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Methods for improving the Niryo One educational robotic platform. Part I

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Abstract. Recently, educational robotics has undergone rapid development, which is due to the integration of such technologies into the education system, in particular, the need to train a new generation of specialists capable of designing, programming, and operating robots and manipulators. Approaches to training robot engineers require not only theoretical training, but also practical mastery of the principles of design, programming, and interaction with real technical objects. In this regard, special attention paid to the creation of robotic platforms designed for educational applications. Such platforms are typically develop with accessibility, modularity, ease of use, and versatility in various learning environments in mind. One example of such platforms is the Niryo One educational robotic system.

Niryo One is an open architecture robot manipulator that has a compact design and a relatively easy-to-modify solution, allowing students and faculty to gain hands-on experience in the field of mobile robotics. The architecture of Niryo One contains the next standard components: position sensors, actuators, a microcontroller and microcomputer, and basic software that provides basic navigation tasks, response to the external environment, and interaction with the user.

In this work, the possibilities of modernization of the mechanical system of the robot considered, in particular, the load in the drive mechanism of the robot arm investigated and the design of the cycloid reducer, which was develop for this robot, is shown.

Keywords: Niryo One, cycloid gearbox, robotics, educational platform.

INTRODUCTION

Niryo robots have several generations. The first generation is the simplest design that can used in the educational process [1]. Despite the well-thought-out concept and the availability of basic functionality, the first model of the Niryo robot has a number of significant shortcomings that limit its application in real educational scenarios. Firstly, it is a simplified mechanical design of the drive sections of the manipulator links [2, 3]. This leads to insufficient stability of the structure under minor external mechanical influences and reduces the durability of the robot during intensive operation. Secondly, the software architecture of the robot demonstrates limited possibilities of scaling and adaptation to different educational modules. The original model of the Niryo robot has a special closed-architecture controller, the reprogramming of which requires significant knowledge and special skills. Such a controller is built based on Raspberry Pi, however, the module for working with sensors and executive stepper motors and servos is Niryo's own original development. Such modules have a rather high cost, which prevents the implementation and quick integration of this robot into complex courses related to autonomous control, machine learning or group interaction of robots [2-4].

Taken together, these problems pose an urgent task of improving the first version of the Niryo One robot. It is worth noting that today there are new advanced models of Niryo One robots, but their cost is significantly overestimated and exceeds the cost of similar robots for educational purposes [4, 5].

The relevance of this task is also due not only to the desire to improve the existing model, but also to the need to create a more universal educational platform that can be adapted to the requirements of changing curricula and technical standards.

PURPOSE OF THE ARTICLE

The purpose of this article is to show directions and methods of modernizing the design and software of the Niryo One robot in order to increase its functionality, reduce cost, and increase accessibility.

REVIEW OF EXISTING ANALOGUES

The modern market for educational robotics platforms characterized by a high level of diversity in terms of technical solutions. There are both commercial, widely distributed systems and research developments that targeted at specific training courses and knowledge levels. In the context of the analysis and further improvement of the Niryo One platform, we will consider several analogs, which can be conventionally divided into three categories: platforms for the primary level of education, platforms for engineering faculties, as well as open systems with the possibility of deep modification.

DOBOT Magician is one of the most common entry-level educational manipulators (Fig. 1). This robotic system was design for educational institutions and supports a variety of scenarios: object capture, 3D printing, laser engraving, etc. Magician has 4 degrees of mobility, integration with Arduino and Raspberry Pi, support for visual programming (Blockly), Python, C++ and MATLAB. It also has the availability of SDK and API.

DOBOT Magician is widely used in school programs due to its use of visual programming. However, this system has fewer possibilities for modular modification. The cost of such a robot is about $1000. The link sections have driven by stepper motors with planetary gearboxes and gearing.

The uArm Swift Pro is a compact 4-axis manipulator from UFactory, which also was focus on learning and easy automation.

Fig. 1. Robot DOBOT Magician

The uArm (Fig. 2) has a positioning accuracy of up to 0.2 mm and can perform pick-and-place tasks, sensor interaction, sorting, and other simple scenarios. This system has an Arduino-compatible board, support for Python, ROS, and visual programming.

Fig. 2. uArm Swift Pro robot

In contrast to DOBOT, the uArm Swift Pro platform has a lever-pantographic system for the arm drive and the forearm of the manipulator. This mechanical part is more complex and contains moving elements, but it allows you to relieve the robot's hand and forearm from the weight of the drive. Theoretically, such a solu-

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tion allows you to increase the payload of the robot.

