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CONTROL AUTOMATION OF ASSEMBLY OPERATIONS USING A COMPUTER VISION SYSTEM IN INTELLIGENT PRODUCTION

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ABSTRACT

The using principles of control means of assembly operations in production are described. A methods analysis for assessing the accuracy of component installation during assembly work was carried out. The scheme of the automated system operation for controlling the execution of assembly operations has been developed. The mathematical model synthesis of the proposed automated system was performed. The experimental research result is described.
Keywords: Computer vision, assembly operations, Industry 4.0, Emgu CV.

1. INTRODUCTION

Computer vision systems are now considered an integral part of many industrial processes because they can offer fast, precisely reproduced control capabilities. The introduction of automated quality control systems for products produced by a manufacturing enterprise is a very urgent task, especially in the case of the implementation of the Industry 4.0 concept [1, 2]. Various additional software and hardware tools are used for this. For example, the use of a computer vision system to perform the tasks of monitoring assembly operations is currently very popular.

The quality of production means the degree of compliance of the manufactured product with the specified dimensions, shape, mechanical, physical and other characteristics, which are the purpose of this product. The accuracy of the operation differs from the accuracy of the entire process. The application of control operations at each stage of production increases the quality of production and reduces the consumption of materials, thereby reducing the cost of final products.

Thus, the purpose of this work is to choose a method of automated determination of the components location error assembly base after the assembly operation.

2. THE MATHEMATICAL MODEL SYNTHESIS OF THE TECHNOLOGICAL EQUIPMENT CONTROL SYSTEM FOR CONTROLLING THE ASSEMBLY OPERATIONS PERFORMANCE

The proposed scheme basis is a technical vision system for detecting defects after assembly operations. The technical vision system is integrated into the technological sequence of operations on the conveyor of the assembly department (Figure 1).

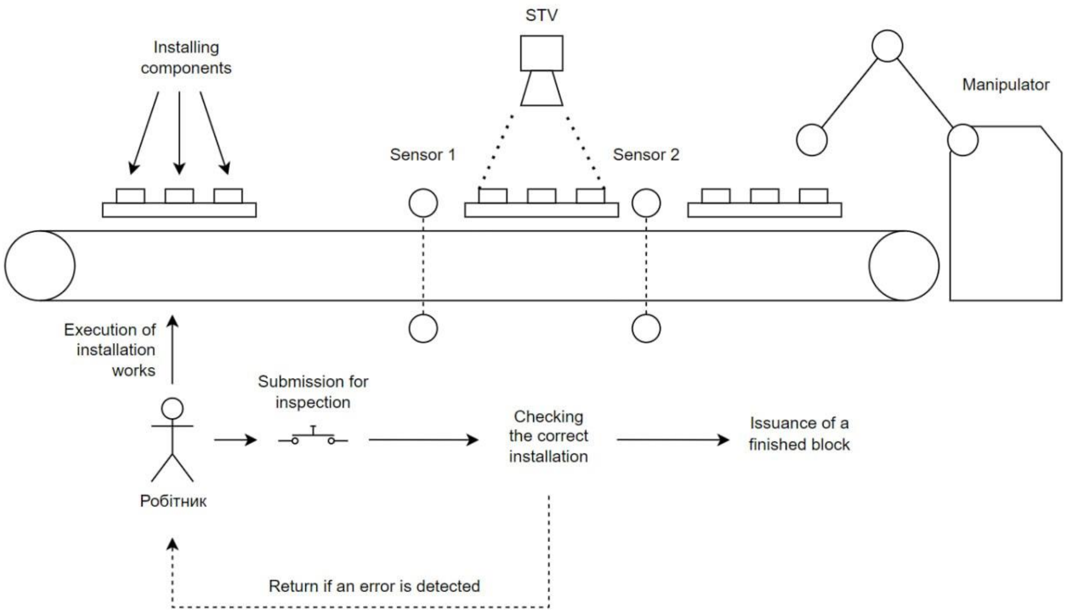

Figure 1. Scheme of automated system operation for monitoring the assembly operations execution

