2-бөлім **Раздел 2** **Section 2**

Механика **Механика** **Mechanics**

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K. Bakhiyeva[1*], S. Kaimov[1], N. Aimbetov[2], Z. Saurova[3], Aidarkhan Kaimov[1], Abylay Kaimov[1]
[1]Al-Farabi Kazakh national university, Kazakhstan, Almaty
[2]Halyk Bank of Kazakhstan JSC, Kazakhstan, Almaty
[3]Kazakh Medical University of Continuing Education, Kazakhstan, Almaty
*e-mail:kalima06@mail.ru

MODEL OF GRIPPER OF ROBOT MANIPULATOR WHEN OVERLOADING PLANT MICROSHOOTS FROM THE TRANSPORT CONTAINER TO THE WORKING CONTAINER

In this article, a model is proposed for determining the parameters of the structural elements of a novel pincer robot for transporting plant microsprouts from a transport container in vitro to a working container with soil at the stage of their adaptation in soil during microclonal propagation. Scientific and practical result of the research is the creation of an innovative robotic complex of a manipulation device with a phalanx gripper for the transfer of plant microsprouts from a transport container in vitro to a working container with soil at the stage of their adaptation in soil during microclonal propagation, and the testing of its physical prototype in the adaptation of 3000 pieces of woody microsprouts. Plants with roots in the soil. The obtained research results will affect the scientific and technical potential and competitiveness of scientists in the Republic of Kazakhstan. In the Republic of Kazakhstan there are no studies on automation of the technology of microclonal propagation of plants for their mass production, the application of which would allow obtaining a large number of plants and reducing the cost of planting materials. Besides, the practical results of research on an innovative robotic complex will reduce the import of planting material of woody plants from other countries for the design of settlements in the Republic of Kazakhstan.
In this regard, the need for native, high-quality planting material for woody plants will increase. One of the main solutions to the problem of landscaping in the settlement areas of the Republic of Kazakhstan is to obtain native high-quality planting material for woody plants by microclonal propagation.
Key words: Robotic complex, manipulator, overload, microshoot, microclonal plant propagation, gripping force.

К. Бахиева[1*], С. Каимов[1], Н. Аймбетов[2], З. Саурова[3], А. Каимов[1], А. Каимов[1]
[1]Әл-Фараби атындағы Қазақ ұлттық университеті, Қазақстан, Алматы қ.
[2]Қазақстан Халық Банкі АҚ, Қазақстан, Алматы қ.
[3]Қазақ медициналық үздіксіз білім беру университеті, Қазақстан, Алматы қ.
*e-mail:kalima06@mail.ru

Тасымалдау контейнерінен жұмыс контейнеріне микробұйымдарын қайта тиеу кезіндегі робот-манипулятордың ұстағышының моделі

Бұл мақалада өсімдік микроөсірулерін in vitro тасымалдау контейнерінен топырақпен жұмыс істейтін контейнерге олардың микрокөбейту кезінде топырақта бейімделу сатысында жылжытуға арналған қысқышы бар инновациялық роботтың құрылымдық элементтерінің параметрлерін анықтау моделі ұсынылған.

Зерттеудің ғылыми-тәжірибелік нәтижесі өсімдіктердің микро өсінділерін тасымалдау контейнерінен in vitro жағдайында топыраққа бейімделу кезеңінде топырақпен жұмыс істейтін контейнерге ауыстыруға арналған фалангты ұстағышы бар манипуляциялық құрылғының инновациялық роботтық кешенін құру болып табылады. Микроклондық көбею және оның физикалық прототипін сынау 3000 дана сүректі микроөркендерді бейімделген, топырақта тамыры бар өсімдіктер. Алынған зерттеу нәтижелері Қазақстан Республикасындағы ғалымдардың ғылыми-техникалық әлеуетіне және бәсекеге қабілеттілігіне әсер етеді. Қазақстан Республикасында оларды көптеп өндіру үшін өсімдіктерді микроклондық көбейту технологиясын автоматтандыруға байланысты зерттеулер жоқ, оларды қолдану өсімдіктердің көп мөлшерін алуға, отырғызу материалдарының құнын төмендетуге мүмкіндік береді. Сондай-ақ, инновациялық роботтық кешен бойынша зерттеулердің практикалық нәтижелері Қазақстан Республикасының елді мекендерін абаттандыру үшін басқа елдерден ағаш өсімдіктерінің отырғызу материалдарының импортын қысқартуға мүмкіндік береді.
Осыған байланысты ағаш тектес өсімдіктер үшін отандық жоғары сапалы отырғызу материалына деген қажеттілік артады. Қазақстан Республикасының елді мекендерінің аумақтарын көгалдандыру мәселесін шешудің түбегейлі шешімдерінің бірі ағаш тектес өсімдіктерге олардың микроклондық көбеюі арқылы отандық жоғары сапалы отырғызу материалын алу болып табылады.
Түйін сөздер: Роботтық кешен, манипулятор, шамадан тыс жүктеме, микроатылым, өсімдіктердің микрокөбейтілуі, ұстау күші.

