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DEVELOPMENT OF THE INTELLIGENT SOFTWARE AND HARDWARE SUBSYSTEM FOR CAPTURING AN OBJECT BY ROBOT MANIPULATOR

Abstract*. In this paper, it is shown that based on an analysis of the implemented functions of existing robot manipulators the task of automation of the safe capture of objects by a robot during the assembly process is poorly developed. In the process of analysis, there were discovered technological solutions to three main tasks for the development of a subsystem for capturing objects by a robotic manipulator: determination of the dimensions and shape of the capturing object; determination of the distance from the robot manipulator to all the points of the capturing object, determination of the capture point of the object and clarification of the distance to the robot manipulator. It is shown that all of the above tasks are not sufficiently solved. Therefore, it was proposed to develop a methodology for creating an intelligent software and hardware subsystem for capturing an object by robot manipulator. The developed methodology consists of six steps: obtaining a stereo image and building an in-depth map; determination of the distance from the robot manipulator to all the points of the object; determination of the contour of the object; determination of the capture point of the object and clarification of the distance to the robot manipulator; determination of the degree of capturing the object; determination of the movement of the manipulator to capture an object at the desired point. To find the capture point, it is proposed to use the contour search method on the object's depth map, and to search for the finest part on the contour, limit it to a segment and find its middle point. To implement the algorithm for determination of the distance to the object, the degree of its capture and movement to the desired point, the dependencies of the calculations on the depth map and the physical characteristics of the manipulator are formalized. The capabilities of the StereoPi microprocessor are analyzed and its use for the hardware solution of the capture function by the robotic arm is proposed. The simulation of the intelligent software and hardware subsystem for capturing an object of complex shape has been performed. Conclusions are drawn about the independence of the developed subsystem from the type of object and its viewing angle by a robot manipulator. In addition, an increase in the accuracy of capturing the object by a robot manipulator equipped with an intelligent subsystem is shown in comparison with its existing analog. Potential problems in the implementation of the proposed methodology are highlighted.*

Keywords*: robotic manipulator; determination of distance; depth map; object capture; StereoPi*

Introduction. The use of modern technology in industry has allowed robots to replace humans at most stages of manufacturing. Modern robots are devices that independently perform a complex series of tasks [1], which they are trained or programmed to perform. Robotic manipulators (RM) are most often used to solve manufacturing problems, they imitate the work of a person's hand and look like claws or like the hand itself.

Typically, RMs is used for solving the sorting or moving problem by using capture functions. In case of using RM for assembling certain objects, the implementation of the object capture function becomes complicated, because the RM must capture the object at a certain point, taking into account the previously obtained parameters of the object.

Therefore, before capturing the object, there must be first determined the dimensions of the object with possible particular characteristics of its shape, as well as the distance to the capture point of the object. However, studies show that the widespread use of RMs for assembly is hampered by its limited ability to accurately capture an object, due to the problem of often incorrect determination of the shape and dimensions of the object, as well as the distance to the capture point based on them [2]. In addition, RMs most often operate in automatic mode with pre-adjusted servomotors to capture a specific object at a specific point [3]. Thus, problems arise, without the solution of which the normal use of RMs is impossible – capture of a previously unknown object by the manipulator and increase the accuracy of this capturing during the assembly of the RM by developing an intelligent subsystem that can calculate the trajectory of the RM to capture the object at a certain point based on preliminary recognition of the dimensions and shape of the object, a possible capture point based on them, as well as calculating the distance from the RM to the capture point of the object.