The Baxter and Sawyer robots (Fig. 3) from Rethink Robotics are industrial robots, but these systems have found wide application in scientific and educational institutions for performing laboratory work. Unlike Niryo, these robot constructions designed for complex human interaction scenarios and have much more complex drive design that includes motors, gearboxes, and position and load control sensors. The Sawyer robot uses cameras and computer vision systems. The drive mechanisms of the arm of this manipulator are located in the articulated joints of the links of its manipulator, and therefore, to increase the torque in the drive, planetary and wave gears with large gear ratios are used. Programming Sawyer requires specialized skills and knowledge. This robot design is significantly more expensive than the Niryo robot design, which limits its use in most higher education institutions.

Fig. 3. Robot Sawyer

The widespread use of Arduino microcontrollers and Raspberry Pi single-board computers has led to the emergence of a large number of designers and platforms designed for teaching robotics. For example, platforms such as mBot and GoPiGo have an open control system architecture based on Arduino and Raspberry Pi. This allows users of these platforms to modify and adapt software and hardware to their tasks. The main advantage of such solutions is their flexibility. The disadvantage remains the need for a certain level of training for students, which can complicate the use of these systems at the initial stages of training.

On Fig. 4 shows a robot manipulator built on the basis of servo motors and a control system based on Raspberry Pi.

A significant disadvantage of this design is its simplicity, namely, the hinged connections of the links were make by directly connecting the servo motor shaft to the support link through a splined coupling. During the operation of such a system, there are significant oscillations of the links, which be amplified when the external load increases.

Fig. 4. 5-DOF robot based on Raspberry Pi

In addition to commercial solutions, there are a large number of research developments and individual platforms created by universities and laboratories. These systems are usually completely open and can be adapted for specific educational programs. For example, projects such as: EduMIP, Duckietown, OpenROV was aim at students of technical specialties and require independent assembly and configuration, but at the same time provide a high level of involvement in the learning process. However, their implementation requires specialized knowledge among the teaching staff and an appropriate material and technical base.

Let's note the common characteristics for all considered samples of educational platforms. Most platforms can be adapted to use an open control system architecture, such as those built on Raspberry Pi and Arduino. RAPS 1.4 systems are being develop quite actively among Arduino developments.

The Niryo One robot was developed as a learning platform for learning the basics of robotics, programming and mechatronics. The general structure of such a learning platform is show on Fig. 5. In general, such a robot manipulator consists of a system for moving and orienting the robot's working body. The mechanism of moving the robot include a support post *1*, a rotary bracket *2*, an arm *3*, a handle *5* and the mechanisms of the stepper motors of the arm lifting drive *6*, handles *4* and the rotation mechanism of the handle *7* based on a servo.

The arm and handle drive mechanisms have a rather primitive design, namely: the main elements are Nema 17 stepper motors and a toothed belt transmission. For the arm drive, the diameters of the belt pulleys are d_1 = 13 mm and d_2 = 85 mm, respectively. In the handle drive mechanism, the pulley diameters are equal to d_3 = 13 mm and d_4 = 79 mm, respectively. Such ratios between the diameters of the gear wheels for belt drives indicate that the reduction ratio of the gear belt drive of the arm is i_1 = 6,53 and to handle drive is i_2 = 6,07.

According to the passport data, the torque for the Nema 17 stepper motor is 5,5 kg·cm (0,539 N·m) in the operating state of rotation and 2,8 kg·cm (0,274 N·m) in the state of equilibrium. Since in the Niryo design the drive of the arm and handle implemented from the engine to the hinge of the drive link through belt gears, then we can conclude that the maximum torques in the hinges of the arm will be 35 kg·cm (3,43 N·m) for the state of movement and 18.28 kg·cm (1,79 N·m) for the state of static equilibrium, and for the handle, respectively, 33,38 kg·cm (3,27 N·m) and 16,99 kg·cm (1,66 N·m).

It should be note that the Niryo design designed in such a way that the handle drive is located at the end of the arm, which means that during operation the manipulator will move the mass of such a drive, and therefore the total payload will be significantly smaller.

