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# THE STUDY OF THE POSITIONING OF A FLEXIBLE MANIPULATOR

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*The purpose of this paper is a theoretical study of the positioning accuracy of the end part of the developed flexible manipulator. The research was carried out on the basis of its computer and physical models. In the process of computer modelling with the use of Matlab Robotics Toolbox software environment and on the basis of the developed physical model, the principles of determining the position of the end part of a flexible manipulator at known tilt angles of links were set up, taking into account that the geometric dimensions of the models were identical. The results of modelling are presented in the graphs of the coordinate comparison. Based on the results of experiments, we can conclude that, in order to achieve high accuracy of positioning of the end part of a flexible manipulator, it is recommended to avoid the use of cardan joints between the links, or to choose cardan mechanisms with reduced free travel.*

*Key words: Flexible manipulator; Positioning accuracy; Physical model; Computer model*

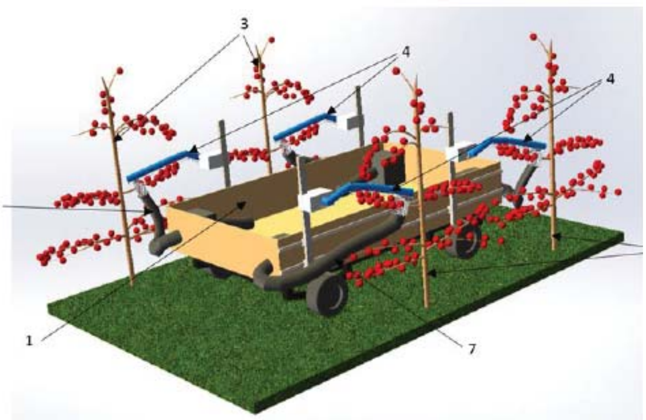
## INTRODUCTION

Flexible manipulators are promising devices that can be used in many areas. In agriculture, to harvest apples, these devices are able to pick apples with the necessary precision and accuracy [1-3]. For this purpose, it was suggested to use equipmentfor collecting apples using flexible manipulators (fig. 1) [4].

The technological process of collecting apples is carried out as follows. Initially, with the help of a tractor, the equipment for collection is placed near the apple tree being processed 3. With the position controller 2, the flexible manipulator 4 is installed near the serviced branch. Then the manipulator is installed along the branch, so that the elements repeat all the turns and bends of the branch. The process of harvesting apples is based on the movement of the combing device 6 along the body of the manipulator. In this case, the combing device picks apples growing on a branch. After that the apples fall into the hose 7 and move to the container 1. After the apple tree is serviced, the installation moves to the next one and repeats the collection process.

At the present time, various designs of flexible manipulators have been developed. But their successful application in the process of harvesting apples is limited by significant drawbacks associated with the possibility of using them only at lowloads. It is also worth noting that the existing flexible manipulatorsneed more complex control in comparison with the ones used other types of joints. Thus nowadays the use of flex manipulators is problematic, and therefore it is necessary to find a design without the above disadvantages.

In [5, 6, 7, 8], a description of various variants of the structures of flexible manipulators for collection of fruitswere given. On the basis of experimental data, it is determined



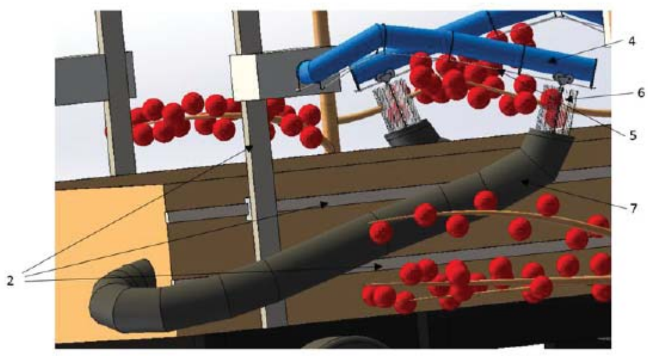




*Figure 1: The principle of operation of equipment for collecting apples using four flexible manipulators: 1-container for collecting apples; 2- position controllers for flexible manipulators; 3- apple trees; 4- flexible manipulators; 5- guide for combing device; 6- combing device, 7-transporting hose.*

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that the use of such facilities is promising. But to further develop systems based on flexible joints, it is needed to create designs capable to position the manipulator arms with high accuracy. The existing manipulators with flexible joints show less accurate positioning results [9-16].