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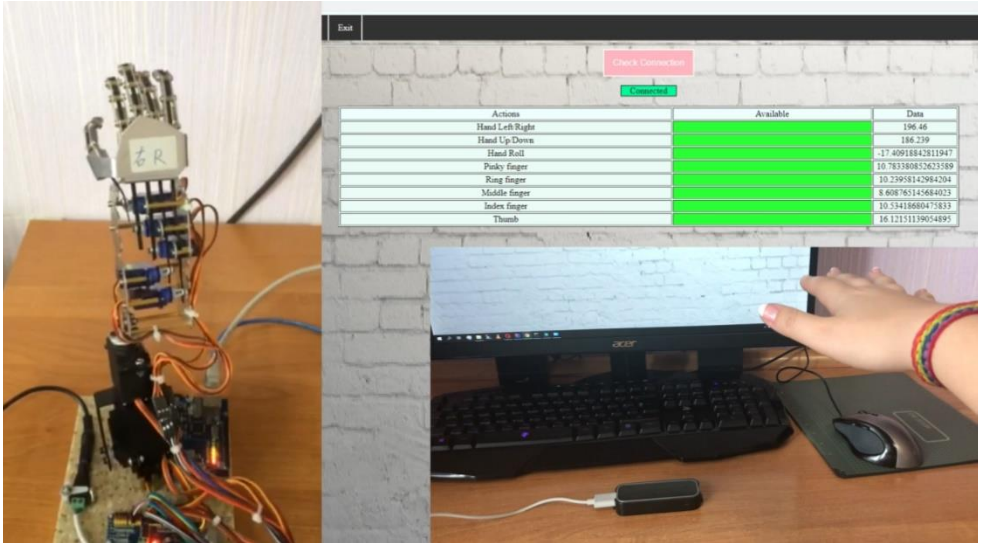
Analysis of recent scientific publications and achievements. A typical RM is constructed using rigid links connected by joints with one fixed end and one free end to perform a given task, such as moving a box from one location to the next. The joints to this RM are the movable components, which enables relative motion between the adjoining links. There are also two linear joints to this RM that ensure non-rotational motion between the links, and three rotary type joints that ensure relative rotational motion between the adjacent links [6].

As a prototype for the development of an intelligent subsystem, we consider the capabilities of the RM, which allows you to grab and carefully put in place two types of objects – cups and shoes, even if they are unknown to RM, but relate to these types of objects. A convolutional neural network (CNN) is used to recognize objects. At the same time, the following three marks are used to separate objects: the highest point, the lowest point, and the axis of the object connecting these two points. Using built-in algorithms, a 3D model of the object is created and the capture parameters are analytically determined. A feature of this development is the use of the kPAM framework, which allows you to build a 3D model of the object and, on the basis of its analysis, obtain the so-called "cost" of key points. As a result, the RM "knows" at what point it is possible to safely take an object without damaging it [2]. The described RM is tied to the recognition of specific object, on which it was previously trained, and is still a toy rather than a specific practical application. However, for the further research it is interesting to consider the implemented approach to determine the safe capture point of objects.

In previous works of the authors [4-5], an example of a hardware implementation of the function of capturing objects by a controlled RM that copies the actions of a person's hand is shown (Fig. 1). This RM has 8 servomotors, where 5 of them are responsible for the movement of the fingers, which allows the RM to perform the capture function. RM works using a software complex that is running on a personal computer. At the same time, the operator controlling the RM sees an array of coordinates of the key points of the movement on the screen. The movement of the RM is ensured by the Leap Motion sensor, which records the coordinates of the movement of the operator's hand and transmits them to the input of the corresponding software module. This module, using a network connection with the ArduinoUno microprocessor on the RM sends digital data to control the inclination of a particular servo motor. This provides a user-friendly RM movement. An example of the operation of a hardware-software complex is shown in Fig. 1. Here RM with ArduinoUno, Leap Motion and a view of the screen for the operator, who manually performs control functions above the sensor are shown.

Thus, the main disadvantage of the hardware-software complex developed by the authors is the provision of only manual control of the RM. The authors of the development understand that for the automatic control of the RM it is necessary to create an intelligent subsystem that, based on the definition of the capturing object, will calculate the "digital" script for controlling the RM's servomotors that are necessary for capturing and raising the object.



Actions	Available	Data
Hand Left/Right	🟩	196.46
Hand Up/Down	🟩	186.239
Hand Roll	🟩	-17.40918842811947
Pinky finger	🟩	10.783380852623589
Ring finger	🟩	10.23958142984204
Middle finger	🟩	8.608765145684023
Index finger	🟩	10.53418680475833
Thumb	🟩	16.12151139054895

Fig. 1. An example of the operation of the hardware-software complex for RM, which copies the movements of the operator's hand

Based on an analysis of the existing developments and the authors' own experience for the development of the intelligent software and hardware subsystem (ISHS) for capturing objects by RM, it is necessary to analyze the existing technological solutions of the following three interrelated subtasks (Fig. 2):

– determination of the dimensions and shape of the capturing object;

– determination of the distance from the RM to all the points of the capturing object;

– determination of the capture point of the object.

