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SOFTWARE COMPLEX FOR PARTS RECOGNITION AS THE BASIS OF EDUCATIONAL LABORATORY WORK

Elena Samarkina
Pskov State University, Russian Federation

Alexandr Samarkin
Pskov State University, Russian Federation

Vladimir Belov
Pskov State University, Russian Federation

Abstract. *The article discusses the scientific and methodological foundations of laboratory work in vision systems using the author's algorithms for pattern recognition. The results were used to prepare masters of technical specialties at the Pskov State University. Another approach to using digital technologies for processing images of the working area is proposed. Some aspects of solving problems of identification of parts, determination of their location, control in automated assembly is described. The hardware-software complex in the article performs data processing and measurements in parallel with the flow of the technological process. The hardware and software complex expands the capabilities of flexible assembly platforms when assembling parts with different mass-inertial characteristics due to the geometric shape and dissimilar materials.*
Keywords: *assembly platform, Bayesian criterion, digital image, digital image processing, machine learning, pattern recognition, technological area.*

Introduction

Modern education in higher education is largely based on a project-based approach, which implies the implementation of such solutions as term papers and theses that would demonstrate not only the level of education of the graduate, but also his ability to solve real production problems. This is especially important in the context of the "digital" economy and production, equipped with equipment with numerical control. Digitalization covers most stages of engineering production. It is of particular importance in the technological processes of assembly and machining. It uses both numerical control equipment and software that uses pattern recognition and machine learning technologies.

The aim of the research is to train students in modern computer vision technologies by solving the real production problem of automating the assembly

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processes and introducing the results into the learning process. This objective is achieved by applying by student's algorithms for processing and improving digital images, and the algorithms developed by the authors of the article for recognizing and positioning individual details on the assembly platform, as described below.

Control programs were formed based on information about the part reflected in flat drawings or volumetric models and were corrected at the place of processing under the real position of the workpiece, the position and geometry of the cutting tool, and so on. Such correction is a feedback that can be discrete or continuous and can be implemented in various ways. Feedback in CNC equipment involves the use of a variable or variables provided in the control program, the values of which are redefined during the processing of the control program (for example, by correcting the angle of rotation of the workpiece). The purpose of obtaining data and forming a digital image of a product is to change the technological process, due to the specifics of the changing technological environment. Thus, a machine with a contact sensor can determine the coordinates of a specific workpiece, and an operation controlled by a numerical control system can use the results of digital processing of the signal generated by the interaction of the stylus with the surface of the part to correct the zero point of the program, the location of the coordinate axes, etc.

Before each workpiece is machined, the contact sensor is called from the tool magazine by the command of the control program. The sensor automatically "bypasses" the workpiece, contacting the specified surfaces. Then the CNC system automatically enters the updated data, recalculates the NC program and gives the command to machine the part. The position of the zero point of the CNC of the workpiece coordinate system, corrected in this way, is called floating zero and is used in batch production to increase the processing accuracy and reduce the requirements for the accuracy of machine tools. Thus, a digital image of the product is formed on a CNC machine in a set of data available for analysis not only in the CNC system of the machine (its capabilities are inevitably limited to purely production tasks and the supplier's implementation), but also by external software, which allows using the digital image, formed during processing on a CNC machine, not only for discrete or dynamic correction of the NC, but also for solving other tasks related to preparing production.

Methods and Materials

The Tasks of Analysing Visual Information and the Possibility of Their Integration into the Technological Process

Of particular interest is the search for tasks that can be automatically solved using digital images of the working (technological) zone. A technological zone is understood as a limited space in which technological processes of production and movement of products are carried out. The digital image of the zone is obtained using a photo or video camera (discrete or dynamic image, respectively). The digital image captures the objects (parts) involved in the technological process (assemblies, measurements) and is used to obtain data that make up the digital image of the product. Photos (video frames) taken at certain time intervals give a dynamic digital image of the product (Fig. 1).

