Complex Control Systems

ISSN 1310-8255

Proceedings of the International Conference"Robotics & Mechatronics and Social Implementations"2018

EFFECTIVE SOLUTIONS FOR AUTOMATION AND ROBOTIZATION OF MANUFACTURE

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Abstract: *This article discusses the essentials and approaches of automation and robotization of production. The state of automation and robotization of production in Bulgaria and globally is analyzed. Considerable attention is paid to achievements in this area. Data on the degree of automation is generally provided for the discrete production processes in Bulgaria and abroad. The requirements and factors influencing the development of efficient solutions for automation and robotization of production are specified. Variation of solutions and choice of the optimal option for automation and robotics is considered. Exemplary developments of robotic systems are given by the authors.*

Key words: *automation, robotics, robots, automation, robotic systems, efficient solutions, factors, optimization.*

1. NATURE AND PURPOSE OF AUTOMATION OF DISCREET PRODUCTION

The main purpose of automation of discreet production is to produce more, better quality and less human resources, ie. to increase the efficiency of production.

There are two types of basic processes in industry:

- Continuous production processes - chemistry, metallurgy, etc.
- Discrete manufacturing processes – these are interruptible processes. These processes in the Republic of Bulgaria and globally are over 80%. All processes in engineering, electronics and electrical engineering, pharmaceuticals, food processing, woodworking, construction-ceramic products, etc. are discrete.

There are two main approaches to automating discrete production processes [3]:

- Automation of existing machinery and equipment, based on existing technologies
- Design of new automated facilities based on the introduction of new technologies.

In the automation of existing machines and equipment, the flow of parts is automated, with universal machines and semiautomatic machines turning into automatic machines. In these cases, productivity growth λ typically ranges from 1.1 to 2 :

$$\lambda = \frac{Qa}{Qo} \qquad (1)$$

where: Qa is the productivity when introducing automation; Qo - The performance of the facilities in the existing situation.

When designing new machines and equipment, productivity growth λ typically ranges from 2 to 5, but may also have significantly higher values, e.g. up to 50. This is possible with the introduction of new innovative automated technologies.

The effect of the automation of discreet production is economic and social.

The economic effect is the result of the decrease in human resources in the production of certain products, the increase in productivity and the improvement of the quality of the products. The economic effect can also be determined by the reduction in the cost of production.

The social effect is reflected in the reduction of heavy, monotonous and physical labor, often related to unhealthy working conditions - polluted environment, high noise, impact loads, high temperature, radioactive environment, etc.

In order for an automation solution to be effective, the following prerequisites must be met [4]:

- Use innovative technologies;
- To allow increased productivity and reliability of machines and equipment;
- To improve the quality of production and reduce marriage;
- To be economically profitable, ie. to produce less human resources with a minimum of two-shift operation;
- To provide a social effect, ie. reduce harmful, heavy and monotonous manual labor and significantly reduce accidents at work and occupational diseases;
- Possibility of adjustment of the automation technique for execution of other production tasks;
- To operate the automation equipment for a long time without the intervention of the workers;

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• Allow the solution to be included in more sophisticated automated systems.
• To increase the competitiveness of manufactured products.
• Allow complete production of a particular product and provide preconditions for multiplying the new technology for other products;

2. STATE OF AUTOMATION AND ROBOTIZATION OF PRODUCTION

The degree of automation indicates what part of the process is automated, ie. is performed without the participation of the human [1, 2].

The degree of automation **A** is a representative indicator, which can serve as a reference both for designing automation equipment and for assessing the development of the economy in Bulgaria and globally.

When reviewing the state of automation, we usually look at the types of technological operations and processes in Bulgaria and globally.

The levels of automation are given worldwide in the period 1980-2017 [1, 2, 7, 8].

Globally, in industrialized countries there is an increase in automation, which is now as follows: Germany - 40%; USA - 44%; Japan - 54% and others.

For the past 10 years, the degree of automation has been steadily increasing. This is also reflected in sales of industrial robots worldwide, which have grown about twice - from around 115,000 on average for the period 2005-2008, reaching 229,261 robots sold in 2014. The main robot market for 2014 is Asia with 139,300 units (41% increase from 2013), ahead of Europe - 45,600 units (5% growth compared to 2013) and America with sales of about 32,600 items 8% more sales since 2013). A total of 5 countries account for 70% of global sales: China, Japan, the United States, South Korea and Germany. In Europe, after Germany, the sales chart for 2014 is as follows: Italy - 6200 pcs. (32% growth), France - 3000 pcs. (36% growth), Spain - 2300 pcs. (16% decline due to previous investments in the automotive industry), UK - 2,100. and respectively the Czech Republic, Poland and Turkey. For the year 2016, the total number of robots used in the world is about 1 668 000 [1, 7, 8].