Infrared rangefinder by Sharp measures distance by calculating the time delay between the transmission of a Near-Infrared laser signal and its reception after reflecting off of a target. This translates into distance using the known speed of light. This unique signal processing approach transmits a coded signature and looks for that signature in the return, which allows for highly effective detection with eye-safe laser power levels. Proprietary signal processing techniques are used to achieve high sensitivity, speed, and accuracy in a small, low-power, and low cost-system [12]. It is often used in security systems, the time of day does not affect its work, it is able to measure the distance to objects with complex surfaces. However, it is very expensive, has a limited measurement range and is unstable to weather conditions. In the *LIDAR* (Light Detection and Ranging) – detection and range determination are performed by using light, a remote sensing method is implemented that uses light from a pulsed laser to measure ranges when determining the Earth's surface in the form of a sufficient accurate three-dimensional map of the relief and models of houses. It has a high measurement range, a high refresh rate, the time of day does not affect its work, but it is not safe for the human eye. It is interesting for further development to consider the depth map construction method implemented in LIDAR. LIDAR collects data this way: when an airborne laser is pointed at a targeted area on the ground, the beam of light is reflected by the surface it encounters. A sensor records this reflected light to measure a range. When laser ranges are combined with position and orientation data generated from integrated GPS and Inertial Measurement Unit systems, scan angles, and calibration data, the result is a dense, detail-rich group of elevation points, called a "point cloud". Based on this cloud, you can get an in-depth map where you can see the approximate distance to objects by color intensity.

Each point in the point cloud has three-dimensional spatial coordinates (latitude, longitude, and height) that correspond to a particular point on the Earth's surface from which a laser pulse was reflected. The point clouds are used to generate other geospatial products, such as digital elevation models, canopy models, building models, and contours [13]. Most of the works devoted to the *determination of the capture point* suggest the presence of a pre-built 2D or 3D model of the capture object. It was discovered that many developers used a simulated environment to study the effectiveness of solving the problem of capturing an object for different purposes. For example, the authors [14] used partially observable Markov decision-making processes (POMDP) to select the optimal control policies for two fingers. And [15] used heuristic rules to generate and evaluate a three-finger hand grip assuming that the objects are made of simple shapes such as spheres, cubes, cones and cylinders, each with pre-calculated capture primitives. In addition to the fact that these methods are based on prior knowledge of the 3D model of an object, they were not tested in real experiments, but were evaluated on a simulator.

In real conditions [16-17] were tested to capture an object. In this case, after the capture object was localized in [16], *visual servoing methods* were used that align the robot to the desired location, in [17] the *tactile feedback* was used to capture the object.

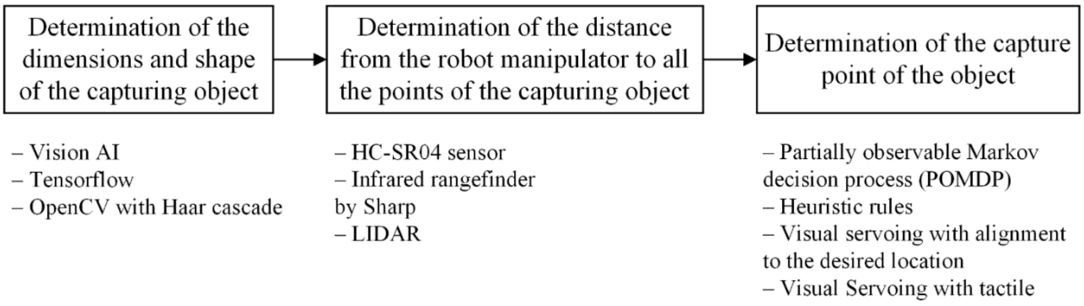


Fig. 2. The main subtasks and their technological solutions in the development of ISHS for capturing objects by RM

Thus, after analyzing the identified main subtasks and their possible technological solutions for automating the capture function of the RM, we make it necessary to develop a specialized methodology for creating an intelligent software and hardware subsystem for automating the safe capture function of an object by RM with increased accuracy, which is presented in Fig. 1.

The purpose of the article. The developed subsystem will allow to solve the problem of capturing an object automatically, based on an analysis of the object, RM will carry out calculations according to the given algorithms and display a solution in the form of the angle of inclination of the servomotors, which will be visually converted to capturing the object. Therefore, the subsystem is considered intellectual.

The *purpose* of this article is to develop an intelligent software and hardware subsystem to automate the function of safe capture of an object by RM with increased accuracy.

To achieve the goal, the following tasks were solved:

1. To highlight the main subtasks for automating the function of capturing the object by RM and to analyze their possible technological solutions.
2. To develop a methodology for creating an intelligent software and hardware subsystem for capturing the object by RM.
3. Perform a simulation to test the created hardware-software subsystem for capturing the object.