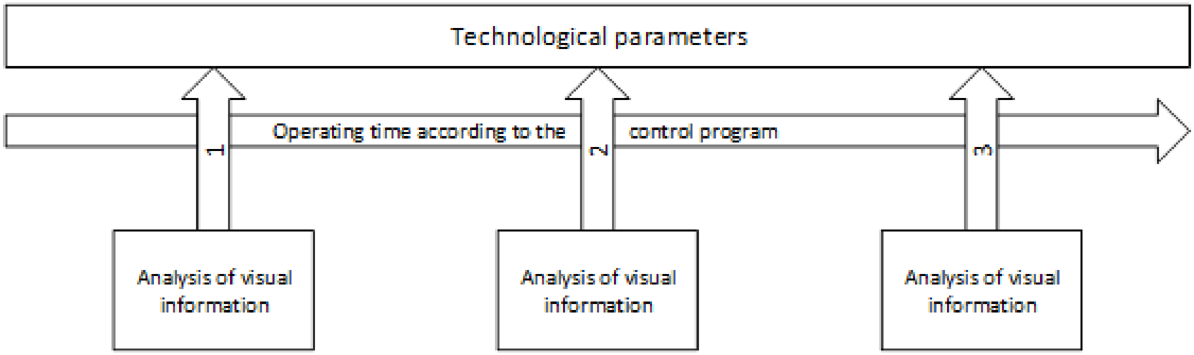


Figure 1 ***Formation of a Dynamic Digital Image of the Product. Here, 1, 2, 3, are data streams obtained because of digital image processing processes that record certain stages of product assembly***

The time intervals between the launches of these processes can be different, but must be synchronized with the technological process of the program. An example of equipment that uses a digital image of a product, formed not only by sensors, but also based on photo and video filming, are modern flexible assembly platforms Uflex (Direct Industry by VirtualExpo Group, 2021).

These flexible assembly platforms have video cameras for visual inspection (using a vision system) by an operator who monitors the assembly process or performs quality control. The location of the photo or video camera on the assembly platform ensures that the objects (parts) involved in the technological process (assembly, measurement) and on the flat surface of the pallet fall into the frame (Kayasa & Herrmann, 2012; Lanza, Haefner, & Kraemer, 2015). When using automatic equipment, a certain arrangement of all assembled elements in the space of the working (technological) zone must be maintained after each assembly transition (action). On the machine or on the assembly platform it is ensured, first, the correct orientation of the product, and, second, its fixation. With automatic assembly, there is a possibility that the assembled products will receive an arrangement not provided for by the technological process, which can lead to accidents and breakdowns of the product, tool, device. This limits the possibilities of automatic assembly of products, while the automatic orientation of several products is impossible, while others - it involves serious and, often, economically unprofitable changes in the design of products. Several tasks can be distinguished during automatic assembly, namely: identification – determination of the part from the set submitted for assembly; determination of the location of the identified part – finding its coordinates and position; checking the suitability of the part. The tasks of identifying, determining the location and control of the assembled parts must be solved jointly and comprehensively. From this viewpoint, a digital image of the working area can provide data for solving the problem of identification, locating control points. Here, the sensors of the control system provide data for solving the measurement problem by refined control points, see Fig. 2.

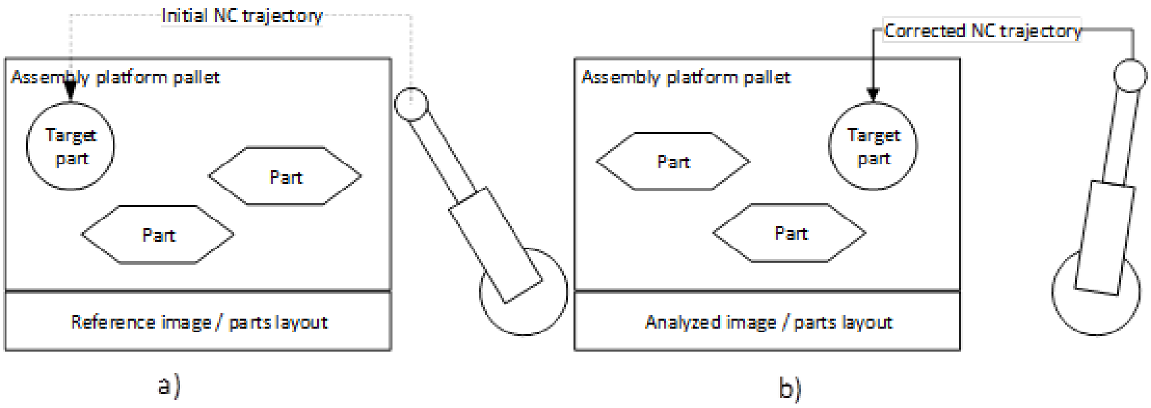


Figure 2 ***Changing the Trajectory of Approach of the Manipulator from the Programmed (a) to the Corrected, Considering the Actual Location of the Target Part (b).***

Part a) of the figure shows the reference image of the pallet of the assembly platform, which corresponds to the values of the parameters of the developed control program b) - the actual image of the location of the parts. The trajectory of movement of the manipulator is changed under the observed arrangement of parts. Thus, the location of the part in the working (technological) zone is specified, the correction of the approach path to the controlled point is carried out by providing feedback (Fig. 3). Refinement is made based on identification, determination of the position of parts in the working area and control.