Looking ahead, let's note that the design of the arm drive of such a manipulator is the weakest link. In the process of operation of this robot, with minor overloads, an overload of the stepper motor of the arm drive occurs, which leads to the skipping of its steps and incorrect further work. In order to compensate for this phenomenon, in the original version of the Niryo One robot, a special additional spring with preset parameters is installed in the arm drive joint. This spring is non-standard and has no analogues for its replacement.

This paper proposes a study that shows the patterns of changes in the loads in the arm drive hinge. Based on the obtained research data, possibilities for upgrading the drive are proposed, which will allow using this manipulator without using an additional spring in the hinge.

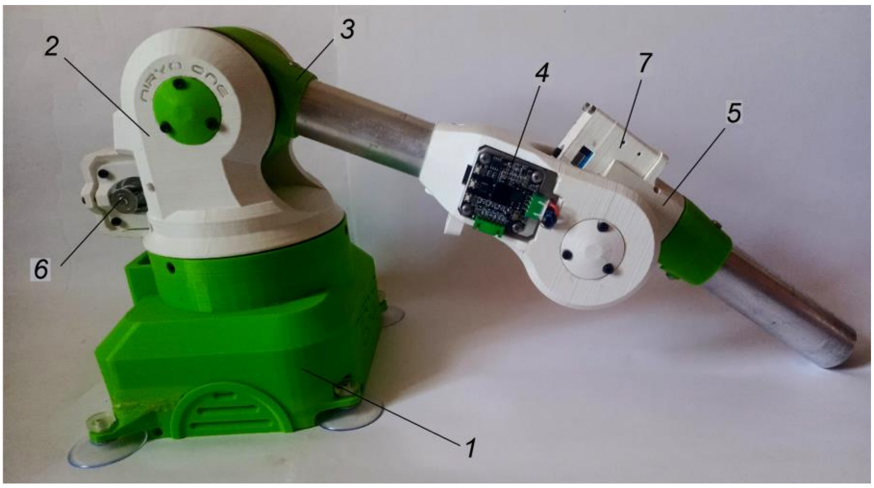

Fig. 5. Design of the Niryo One robot movement system

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THE MAIN MATERIAL OF THE WORK

To determine the directions of modernization of Niryo One, the architecture of this robot was considered and analyzed in such key aspects as hardware, software and system integration.

The drive design of the first Niryo model based on the use of belt drives with a toothed pulley to drive the main arm section and rotate the arm handle. This solution poses a number of problems, which is associated with the low torque of the stepper motor Nema 17 without a gearbox, as implemented in the Niryo One drive design. To analyze the loads in the drive mechanism, the scheme of this robot was consider and its dynamic model was built (Fig. 6).

In the given dynamic model, it was assume that the main external influence on the design of the robot arm drive created by the moving masses m_1 and m_2. The generalized coordinates were take to be the angles of rotation α and β.

The kinetic energy of such a system is equal to [5, 6]:

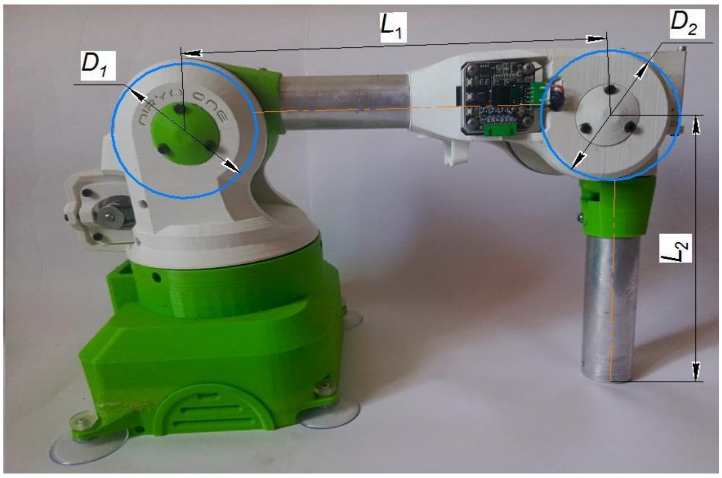
$$T = \frac{1}{2}J_1\dot{\alpha}^2 + \frac{1}{2}J_2\dot{\gamma}^2 + \frac{1}{2}m_2\dot{x}_2^2 + \frac{1}{2}m_2\dot{y}_2^2, \quad (1)$$

where $J_1 = m_1 l_1^2$ and $J_2 = m_2 l_2^2$ moments of inertia, which is determined through the parameters of the moving masses; $\gamma = \pi - \alpha - \beta$; $x_2 = l_1\cos\alpha + l_2\cos\gamma$; $y_2 = l_1\sin\alpha - l_2\sin\gamma$.