Main part. Development of methodology for intelligent software and hardware subsystem for capturing an object by RM

The developed methodology consists of the following steps (Fig. 3):

1) obtaining a stereo image and building an in-depth map;
2) determination of the distance from the RM to all the points of the object;
3) determination of the contour of the object;
4) determination of the capture point of the object and clarification of the distance to the RM;
5) determination of the degree of capturing the object;
6) determination of the movement of the RM to capture an object at the desired point.

We consider the implementation of the development of an intelligent software and hardware subsystem for capturing the object by RM using the classic example of a fragile object with an asymmetric shape – a cup.

Obtaining a stereo image and building an in-depth map. The technologies described in the analysis of existing scientific achievements to determine the object are not applicable to use for solving the problem in this paper due to their suggestion of implementing neural networks and the in-advance training of the RM to capture a specific object. The described sensors for determination of the distance to all points of the object cannot be used in this paper, since they offer the determination of the distance to a specific point, have a limited measurement range, are unsafe when interacting with a person or expensive.

Since in this paper a previously unknown object, a cup, is placed in front of the RM, it is proposed to use a stereo image and convert it to a depth map as the basis for determining the previously unknown object and calculating the distance to it, this will allow us to get the distance to each point of the object. Unlike other technologies, this will provide a complete picture of the object.

To effectively obtain stereo images and depth maps, it is proposed to use *StereoPi* microprocessor based on the RaspberryPi 3 board with the connection of two wide-angle (160°) cameras with ribbon cables [18]. This will allow us to take images from two StereoPi cameras (located at a distance from each other), where the position of the cup on one of them is shifted. Therefore, the stereo image, in this paper, is a combined image from two cameras of the StereoPi sensor. Based on the received stereo image, using the OpenCV support that is integrated into the microprocessor, a depth map was constructed, which is a color conversion of the displacement of the cup in each image,

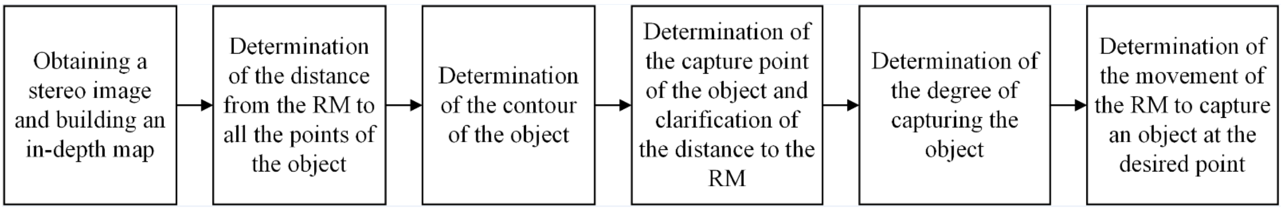
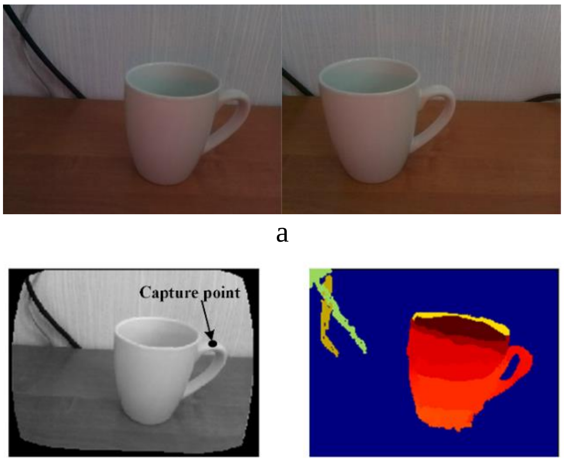


Fig. 3. The scheme of the relationship of steps in the development of ISHS for capturing the objects by RM

the pixel brightens with decreasing distance of the object to the cameras and darkens with its increase (Fig. 4).



a

b

Fig. 4. Image of a cup with its capture point:
a – a pair of images for constructing a stereo image;
b – stereo image and depth map of the cup

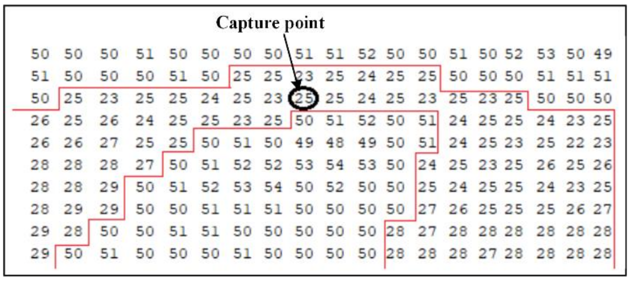
Determination of the distance from the RM to all the points of the object. To solve this problem, it is proposed to find the distance from the camera on RM to each pixel of the image of the depth map:

$$D = \frac{b*f}{d}, \qquad (1)$$

where: D – the distance of a point in the real world; b – the base offset (distance between two cameras); f – the focal length of the camera (depends on the lens); d – the depth. The d parameter can be obtained when building the depth map, since each of its pixels will be constructed relative to this parameter by color. Parameters b and f depend on the characteristics of the device in the robotic system. This formula helps to obtain distances in the form of a two-dimensional matrix of distances (Fig. 5).

