensions of the engine, such as size and weight, are gradually reduced; on ours, we used a 50 mm frame stepper motor for the base part, and 42 mm and 35 mm frame motors for the middle joints respectively. The end effector that holds and drives the cleaning tool is designed with a 28 mm stepper motor (see Figure 2).

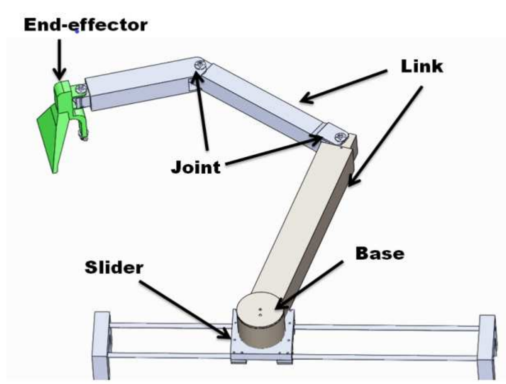


Figure 2: CAD design of the robot.

For the design of the robot, a two-shaft stepper motor was chosen, the effect of skew of the links is important to us. The two-shaft motor has its own characteristics, for example, the use of a two-shaft motor allows the link to be fixed on both sides; side links up and down [5]. In addition, this design simplifies the connection mechanism of the robot.

4 Robot kinematics

4.1 Forward and Inverse Kinematics

The kinematics and dynamics of SCARA robots have also been obtained and modeled using various programs. The experimental results of the SCARA robot were obtained and compared with the simulation results [4].

The researched SCARA robot is widely used as an assembly robot and is a kind of selective picking robot arm. The main features of the robot are the accuracy of the repeating position index and the ease of dynamic execution. The first generation of robots, the serial arm has developed rapidly, and mature designs have already been formed, the connection of which is mainly composed of a servo motor and gearboxes with high speed ratio and good accuracy, such as harmonic reducer [6]. The kinematics of the robot has one translational joint, forming a sequential mechanism, and three rotational joints between the links. The gear mechanism in the rotary joints is a harmonic gear, without shading on the third axis, which makes it possible to obtain a high reduction ratio in sufficient space.

A special advantage of the proposed robot design is the kinematic structure of the robot, which facilitates the kinematic solution of the robot. Because we use serial manipulators, it is much easier to get forward kinematic solutions. As mentioned earlier, the SCARA robot [6] rotates only along the Z axis, and the design of the SCARA robot has the simplest kinematic structure, which means it provides great advantages.

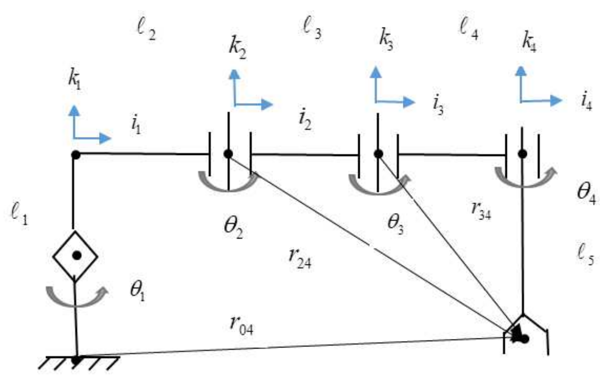


Figure 3: Kinematic structure of the robot.

The robot kinematics starts with Determination of Denavit-Hartenberg parameters. The coordinate systems are directly attached to the robot in accordance with the DH convention [4] and is shown in Table 1.