К. Бахиева[1*], С. Каимов[1], Н. Аймбетов[2], З. Саурова[3], А. Каимов[1], А. Каимов[1]
[1]Казахский национальный университет имени аль-Фараби, Казахстан, г. Алматы
[2]АО Народный банк Казахстана, Казахстан, г. Алматы
[3]Казахский медицинский университет непрерывного образования, Казахстан, г. Алматы
[*]e-mail:kalima06@mail.ru

Модель инновационного схвата манипулятора робота при перегрузке микропобегов растений из транспортного контейнера в рабочий контейнер

В данной статье предлагается модель определения параметров конструктивных элементов инновационного робота со схватом для перемещения микропобегов растений из транспортной емкости invitro в рабочую емкость с почвогрунтомна этапе их адаптации в почвогрунте при микроклональном размножении.
Научно-практическим результатом исследований является создание инновационного роботизированного комплекса манипуляционного устройства с фаланговым схватом для перемещения микропобегов растений из транспортной емкости invitro в рабочую емкость с почвогрунтомна этапе их адаптации в почвогрунте при микроклональном размножении и осуществлении тестирования его физического прототипа при адаптации 3000 штук микропобегов древесных растений с корнями в почвогрунте. Полученные результаты исследований повлияют на научно-технический потенциал и конкурентоспособность ученых в Республики Казахстан.
В Республике Казахстан отсутствуют какие-либо исследования, связанные с автоматизацией технологии микроклонального размножения растений для их массового производства, применение которой позволит получить большое количество растений, снизить себестоимость посадочного материала. Также практические результаты исследований инновационного роботизированного комплекса позволят уменьшить завоз из других стран посадочного материала древесных растений для озеленения населенных пунктов Республики Казахстан.
В связи с этим возрастет потребность в отечественном качественном посадочном материале древесных растений. Одним из кардинальных решений проблемы озеленения территорий населенных пунктов Республики Казахстан является получение отечественного качественного посадочного материала древесных растений путем их микроклонального размножения.
Ключевые слова: Робототехнический комплекс, манипулятор, перегрузка, микропобег, микроклональное размножение растений, сила захвата.

1 Introduction

One of the radical solutions to the problem of landscaping in the Republic of Kazakhstan is to obtain high-quality native planting material by micropropagation through further enlargement of woody plants. Replacing people who perform plant micropropagation is neither technologically simple nor economically feasible (Sluis C.J., 2008). The main problem in this context is the technological process of plant micropropagation. During the experiment, it becomes increasingly important to create an innovative robotic manipulation device to transfer microprocessors in vitro from the container of the device to the working tank with a bottom cover. In vitro processes are artificial and recreate the environment in vivo [1].

The main reason for the destruction and depletion of natural resources around the world is the industrial development of cities. Urbanization affects the composition of plant species, the atmosphere and land cover. The degradation of biodiversity increases the pressure on the environment and, consequently, on humans. For this reason, it is becoming increasingly urgent to find solutions to improve the environmental situation in cities (Imam AUK, 2016). One of the most important tools of gardening is tree planting. Planting trees is one of the mechanisms to stabilize the ecological situation in cities. They absorb various chemical toxins from the air, contribute to the formation of urban microclimate and provide protection from adverse climatic conditions (Ray Benayas JM, 2012; Jim Si Yu, 2013; Karinanos P., 2017; Jennings W., 2019) [2].