Determination of the contour of the object. Before capturing an object, it must be localized taking in consideration that it lies on a surface, the distance to which is also determined in the matrix of distances. Therefore, it is proposed to conduct a closed contour search on a two-dimensional distance matrix. Thus, the coordinates of each point of the contour on the matrix will be obtained.

In Fig. 5 part of the distance matrix (in centimeters) of the upper part of the handle of the cup is shown and the contour is detected as a result of the search for closed contours. This kind of search allows the RM not to depend on knowledge of the object, therefore, it can capture any previously unknown object.



50	50	50	51	50	50	50	50	51	51	52	50	50	51	50	52	53	50	49
51	50	50	50	51	50	25	25	23	25	24	25	25	50	50	50	51	51	51
50	25	23	25	25	24	25	23	25	25	24	25	23	25	23	25	50	50	50
26	25	26	24	25	25	23	25	50	51	52	50	51	24	25	25	24	23	25
26	26	27	25	25	50	51	50	49	48	49	50	51	24	25	23	25	22	23
28	28	28	27	50	51	52	52	53	54	53	50	24	25	23	25	26	25	26
28	28	29	50	51	52	53	54	50	52	50	50	25	24	25	25	24	23	25
28	29	29	50	50	51	51	51	50	50	50	50	27	26	25	25	25	26	27
29	28	50	50	51	51	50	50	50	50	50	28	27	28	28	28	28	28	28
29	50	51	50	50	50	51	50	50	50	50	28	28	28	27	28	28	28	28

Fig. 5. A part of the matrix of distances and part of the found cup contour on it with the highlighted capture point

Since the size of the image is known in pixels in advance, the coordinates of each point in the contour will indicate its specific location on the image, which will allow us to find the specific position in which the RM should capture the object.

There might be a problem when using this method – the image could contain not one cup, but two or three, so that there are several contours there and it is not clear with which one to continue working. It is proposed to solve this problem by searching for the first closed contour and stop the search after that.

Determination of the capture point of the object and clarification of the distance to the RM. It is proposed to capture the object by its thinnest part in order to avoid the problem of capturing a larger area than the maximum value of the unclasped claw of the RM. In this case, it is proposed to find the coordinates on the found contour that form an almost straight and thin line, as a result a certain segment of points will be obtained.

Then it is proposed to find the coordinates of the middle point of segment, which will be the capture point:

$$x_m = \frac{x_a + x_b}{2} \quad y_m = \frac{y_a + y_b}{2}, \qquad (2)$$

where: x_m – the horizontal coordinate of the capture point; x_a – the horizontal coordinate of the extreme point of one end of the segment; x_b – the horizontal coordinate of the extreme point of the other end of the segment; y_m – the vertical coordinate of the capture point; y_a – the vertical coordinate of the extreme point of one end; y_b – the vertical coordinate of the extreme point one end of the segment (Fig. 6).

In this case, when capturing the cup, the capture point will be determined on the cup itself or in the middle of the cup handle, depending on the shape of the cup itself. In the example considered, the center of the handle of the cup was the capture point.

The search for the distance of the object to the RM depends on the specifics of the RM and its characteristics. This paper proposes to capture the object close to the point of the center of capture.

RM goes up or down due to the operation of the built-in servomotor, which has its own angle of inclination (in this example, 0°-90°). In this case, it is proposed to translate the distance to the capture point into the inclination angle of the desired servomotor:

$$A = \frac{a*D}{l}, \qquad (3)$$

where: A – the angle of inclination of the servomotor; a – the current angle of inclination of the servomotor; D – the distance to the capture point according to (1); l – the current distance of the manipulator to the surface of the table/ground. All parameters are shown in Fig. 6.