Table 1: Denavit-Hartenberg parameters

	R_z	R_x	T_x	T_z
	θ	α	h	d
$\sum_{0\to1}$	θ_1	0	0	ℓ_1
$\sum_{1\to2}$	θ_2	0	ℓ_2	0
$\sum_{2\to3}$	θ_3	0	ℓ_3	0
$\sum_{3\to4}$	θ_4	0	0	ℓ_4
$\sum_{4\to5}$	0	0	0	ℓ_5

4.2 Forward kinematics of robot

Table 1 shows the homogeneous transformation formula.

$$H_{01} = \begin{pmatrix} \cos\theta_1 & -\sin\theta_1 & 0 & 0 \\ \sin\theta_1 & \cos\theta_1 & 0 & 0 \\ 0 & 0 & 1 & \ell_1 \\ 0 & 0 & 0 & 1 \end{pmatrix}, \quad H_{12} = \begin{pmatrix} \cos\theta_2 & -\sin\theta_2 & 0 & \ell_2 \\ \sin\theta_2 & \cos\theta_2 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix},$$

$$H_{23} = \begin{pmatrix} \cos\theta_3 & -\sin\theta_3 & 0 & \ell_3 \\ \sin\theta_3 & \cos\theta_3 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}, \quad H_{34} = \begin{pmatrix} \cos\theta_4 & -\sin\theta_4 & 0 & 0 \\ \sin\theta_4 & \cos\theta_4 & 0 & 0 \\ 0 & 0 & 1 & \ell_4 \\ 0 & 0 & 0 & 1 \end{pmatrix}, \quad H_{45} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & \ell_5 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Here we have obtained a homogeneous transformation, then it is necessary to multiply the matrices from H_{01} to H_{45}.

$$H_{05} = H_{01} * H_{12} * H_{23} * H_{34} * H_{45} = \begin{pmatrix} i_{05} & j_{05} & k_{05} & r_{05} \\ 0 & 0 & 0 & 1 \end{pmatrix} \tag{1}$$

4.3 Inverse kinematics of robot

The robot has inverse kinematics and is quite simple compared to other existing robotic arms [6]. As mentioned earlier, the rotation function of the robot rotates only along the Z axis and this allows us to simplify the calculation and formulation of inverse kinematics (Figure 3).

For inverse kinematics, the robot has four variables as: linear prismatic movement is the main difference from the SCARA robot.

$$q_4 = (\theta_1, \theta_2, \theta_3, \theta_4) = (q_1, q_2, q_3, q_4) \tag{2}$$

$$\nu_4 = \begin{pmatrix} \omega_4 \\ r_{04} \end{pmatrix} \tag{3}$$

Derivation of variables by the Jacobian method

$$\nu_4 = Jq_4 \tag{4}$$

$$j = \begin{pmatrix} k_1 & k_2 & k_3 & k_4 \\ k_1 \times r_{04} & k_2 \times r_{24} & k_3 \times r_{34} & 0 \end{pmatrix} \tag{5}$$

Here r_{04}, r_{24}, r_{34} are the access vectors of the individual rotation. Instead $\vec{r}_{04}$ we can use $\vec{r}_{14}$. Here $r_{44}\vec{k}_4$ parallel connection is equal to 0.

$$k_{0\ldots4} = \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \tag{6}$$

$$r_{04} = \begin{pmatrix} \ell_1\cos(\theta_1) + \ell_2\cos(\theta_1+\theta_2) + \ell_3\cos(\theta_1+\theta_2+\theta_3) + \ell_4\cos(\theta_1+\theta_2+\theta_3+\theta_4) \\ \ell_1\sin(\theta_1) + \ell_2\sin(\theta_1+\theta_2) + \ell_3\sin(\theta_1+\theta_2+\theta_3) + \ell_4\sin(\theta_1+\theta_2+\theta_3+\theta_4) \\ \ell_1 - \ell_5 \end{pmatrix} \tag{7}$$

Here: $\ell_1\cos(\theta_1) = \ell_1 c_1$; $\ell_2\cos(\theta_1+\theta_2) = \ell_2 c_{12}$; $\ell_1\sin(\theta_1) = \ell_1 s_1$; $\ell_2\sin(\theta_1+\theta_2) = \ell_2 s_{12}$;

$$r_{24} = \begin{pmatrix} \ell_3\cos(\theta_1+\theta_2+\theta_3) + \ell_4\cos(\theta_1+\theta_2+\theta_3+\theta_4) \\ \ell_3\sin(\theta_1+\theta_2+\theta_3) + \ell_4\sin(\theta_1+\theta_2+\theta_3+\theta_4) \\ -\ell_5 \end{pmatrix} \tag{8}$$