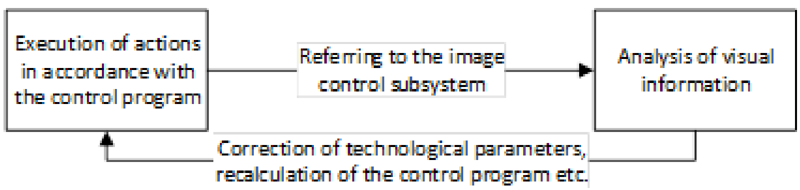


Figure 3 ***Scheme of Embedding the Analysis of Visual Information into the Technological Process***

For numerically controlled equipment and various kinds of machines, it is necessary to analyse visual information automatically. The authors were tasked with creating a tool for the automatic identification of parts, determining their location and monitoring their suitability for performing a technological operation, mainly in automatic assembly.

Hardware and Software Complex for Processing Digital Images of the Working Area

For automatic identification of parts and their location during assembly, the authors propose to use digital images of the technological area. The identification of parts and their location is carried out using a software and hardware complex for processing digital images of the working area, using algorithms for statistical image processing.

The hardware and software complex for processing digital images of the working area in several cases makes it possible to supplement, transform the data obtained using traditional sensors, and provides automatic feedback wherever the location of the collected objects within the working area is uncertain. This allows you to correct the instructions of the control program and automatically correct the coordinates of the motion paths calculated in the control program. Note that the acquisition and processing of images is deployed outside the working area, contactless.

Object of Analysis

The most common connection is the connection using fasteners, and these parts are distinguished by both high standardization and a significant variety of configurations and sizes. The software and hardware complex for processing digital images of the working area processes photo files similar to that shown in Fig. 4.

Figure 4 ***Test Image of the Working Area***

Description of the Hardware and Software Complex

The hardware and software complex were created using the programming language built into the Matlab software package. Here, the author's algorithms for processing digital images were used, using the Matlab library of functions.

Hardware and software complex are a software environment in which (Patrick & Fattu, op. 1986):

- preparation of digital data,
- training,
- identification.

Digital image processing includes:

- image visualization,
- converting the image to black and white for subsequent segmentation,
- automatic recognition of all its closed areas (segmentation),
- definition of sets of graphical characteristics (coordinates of the bounding rectangle, area of the object, coordinates of the centroid, etc., required for the calculation).

Converting a color image, carried out by standard Matlab functions, is sequential automatic:

- converting a color image into a gray-scaled by forming a weighted sum of the R, G, and B component,
- filling small areas inside the plate border - "voids",
- converting a "gray" image into an image containing only black and white color - binarization by thresholding (Fig. 5).

Figure 5 ***Result of Binarization***

Binarization replaces conventionally light gray pixels with white ones (code-1) (we mean the value of the code corresponding to the color shade in the image matrix), dark pixels into black ones (code-0). The standard Matlab function of automatic object recognition in a digital image allows you to distinguish two types of objects: the background is black and spots are white (or vice versa). An array of objects is formed. Each object is associated with its own binary matrix (Fig. 6).

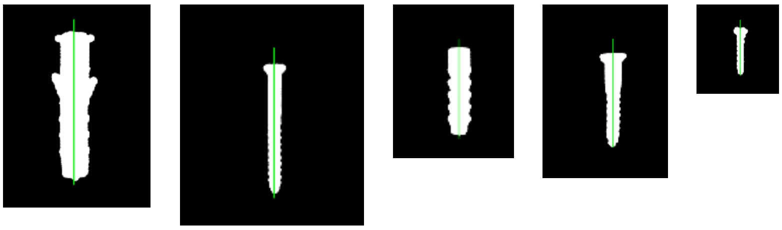


Figure 6 ***Recognized Objects***

Here, the vertical line is the main axis of the ellipse enclosing the recognized object. Objects are rotated so the main axis is vertical. The author's technique described in (Samarkina, Samarkin, Sokolova, & Zharov, 2019) allows to obtain the relative coordinates of the points of the outer contour of parts, the centroid coordinate acts as a base point.

The result of the stage "Determining the parameters of each object" is to obtain the relative coordinates of the outer contour of the parts. Figure 7 shows graphically the parameters of six parts of the same standard size as an example. This data in tabular form is used for object recognition.