The dynamic equation of equilibrium of the moments that arise in the arm drive defined as follows:

$$\begin{aligned} & J_{зв1}\ddot{\alpha} + J_{зв2}\ddot{\beta} + (2\dot{\alpha}\dot{\beta} + \dot{\beta}^2) l_1 l_2 m_2 \sin\beta = \\ & = M - m_1 l_1 g\cos\alpha - m_2 g(l_1\cos\alpha - \\ & - l_2\cos(\alpha+\beta)), \end{aligned} \quad (2)$$

where



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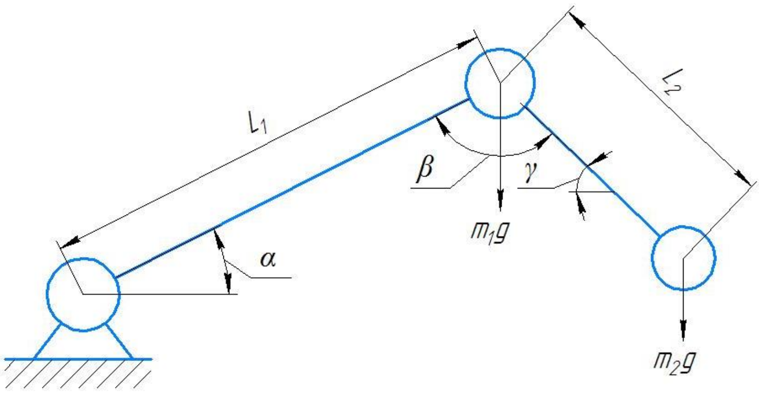

b

Fig. 6. Robot design and its dynamic calculation model (*a*) and his dynamical model (*b*)

$J_{зв1} = l_1^2(m_1 + m_2) + 2m_2 l_2^2 - 2l_1 l_2 m_2 \cos\beta$.

In this way, the driving moment of the handle will be equal to:

$$M = J_{зв1}\ddot{\alpha} + J_{зв2}\ddot{\beta} + (2\dot{\alpha}\dot{\beta} + \dot{\beta}^2)l_1 l_2 m_2 \sin\beta + m_1 l_1 g \cos\alpha + m_2 g(l_1 \cos\alpha - l_2 \cos(\alpha+\beta)). \quad (3)$$

Analyzing equation (3), we note that the driving torque will consist of a static resistance torque and a dynamic torque, which will arise only in the driving mode. In this case, the dynamic moment will depend on the mode of motion of the manipulator links. Let us examine equation (3) for different modes of motion.

A typical linear mode with proportional speed change can be describe by the following equation [7, 8]:

$$\begin{cases} \dot{\alpha} = \dot{\alpha}_0 + k_1 t; \\ \dot{\beta} = \dot{\beta}_0 + k_2 t; \\ \ddot{\alpha} = k_1; \\ \ddot{\beta} = k_2, \end{cases} \quad (4)$$

where k_1 and k_2 is coefficients of proportionality of speed change.

If we assume that the mechanical system under consideration accelerates from a standstill state, then the acceleration time will be equal to t_1 and the final acceleration speed will be $\dot{\alpha}_{max}$ and $\dot{\beta}_{max}$. The proportionality coefficients for the system of equations (4) with the assumptions made are determined as follows: $k_1 = \dot{\alpha}_{max}/t_1$ and $k_2 = \dot{\beta}_{max}/t_1$.

The equations of displacement change for mode (4) in the absence of initial velocity will have the following form:

$$\begin{cases} \alpha = \alpha_0 + \frac{1}{2}k_1 t^2; \\ \beta = \beta_0 + \frac{1}{2}k_2 t^2, \end{cases} \quad (5)$$

where α_0 and β_0 is the initial coordinates from which the movement starts.

The next mode of speed change is one that creates a linear change in acceleration:

$$\begin{cases} \dot{\alpha} = \dot{\alpha}_0 t + \frac{1}{2}c_1 t^2; \\ \dot{\beta} = \dot{\beta}_0 t + \frac{1}{2}c_2 t^2; \\ \ddot{\alpha} = \ddot{\alpha}_0 + c_1 t; \\ \ddot{\beta} = \ddot{\beta}_0 + c_2 t, \end{cases} \quad (6)$$

where c_1 and c_2 is coefficients of proportionality of the change in acceleration.