In this scheme, the automated system monitors the worker activity who performs manual assembly operations for installing components on the device chassis.
The worker performs the necessary operations and after their completion starts the conveyor with a special tray to move the chassis to the control areas. To do this, he places the chassis in the guides and can click on the "Complete operation" button.
When the chassis reaches the control zones, the technical vision system is activated to check the correct location of the elements. If the defect is not detected, then after a certain time the chassis is moved to the delivery area. In the dispensing area, the robot manipulator [3] picks up the chassis from the tray. After that, the empty tray is returned to the worker again.
In the event that the technical vision system detects a defect in the assembly operation, the tray from the chassis is returned to the worker to correct the error. Found errors are indicated on the work monitor in the worker's assembly area.
The proposed scheme of the automated system for monitoring the assembly operations execution allows you to perform current control at the stage of the operation to quickly eliminate defects. Thus, the time for correcting errors decreases, and the number of defective products in production decreases [4].
Consider our system as a finite state machine with several stable states, which can be imagined as triggers. When synthesizing systems using triggers, the operating conditions of circuits with several states are presented in the form of transition graphs. The graph vertices number during the synthesis of asynchronous schemes on RS triggers is determined from the condition

$$2^n \geq S \tag{1}$$

where S is the number of circuit states; 2^n is the number of graph vertices; n is the number of triggers.
It is recommended to place the vertices of the graph so that when $n = 2$ they create a 2×2 configuration, when $n = 3$ they create a 4×2 configuration, and when $n = 4$ they create a 4×4 configuration.
The output signals of the triggers act as intermediate variables, therefore the triggers and their output signals are denoted by the letters P_1, P_2, ... These designations are written on the top left of the graph.
Each vertex of the graph is encoded by a set of values of the output signals of the triggers. The codes are chosen so that for neighboring vertices they differ in the value of only one variable. In the initial state of the circuit (waiting state), it is usually assumed that all intermediate variables are equal to zero. The values of the intermediate variables for each vertex are written above the circles in the order in which the trigger designations are written.
Vertices between which transitions should occur are connected by edges with arrows. Above the arrows or to the right of them, if the edges are directed vertically, write the designations of the input signals that cause these transitions.
When building circuits on asynchronous RS triggers, transitions can be made only between adjacent vertices. If this condition is not fulfilled, then it is necessary to provide for the so-called natural transitions (due to the supply of the input signal unit) through intermediate unstable states.
Let's consider the proposed scheme of the automated system for monitoring the execution of assembly operations, shown in Figure 2, and create a graph of transitions for it. The transition graph being developed describes the operation of the control scheme of the conveyor mechanism, which operates in the mode of repeating cycles.
In the initial position of the mechanism, the end sensor SQ1 is in the on state. This is the case when the tray from the device chassis is in the area of installation operations (green area in Figure 2).
The work cycle begins when the "Start" command is received from the worker after the installation operation is completed. The mechanism is moved to the position fixed by the limit switch SQ2, this is the control execution zone. The system is in this state during the time Δt_1 (yellow zone in Figure 2).
If no installation errors are found, the tray moves to the position fixed by the limit switch SQ3. In this position, the landing gear stands for time Δt_2 (red zone in Figure 2).
After removing the chassis from the tray using the manipulator, the mechanism returns to its initial position. To repeat the cycle, it is necessary to submit the "Start" command again.
If the technical vision system finds an error in the assembly, the chassis moves to the priority position. If the command from the worker will be received continuously, then after one cycle is completed, the next one will automatically start.
We will accept the following designations of input and output signals, as well as timer signals, which must be considered as input signals for the transition graph.
Input signals:

- a is the "Start" command;
- b, c, d are the signals of limit switches SQ1, SQ2, SQ3 respectively;
- t_1, t_2 are the timer signals giving the delays Δt_1 and Δt_2.

Output signals:

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- f_1 is a command to move the mechanism from its initial position;
- f_2 is a command to return the mechanism to its initial position.

We begin the construction of the transition graph by determining the number of states in which the automatic control scheme can be. There are six such states:

- 1 is initial position;
- 2 is moving from the starting position;
- 3 is stopping during the time Δt_1;
- 4 is further movement;
- 5 is stopping during the time Δt_2;
- 6 is return to the initial position.