In the table. 1 shows data on the degree of automation in the Republic of Bulgaria and in some of the industrialized countries in the period 1985-2017.

Table 1. Degree of automation in Bulgaria, Germany, USA and Japan

Year	Degree of automation A in%			
	Bulgaria	Germany	USA	Japan
1985	17	26	29	35
1990	12	28	31	38
1995	12	31	34	42
2000	12	33	37	45
2005	13	36	39	47
2010	14	38	41	49
2015	19	40	44	52
2017	24	42	47	55

In Fig. 1 the degree of automation by years is presented in graphical form.

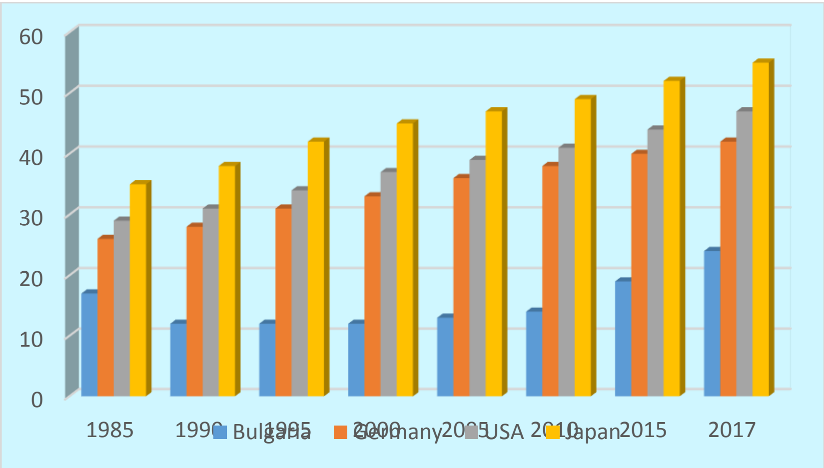

Fig. 1 Degree of automation.

3. FACTORS INFLUENCING THE AUTOMATION OF DISCRETE MANUFACTURING PROCESSES

Automation and robotization of discreet production is complex and diverse. For each individual case it is approached individually. However, a summary of the key factors that have the most significant impact in generating automation solutions can be made.

The main factors on which the automation and robotization of discrete production processes depend are [4]:

- Technical characteristics of the production sites (shape, dimensions, mass, material, physico-mechanical properties, etc.).
- Annual production program.
- Batch Size and Frequency of Redesign.
- Type of process and operations.
- Type of technological units and their work area.
- Production conditions.
- Requirements for safety technique and fire requirements.
- Sanitary and hygiene requirements.
- Specific features of the environment, etc

The properties of the construction-dependent automation technique can be divided into the following groups:

- Production techno-economic.
- Operational techno-economic.
- Exploitation not economical.

The first group refers to such properties, which can be determined by design documentation and in the development of an experimental model. They appear to a certain extent in the production and commissioning of automation techniques. Here are the following properties: technology and simplicity of structures; Progressivity of the used technologies for the realization of the constructions; labor-absorption during production and assembly; degree of standardization and interchangeability of details and assemblies; material absorption; energy absorption; novelty and patent purity.

The functional properties of **the second group** are: accuracy of the operations; cyclic productivity; ergonomics; operational energy absorption; adjustability (flexibility). They can be determined by short-term automation testing. Reliable properties of the second group can be determined only during the operation process or as a result of special long-term tests. They characterize the stability of functional properties.

The efficiency and effectiveness of automation technology is determined by the performance of the operations for which it was created.

The third group refers to properties that do not have an obvious economic effect but have a social and psychological significance. These are harmlessness, safety, aesthetics, prestige, and more.

The brought automation techniques are not exhaustive, but they give it its basic look. They have a practical significance for designers and designers in choosing the optimal version of automation technology and manufacturing - for choosing efficient automation solutions for specific technological processes and operations.

Parameters of automation technique are called the quantitative characteristics of its properties, incl. performance, mass, gauges, power, speed, and so on.

Indicators of automation technique are called quantitative characteristics determining its quality. These are the load factor (actual technical utilization), operating economy, techno-economic efficiency, etc.