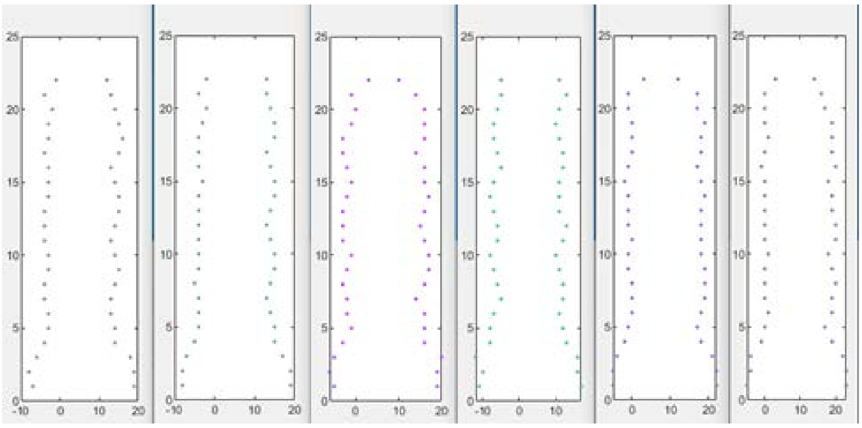


Figure 7 ***Coordinates of the Points of the Outer Contour of Parts of the Same Size***

Analysis of Digital Data of Recognized Objects

As in all tasks of pattern recognition, the stage of the workflow is training. The method under as in all tasks of pattern recognition, the stage of the workflow is training. The method under consideration uses a method of object recognition based on the Bayesian approach (Patrick, 1972; Shirman, 1998). For training, a few examples are required in comparison with other methods; high training efficiency is also mentioned (Shirman, 2000; Wang, Pau, & Chen, 1993).

Suppose that in observation a certain set of measured features of the object that make up the observation vector is obtained. Suppose that the observation vector is a random vector with a conditional probability density, depending on its belonging to a certain class. If the conditional probability density is known for each class of products, then the problem of recognizing product classes is reduced to statistical testing of hypotheses. Let's assume that the vector X is the vector of observations of the object. Then the classification rule for the vector X has the form (1) (Shirman, 2000; Wang, Pau, & Chen, 1993):

$$h(x) = -\ln p\left(\frac{X}{\omega_1}\right) + \ln p\left(\frac{X}{\omega_2}\right) \mathop{\gtrless}\limits^{<}_{>} \ln\left(\frac{P(\omega_1)}{P(\omega_2)}\right) \quad (1)$$

Here: ω is the class to which the analyzed part can be assigned (distinguished by indices), $p(\frac{X}{\omega})$ is the conditional probability density of the vector X when determining its belonging to the class ω. In turn, $p(\omega)$ is the prior probability of the corresponding class of products, $T = \ ln(\frac{p(\omega_1)}{p(\omega_2)})$ is the threshold value of the likelihood ratio.

The software package includes a toolkit that allows you to upload photos for training. During the training phase, digital photographs contain only objects of the same class. The enlarged stages of the training cycle are shown in Fig. 8.

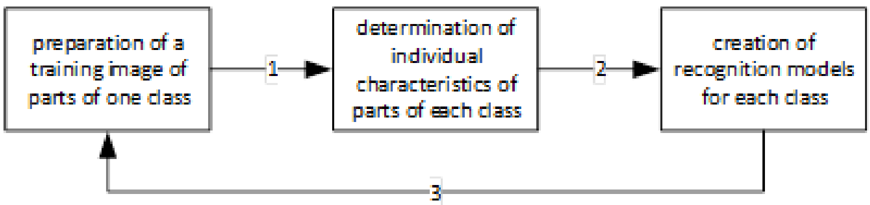


Figure 8 ***Learning Cycle***

The result of training is a data table. Each row of the table corresponds to one class of parts involved in the technological process. The class can correspond to both a new class of a product, and a separate standard size (execution, design option).

After training, the formation of a table, the complex allows you to perform the identification process, the enlarged stages of which are shown in Fig. 9.

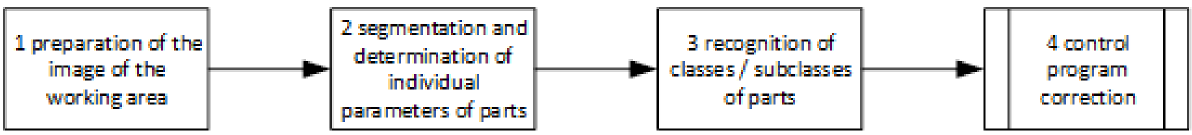


Figure 9 ***Identification Stage***

The automatic recognition of objects here means the correlation of the object image to the class name - identification. Individual parameters of parts of the n-th class or subclass, means the geometric shape (points of the outer contour, areas).

Recognizing standard sizes is reduced to statistical hypothesis testing. To decide on the classification of the target, the definition of a minimax criterion is used, which solves the worst case.