If we consider only the acceleration section, then at the beginning of the movement the speed is equal to 0, and at the end of the acceleration at time t_1 the speed will be $\dot{\alpha}_{max}$ and $\dot{\beta}_{max}$. This means that the proportionality coefficients must have the following form:

$$\begin{cases} c_1 = \frac{2\dot{\alpha}_{max}}{t_1^2}; \\ c_2 = \frac{2\dot{\beta}_{max}}{t_1^2}. \end{cases} \quad (7)$$

The equations of motion for mode (6) in the absence of initial velocity will be as follows:

$$\begin{cases} \alpha = \alpha_0 + \frac{1}{6}c_1 t^3; \\ \beta = \beta_0 + \frac{1}{6}c_2 t^3. \end{cases} \quad (8)$$

where α_0 and β_0 is the initial coordinates from which the movement starts.

Let's analyze the change in the driving torque during the implementation of the indicated modes of movement of the robot's drive mechanism. At the same time, for a correct analysis of the obtained data, we will consider equivalent sections of movement, that is, when the movement will be the same for both specified modes of movement. Since the systems of equations (5) and (8) have different dependencies, this means that the travel time for both modes must be different. Let us equate the displacement ratio for both displacement modes and determine the time ratio:

$$t = t_1 \sqrt[3]{\frac{3}{2}}, \qquad (9)$$

where t_1 is the base acceleration time for driving mode (5).

Analysis of formula (9) shows that the motion mode with a linear change in acceleration requires 14.4% more time to execute than the mode with a linear change in velocity.

Let's examine the change in the drive torque in the arm of the Niryo manipulator with a basic start-up time of 3 seconds. If it was assume that the base time would be apply for the linear speed mode, then for the mode with a linear change in acceleration, we will have a start-up time of 3,434 seconds.

For this model of the Niryo Ona manipulator, we will assume the following parameters of the dynamic model, which were determined experimentally on the developed test bench: m_1 = 0,912 kg; m_1 = 0,5 kg; l_1 = 0,25 m; l_2 = 0,2 m; α_{max} = 0,5 rad/s; β_{max} = 0,5 rad/s.

On Fig. 7 shows graphs of the change in the rotation angle α boom, angular velocity $\dot{\alpha}$ and acceleration $\ddot{\alpha}$ for a typical driving mode with a proportional change in the angular velocity of the boom.

On Fig. 8 shows graphs of the change in the rotation angle α boom, angular velocity $\dot{\alpha}$ and angular acceleration $\ddot{\alpha}$ for a typical driving mode with proportional change in angular acceleration of the main boom section.

Fig. 9 shows two graphs of the change in the driving torque of the forces in the hinge of the Niryo One manipulator boom arm to consider typical modes of movement. The graphs show a solid line for a typical linear mode of movement with a proportional change in angular acceleration, and a dotted line shows the change in the driving torque for a mode of movement with a linear change in angular velocity in the hinge of the main manipulator boom arm.

