Evaluation of the efficiency of apple picking using a flexible manipulator

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Abstract. Flexible manipulators are a promising executive tool in various technological complexes. In the process of collecting fruits, they can, in addition to their main task of delivering working bodies to the object of labor, also perform the functions of flexible guides. For the use of flexible manipulators in agriculture, namely in the operations of harvesting apples, developments are needed that are relatively cheap to manufacture in comparison with other flexible manipulators. To analyze the efficiency of apple picking using a flexible manipulator, a series of tests was carried out. As part of the tests, the process of picking apples was simulated using a flexible manipulator. The number of apples harvested for branches of various geometries was estimated. Within the framework of the discussion, the prospects of introducing a flexible manipulator in super-intensive gardens in Russia were assessed.

1. Introduction

Flexible manipulators are a promising executive tool in various technological complexes. Currently, in those areas of activity where work is carried out in confined spaces, manipulators based on flexible joints are being introduced. [1-3] In the process of collecting fruits, they can, in addition to their main task of delivering working bodies to the subject of labor, also perform the functions of flexible guides [4].

Based on a review of technologies for designing flexible manipulators, it follows that for use in agriculture, these manipulators have disadvantages associated with the high cost of manufacturing and the complexity of maintenance. [5-8] For the use of flexible manipulators in agriculture, namely in the operations of harvesting apples, developments are needed that are relatively cheap to manufacture in comparison with other flexible manipulators. At the same time, they have low indicators of the time spent on maintenance and repair. [9]

Flexible manipulators have a number of advantages for use in the apple picking process:
1) Ability to work in confined spaces;
2) Ability to use the manipulator body as a flexible guide;
3) The working area of the flexible manipulator is much larger in comparison with the articulated manipulator;
4) Increased maneuverability of the flexible manipulator. [ten]

An analysis of developments for harvesting fruits showed that for the mass use of mechanized systems, devices are needed that allow harvesting fruits with the necessary accuracy. A manipulator
with flexible joints can be used as such a mechanism. For these purposes, the design of a flexible manipulator has been developed using non-elastic assemblies and mechanisms (Figure 1) [11]. Due to which the required strength and rigidity of the structure is achieved.

On the basis of the arrangement of branches and their sizes according to the modified slender spindle system on apple trees, the principle of apple harvesting has been developed. Fruit picking with the help of a flexible manipulator combines the technological operation of delivering apples to the conveyor and the operation of removing them from the branches. Figure 1 shows the process of installing the manipulator body along the processed branch on an apple tree formed according to the principle of a modified slender spindle. The maximum possible length of a processed branch is no more than 1.5 m. For processing an apple tree, a manipulator with four links with a length of 0.38 m is used [12].

![Manipulator body installation process along the processed branch.](image)

**Figure 1.** Manipulator body installation process along the processed branch.

2. **Materials and methods**

To analyze the efficiency of apple picking using a flexible manipulator, a series of tests was carried out, including:

- installation of an apple tree branch in a position that repeats its location on an apple tree, namely, the principle of crown formation, a modified slender spindle;
- fixing apples on a branch, based on how they grow on a tree;
- installation of the manipulator structure along the apple tree branch;
- movement of the stripping device along the body of the manipulator with the included vacuum cleaner in order to collect apples;
- analysis of test results.

The test procedure was as follows. At first, the manipulator was installed along the processed branch. The stripper was carried along the branch and apples were collected. In this case, the speed of
movement of the stripping device was constant. 16 apples were hung on a branch. Apples that fell into the sleeve were recorded, as well as apples that did not fall into the sleeve. After that, the apples were again hung on the branch and this process was repeated four more times. For the reliability of the data obtained, tests were carried out on five different branches. At the same time, on each branch, five passes of the combing device were carried out with the apples re-fixed on the branch (Figure 2).

![Figure 2. Experimental check of picking apples from a branch.](image)

As part of the study of the flexible manipulator, 5 series of experiments were carried out with branches of various shapes. Moreover, their length was in the range of 1.5 ... 2.0 meters. Figure 3 shows the installation of the manipulator along various branches.