Parameters and metrics are most often in correlation. Parameters are typically dimensioned, some of them dimensional. The metrics can be both dimensional and non-dimensional (relative) dimensions.

The quality level of the automation technique is a relative feature based on the comparison of the set of indicators of the automation under consideration with the benchmarks - automation equipment of the same class.

Automation technique indicators can be single and complex.

Single ones are those referring to only one property of automation technique.

Comprehensive are the automation technique quality metrics referring to several properties that are merged into one metric. For example, the standby ratio is a complex indicator, including faultlessness and repairability.

The following key performance indicators are important for the development of automation projects and for choosing the right solution: performance, reliability, feasibility, reliability, degree of flexibility, degree of differentiation and concentration operations, occupied area, energy absorption, material absorption, etc.

Productivity is the quantity produced over a given period of time. The volume of production is dependent on the productivity of the automation technique and the production time of the production.

The productivity of automation technology is a very important indicator of its operation. The design performance is determined, which is determined at the design stage, and the actual productivity determined by the actual operation of the automation technique.

Depending on the cost accounting of the automation technique, different performance categories differ: cycling, technological, technical and factual.

In designing automation techniques, **the cyclic performance Qц** is most commonly used.

The reliability of an automation technique means that it retains its capacity for a certain period of time by performing its assigned functions.

Private and complex reliability indicators are distinguished.

Private reliability indicators are: reliability, reliability and durability.

Knowledge of private automation techniques is a necessary condition, but is not sufficient for its design and operation. In these cases, complex reliability indicators are usually used.

Complex reliability metrics are: readiness ratios, technical utilization ratio, actual use factor, and over-cycle time losses.

The **Кг** coefficient of readiness includes two major private indicators: reliability and reliability. It is determined by formula 2.17, taking into account the mean fault time between two rejections **Тр** and the average recovery time of a given **Тв** failure.

The coefficient of technical utilization **Кти** represents the ratio of the mathematical expectation of the time, during which the automation technique is in the working state (**Тр**), the sum of **Тр** and the mathematical expectations of the waiting times for repair (**Тв**) and for maintenance (**Тоб)** for a certain period of time.

The actual technical utilization coefficient **Кфти**, in addition to the stated times, also counts the organizational stays (**Тор**). It represents the relation of time (**Тр**) to the sum of times (**Тр**), (**Тв**), (**Тоб**) and (**Тор**).

The automation of production processes has the task, by means of additional capital investments (investments), to reduce the cost of manufactured products by increasing their quality characteristics.

The following economic indicators can be used to justify the choice of the automation technique: annual economic effect **Иг**, additional capital investments **ΔK,** repayment term n, cost of the produced product **C** and others. Until recently, the payback period **n** was most commonly used as a techno-economic indicator.

4. VARIANCE OF AUTOMATION SOLUTIONS AND CHOICE OF OPTIMAL SOLUTION

Optimization provides a systematic approach for choosing the best project solution from all possible options under the specific conditions of project implementation. The best solution is called optimal for the specific conditions. Through optimization, there is an opportunity for improvement, that is, to improve design solutions. Optimization is thus not only a process of finding the most perfect solution, but also a process of moving forward to improve the solution.

Two types of optimization differ depending on the type of engineering and technical tasks: *structural and parametric*. In structural optimization, the best structures or schemes of the system or process are chosen. In the initial stages of the design, many variants of the structure of the designed objects are formed.

Parametric optimization determines the optimal design or technological parameters of the designed object [4,8]. Once the design goal, optimality criteria and constraints have been determined and the mathematical model has been developed, a mathematical method has to be chosen to solve the optimization task, requiring the least time and cost loss. Depending on the nature of the links between the project parameters and the quality indicators and the possibilities for some or other simplifications in the general formula, different methods are used to solve the optimization tasks.

The methodological basis of decision theory is the complex system approach. The multi-criteria model of the decision-making process can be expressed by the following structural dependence [3]:

$$< G, V, K, K_T, S, R >, \qquad (2)$$

where G is the assignment of the task.

The range of optimality criteria includes the metrics of RTM:

$$K = \{ Q, P, A, G, \Delta K, \ldots \} \qquad (3)$$

The individual indicators are determined by analytical dependencies.

The range of decision rocks includes the weighting factors of each of the assessment criteria for the variants:

$$K_T = \{ K_{Tj}, j = 1 \div n \} \qquad (4)$$

Usually $\sum_{j=1}^{n} K_{Tj} = 1$;

The plurality of preference systems is formed as a result of experience gained and reflects the views of the person taking the final remittance. In a number of cases, this set is mixed with the set of scales where it is possible to give preference to a particular criterion.