To increase the strength of the flexible manipulator structure, it is proposed to use rigid couplings on the hinge elements as joints between the manipulator links, as well as a rigid axial jointing with cardan mechanisms. (fig. 2).

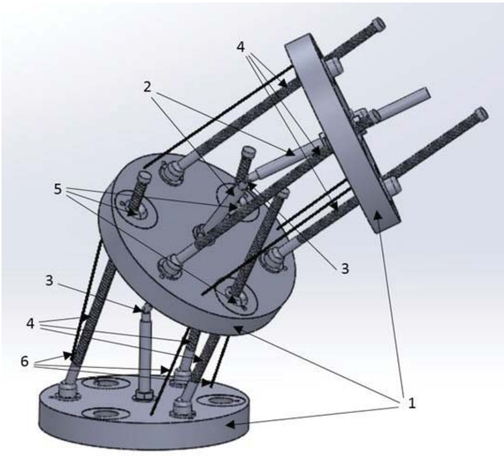


*Figure 2: External appearance of two sections of a flexible manipulator: 1- Baseof sections; 2-Central axis; 3- Cardan mechanisms; 4-Fixing rods; 5-Holders; 6-Control cables.*

The use of a flexible manipulator when collecting apples allows picking fruits without harm to the trees. But for further introduction, it is necessary to eliminate a number of drawbacks in the flexible manipulators associated with the insufficient strength of the structure and the difficulty of working in industrial orchards.

In order to verify the results of determining the position of a flexible manipulator, we determined the coordinates of its end part. To verify the data of the physical and computer models, as well as the matrix of the operating device position, we compared the coordinates for given tilt angles of the flexible manipulator sections.

To verify the validity of the data obtained during the simulation of the process of setting the gripper to the required position, the following research program was determined:

- Development of research methods;
- Experimental studyfor the accuracy of the position of the operating device in laboratory conditions;
- Analysis of the experimental results.

### *MATERIALS AND METHODS*

A study of the positioning accuracy of the end part of a flexible manipulator was carried out on the basis of a comparison of the experimental data of two models. One of the models was the result of computer programming, a detailed description of which is given in the paper [9]. Another one was the result of physical modelling, a detailed description of whichis given in the work [10] (fig. 3).

The obtained models allow displaying the process of motion of all links of the manipulator when the operating device moves from the initial position to the required one.

The main task of the study was to determine the accuracy of model positioning. During the experiment, the computer model was set to a free position and the tilt angles of each section were registered.

In accordance with the chosen range of tilt angles (table 1, fig. 4), the simulation of the process of setting the physical model of the manipulator at the indicated angles was carried out.

