PERFECTION OF LEARNING METHODS FOR MECHATRONICS BASIC IN MECHANICAL ENGINEERING AND INDUSTRIAL DESIGN STUDIES

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Abstract. The article deals with technics and technology for the rapid development of a new set of knowledge and skills that must be learned not only in engineering, but also in industrial design studies. A large part of this new knowledge can be applied to mechatronics or fields close to it. It may be argued that new knowledge and skills qualitative perfection can only be guaranteed by proportion of sufficient practical and laboratory works in the studies and the students' interest in these works. Therefore, cost-effective, functionally varied and creative interest technical learning aids are viewed that can be used for practical and laboratory classes as well as in product design model creation with mechatronics elements. The technical aids functionality and quality can be increased by adding to the elements the 3D printing technology. By using these technical tools, it is possible to create a wide range simple model products, usually in a reduced scale, and the practice do it research, for example, such as the work capacity assessment, to find and prevent constructive imperfections, etc. In practice, the results can be compared with the results that are obtained with traditional calculation or CAE tools. Examples are given. Equipping these models with electric or pneumatic actuators, sensors and programmable control tools can work off these objects various control algorithms. For programming basics acquisition, which is necessary to ensure automated control, teaching mechanics and designers, main attention is given to the skills to write down the machine control algorithm, and at least in the initial learning phase to use visual programming languages, that allows intended and not too difficult work goals to achieve very easily and in a short time.

Keywords: education, mechatronics, automation, visual programming, Fischertechnik models.

Introduction

Developing new products, we look forward to their success that can only be putting the innovative ideas. Most of them are created by working in interdisciplinary areas. This century and also in advance the success of rapidly acquired products got which can be called as a mechatronic or who are close to them. As it is known, there are combine mechanics, electronics and computer components and the most important role of them plays design. They has the functions and properties that did not had these products ancestry. Domestic robot (Robotic vacuum cleaners, robotic lawn mowers, etc.), electric vehicles (Segways, e-bike, Dron, etc.), toys (Furby, the robot dog AIBO, etc.), automated kitchen equipment and even electric toothbrushes with microprocessor management becomes everyday things of life. Should be developed a new automated production equipment, which includes the already mentioned elements of mechatronics.

Mentioned type of products and production equipment development are collaborate by experts from different disciplines, but the success of their teamwork can only be done if the specialist knowledge areas partly is overlap in. Thereby, today's mechanical engineers and also industrial designers has demands on the electronics, information technology basics and those area trends in knowledge have increased considerably. Therefore, institutions of higher education interest to activate the question of how this additional information can be included in the study programs, without reducing amount of traditionally taught knowledge, and how students interested in this so far as "foreign" knowledge acquisition. It is necessary to get and analyze information on how to deal with the problems of other countries in educational institutions and to try to apply this experience in our public education system specifics.

Materials and methods

Methods of research include studies of scientific and technical literature and reflection of personal pedagogic experience. One of the main aims of was to find out the ways how learning the basics of mechatronics and basic of production automation for better to realize the Project-Based teaching method, which also provides creation for functional mockup. This problem is important in study programs as in "Engineering Technology, Mechanics and Mechanical Engineering", "Industrial Design", "Mechanical and Instrumental Engineering" un "Mechatronics" that are implementing by Riga Technical University (RTU), Faculty of Mechanical Engineering, Transport and Aeronautics. Every year more than 90 students began the studies in mentioned study programs. Although the study programs are quite different, they all are studied subjects as “Basics of Production Automation” (mechatronics students instead of it learns “Robotics”), “Electro, Pneumo and Hydro Automatics” (mechatronic students – “Electropneumatic Technique”). In Industrial design studies in intended to introduce the subject of “Fundamentals of mechatronics”. The effectiveness of teaching methods mentioned area depends on the training laboratories of the technical equipment. Now practical and laboratory work proportion is not enough in most of the mentioned subjects or it is a time to try a new, not before used practical study methods. In the research process the traditional, as well as to us less used easily changeable technical learning aids for laboratories were identified and analyzed.

Results and discussion

1. Modern trends before the university education system that promotes the acquisition of the new technology

The way, how the problem huge additional information acquisition problem in education is trying to solve in the world is relatively easy to see, and here primarily need to talk about before - about the university education system of pre-university education system organization. In many places the education is organized in such way that from an early age, children who wish and are able, in-depth learn a subject block, which is internationally recognized by abbreviation STEM (Science, Technology, Engineering, and Mathematics). This learning is characterized by the fact that is widely used for Project-based learning, where pupils at a problem-solving is working in groups. These projects often contain all main mechatronics elements, and they ended with a functional mock-up creation and presentation of their projects. Before University (schools, colleges) obtained knowledge and skills in engineering and design, well shown in the textbook [1].