Determination of the degree of capturing the object. Since the capture in RM is similar to going up or down, servomotor needs to know the angle of its inclination to perform one or another action, it is proposed to calculate this angle by the formula:

$$A = \frac{2R*A_{max}}{D_{max}}, \qquad (4)$$

where: A – the angle of inclination of the servomotor for gripping; R – the radius (the distance from the center point of the object to its border); A_{max} – the maximum angle of the servomotor when unclenching the claw (fingers); D_{max} – the real maximum distance between the claws (fingers).

Thus, knowing the characteristics of the claw on the manipulator, as well as the radius of the object (Fig. 7), we can calculate the angle of inclination for the desired servomotor.

Determination of the movement of the RM to capture an object at the desired point. Based on the knowledge of the coordinates of the capture point, the resolution of the image of the depth map and the maximum angle of the servomotor, it is proposed to calculate the angle of inclination of the servomotor responsible for the horizontal movement of the RM according to the formula:

$$A_G = \frac{x_p*A_{max}}{x_m}, \qquad (5)$$

where: A_G – the angle of the servomotor for horizontal movement; x_p – horizontal image resolution of the depth map; A_{max} – maximum angle of the servomotor when moving horizontally; x_m – the horizontal coordinate of the capture point.

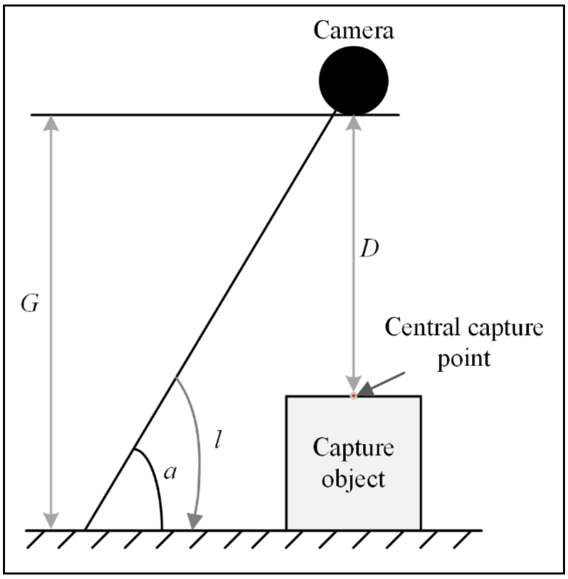


Fig. 6. Parameters for calculating the formula (3) of the inclination of the RM

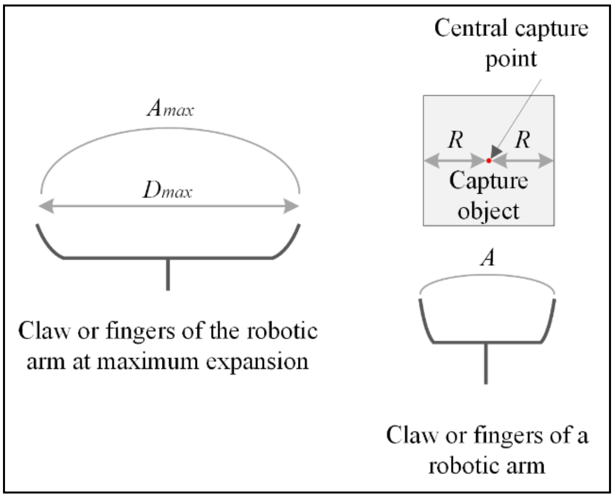


Fig. 7. Parameters for calculating the formula (4) of capture the object by RM

Similarly, it is proposed to calculate the angle of inclination of the servomotor, which is responsible for the vertical movement of the RM by the formula:

$$A_V = \frac{y_p*A_{max}}{y_m}, \qquad (6)$$

where: A_V – the angle of the servomotor for vertical movement; y_p – vertical image resolution of the depth map; A_{max} – maximum angle of the servomotor when moving vertically; y_m – the vertical coordinate of the capture point.

Simulation of the subsystem for capturing the object. To verify the fulfillment of the research purpose, that is, to increase the accuracy of capturing an object, a simulation of the situation of capturing an object was performed on the basis of the developed methodology. As a preparation, there were taken pictures of five types of cups of various sizes with two cameras with a resolution of 1280x480 pixels. Based on the photos, a stereo image was formed (with a resolution of 640x480 pixels), and then an in-depth map was obtained (an example of which is shown in Fig. 4). Using the depth map, the matrix of distances was calculated and a closed contour was searched to find the capture point (Fig. 5). Based on this, the angle of inclination of the servomotors for lowering and compressing the RM for capturing cups was obtained.