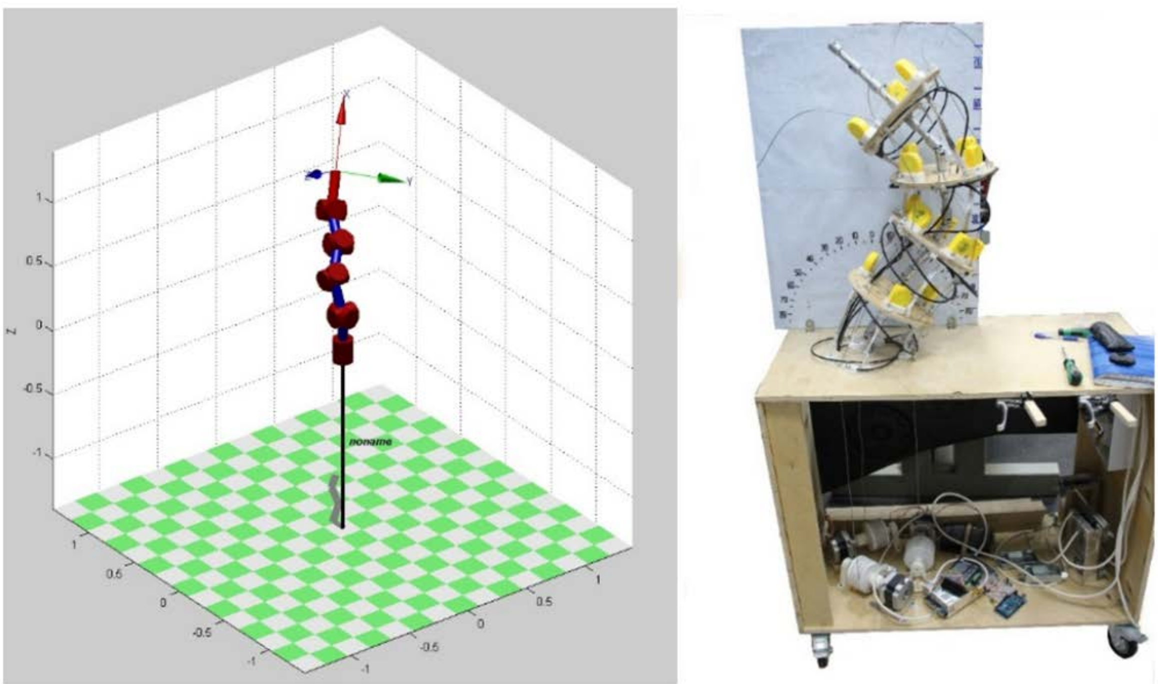

*Figure 3: The computer and physical modelsof the developed manipulator*

*Table 1: The values of the slope angles of sections*

| № position of the manipulator | Angles of sections | | | |
|---|---|---|---|---|
| | 1 section | 2 section | 3 section | 4 section |
| 1 | 5° | 15° | -5° | 5° |
| 2 | 5° | 15° | -15° | 5° |
| 3 | 35° | 2,5° | -45° | -40° |
| 4 | -35° | 25° | 25° | -45° |
| 5 | 0 | 0 | 0 | 0 |

Each position of the end part of the manipulator of the physical and computer models was registered. The position of the physical model was recorded by a laser with a projection onto a scaled paper. The position of the computer model was registered with the help of program commands, for a given position. An example of registering the position of the manipulator is shown in fig. 5.

Since the purpose of the experimental research is verification of data obtained during the computer modelling of the process of setting the operating device in the required position, measurement errors cannot be ignored.

Standard deviation was calculated basing on the following formula [Yashericyn]:

$$S = \frac{R_m}{d_m} = \frac{10}{3,735} = 2,68$$

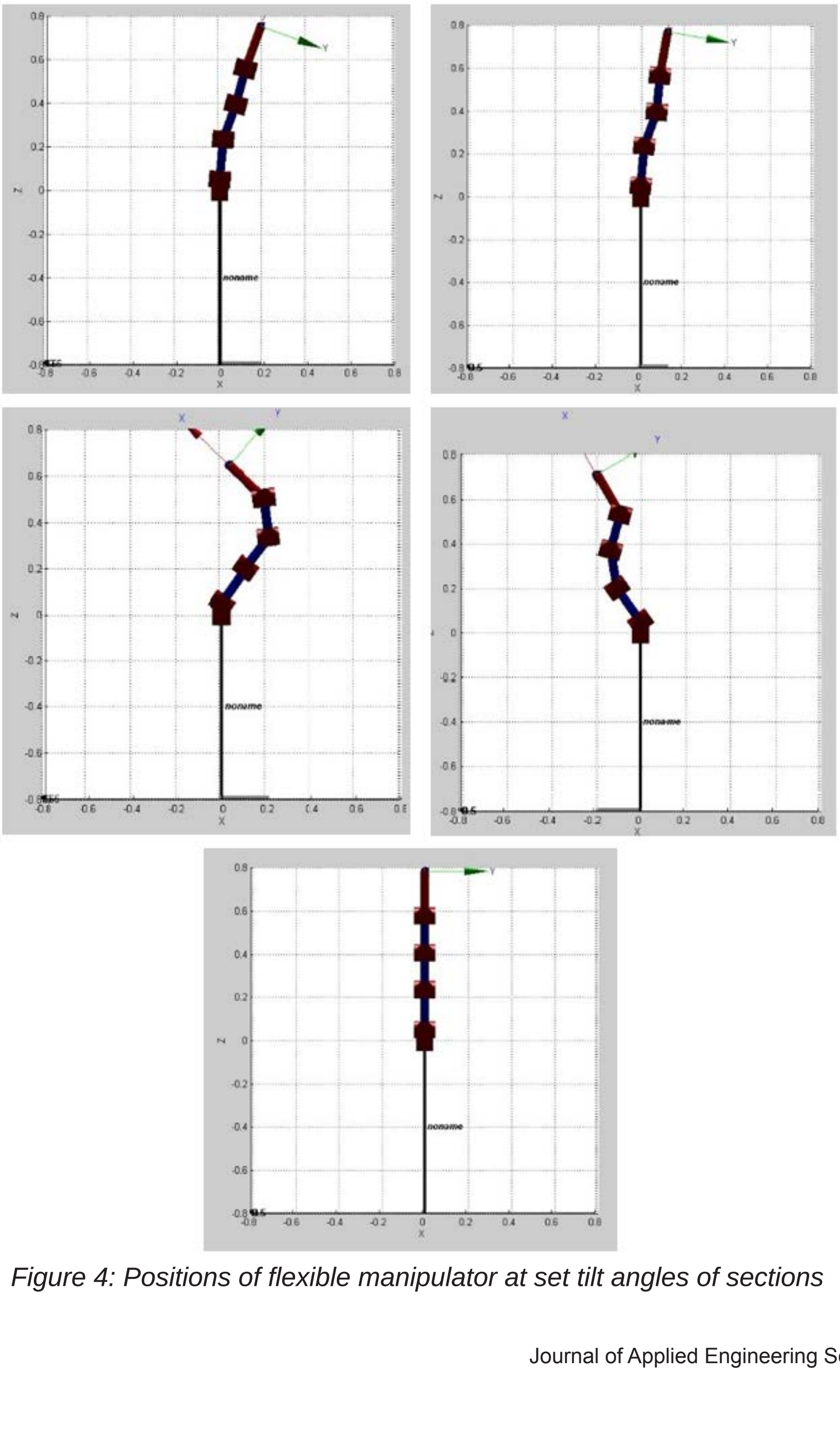

*Figure 4: Positions of flexible manipulator at set tilt angles of sections*

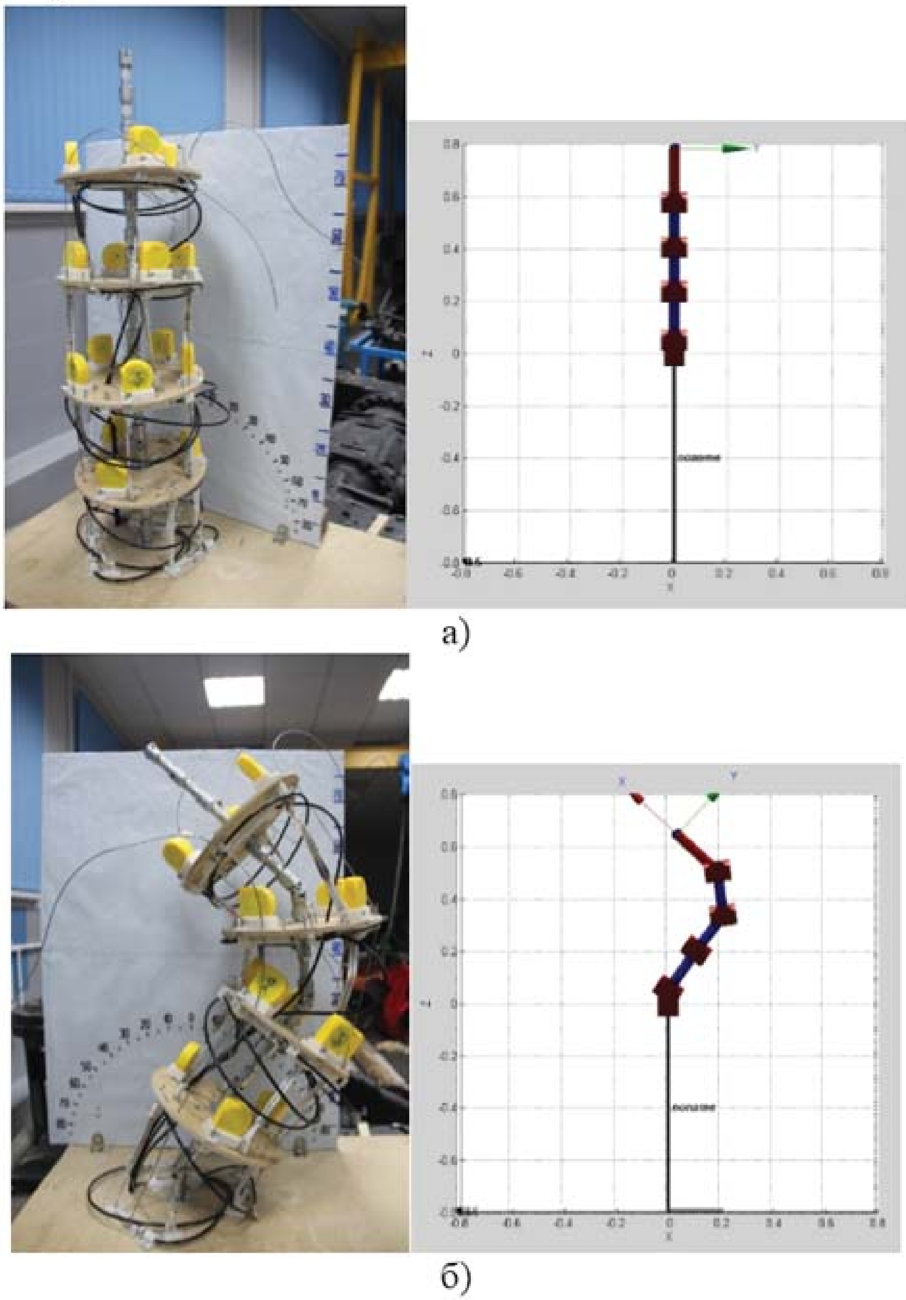


*Figure 5: An example of experimental verification of the positioning accuracy of the computer and physical manipulator models: a) Vertical position; b) The position obtained during the experiment*

where $R_m$ is the span;

$d_m$ is the mean value relative to the span (table P.5 [19]).

The number of replicate tests was determined basing on the following formula[19]:

$$m \geq \frac{t^2(P,m)\cdot S^2}{2\cdot \Delta^2(\sigma)} = \frac{2{,}093^2 \cdot 2{,}68^2}{2\cdot 1^2} = 15{,}7$$

where *t(P,m)* is the Student's t-test value for the confidence factor 0.95 and the number of tests equals to16 (tableП.1[11]);

Δ(σ) is the accuracy parameter.