The results of the study affect the scientific and technological potential and competitiveness of domestic scientists, as there is no research on the automation of microclonal plant propagation technology in mass production, which allows to obtain large quantities of plants in the world and in Kazakhstan. Reducing the cost of planting materials. The practical results of the research (innovative robotic complex) will also reduce the import of planting material from abroad for landscaping. In this regard, there is a growing need for high-quality domestic planting material for woody plants [3-4].

One of the radical solutions to the problem of landscaping in the Republic of Kazakhstan is to obtain high-quality native planting material by micropropagation through further enlargement of woody plants. Replacing people who perform plant micropropagation is neither technologically simple nor economically feasible (Sluis C.J., 2008).

In this regard, the main problem is the technological process of micropropagation of plants. During the experiment, it becomes increasingly important to create an innovative robotic manipulation device to transfer microprocessors in vitro from the tank of the device to the working tank with a ground cover. In vitro processes are artificial and they are the restoration of the environment in vivo.

Artificial conditions are created by mixing the necessary components and reagents under controlled conditions in glass containers in the laboratory. Many molecular and biochemical experiments are performed in vitro in experimental laboratories. In vitro methods are widely used in the pharmaceutical industry in the production of large pharmaceuticals using microorganisms because of the simplicity and cost-effectiveness of production.

The agricultural tasks that robots are involved in vary, but can be categorized as soil preparation, seeding, transplanting, seeding, precision fertilization, pruning, defoliation, pest detection, harvesting, pruning, crop removal, and post-harvest operations.

The main phases of the agricultural cycle are land preparation, planting, production, and harvest. In each of these phases, there are specific tasks to be performed, some of which are amenable to robotics.

The remotely controlled mobile robot (Figure 1.1) consists of 1 support column with innovative adaptive handgrip drives, 2 horizontal supports, 3 vehicles (wheels, caterpillars, walkers, etc.) to which the manipulator is attached 4 PR. several degrees of freedom of movement, like the human hand. The holder is attached to 4 PR edges of 5 manipulators. The innovative holder 5 is removed from the intermediate container 7. 7 invitro removed and transported to the soil 8.

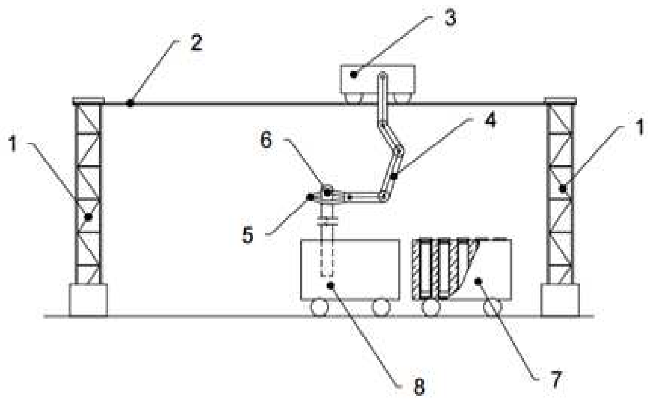

Figure 1: Scheme of transshipment of plant sprouts from a shipping container into a cargo container with soil using an innovative phalanx gripper of the IR manipulator: 1 - support post; 2 - horizontal crossbar; 3 - vehicle; 4 - manipulator; 5 - innovative phalanx tong; 6 - plant microshoot; 7 - transport container; 8 - cargo container with soil.

The operation of this robotic complex is described in the articles [1]. All major methods for engineering improvements in the grasping capabilities of elastic and fragile thin-walled objects have been investigated using the model of a thin-walled ring, which most accurately replicates the outer "delicate" surface [2] of plant microsprouts. When grasping plant microsprouts, it is necessary to take into account the limits of the magnitude of the grasping forces resulting from the conditions for ensuring the required reserves of grasping safety and the insignificance of the elastic movements at the points of contact of the phalangeal gripper with the plant microsprout.

2 Literature review and problem statement

The development of cities in the countries of the world is the main cause of the destruction and degradation of natural resources. Urbanization changes the composition of plant species, atmosphere and land cover. With the degradation of biodiversity, the burden on the environment and the population in the countries of the world increases. For this reason, it is becoming increasingly important to find solutions to improve the ecological condition of cities (Imam A.U.K., 2016) [12].