The success criterion for the RM is finding the capture point *on* the cup, calculating the exact distance to this point, calculating the exact compression ratio and calculating the exact angles of the servomotors for the movement of the RM.

The following indicators were obtained in the MIT’s similar development [2]: 100 % success in capturing and moving a regular-sized cup, 50 % success in capturing and moving small-sized cups, and on average, the success rate of a manipulator when capturing an object generally reaches 86 %.

Simulation was performed 10 times with each cup of 5 types, which provided 50 cases for capturing objects. In 47 cases, the capture point, the distance to the point, and the angles of capture were calculated correctly compared to manual calculations. In 1 case, the distance to the point did not match the real one. In 2 cases, the angles of capture were not calculated correctly (bigger angle than required), which in a real situation would not allow the manipulator to raise the cup.

Thus, 47/50 successful calculations to capture the cup give 94 % success in simulation of this subsystem, regardless of the size of the cup. That is, the accuracy of capturing and moving an object was increased by 8 %, while for the operation of the proposed subsystem RM it is not necessary to know the object initially, and manipulator does not need to be trained in any way, as it is done in MIT development.

Potential problems. With the real implementation of this subsystem, the following problems may arise:

1. Incorrect contour definition. Since the depth map may turn out to be blurry on its own, or the boundaries of the object may be blurred, the distance to the object and the angle of its capture may not be calculated correctly and then there is a risk for the object of not being captured at all.

It is proposed to solve this problem by performing a search for closed contours on a real stereo image or a normal image of an object, and not on a depth map.

2. Incorrect distance calculation. The item may be incomprehensible (as a result, there might be found several contours on one object). The object can also have recesses or cuts, in that case it will be difficult for the RM to find the central capture point and correctly calculate the radius for capture. Then there is a chance that the robot, when going down, will simply crush the object or will be too far away.

In this case, it is proposed to put a feedback sensor on the RM, this will allow the subsystem to obtain data about the captured object – whether the capture was made or there is nothing in the claw. If the capture was unsuccessful, it is proposed to select the next contour and try to capture the object by the capture point in it and check again if the capture is successful, do so until the object is captured or until the amount of contours end.

4. The StereoPi microprocessor takes time to calibrate the cameras. As soon as the cameras are connected to the board, it takes time to calibrate them, which significantly increases the development time. However, this needs to be done only once during the initial connection, so this is not a significant problem.

Conclusions. Thus, the paper proposes the development of an intelligent software and hardware subsystem for capturing an object with a robotic manipulator with increased accuracy. This subsystem offers a solution for all sub-tasks of the robot manipulator when capturing an item.

Subsystem consists of a block for obtaining a stereo image and building an in-depth map, for determination of the distance from the RM to all the points of the object, for determination of the contour of the object, for determination of the capture point of the object and clarification of the distance to the RM, for determination of the degree of capturing the object and for determination of the movement of the RM to capture an object at the desired point (Fig. 3).

To detect the distance from the RM to the object, a methodology is proposed that is based on the building an in-depth map. The methodology consists of the following steps: creating a stereo image of an object, building an in-depth map, calculating the matrix of distances of each image point.

To determine the distance to the object, the calculation of the matrix of distances based on the depth map is proposed.

To find the capture point of the object, a preliminary search for closed contours in the image of the depth map is proposed. Then it is proposed to find the thinnest part of the contour of the object, cut it to a segment and find the center of the segment according to the proposed formulas.

To determine the exact distance to the object, the degree of its capture and the movement of the RM to the desired point, formulas are proposed based on the characteristics of the servomotors, previous calculations and the image of the depth map.

The proposed subsystem was simulated using the example of the correct detection of the capture point, the distance to it, the degree of capturing the cup, and the calculation of the exact angles of the servomotors for the movement of the RM. The success was the correct calculation of all parameters. Out of 50, only 47 times all parameters were correctly calculated, which gave the methodology 94% success in capturing an item. This allowed to increase the capture accuracy by 8 % in comparison to other technologies.

It is shown that this methodology and algorithms do not depend on the type of an object and its characteristics, as well as viewing angle.

To physically implement this robot manipulator, the use of the StereoPi microprocessor is proposed, with the help of which stereo images are easily created and an in-depth map is built.