R - rules for decision making. The deciding rule is an analytical expression or algorithm that allows the ordering of variants by degree of importance and leading to the best solution;

K - a set of criteria for decision-making;

K_T - a set of criteria scales;

S - system of decision-making preferences;

V - a variety of decision options;

The plurality of decision options is formed after the implementation of the main and additional variables:

$$\begin{aligned} &V < E, O_{PR}, D_{PR} > \\ &V = \{ V_i, i = 1 \div m \} \\ &E = \{ E_j, j = 1 \div p \} \qquad (5) \\ &O_{PR} = \{ O_{PRKi}, k = 1 \div q \} \\ &D_{PR} = \{ D_{PRe}, e = 1 \div r \}, \end{aligned}$$

where: **E** is the set of structural units; $\mathbf{O_{PR}}$ - the set of the main variables; $\mathbf{D_{PR}}$ - the set of additional variables; **m** - the number of variants; **p** - the number of structural units; **q** - the number of the main variables; **r** - the number of additional variables.

Following the formation of the variants, a quantitative or qualitative analysis of each of them is done, taking into account the relevant criteria for choosing a solution.

The quantitative analysis uses two basic methods - the ball estimation method and the non-dimensional coefficient method.

Qualitative analysis takes into account the advantages and disadvantages of individual options, but subjectivity is possible on the part of the analyst.

The most commonly used methods for quantifying the options for automation solutions and choosing the optimal option are the Balance Evaluation Method and the Non-Dimensional Coefficient Method, which allow multicriteria optimization to be performed using all optimization criteria simultaneously.

In the table, the expert balance scores **Xij** [i =1÷m, j =1÷n] of the individual variants **Vi** (i = 1÷m), taking into account the coefficient of gravity $\mathbf{K_Tj}$ (j=1÷n), for the individual criteria of optimality **Kj** (j=1÷n).

$$X_{ij} = 1 \div 10 \; ; \; \sum_{j=1}^{n} K_{Tj} = 1 \qquad (6)$$

For each variant, calculate the cumulative ballistic estimates **S_i** (i=1÷m) by the following dependence:

$$S_i = \sum_{j=1}^{n} \left(X_{ij} . K_{Tj} \right), \quad i = 1 \div m \qquad (7)$$

Optimal is the option for which a maximum cumulative total score was obtained, i.e.

$$S_k = \max \{ S_i,\ i = 1 \div m \} \qquad (8)$$

The **S_k** estimate is maximum, which means that the **V_k** option is optimal when applying all the optimality criteria simultaneously.

When selecting an effective solution for robotic systems, relative (non-dimensional) coefficients can also be used, calculating the sum coefficient **K_{oi}** for each of the options considered **i** (i = 1 ÷ m; m - number of variants):

$$K_{oi} = \prod_{j=1}^{n} \left(K_{ij} \right), \quad i = 1 \div m, \qquad (9)$$

where **n** is the number of non-dimensional coefficients.

Optimal is the variation that has a maximum aggregate coefficient **Koi**, i.

$$\max \{ K_{oi},\ i = 1 \div m \} \qquad (10)$$

This method is more objective. A subjective factor is avoided and the choice of an optimal solution is given.

5. APPROACH FOR THE DESIGN AND IMPLEMENTATION OF AUTOMATION EQUIPMEN

The purpose of an automation project is to develop a new efficient technological process for automated production of the product, based on new innovative technology and implemented in the industry this complex. Achieving this goal enables a company to become an equal partner on the European market, increase its share of exports, attract foreign investment, and also provide resources for new projects to improve the overall organization of production.

The project allows for a good organization of the maintenance, maintenance and repair of the specialized automated equipment, which will lead to better working conditions and improved social environment.

The optimal degree of automation of the automation technique, tailored to the particular production and the conditions that determine it, must be selected.

Automation has always been and will be a powerful means of achieving high techno-economic performance of production, obtaining a sufficient quantity of manufactured products, achieving growth in production, improving the nation's standard of living, product competitiveness, improving the environment environment through the use of waste-free technologies and others.

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Investing in automation will lead to future positive results that will help further investments in the name of the nation's future. The appearance of a country is determined largely by the level of technology and the technique of producing a variety of products. Only highly-sophisticated technical policies can create highly automated production that will make our countries highly industrialized and citizens - more rich and successful.