One of the most important factors in the design of settlement areas is the planting of plants. Tree plantations are one of the ways to improve the ecological situation in settlements. They absorb various chemical toxins from the air, contribute to the formation of the microclimate in the settlement, and provide protection for people from adverse climatic influences (Rey Benayas J. M., 2012; Jim C. Y., 2013; Carinanos P., 2017; Jennings V., 2019) [11].

One of the main solutions to the problem of landscaping in the settlement areas of the Republic of Kazakhstan is to obtain native, high-quality planting material for woody plants by their microclonal propagation (Sluis C.J., 2008). In this regard, the article proposes a solution to the extremely urgent task of automating the main stages of the technological process of microclonal propagation of plants [13].

Elasticity theory, theory of machines and mechanisms, and methods of mathematical modeling were used in the study. All major methods for engineering improvements in the gripping capabilities of elastic and fragile thin-walled objects were studied using the model of a thin-walled ring, which most accurately represents the outer "delicate" surface of plant microsprouts. When grasping plant microsprouts, constraints on the magnitude of the grasping force must be considered due to the conditions of ensuring the required safety margin and the smallness of the magnitude of the elastic displacements at the contact points of the gripper with the plant microsprout. The design of the structure of the robotic gripper was based on a 3D model CAD [1]. A prototype of the phalanx gripper was 3D printed. An experimental study of the movement of a plant microsprout was tested using the example of the movement of a tennis ball [2], which was removed from the transport tank and transported to the working tank. Another test of the gripper involved testing the stability of a grip on, for example, a round tennis ball, moving the gripper with the ball along a predetermined trajectory at a maximum speed of, for example, 1.0 m/s to test the reliability of gripping the tennis ball. At Greenlab Micropropagation, innovative pincer prototypes were tested for transferring plant microsprouts from a shipping container to a soil treatment container to propagate woody plants. For a scientifically sound selection and justification of geometrical, structural-kinematic and dynamic values of the parameters of the structural elements of the innovative gripper of an industrial robot manipulator, a mathematical model for their calculation was developed, taking into account the stochastic processes of their interaction with the object, i.e. with the object to be transported. Accuracy of determination of geometrical, structural-kinematic and dynamic values of parameters of structural elements of adaptive three-phalanx gripper of industrial robot manipulator taking into account stochastic processes of its interaction with the upper part of the body of a round tennis ball was carried out on the basis of determination of optimal value of Kalman weight coefficient [1-2].

Correction of kinematic and dynamic values of parameters of prototype designs of handles was carried out on the basis of developed algorithms and computer programs for calculation of values of parameters of structural elements of handles and use of integrated technology systems for virtual modeling and technical analysis of CAD / CAM / CAE / PDM systems. The creation of the software and mathematical software is carried out on computers compatible with the systems Inventor, AWP WinMashine. On the basis of modeling and testing, appropriate changes are made to the drawings of the design documentation of models of their physical prototype. Based on the corrected drawings of the design documentation, demonstration models of innovative gripper designs were created. Invention applications were submitted to the Patent Office of the Republic of Kazakhstan for the created gripper samples.

3 The aim and objectives of the study

Improvement of settlements is one of the main problems today. The most effective way of landscaping is to improve the ecological condition of forest plantations. They absorb various chemical toxins from the air, are located in the microclimate of a settlement and increase protection from adverse climatic conditions (Ray Benayas J.M., 2012; Jim S.Y., 2013; Karinanos P., 2017; Jennings V., 2019) [14].

One of the ways to solve the problem of landscaping settlements in our country is to obtain high-quality native planting material through microclonal propagation of woody plants (Sluis C.J., 2008). In this context, this article proposes a solution to automate the main stages of the technological process of microclonal propagation of plants.

At the same time, biotechnological methods were used: Sterilization of plant shoots, introduction of axillary buds into in vitro culture, propagation of plant microsprouts, rooting of plant microsprouts in vitro, and the following biotechnological and plant cultivation methods: transfer, adaptation, and cultivation of rooted plant clones in soil substrate.

4 Materials and methods

When grasping microsprouts of plants, it is necessary to take into account the constraints on the magnitude of the gripping force resulting from the conditions for ensuring the required safety margin and the smallness of the magnitude of elastic displacements at the contact points of the gripper with the microsprout of the plant. The design of the structure of the robotic gripper was carried out using a 3D model CAD. A prototype of the phalanx gripper was 3D printed. An experimental study of the movement of a plant microsprout was tested using the example of the movement of a tennis ball, which was removed from the transport tank and transported to the working tank. Another test of the gripper involved testing the stability of a grip on, for example, a round tennis ball, moving the gripper with the ball along a predetermined trajectory at a maximum speed of, for example, 1.0 m/s to test the reliability of gripping the tennis ball.