In the study of the positioning accuracy of the flexible manipulator, 5 series of experiments with different tilt angles of the sections were carried out (fig. 4). When measuring the positioning accuracy of the end part of the manipulator, 5 series of experiments with different tilt angles of sections were carried out, with the number of parallel experiments equal to 16 in orderto reduce the influence of errors [19].

## RESULTS AND DISCUSSION

During the experiment, position values were obtained for the end part of the manipulator models which are shown in table 2. Basing of the results weobtained a graph, which is shown in fig. 5 and reflects the results of positioning of the physical and computer models.

*Table 2: Flexible manipulator positioning accuracy research results (mm)*

| Test No | Values obtained during experiment | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Manipulator position 1: 1 section: 5°; 2 section: 15°; 3 section: -5°; 4 section: 5°. | | Manipulator position 2: 1 section: 5°; 2 section: 15°; 3 section: -15°; 4 section: 5°. | | Manipulator position 3: 1 section: 35°; 2 section: 2,5°; 3 section: -45°; 4 section: -40°. | | Manipulator position 4: 1 section: -35°; 2 section: 25°; 3 section: 25°; 4 section: -45°. | | Manipulator position 5: 1 section: 0°; 2 section: 0°; 3 section: 0°; 4 section: 0°. | |
| | X | Y | X | Y | X | Y | X | Y | X | Y |
| 1 | 181 | 753 | 108 | 773 | 16 | 656 | 220 | 694 | -16 | 774 |
| 2 | 181 | 748 | 110 | 777 | 18 | 662 | 219 | 700 | -11 | 773 |
| 3 | 187 | 761 | 111 | 766 | 19 | 665 | 216 | 701 | -10 | 778 |
| 4 | 190 | 742 | 112 | 772 | 23 | 651 | 215 | 688 | -6 | 769 |
| 5 | 192 | 751 | 113 | 772 | 24 | 660 | 211 | 696 | -4 | 774 |
| 6 | 195 | 757 | 116 | 761 | 27 | 668 | 211 | 706 | -3 | 770 |
| 7 | 196 | 764 | 116 | 766 | 27 | 647 | 211 | 688 | -1 | 782 |
| 8 | 199 | 742 | 116 | 781 | 29 | 653 | 209 | 696 | 3 | 776 |
| 9 | 200 | 749 | 117 | 777 | 30 | 663 | 208 | 697 | 4 | 786 |
| 10 | 201 | 735 | 120 | 769 | 31 | 658 | 201 | 703 | 5 | 778 |
| 11 | 201 | 758 | 122 | 773 | 32 | 643 | 198 | 693 | 6 | 774 |
| 12 | 206 | 739 | 123 | 767 | 33 | 656 | 194 | 699 | 10 | 764 |
| 13 | 207 | 745 | 123 | 778 | 36 | 666 | 191 | 704 | 11 | 770 |
| 14 | 210 | 757 | 127 | 769 | 37 | 652 | 190 | 692 | 11 | 781 |
| 15 | 212 | 749 | 128 | 774 | 39 | 660 | 188 | 701 | 12 | 776 |
| 16 | 215 | 742 | 130 | 772 | 44 | 664 | 187 | 702 | 15 | 773 |
| Experimental value | 198,3 | 749,5 | 118,25 | 771,69 | 29,06 | 657,75 | 204,3 | 697,5 | 1,625 | 774,88 |
| Theoretical value | 197 | 751 | 118 | 767 | 27,7 | 645,25 | 196 | 714 | 0 | 782 |
| Divergence, % | 0,7 | 0,2 | 0,2 | 0,6 | 4,9 | 1,9 | 4,2 | 2,4 | - | 0,9 |

In accordance with the results, a comparison between the data obtained on different models of the manipulator was made. The graph is shown in fig. 6. By comparison, the error did not exceed 5% that allows us to conclude that the constructed physical model fully reflects the property of a flexible manipulator consisting in the possibility of the accurate positioning.