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РОЗРОБКА ІНТЕЛЕКТУАЛЬНОЇ ПРОГРАМНО-АПАРАТНОЇ ПІДСИСТЕМИ ЗАХВАТУ ПРЕДМЕТА РОБОТОМ-МАНІПУЛЯТОРОМ

Анотація. *У роботі на основі аналізу реалізованих функцій існуючих роботів-маніпуляторів показано, що задача автоматизації безпечного захвату предметів роботом в процесі збірки є недостатньо пробленою. У процесі аналізу встановлено, що для побудови підсистеми захвату предметів роботом-маніпулятором існують технологічні рішення трьох основних завдань: визначення габаритів та форми предмета захвату; визначення відстані від робота-маніпулятора до всіх точок предмета захвату, визначення точки захвату предмета і уточнення відстані до робота-маніпулятора. Показано, що всі перераховані завдання є недостатньо пробленими. Тому запропоновано розробити методику створення інтелектуальної програмно-апаратної підсистеми захвату предмета роботом-маніпулятором. Розроблена методика складається з шести кроків: отримання стереозображення і побудова глибинної карти; визначення відстані від робота-маніпулятора до всіх точок предмета; визначення контуру предмета; визначення точки захвату предмета і уточнення відстані до робота-маніпулятора; визначення ступеня захвату роботом-маніпулятором предмета; визначення руху робота-маніпулятора по захопленню предмета в потрібній точці. Для знаходження точки захвату запропоновано використовувати метод контурного пошуку на глибинній карті предмета, а на знайденому контурі шукати найбільш тонку частину, обмежувати її відрізком і знаходити його середину. Для реалізації алгоритму визначення відстані до предмета, ступеня його захвату і руху до потрібної точки формалізовані залежності обчислень на глибинній карті і фізичних характеристик маніпулятора. Проаналізовані можливості мікропроцесора StereoPi і запропоновано його використання для апаратного рішення функції захвату роботом-маніпулятором. Проведено моделювання інтелектуальної програмно-апаратної підсистеми на захвату предмета складної форми. Зроблено висновки про незалежність розробленої підсистеми від типу предмета і кута перегляду роботом-маніпулятором. Крім того, показано підвищення точності захвату предмета роботом-маніпулятором, оснащеним інтелектуальної підсистемою в порівнянні з існуючим його аналогом. Виділено потенційні проблеми при реалізації запропонованої методики.*

Ключові слова: *робот-маніпулятор; визначення відстані; глибинна карта; захват предмета; StereoPi*

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РАЗРАБОТКА ИНТЕЛЛЕКТУАЛЬНОЙ ПРОГРАММНО-АППАРАТНОЙ ПОДСИСТЕМЫ ЗАХВАТА ПРЕДМЕТА РОБОТОМ-МАНИПУЛЯТОРОМ

Аннотация. *В работе на основе анализа реализованных функций, существующих роботов-манипуляторов показано, что задача автоматизации безопасного захвата предметов роботом в процессе сборки является недостаточно проработанной. В процессе анализа установлено, что для построения подсистемы захвата предметов роботом манипулятором существуют технологические решения трех основных задач: определение габаритов и формы предмета захвата; определение расстояния от робота манипулятора до всех точек предмета захвата, определение точки захвата предмета и уточнение расстояния до робота манипулятора. Показано, что все перечисленные задачи являются недостаточно проработанными. Поэтому предложено разработать методику создания интеллектуальной программно-аппаратной подсистемы захвата предмета роботом манипулятором. Разработанная методика состоит из шести шагов: получение стереоизображения и построение глубинной карты; определение расстояния от робота манипулятора до всех точек предмета; определение контура предмета; определение точки захвата предмета и уточнение расстояния до робота манипулятора; определение степени захвата роботом манипулятором предмета; определение движения робота манипулятора по захвату предмета в нужной точке. Для нахождения точки захвата предложено использовать метод контурного поиска на глубинной карте предмета, а на найденном контуре искать наиболее тонкую часть, ограничивать её отрезком и находить его середину. Для реализации алгоритма определения расстояния до предмета, степени его захвата и движения к нужной точке формализованы зависимости вычислений на глубинной карте и физических характеристик манипулятора. Проанализированы возможности микропроцессора StereoPi и предложено его использование для аппаратного решения функции захвата роботом-манипулятором. Проведено моделирование интеллектуальной программно-аппаратной подсистемы на захвате предмета сложной формы. Сделаны выводы о независимости разработанной подсистемы от типа предмета и угла его просмотра роботом манипулятором. Кроме того, показано повышение точности захвата предмета роботом манипулятором, оснащенным интеллектуальной подсистемой по сравнению с существующим его аналогом. Выделены потенциальные проблемы при реализации предложенной методики.*

Ключевые слова: *робот-манипулятор; определение расстояния; глубинная карта; захват предмета; StereoPi*

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