Nowadays, learning basic in information technology, programming and mechatronics before a university education is dominated themes by robotic, and its corresponding study technical means. Most focuses on autonomous robots, obviously because they cause the greatest interest in children and young people, and from a technical point of view, they can be used in a wide range of sensors, drive components and control algorithms. They may also have a relatively difficulty or witty mechanical structures. Using these technical study resources, allows to acquire a wide range of thematic issues. For the constructive base for learning robotic basic in this level, almost always chooses the programmable construction toys. Programming the technical object design is most commonly used visual programming languages. They are most suitable for beginners with rather simple and short program tracing.

Experience in robotics and mechatronics basic for learning pre-university education, using programmable construction toys widely described in numerous publications, for example, [2]. This kind of education is available not only to rather rich countries, such as Germany, but also the less well-off, for example in Hungary, Slovenia, Greece, etc. Latvian robotics classes, or in the distant area of the school programs is not intended. However, many students formed interest groups, dealing with it [3]. It seems that a relatively small number of visitors form such hobby group after leaving school chooses the IT, electronics or mechatronics studies and mechanical engineering and even more design study programs practically do not reach.

2. Mechatronics basic for the acquisition of general issues in universities from different countries

As mentioned above, in the Riga Technical University (RTU), mechanical engineering and design study programs students comes almost without any previous knowledge in the field of robotics or mechatronics. Also in the study programs in mechatronics or close the problem of robotics are just a few training courses, where small scale of our students acquires them. The knowledge amount of the limited training time to learn, for example, in an area such as Algorithmization and Programming of Solutions is very small. The same can be said for the electrical and electronics basic for learning to us. In such situation, particularly consideration is needed for the content of teaching and the organization for a limited time and with limited resources to achieve maximum results and need to make corrections for study programs.

It seems that in countries with high levels of economic development in mechatronics or in robotics as an important interdisciplinary field of study in a range of in the study programs are taken for granted and strategically important. For studies in this area is also allocated sufficient time for learning and pre-university students' level of training is generally higher than that to us. On these issues, there are many publications, such as mechanical engineering studies in the field of robotics or mechatronics [4-6], industrial design studies in these directions [7-8].

An important precondition for a stable and lasting knowledge extraction is a well-organized students' individual work learning laboratories and training project execution. Controversial here is a question of that to what mechatronic hardware base is better make the teaching laboratories. There is no equipollent solutions, because it is very different from view of materials and other options in different countries and educational institutions. For example, [9] discussed the most appropriate solutions for African universities, which differ significantly from the German and the USA options.

3. Festo Didactic laboratories equipment in mechatronics basic studies

RTU mechanics students learning "Electro, Pneumo and Hydro Automatics" or "Electropneumatic Technique" have a small Festo Didactic developed laboratory equipment, including 4 Workstations for learning pneumatic and electropneumatic basic as well as 3 MPS (Modular Production System) stations, and other learning stands. MPS stations and etc. apparatus are suitable for learning subject of "Basics of Production Automation". This is a high quality mechatronics laboratory equipment that is provided for studies. Theoretically, to obtain a full set or partial of MPS, various combinations can create a variety of teaching automated production structures. MPS stations are made from components, which are also used in equipment in real industrial production. It is one of the MPS station advantages to compare with most of the programmable construction toys.

Such equipment is well suited for mechatronics study programs in later courses after learning electropneumatic and PLC programming basic and may be partially useful for mechanical engineers and design studies. Researching such systems can meet with typical automation tasks (String Sorting, Handling, Testing, etc.), technical solutions, e.g. with pre-assembled mechanisms of actuators, sensors and other elements. Practically these stations are used for the learning tasks for which they have been created, and modify them substantially for different tasks is too difficult or even impossible. The main task that solve with the technical equipment is equipment programming. Established production structure can invent a variety of control algorithms, to develop them for appropriate control of the program and to check its operation.

RTU mechanical engineering students to do the following tasks in full is a quite problematic, because study programs is not included control algorithm design and PLC programming foundation courses. Control algorithm principles for the establishment and modification of PLC control programs are viewed by the review form with simple examples. Small complexity tasks the mechanics still also can do. Most realistic to do this is to use a visual programming tools. Working with industrial standards IEC 61131-3 in an appropriate way, the control algorithm graphic records can use the relatively simple Grafcet form and for PLC programming is used like close Grafcet records and visual Sequential Function Chart (SFC) language form. In the Grafcet / SFC form simple equipment control algorithms to be recorded in a transparent and most laconic form. If it is not possible, the control algorithm Grafcet records can be translated into, for example, in a lower level graphic programming languages - Function Blok Diagram (FBD) or Ladder Diagram (LD) language. They both are less suitable in our case, because programming them more like an electric or electronic circuit synthesis, which is also a little-known area of our mechanics students.