Here: $\ell_3\cos(\theta_1+\theta_2+\theta_3) = \ell_3 c_{123}$; $\ell_3\sin(\theta_1+\theta_2+\theta_3) = \ell_3 s_{123}$;

$$r_{34} = \begin{pmatrix} \ell_4\cos(\theta_1+\theta_2+\theta_3+\theta_4) \\ \ell_4\sin(\theta_1+\theta_2+\theta_3+\theta_4) \\ -\ell_5 \end{pmatrix} \tag{9}$$

Here: $\ell_4\cos(\theta_1+\theta_2+\theta_3+\theta_4) = \ell_4 c_{1234}$; $\ell_4\sin(\theta_1+\theta_2+\theta_3+\theta_4) = \ell_4 s_{1234}$;

$$j = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 \\ r_{04} & r_{24} & r_{34} & 0 \\ & & & 0 \\ & & & 0 \end{pmatrix} \tag{10}$$

5 Kinematic validation of the robot

In this study, we used RoboAnalyzer to test the robot's kinematics. The proposed robot arm modeling tested in RoboAnalyzer software [7]. Most industrial robots are described geometrically by Denavit-Hartenberg (DH) parameters, which are also difficult for students to perceive. Students will find it easier to study a subject if they can visualize in three dimensions.

The RoboAnalyzer software [7] was developed using Object Oriented Modeling concepts in the Visual C# programming language. 3D graphics are rendered using OpenGL via the Tao Framework. The ZedGraph open source library is used for graphing. The software has been developed in modules, so adding or changing modules does not affect the entire software. The Forward Kinematics module of serial robots with rotating joints has been reported in a paper. It uses wireframe models. The results of the analysis were viewed in the form of animation and a built-in plotting module. The addition of prismatic connections, inverse dynamics and forward dynamics analysis have been reported. Additional modules have been developed here, such as "Visualization of DH parameters and transformations", "Import of 3D CAD models" and "Inverse kinematics".

The software can simultaneously provide the robot's working space and analyze the movement trajectory (see Figure 4).