![Figure 3. Installing the manipulator along various branches.](image)

3. Results and discussion

The research results are presented in table 1.

To determine the quality of the apple harvest, a comparison of the results was carried out. The average number of apples harvested has been determined. The results are depicted graphically (Figure 4). Thus, on the basis of the data obtained, a graph is built, which reflects the results of fruit collection. It can be concluded that more than 50% of all harvested apples fall into the sleeve, namely 83.75%. Collecting with a flexible arm is efficient. But for use in industrial orchards, it is necessary to increase the percentage of apples entering the sleeve by improving the proposed technology. Improving the design of the funnel, the combing mechanism, the use of a more powerful vacuum cleaner or a suction fan will improve the quality of apple picking.
Table 1. Results of research on the effectiveness of the apple picking process.

| № branch positions | 1 passage | 2 passage | 3 passage | 4 passage | 5 passage |
|---------------------|-----------|-----------|-----------|-----------|-----------|
|                     | Number of apples harvested | Number of unharvested apples | Number of apples harvested | Number of unharvested apples | Number of apples harvested | Number of unharvested apples | Number of apples harvested | Number of unharvested apples |
| 1                   | 12        | 4         | 15        | 1         | 12        | 4         | 12        | 4         | 13        | 3         |
| 2                   | 13        | 3         | 11        | 5         | 12        | 4         | 14        | 2         | 12        | 4         |
| 3                   | 12        | 4         | 12        | 4         | 13        | 3         | 13        | 3         | 14        | 2         |
| 4                   | 14        | 2         | 13        | 3         | 15        | 1         | 14        | 2         | 15        | 1         |
| 5                   | 15        | 1         | 14        | 2         | 15        | 1         | 15        | 1         | 15        | 1         |

Figure 4. Results of a study of the efficiency of apple picking.

To analyze the prospects for the introduction of the installation using a flexible manipulator, the results of the work were discussed at the LLC "Niva" Voronezh region, Eritl. The company is engaged in the cultivation of various legumes, oilseeds, roots, pomes, fruit and many other crops.

The company is currently implementing superintensive garden technologies that are widely used in Canada. In 2020, the enterprise planted columnar apple trees with a "superspindle" pruning scheme when planting apple trees 3 × 0.5 m. Apple trees of the following varieties are grown in these orchards: Hanikrisp, Legal and Ambrosia.

These gardens have a number of features in the formation of the crown, namely:
1) apple trees are columnar;
2) lateral branches and processes do not grow to sizes greater than 40 cm, and are periodically pruned;
3) the maximum tree height does not exceed 3 meters.

An analysis was made of the possibility of using a flexible manipulator in these gardens. The result of installing a flexible manipulator along the apple tree trunk is shown in Figure 5.
During the discussion of the possibility of using the complex for harvesting apples using a flexible manipulator with the chief agronomist for growing apples, it was determined that the use of the complex in super-intensive apple orchards with a super-spindle crown shape is possible taking into account a number of recommendations:

1) in those orchards where tree pruning is used according to the superspindle scheme, the manipulator for harvesting apples should be installed in the vertical position;

2) to perform the operation of picking apples from one apple tree in one pass of the picking device, the length of the manipulator must be increased from 1.5 to 3 meters;

3) it is necessary to increase the size of the stripping device and the funnel into which the apples fall.

4. Conclusions

It can be concluded that the collection using the installation using a flexible manipulator is effective (more than 50% of all harvested apples get into the sleeve, namely 83.75%). But for use in industrial orchards, it is necessary to increase the percentage of apples entering the sleeve by improving the proposed technology.

As a result of the discussion and analysis of the operation of the plant for harvesting apples with the management of the enterprise LLC "Niva", a positive assessment was given about the prospects of introducing this complex for harvesting apples in apple orchards. The relevance of the developed installation is noted and interest is expressed in the implementation of this technology on the basis of the enterprise.
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