In the Greenlab Micropropagation for Woody Plants, innovative tong prototypes were tested for transferring plant microsprouts from a shipping container to a container for tillage. For a scientifically sound selection and justification of geometrical, structural-kinematic and dynamic values of the parameters of the structural elements of the innovative gripper of an industrial robot manipulator, a mathematical model for their calculation was developed, taking into account the stochastic processes of their interaction with the object, i.e. with the object to be transported. Accuracy of determination of geometrical, structural-kinematic and dynamic values of parameters of structural elements of adaptive triple grip of industrial robot manipulator taking into account stochastic processes of its interaction with the upper part of the body of a round tennis ball was carried out on the basis of determination of optimal value of Kalman weight coefficient [1-4].

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5 Results

An increase in the number of working elements of the gripper leads to an expansion of the range of permissible values of gripping forces of a large diameter ring in the conditions of absence of deformation and stress in the area of contact of the working element of the phalanx gripper with a plant microsprout. Therefore, in this study, cases of capturing the ring-shaped structural element of a plant microsprout at four, six and eight contact points of the inner surface of the working element of the phalanx gripper with the outer surface of the plant microsprout are considered. In [5-6], the following formulas for calculating the maximum and minimum allowable values of the gripping force of a thin-walled ring were justified from the conditions for ensuring the reliability of the grip and the insignificance of the values of elastic displacements at the contact points of the working element of the gripper with the ring. The value of the contact force of the outer inner surfaces of each phalanx 3-5 with the holding teeth 8 of each gripper lever attached to them on the outer boundary surface of the upper part of the plant microsprout body 10 (Fig. 3) is determined by the formula [5]:

$$P_{\max} = \frac{\sigma_{\text{add}} l t^2}{0.3967} \tag{1}$$

and

$$P_{\min} = \frac{G + F_I}{8f} \tag{2}$$

where $P_{\max}$ – the value of the maximum allowable gripping force of the gripper ring when performing minor elastic movements at the points of contact of the working element of the gripper with the ring; σ_{add} – the value of the allowable normal voltage of an object having an annular cross section; l and t are the width and thickness of the ring; $P_{\min}$ – the value of the minimum allowable gripping force on the outer surface of the ring for reliable retention of the plant microshoot; G is the value of the weight of the ring and FI is the value of the inertial force acting on the ring [6].

The rotation of the phalanges of the grab levers is planned to be carried out using the two most effective options for the location of the retaining teeth of the phalanges of the grab levers near the upper part of the body of the micro-shoot of the plant [1]:

– two retaining teeth (Fig. 3, a) located on the inner surface of the phalanxes of the gripper levers are located on one side of the outer surface of the microshoot body section of the plant, one retaining tooth located on the outer inner surface of the phalanx of the gripper lever is located near the opposite side of the outer surface of the site plant microshoot bodies;

– two retaining teeth (Fig. 3, b) located on the outer inner surface of the phalanges of the gripper lever are located on one side of the outer surface of the plant microshoot body section and two retaining teeth located on the outer inner surfaces of the phalanges of the gripper lever are located near the opposite side of the outer surface part of the plant microshoot body[2].