In the design and implementation of automated mechatronic complexes the following basic stages can be distinguished [3, 4]:

- Selection of appropriate automation objects.
- Distinguish the basic features of the parts and shaping groups according to size, mass, material and technological process.
- Technological and constructive analysis of the assortment of parts subject to automation
- Analysis of the existing technological process and used technological machines and equipment.
- Choosing an automation approach.
- Development of a technical and economical design task for AMK.
- Preliminary calculations of the AMK project indicators.
- Development of circuit solutions for automatic orientation of the parts.
- Development of variants of AMK.
- Analysis and evaluation of options.
- Choosing the optimal AMK solution option.
- Development of constructive and technological documentation of the selected solution of the AMK.
- Making AMK.
- Programming and tuning.
- Performance of AMK functional tests.
- Perform AMK technology tests
- Carrying out AMC acceptance tests.
- Implementation of AMK and trial operation.
- Real AMK operation.

6. SAMPLE SOLUTIONS FOR AUTOMATION AND ROBOTIZATION OF PRODUCTION

The authoring team has been involved in a number of developments in automation and robotization of production.

In Fig. 2 to Fig. 4 shows some of these developments.

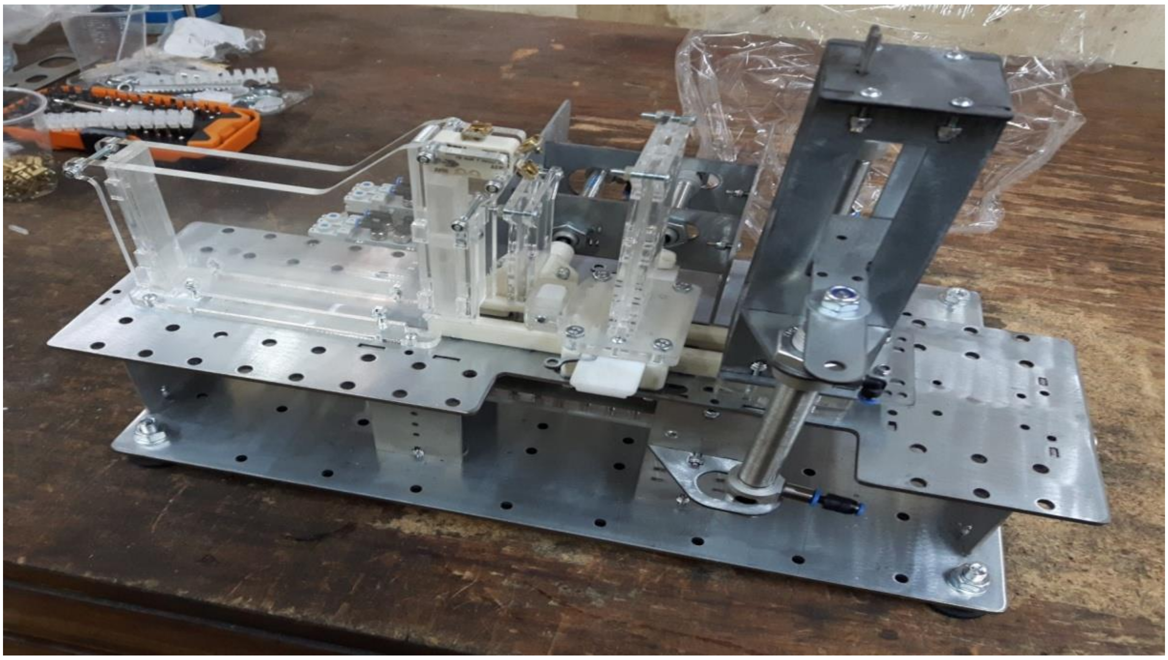

Fig.2 Arbottized mounting system for louver terminals.