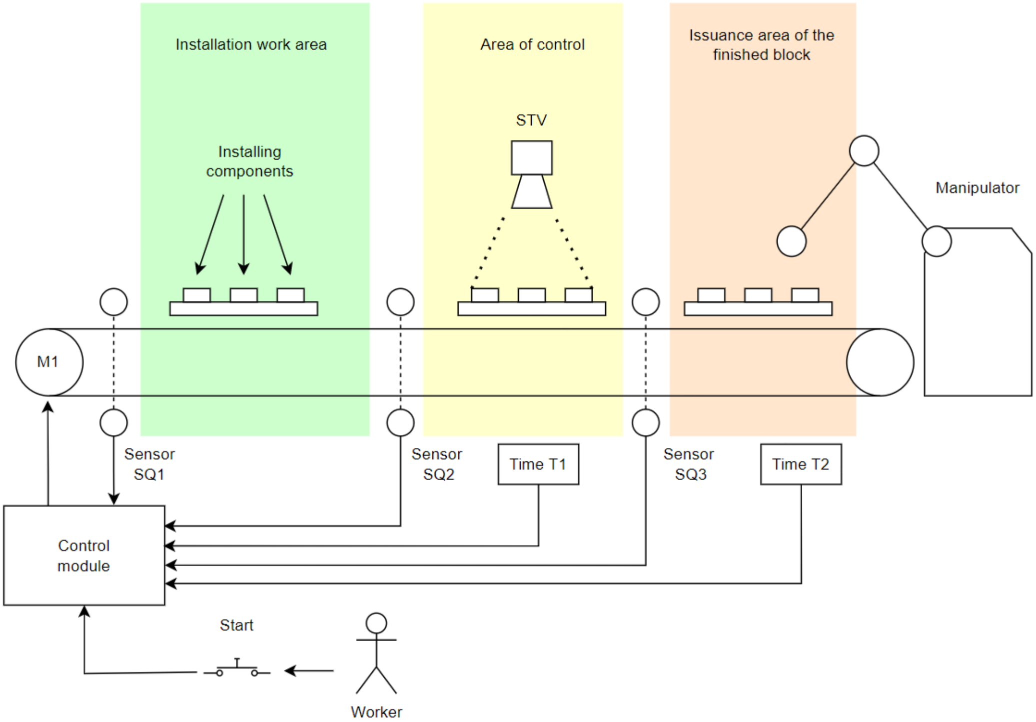

Figure 2. Scheme of industrial equipment operation for the synthesizing task the transition graph

Based on the number of circuit states $6 < 2^3$, we determine the number of triggers n = 3 and the number of vertices of the transition graph $2^3 = 8$. We denote the intermediate variables P_1, P_2, P_3, construct 8 vertices of the graph and code them with combinations of the values of the intermediate variables.

Each state of the circuit is matched with one of the vertices of the graph, and the states between which the transition must occur according to the operating conditions of the circuit are placed in neighboring vertices. Free vertices are used to transition from state 6 to state 2 during operation of the scheme in the mode of repeating cycles, or to state 1 when working out single cycles.

The notation of the output signals f_1 and f_2 is written under the notation of intermediate variables. The values of f_1 and f_2 for each state of the scheme are recorded under the corresponding vertices of the graph.

The scheme synthesis consists in recording the conditions of turning on and resetting each trigger [5, 6]. To do this, a closed line covers all states on the transition graph in which the value of the output signal of this trigger is equal to one. The input signals of the scheme, the designations of which are on the edges entering the resulting closed region, set the trigger to state 1, and the input signals on the edges leaving this region reset the trigger to state 0.

Trigger activation conditions are recorded as the product of the signal on the edge entering the region and the signals of the remaining triggers, the state of which does not change during the transition marked by the edge. For example, if the signal on the edge entering the region with a unit value of the output signal of the trigger P_1 is equal to a, and the triggers P_2 and P_3 do not switch, but keep the state $P_2 = 1$, $P_3 = 0$, then the condition for turning on the trigger P_1 is written as

$$S_{P_1} = ap_2\overline{p_3}. \tag{2}$$

If several edges are included in the closed area, then the trigger activation condition is written as the sum of the products of the corresponding signals added for each edge.
The trigger reset condition is written similarly for each edge coming out of the given region and is given in the form of the RPi formula. The described procedure is performed for each trigger and on and reset conditions are determined for them.
Figure 3 shows the view of the obtained transition graph for the automated control system of assembly operations.

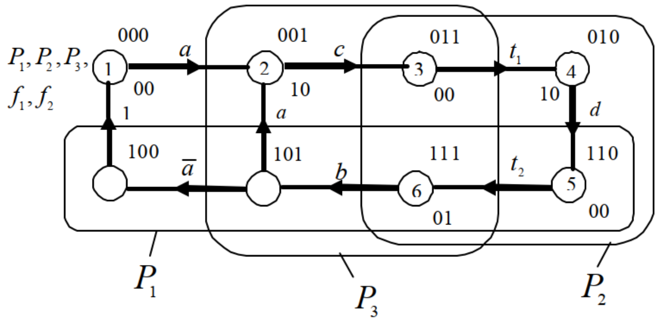

Figure 3. View of the generated graph of transitions for the automated control system of assembly operations

Applying the procedure described in [7], determining the conditions for turning on and resetting the triggers for the graph of transitions in Figure 3, we obtain:

$$S_{P_1} = ap_2\overline{p_3}; \quad (3)$$
$$R_{P_1} = a\overline{p_2}p_3 + \overline{p_2}\,\overline{p_3}; \quad (4)$$
$$S_{P_2} = c\overline{p_1}p_3; \quad (5)$$
$$R_{P_2} = bp_1p_3; \quad (6)$$
$$S_{P_3} = a\overline{p_1}\,\overline{p_2} + t_2p_1p_3; \quad (7)$$
$$R_{P_3} = t_1\overline{p}_1p_3 + \overline{a}p_1\overline{p}_2. \quad (8)$$