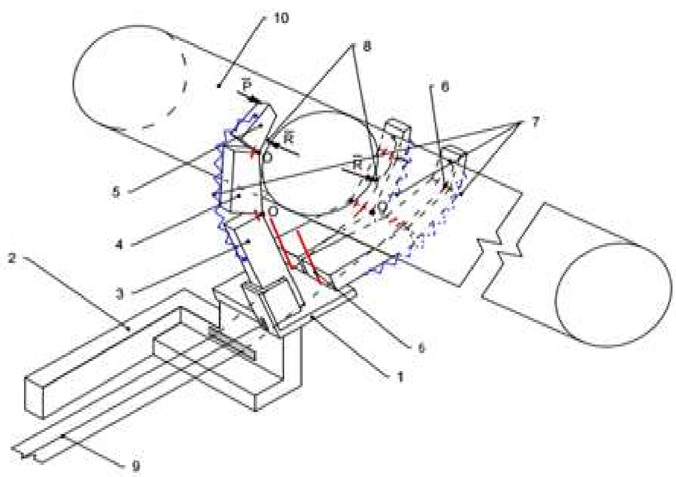

Figure 2: Three-phalanx adaptive gripper of a robotic manipulator for overloading micro-processes of plants from a transport container to a working container with soil: 1 - tile-base for fixing the main phalanx of the gripping lever; 2 - mounting bracket of the manipulator; 3 - main phalanx; 4 - middle phalanx; 5 - pointed phalanx; 6 - hinge for attaching adjacent phalanxes to each other; 7-tension spring; 8 -retaining tooth; 9 - flexible traction element, 10 - micro-process of the plant.

The rotation of the phalanges of the grab levers is planned to be carried out using the two most effective options for the location of the retaining teeth of the phalanges of the grab levers near the upper part of the body of the micro-shoot of the plant [1]:

– two retaining teeth (Fig. 4, a) located on the inner surface of the phalanxes of the gripper levers are located on one side of the outer surface of the microshoot body section of the plant, one retaining tooth located on the outer inner surface of the phalanx of the gripper lever is located near the opposite side of the outer surface of the site plant microshoot bodies;

– two retaining teeth (Fig. 4, b) located on the outer inner surface of the phalanges of the gripper lever are located on one side of the outer surface of the plant microshoot body section and two retaining teeth located on the outer inner surfaces of the phalanges of the gripper lever are located near the opposite side of the outer surface part of the plant microshoot body[2].

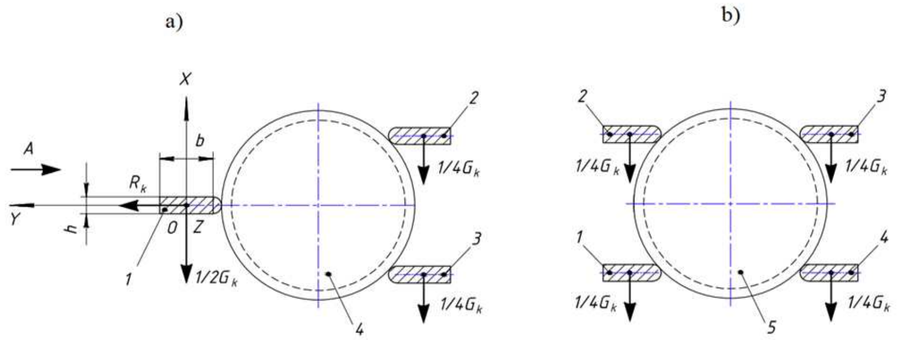

Figure 3: Options for loading the holding teeth of the phalanges of the tong lever (view along the longitudinal axis of the holding tooth): b - when clamping the body part of the microshoot of the plant with holding teeth from above and below 1, 2, 3 and 4 - holding teeth; 5 - plant microshoot b - the length of the holding tooth; h - the width of the holding tooth.