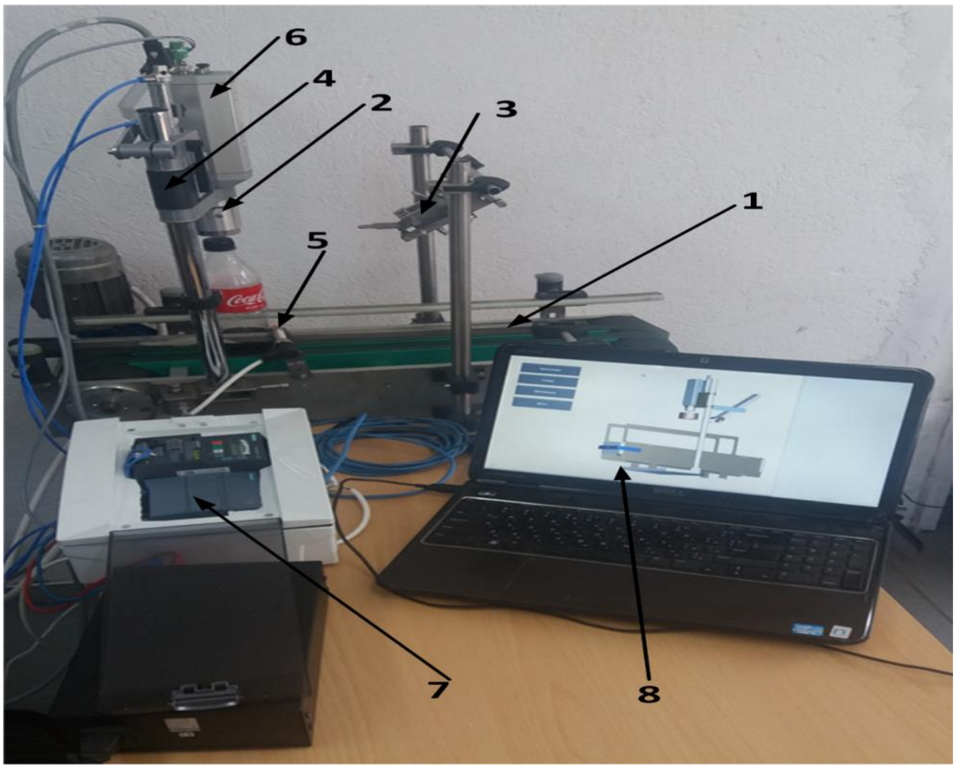

Fig. 3 Robotic system for closing containers with screw caps.

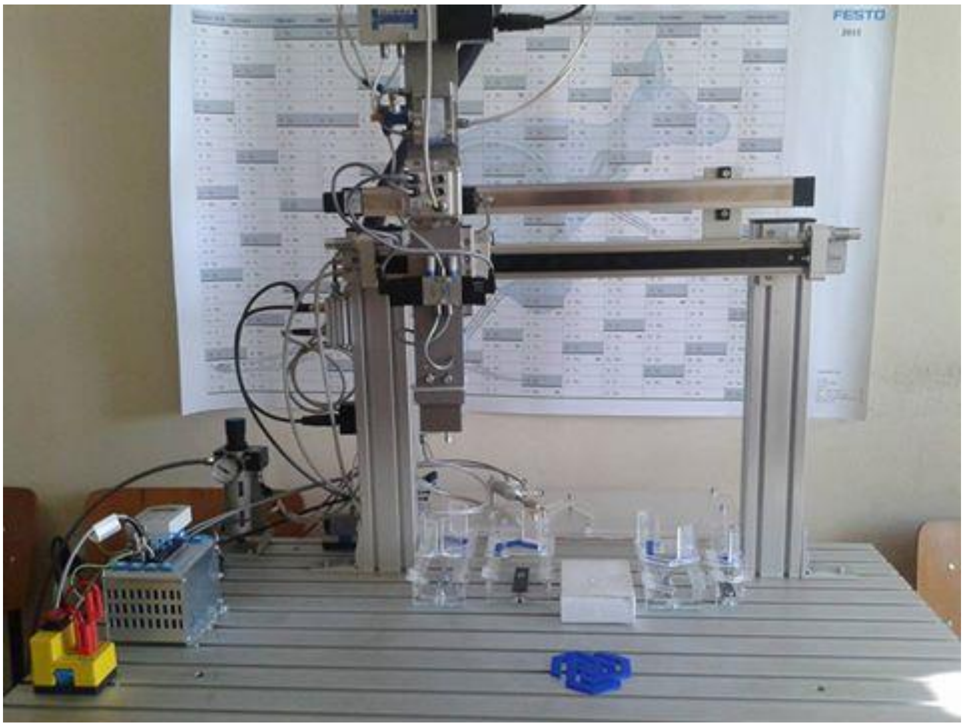

Fig. 4 Robotic system for mounting of "plate".

7. CONCLUSIONS

• The essence and approaches for automation and robotization of production are examined
• An analysis of the state of development of the automation and robotization of production in Bulgaria and worldwide is made.
• The requirements for the development of efficient automation and robotization solutions have been formulated
• Factors influencing the automation and robotization of discrete production processes are analyzed.
• Variants of automation solutions and choice of optimal solution are considered
• Suggested solutions for robotic systems developed with the authors.

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