Formulas for output signals f_1 and f_2 are written as combination functions of output signals of triggers P_1, P_2, P_3. Indeed, the function f_1 =1 in states 2 and 4, that is, in the states corresponding to the following combinations of the values of the output signals of the triggers: $p_1 = 0$, $p_2 = 0$, $p_3 = 1$ and $p_1 = 0$, $p_2 = 1$, $p_3 = 0$. Therefore

$$f_1 = \overline{p}_1\overline{p}_2p_3 + \overline{p}_1p_2\overline{p}_3. \quad (9)$$

Similarly, the function $f_2 = 1$ is in state 6 ($p_1\, p_2\, p_3 = 111$), that is

$$f_2 = p_1p_2p_3. \quad (10)$$

Timer T1 turns on in state 3 ($p_1\, p_2\, p_3 =011$), and timer T_2 turns on in state 5 ($p_1\, p_2\, p_3 =110$), so

$$T_1 = \overline{p}_1p_2p_3, \quad (11)$$
$$T_2 = p_1p_2\overline{p}_3. \quad (12)$$

3. THE ALGORITHM DESCRIPTION FOR DETERMINING THE CORRECTNESS OF ASSEMBLY OPERATIONS

The mounting base can be a printed circuit board, a layout board for quick assembly, or the chassis of the device. The proposed method can be used for any type of assembly when it is necessary to control the correct location of components based on.
The main stages of automated control of installation correctness are:

- obtaining an image of the object of control;
- pre-processing of the image;
- search for components in the image by their color feature;
- applying a mask by color to cut off unnecessary color;
- conversion to gray;
- binarization;
- search for contours of components;

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- filtering results and removing unnecessary areas with a small perimeter;
- selection of significant areas;
- determining the coordinates of their location;
- search for reference points;
- binding to real coordinates;
- determining the correct location of components on the mounting base.

Figure 4 shows the algorithm of the automated determination of the correct location of components on the mounting base.

Different light sources can be used when obtaining an image of an object. Depending on the level of illumination, the correction factor is selected for the pre-processing of the image. After processing the image, the achieved brightness is checked based on data from certain areas of it. If necessary, the correction factor is changed to the appropriate value and this operation is repeated [8, 9].

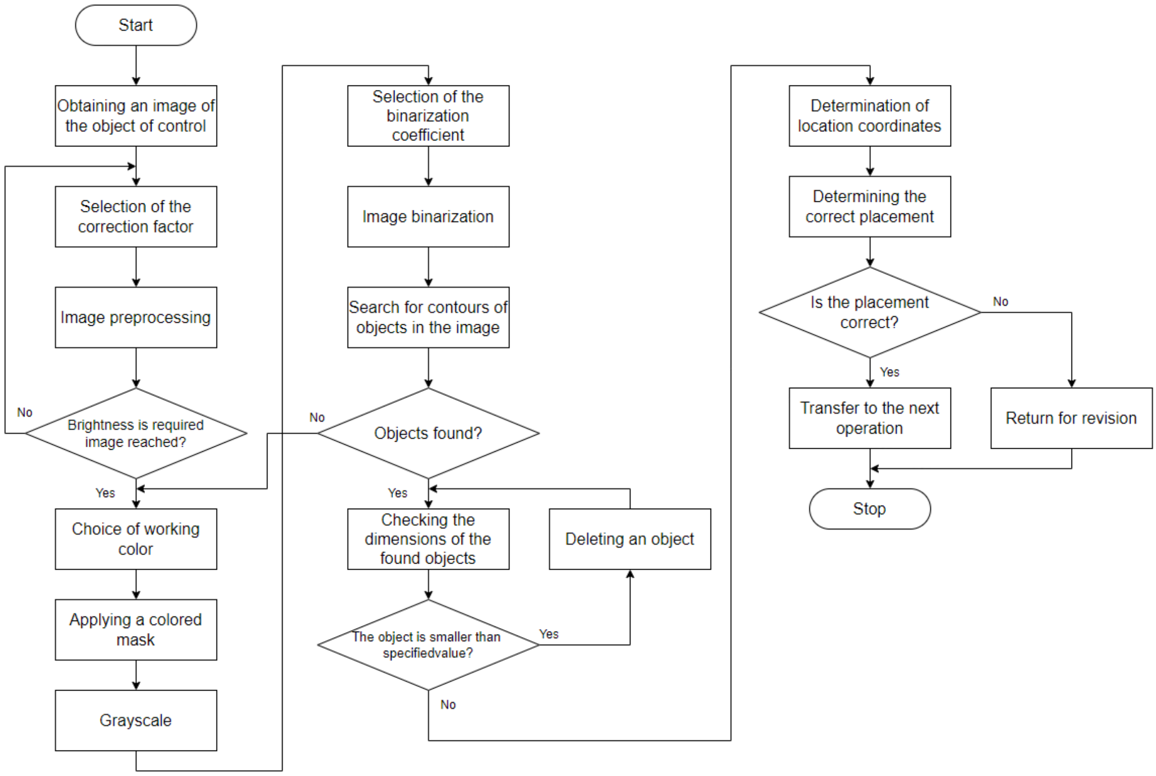

Figure 4. The algorithm of the automated determination system of the correct location of components on the mounting base