Bayesian criterion minimizes the error of assigning a particular part to a standard size. Regarding the technological process, at the identification stage during the assembly of the product, we automatically receive an answer to the question, what are the parts under the camera, how each is located.

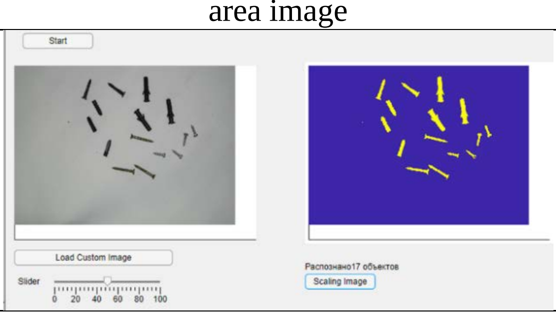
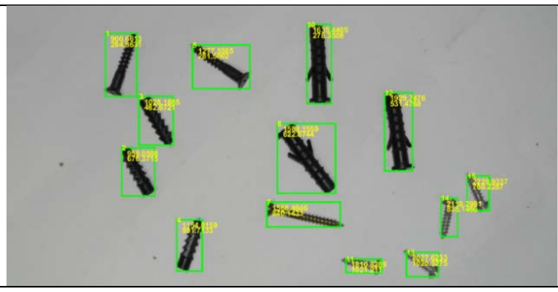
Implementation of the Complex and an Example of Its Work

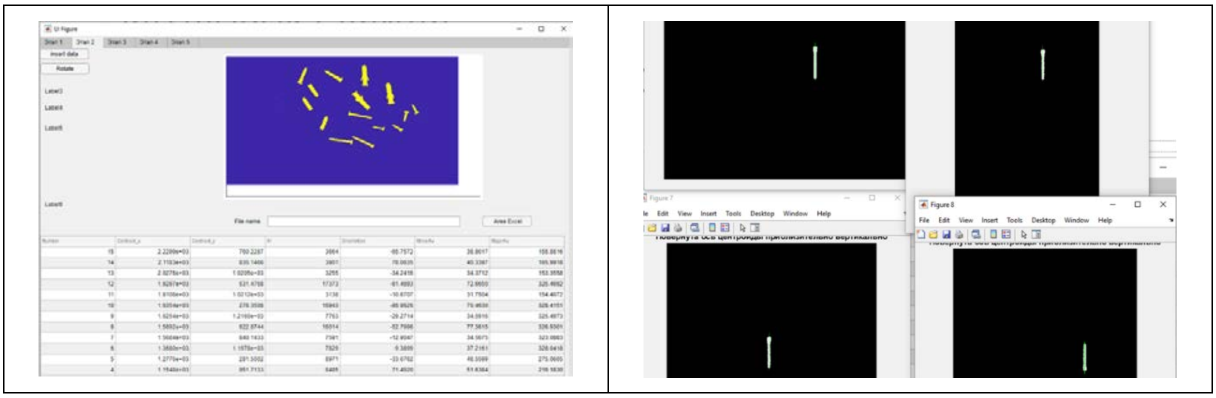
The next series of figures shows the interface of the complex and some stages of its operation, inevitably limited by the volume of the article.

Then the complex creates a table with real data on the classification of objects, the coordinates of their outer contour and location coordinates, including the angles of rotation.

The presented complex is available as a Github repository (Samarkina & Samarkin, 2021) and can be used for further development.

Table 1 ***Stages of the Software Package***

1. Import and binarization of the working area image	2. Image segmentation
	
3. Preliminary analysis of areas occupied by products	4. Object recognition



Discussion

The presented complex has several disadvantages due to both the research nature of the project and the forced limitations set by the authors for themselves. The published version is debug in nature, so it provides redundant information about the recognition process. In the presented version, the algorithm cannot identify internal cavities and pockets (for example, depressions on the contour), which is corrected in the newest version of the 2021 complex. The present version of the complex also does not include a module for interfacing with specific numerically controlled equipment. The noted shortcomings are the basis for further improvement of the program.

Conclusions

Modern mechanical engineering is increasingly being integrated with computer technologies, such as statistical data processing, computer vision systems, and artificial neural networks.

Besides traditional laboratory work, with known input conditions and predictable results, this implies the involvement of students in real or close to real production projects. Students face new working conditions for themselves, requirements for solutions and the level of responsibility. The proposed work is at the junction of laboratory work and full-fledged engineering and scientific developments. This allows both to improve the quality of training and to introduce new competencies into training.

Based on the results, presented in this article, the student defended his graduation work and preparations are underway for implementing new laboratory work on computer vision.

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