## DISCUSSION

The purpose of this paperis to study the positioning accuracy of models of a flexible manipulator.

Along with the fact that as a result of the experiment it was determined that the models that were used to study the manipulator's kinematics were reliable, according to the obtained dependencies (fig. 5), it can be established that the greatest spread of data during the setting of the physical model of the manipulator in the required position occurs along the X axis.

Based on the analysis of the design, it was determined that this regularity wasinfluenced by cardan joints, which had a free travel. Thus, it can be concluded that it is recommended to avoid this kind of jointing between links, or to choose cardan mechanisms with reduced free travel.

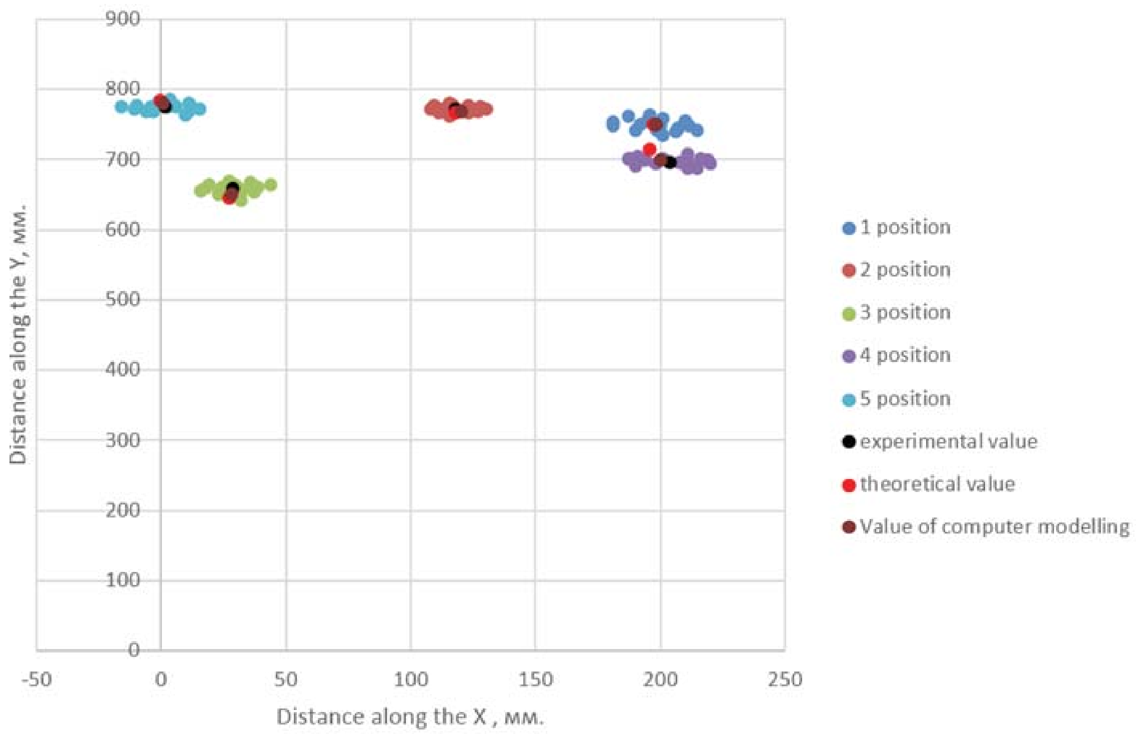


*Figure 6: Graph of experimental data on the determining the position of the end part of the flexible manipulator based on the physical model*