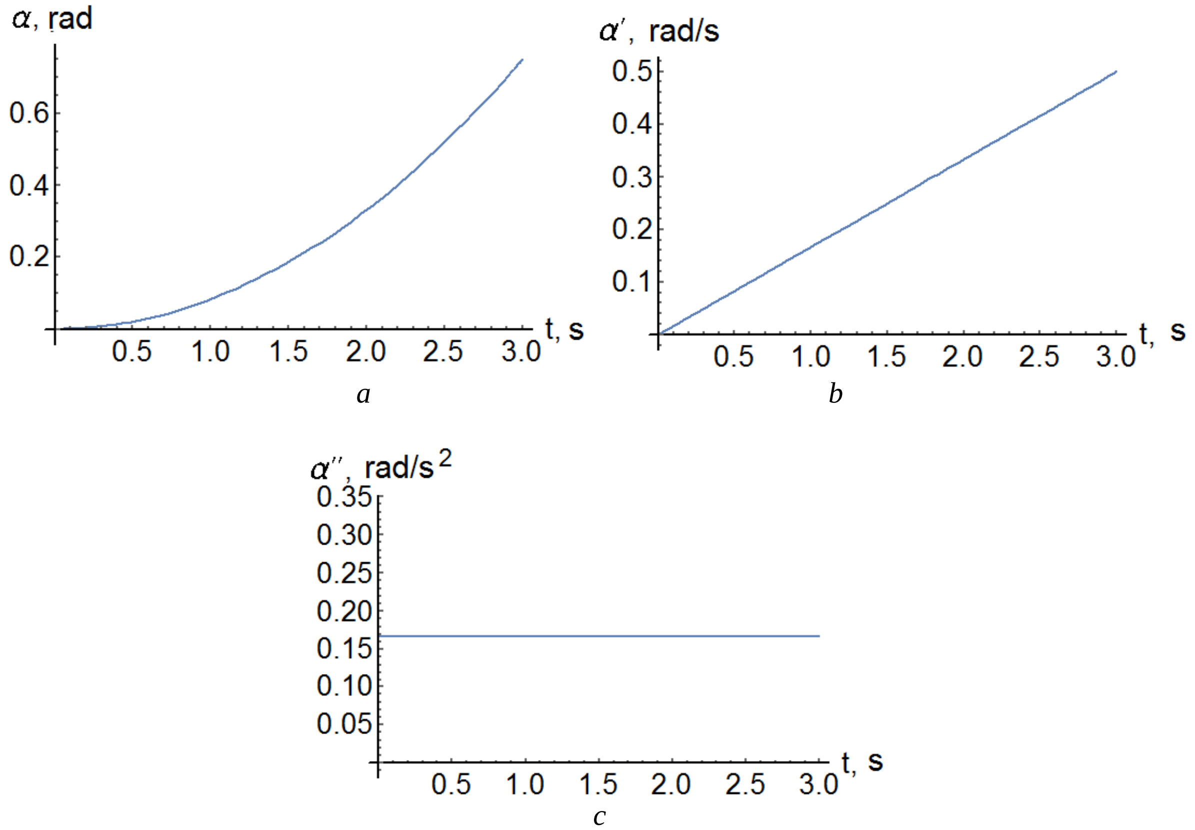

Fig. 7. Graphs of changes in the angle of rotation α (*a*) angular velocity $\dot{\alpha}$ (*b*) and angular acceleration $\ddot{\alpha}$ (*c*) for a typical driving mode with proportional change in angular velocity