Different color masks are used to identify different components [10-12]. For example, to identify microcircuits, a mask with dark colors approaching blue is used. To check the correct installation of yellow jumpers, select the corresponding (yellow) mask. The correctness of the insertion of the terminals is controlled by green or blue color.

After pre-processing the image, binarization is performed – increasing the contrast of areas of the image, the level of illumination of which is greater than a given level. This level is chosen experimentally, or it can be adaptive.

If setting the color mask does not produce search results, the mask type is adjusted and the search procedure is repeated.

Next, the found results are filtered. According to the numerical data of the contour of the objects, too small objects that should not participate in the procedure for determining the correctness of the assembly are removed.

For the remaining image objects, the procedure for determining the coordinates of their placement is performed. For this, the scaling factor is pre-calculated. The calculation of the coefficient is performed on the basis of known information about the location of reference areas in the image. If the dimensions between them are known in advance, then you can automatically obtain the coefficient of conversion of the coordinates of the areas on the image into real coordinates.

After obtaining the real coordinates of the location of the found components, their values are compared with those stored in the database table and considered as standards values. If the coordinates of the placement of the components coincide with their standards, a message is issued to transfer the object of control to the next work operation. If an error is detected in the assembly operation, the control object is returned for revision.

Figure 5 shows the general algorithm of the program.

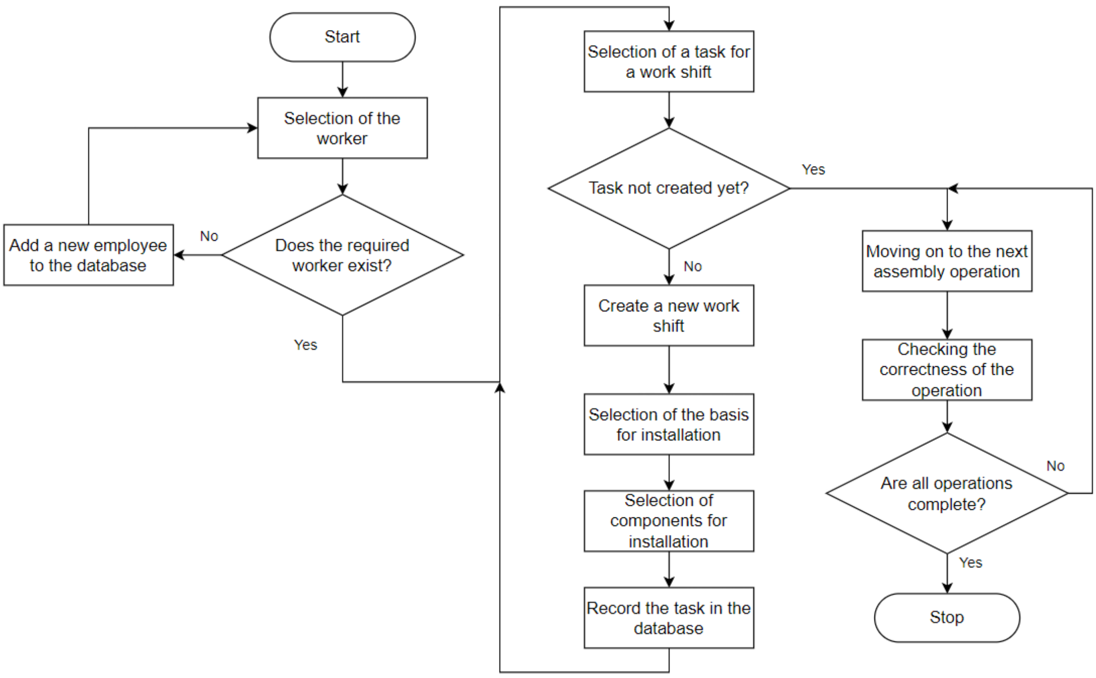

Figure 5. The general algorithm of the program

Work begins with the selection of a worker. If the required worker does not yet exist, basic information about him is added to the database. Figure 6 shows the dialog box for adding a new worker [4, 11, 12].