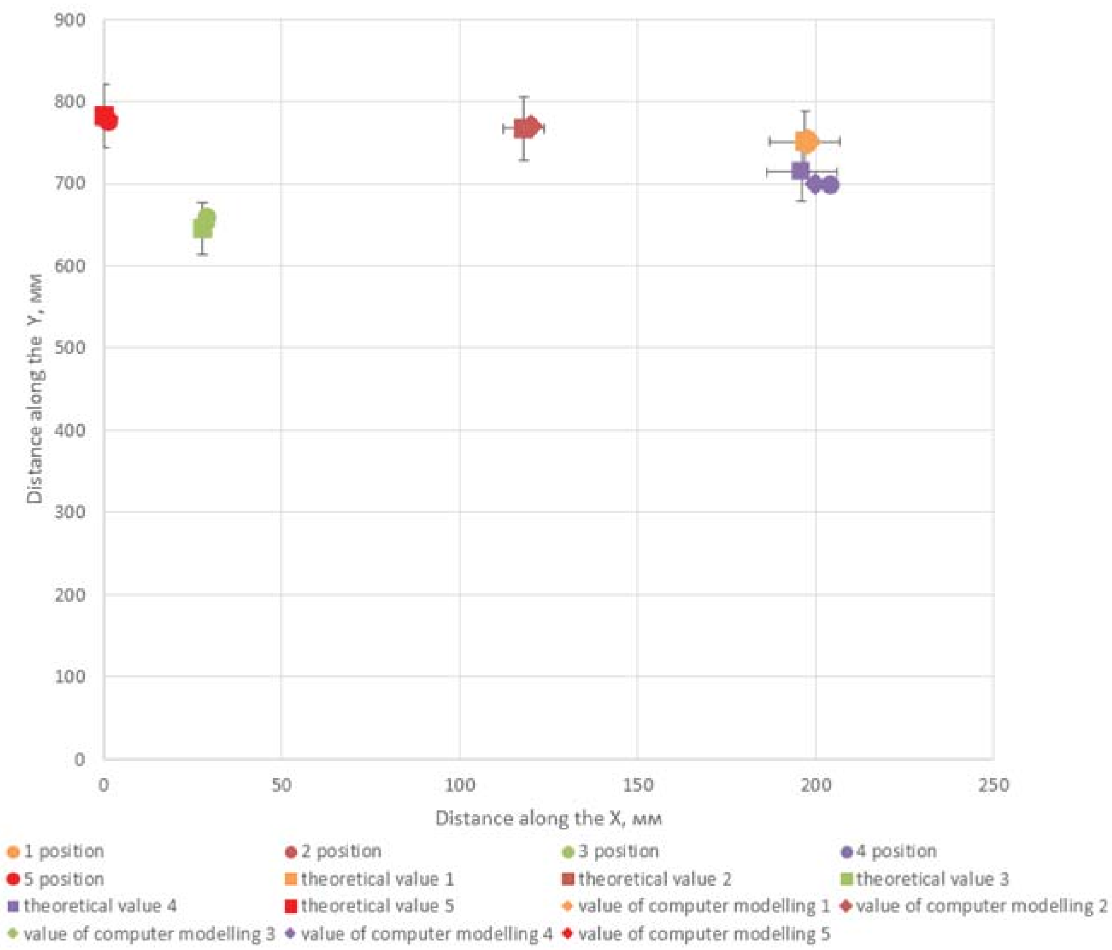


*Figure 7: Graph of positioning accuracy of the end part of a flexible manipulator based on the results of an experiment*

## CONCLUSIONS

The existing designs of flexible manipulators have their drawbacks, including those associated with poor positioning accuracy [12-19]. To improve this parameter, it is necessary to use units and assemblies that have high strength characteristics and to avoid freetravel in links. In the course of the study, we investigated a new design of a flexible manipulator, in which cardan elementswere used as joints between the links. The physical manipulator and the computer model were positioned in five different positions with coordinate registration for every position. According to the results of comparison of coordinates obtained on the basis of the computer model the error did not exceed 5%. To achieve higher accuracy of positioning of the end part of a flexible manipulator, it is recommended to avoid cardan joints between the links in the design, or to choose cardan mechanisms with reduced free travel.

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