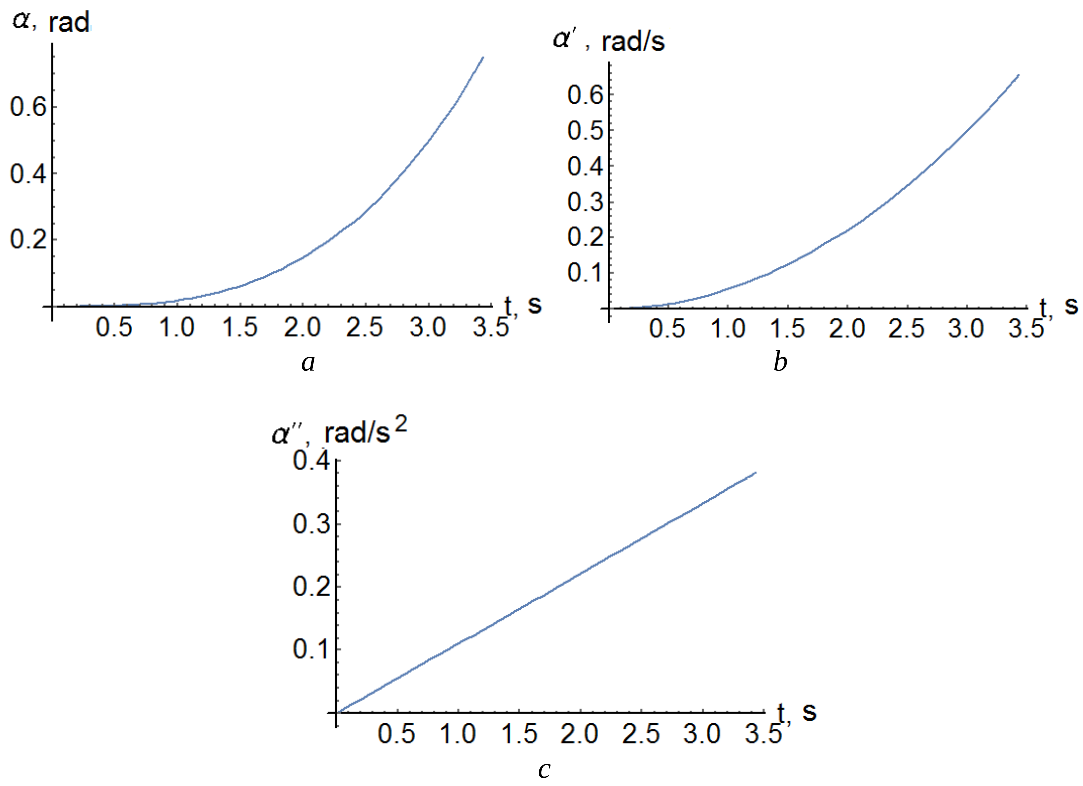

Fig. 8. Rotation angle change graphs α (*a*), angular velocity $\dot{\alpha}$ (*b*) and angular acceleration $\ddot{\alpha}$ (*c*) for a typical driving mode with a linear proportional change in angular acceleration

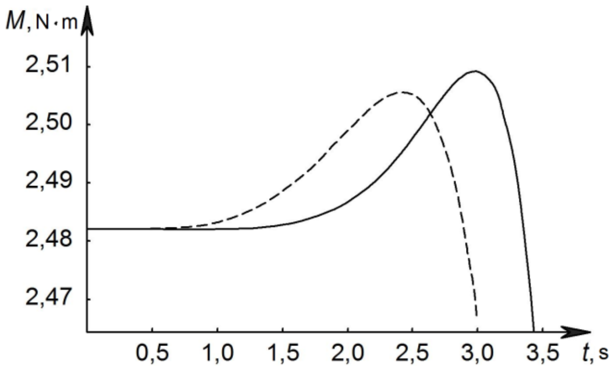

Fig. 9. Graphs of changes in the drive torques of the manipulator boom arm drive

RESULTS ANALYSIS

The graph of the change in driving torque in Fig. 9 shows the dependence of the change in the total driving torque in the main boom arm joint. Analysis of similar graphs for the dynamic and static components of the drive torque showed that the static moment of resistance will be dominant in the design of the Niryo One manipulator. The dynamic moment will be insignificant, since for this design the work of the mass of the elements is insignificant. Therefore, dynamic moment graphs were not present in this work.

The change in the driving torque in the shoulder joint varies in the range from 2,47 N·m to 2,51 N·m. This means that the driving torque created by the engine is insufficient to hold the manipulator boom in a static position, since the driving torque from the engine and belt drive is significantly less than the external resistance torque. At the same time, we note that theoretically this drive can start and move the manipulator boom from the 0 rad position to the 0.8 rad position.

At the same distance of move, the torque for a typical linear motion with a proportional change in speed will have a lower peak load and a shorter duration of action, and therefore a lower load on the electric motor. In this case, the duration of the peak load will be shorter for a linear motion mode with proportional acceleration change.

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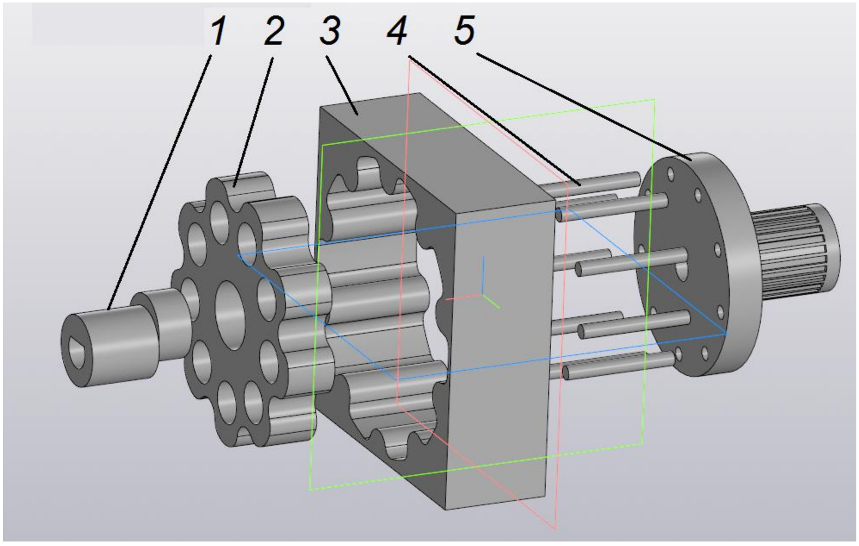
For comfortable operation of the boom arm drive mechanism, it is advisable to additionally use a gearbox with a gear ratio of more than 2.