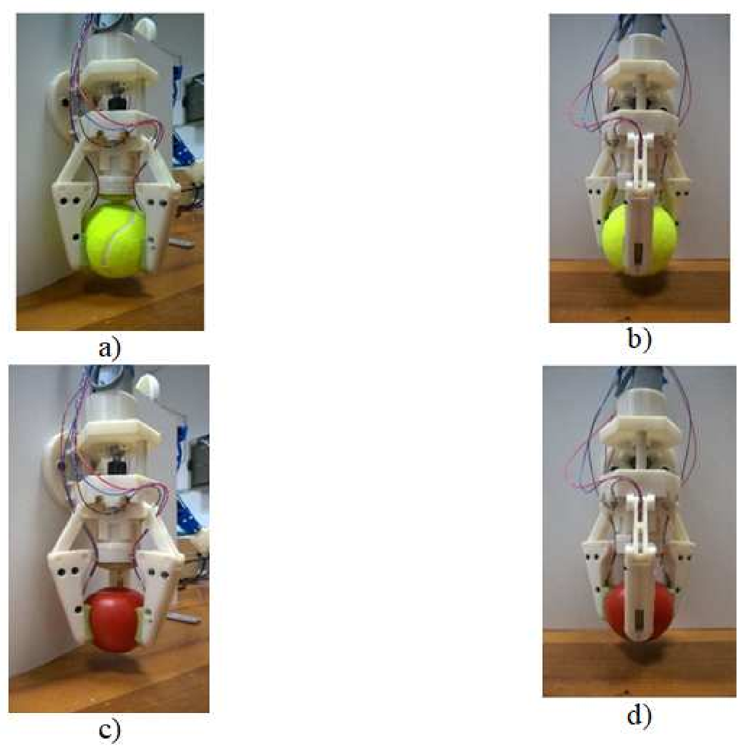

Figure 4: Test configuration for measuring the magnitude of the static grip force: a) tennis ball (side view); b) tennis ball (front view); c) ripe tomato (side view) y; d) ripe tomato (front view).

The prototype three-fingered gripper was tested in several different grasping events, e.g., with the tennis ball and the ripe tomato (see Fig. 5, a-b and c-d). Each test consisted of three to ten main tasks of selecting and placing an overloaded object. During the tests, each item was lifted from its original position and transported to a working bin. In another test, the reliability and stability of the gripping of the reloaded object was tested: The robotic gripper grasped a tomato and moved it at a maximum speed (1.0 m/s) along a predetermined path to test whether the gripper of the robotic arm securely holds the grasped object.

To measure the magnitude of the gripping force, further tests were performed with three force sensing resistors. The sensors were placed between the rigid and the flexible upper outer part of the reloaded object. The system consists of three sensors with force sensing resistors [1-2] connected to the Arduino Nano and three resistors with a value of 10 kOhm. To measure the power consumed by the motor, the ACS 712 power supply module was connected in series to a power supply with a voltage of 6 V[6].

6 Discussion of results

Based on the experimental statistical data obtained during the study, conducted under laboratory conditions, of the pressing of each toe member of the gripper with the holding teeth of each gripper lever attached to it against the surface of the upper part of RM, an experimental relationship was established between the value of the force P and the length of each toe member with the holding teeth attached to it for each gripper lever. Table 1 presents the results of the dependence of the values of the function of the random process of changing the force P of the adaptive three-halanx gripper of the industrial robot manipulator during the performance of stochastic processes of transferring a tennis ball from a transport container to a working container, obtained under laboratory conditions for a conditional example.

Table 1: Results of the dependence of the values of the function of the random process of the change of the force P of the adaptive three-point grip of the industrial robot manipulator during the execution of stochastic processes of reloading a tennis ball from a transport container into a working container, obtained under laboratory conditions for a conditional example.

Indicators	The distance from the conditional axis of the hinge O of the connection of adjacent phalanges of the gripper, with the holding teeth of the gripping lever attached to each of them, to the contact point of the inner surface of all contacting phalanges, with the holding teeth of each lever attached to each of them, with the surface of the upper section OM, X, mm				
	$X_1 = 25$	$X_2 = 30$	$X_3 = 35$	$X_4 = 40$	$X_5 = 45$
The value of the function of the random process of changing the magnitude of the force P	$5 \cdot 10^{-2}$	$3,9 \cdot 10^{-2}$	$1,8 \cdot 10^{-2}$	$0,5 \cdot 10^{-2}$	$0,09 \cdot 10^{-2}$

7 Conclusion

The results of the dependence of the correlation function of the random process of the change of the magnitude of the force P on the values of the parameters of the adaptive three-point grip of the industrial robot manipulator during the performance of the stochastic processes of its interaction with the manipulation object transferred from the transport container to the working container are presented in Table 2.

Table 2: Results of the dependence of the values of the function of the random process of the change of the force P of the adaptive three-point grip of the industrial robot manipulator during the execution of stochastic processes of reloading a tennis ball from a transport container into a working container, obtained under laboratory conditions for a conditional example.

Indicators	The value of the duration of the time period for measuring the value of the force P of the three-phalanx adaptive gripper of the IR manipulator, τ,				
	$\tau_1 = 0$	$\tau_2 = 5$	$\tau_3 = 10$	$\tau_4 = 15$	$\tau_5 = 20$
Correlation function $B(\tau)$, in a given period of time of interaction of the three-phalanx adaptive gripper of the PR manipulator with the upper section of the OM, τ, s	$2,82$	$2,2$	$0,4$	$0,3$	$0,05$

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