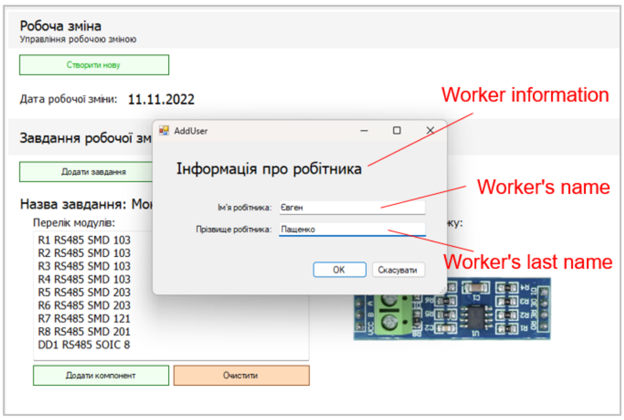

Figure 6. Dialog box for adding a new worker

If the worker already exists, his last name is chosen. The current task for this worker is automatically checked. In this case, the date of the current shift will be highlighted on the screen (Figure 7).

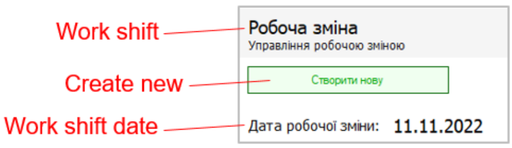

Figure 7. Current shift date

If a working shift has not yet been created, then you need to click on the "Create new" button. In this case, a new work shift record will be automatically created in the database.
Depending on the selected worker, the information about assembly operations that must be performed during the shift also changes. Figure 8 shows an example of task content for two different workers.

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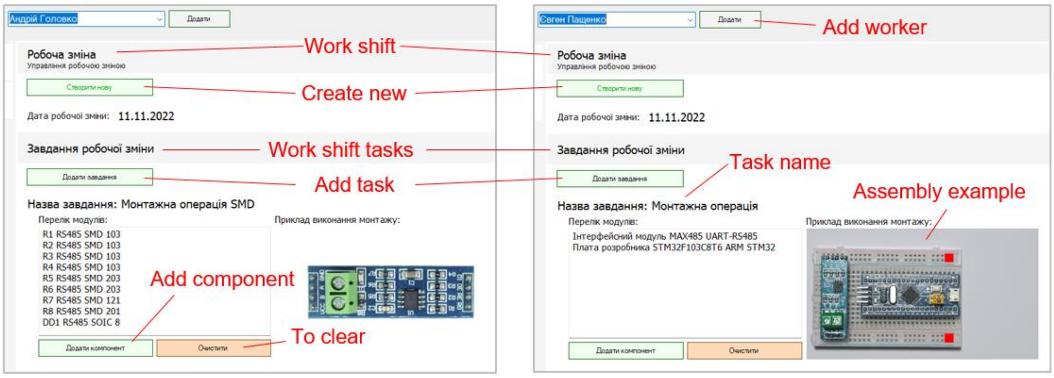


Figure 8. An example of task content for two different workers

In case it is necessary to create a new task, a special form has been developed for filling out (Figure 9).

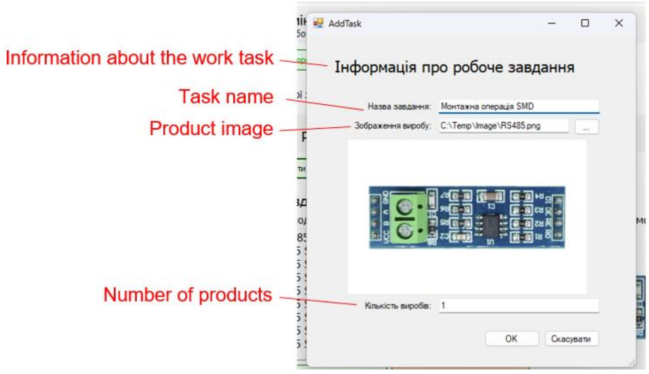
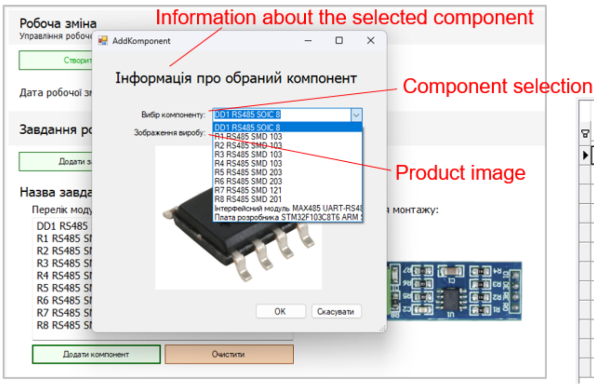