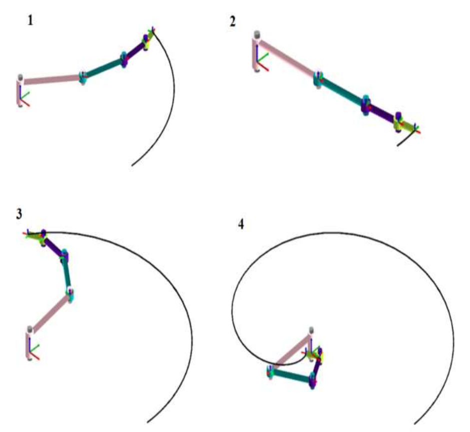
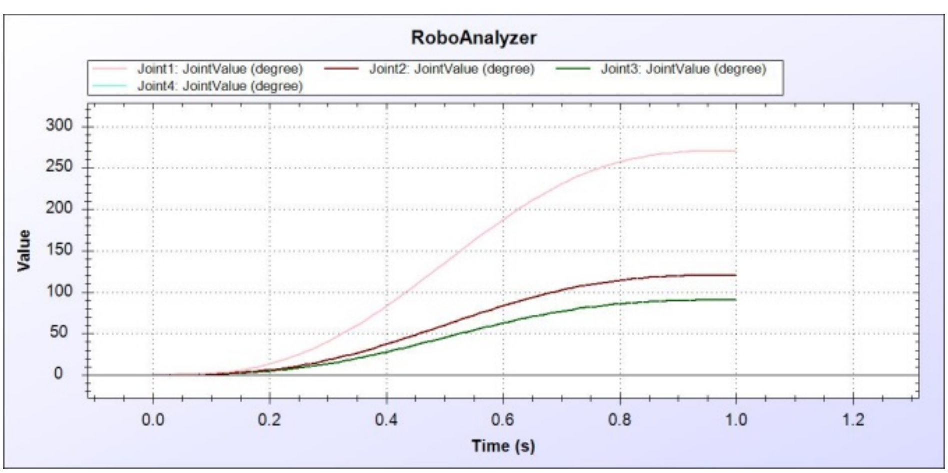
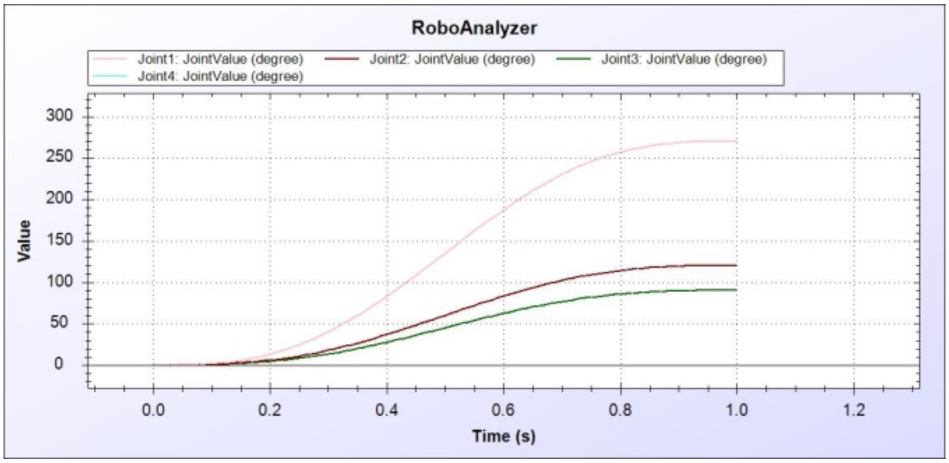


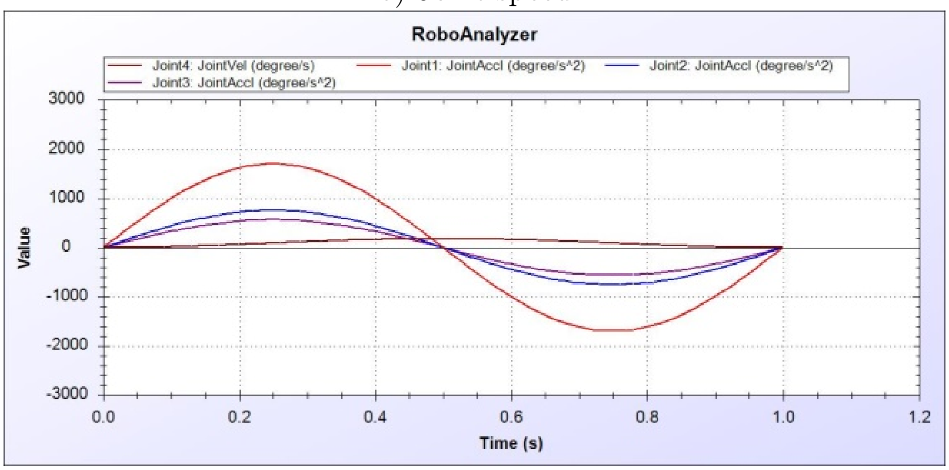
Figure 4: Model of robot movement in the RoboAnalyzer software environment.



a) Joint angle



b) Joint speed



c) Acceleration of the joint

Figure 5: Graph of parameters of robot joints. x-axis describes time; The y-axis describes the angle.

6 Conclusion

This study demonstrates the design and control algorithm of a new robotic system that cleans the bathroom floor. The importance of the robot in quarantine in hospitals is very high. According to the survey, there are bathrooms and toilets in infected areas in public places and hospitals. The world was not ready for COVID-19, and simple places related to hygiene were one of the main drivers of the spread of such infections. In addition, in this study, we took into account human rights.

In the future, we plan to conduct experiments in public places with a laboratory prototype to test the suitability of the proposed robot's signature and system.

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