DISCUSSION OF RESULTS

A planetary gear or cycloidal reducer can be used as the main transmission to increase the torque in the boom arm. For this design of the Niryo One robot, the initial task was to print all its components on a 3D printer. Analysis of the design of the previously proposed gearboxes showed that the planetary gearbox, when printed on a 3D printer, will have dimensions that exceed 42 mm. In particular, this is due to the significant size of the input shaft, which for a Nema 17 motor is 5 mm. Another limitation is the size of the teeth. If the planetary gear changed in size, then the tooth thickness will be so small that printing such a gear model on a 3D printer with a given accuracy will be problematic. Therefore, a pinion cycloid gear was subsequently develop to drive the arm of this manipulator [9-12]. The general structure of the developed cycloid gear is show on Fig. 10.



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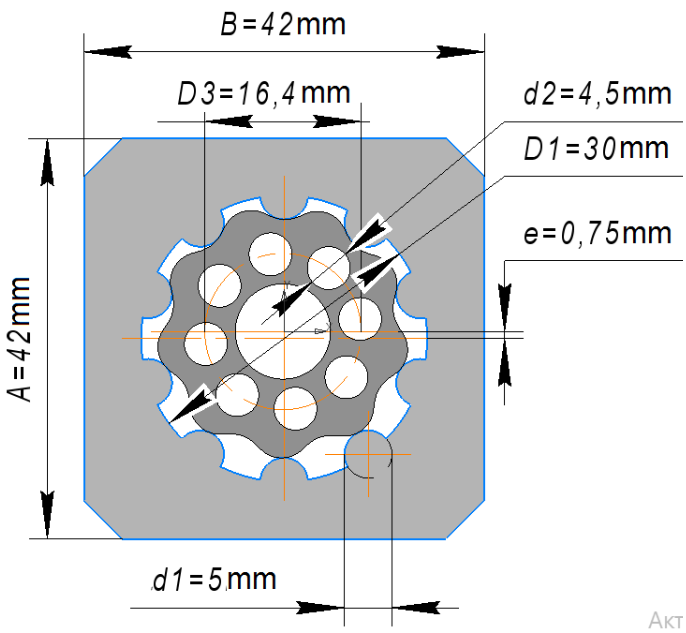

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Fig. 10. Design of a cycloidal gearbox: *a* – general view; *b* – dimensions; *1* – eccentric shaft; *2* – wave generator; *3* – housing; *4* – pins; *5* – output shaft

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Методи вдосконалення освітньої роботизованої платформи Niryo One. Частина I

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Анотація. Останнім часом освітня робототехніка зазнала стрімкого розвитку, що пов'язано з інтеграцією таких технологій у систему освіти, зокрема, необхідністю підготовки нового покоління фахівців, здатних проектувати, програмувати та експлуатувати роботів і маніпуляторів. Підходи до навчання інженерів-робототехників вимагають не лише теоретичної підготовки, але й практичного опанування принципів проектування, програмування та взаємодії з реальними технічними об'єктами. У зв'язку з цим особлива увага приділяється створенню роботизованих платформ, призначених для освітніх застосувань. Такі платформи зазвичай розробляються з урахуванням доступності, модульності, простоти використання та універсальності в різних навчальних середовищах. Одним із прикладів таких платформ є освітня робототехнічна система Niryo One.

Niryo One — це робот-маніпулятор з відкритою архітектурою, який має компактний дизайн та відносно просте в модифікації рішення, що дозволяє студентам та викладачам отримати практичний досвід у галузі мобільної робототехніки. Архітектура Niryo One містить такі стандартні компоненти: датчики положення, виконавчі механізми, мікроконтролер та мікрокомп'ютер, а також базове програмне забезпечення, яке забезпечує основні завдання навігації, реагування на зовнішнє середовище та взаємодію з користувачем.

У цій роботі розглянуто можливості модернізації механічної системи робота, зокрема, досліджено навантаження в механізмі приводу руки робота та показано конструкцію циклоїдального редуктора, який було розроблено для даного робота.

Ключові слова: Niryo One, циклоїдальний редуктор, робототехніка, освітня платформа.