Figure 9. Form for creating a task

To fill out the form, you need to enter the name of the task and select an image of the finished product. Based on this image, the installer will visually control the correctness of the operation before transferring it to the automated control area.
Figure 10 shows the screen form of adding a new component to the mounting base and an example of filling in the table with the characteristics of components.
In this mode, it is necessary to select from the drop-down list the required elements by name and marking. For example, "DD1 RS485 SOIC 8". In advance, a list of all possible components used for installation is created in the database and their characteristics are described.



rowid	ID_Oznaka	ID_Board	XO	YO	ZO	Perimetr	Angle
1	1	1	21	21	0	1116	0.5
2	2	1	36	20	0	1065	1.5
3	3	2	61	16	0	1357	1.5
4	4	3	702	392	0	89	1
5	5	4	701	336	0	86	1
6	6	5	699	284	0	87	1
7	7	6	701	229	0	85	1
8	8	7	456	336	0	88	0
9	9	8	454	280	0	85	0
10	10	9	454	225	0	88	1
11	11	10	339	357	0	74	0
12	12	11	576	344	0	384	0.5

Figure 10. The screen form for adding a new component to the mounting base (left) and an example of filling in the table with the characteristics of the components (right)

In this table, along with the coordinates of the correct location, such features as the perimeter of the image border surrounding the component and the angle of its correct orientation on the mounting base are also indicated.
After creating a task for a work shift, you can proceed to the execution of these tasks. Figure 11 shows a fragment of the program interface, which shows the working window of the installer.

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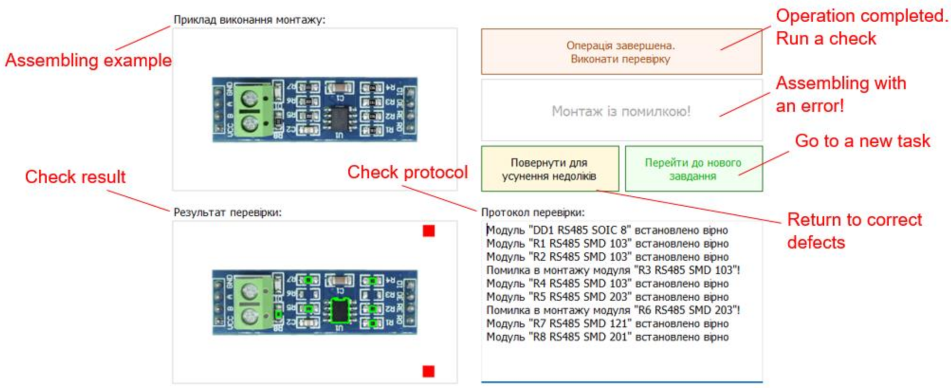

Figure 11. Installer working window

In accordance with the algorithm (Figure 5), the worker, looking at the example of the assembly operation, installs the components on the assembly base. After a visual inspection, he transfers the assembled product to the automated control area. To do this, he clicks on the button "Operation completed. Run a check". The product is automatically moved to the control area, where the correctness of the operation is checked with the help of a computer vision system.

The result of the test is displayed on the screen, which also shows the research report indicating whether or not the components are correctly positioned on the mounting base. If all components are located correctly, then you can proceed to the next operation. If not, the product is sent back for revision and the procedure is repeated.

3. EXPERIMENTAL RESEARCH RESULTS

As a result of the experiment, real data on the operation of the proposed method were obtained. Figure 12 shows the location coordinates of the main components on the boards installed on the mounting base.

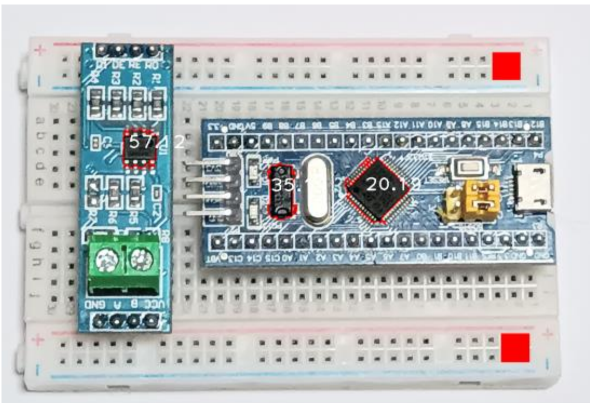

Figure 12. Coordinates of the main components placement on the boards

Based on the results of the experiment, it can be concluded that the "MAX485 UART-RS485 Interface Module" board is installed incorrectly. Compared to the reference, the coordinates of the characteristic feature (DD1 microcircuits) differ along the X-axis and Y-axis by 4 mm, which means the displacement of the board relative to its specified installation location.

The following experiment was conducted to check the correct installation of SMD components. Table 1 shows examples of correct and incorrect results.

As a result of the analysis of the obtained data, it can be seen that in the first experiment the installer did not install two SMD components - R3 and R6. The proposed method detected this error and showed it in the verification report. As a result of the second experiment, you can see the absence of SMD component R6. The recognizer detected this error (Table 1).

In the third experiment, all SMD components are installed correctly. Deviations from the sample are minimal. In the fourth experiment, the SMD resistor R4 is set with an offset of 1 mm in the vertical Y axis. The program detected this error.

In the fifth experiment, all components are installed correctly. In the sixth experiment, the resistor R3 is set incorrectly. The component is rotated by an angle of more than 3 degrees relative to the specified position. It is also shifted up by 0.5 mm. The proposed method detected this error.

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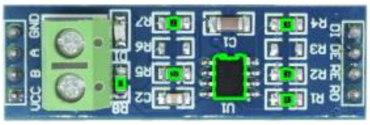
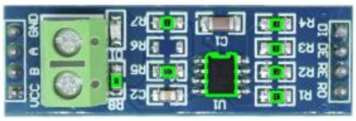
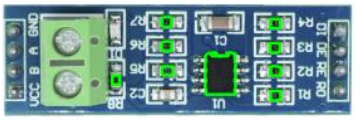
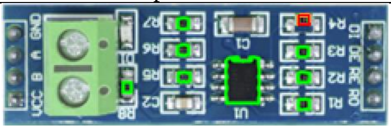
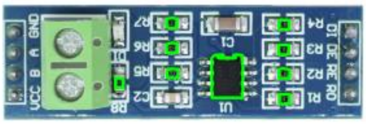
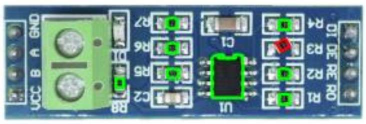
Table 1. The results of checking the correct installation of SMD components

Experiment 1	Experiment 2	Experiment 3
 Module "DD1" is installed correctly Module "R1" is installed correctly Module "R2" is installed correctly Module installation error "R3"! Module "R4" is installed correctly Module "R5" is installed correctly Module installation error "R6"! Module "R7" is installed correctly Module "R8" is installed correctly	 Module "DD1" is installed correctly Module "R1" is installed correctly Module "R2" is installed correctly Module "R3" is installed correctly Module "R4" is installed correctly Module "R5" is installed correctly Module installation error "R6"! Module "R7" is installed correctly Module "R8" is installed correctly	 Module "DD1" is installed correctly Module "R1" is installed correctly Module "R2" is installed correctly Module "R3" is installed correctly Module "R4" is installed correctly Module "R5" is installed correctly Module "R6" is installed correctly Module "R7" is installed correctly Module "R8" is installed correctly
Experiment 4	Experiment 5	Experiment 6
 Module "DD1" is installed correctly Module "R1" is installed correctly Module "R2" is installed correctly Module "R4" is installed correctly Module installation error "R4"! Module "R5" is installed correctly Module "R6" is installed correctly Module "R7" is installed correctly Module "R8" is installed correctly	 Module "DD1" is installed correctly Module "R1" is installed correctly Module "R2" is installed correctly Module "R3" is installed correctly Module "R4" is installed correctly Module "R5" is installed correctly Module "R6" is installed correctly Module "R7" is installed correctly Module "R8" is installed correctly	 Module "DD1" is installed correctly Module "R1" is installed correctly Module "R2" is installed correctly Module installation error "R3"! Module "R4" is installed correctly Module "R5" is installed correctly Module "R6" is installed correctly Module "R7" is installed correctly Module "R8" is installed correctly

4. CONCLUSION

Thus, this work presents the developed scheme of the automated system for monitoring the execution of assembly operations. The basis of the proposed scheme is a technical vision system for detecting defects after assembly operations. The technical vision system is integrated into the technological sequence of operations on the conveyor of the assembly department. The synthesis of the mathematical model of the proposed automated system was performed and the transition graph for the control automated system of assembly operations was generated. The proposed scheme of the automated system for monitoring the execution of assembly operations allows you to perform current control at the stage of the operation to quickly eliminate defects. The work algorithm and program interface for performing experimental studies are described. The control developed method implementation the correctness of assembly operations in the form of a test program is described. The proposed method is based on the Emgu CV library.

As a result of the experimental studies, an analysis of the obtained results was performed, reporting tables were given to describe the obtained results of checking the correctness of assembly operations. The results of mounting both overall components and SMD components on the mounting base are analyzed.

Thus, the proposed method showed its efficiency and the possibility of determining the minimum deviation in the location of components on the board ±1 mm. The maximum permissible error for the coordinates of the placement of components is ±2 mm, for the angle of rotation during installation ± 0.3 degrees.

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