Teaching study subject of "Basics of Production Automation" for our Mechanical Engineering students, the practical lessons are organized particularly in computer classes, where with Festo software FluidSIM is modeled relatively simple programmable, electro-pneumatic systems action. For programing is used Grafcet and FBD language. Real apparatus is mainly used in the form of demonstrations, as little funding until now is not managed to organize students' work with laboratory equipment in small groups. Experience shows that at one lesson should work no more than 2-3 students. However, organize it, sometimes even 30 students for academic group temporarily fails. May find that practical exercises in current form improves students' understanding about the studied material, but the practical capabilities with a real, mainly in electrical/electronic equipment to carry out specific, professional activities close tasks are quite distant from the desired. For example, it observed that most students are unable to design computer programs to model the electrical circuits to convert them into electric circuit reality. Such problems cause is insufficient experience in such work. It is also recognized by students and most active of them in this case calls for an increasing amount of executed works.

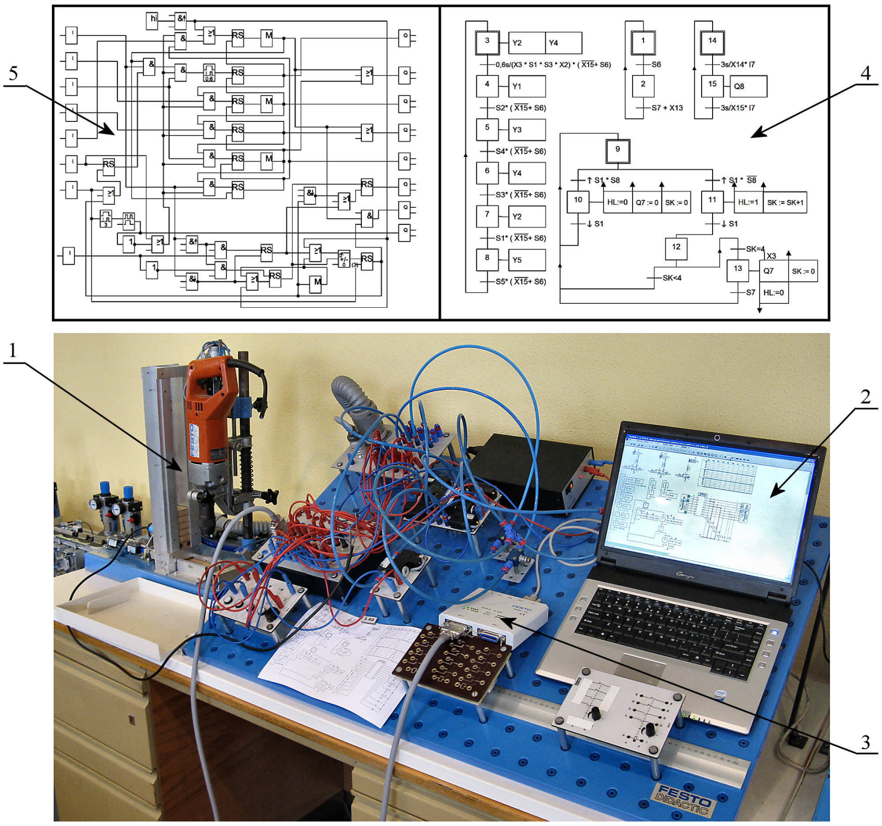

Fig. 1. **Festo Didactic learning stand with automatic drilling machine:** 1 – drill with preforms magazine; 2 – a computer with FluidSIM software; 3 – EasyPort; 4 – the control algorithm and program Grafcet form; 5 – the control program in the form of FBD

Fig. 1 shows one of our possession learning stands on which can imitate simple manufacturing automation tasks – into drilling blank, which is automatically fed from a magazine and after drilling moved the final product container. Task can be supplemented by the presence of control blanks in magazine, by produceing production accounting, setup and emergency stop mode and other features. Drilling equipment 1 in this example is controlled from the PC 2, which simulates PLC operation. This can be realized with help of Festo software FluidSIM and EasyPort interface device 3. Using FluidSIM software, equipment can be controlled directly with Grafcet 4 as a high-level graphical programming language or with a control program in the form of FBD, close to Siemens Logic module Logo Soft, the Comfort software performance.

Also, industrial design students need to get acquainted with automated manufacturing technologies and equipment which in the field is used. However, the practical handling of the MPS stations and similar equipment as described above of this specialty students will be even less ready as mechanical engineering students of both the previous training and by the motivations. Students from this spatiality should be able to develop new ideas for a wide range of products for the creation and production. For example, these can be household appliance products. However, automated production systems usually goes out of the scope of the designer.

4. Easily transformed technical platforms choice or development of mechatronics learning laboratories

In the field of technical education is a lot of discussion about the technical platforms choice of laboratory activities and training projects in the field of mechatronics, which give students the greatest creative freedom and technical possibilities of their idea realization [10]. The above mentioned Festo MPS stations and similar equipment do not exactly meet these requirements. It is about reconfigurable mechanical structure, selection or creation that compatible with a wide variety of sensors and drive elements. Also, universities, similar to the in a lower level of educational institutions, usually comes to the conclusion that the mechatronic products, robotics and manufacturing automation object mockup creation presently is difficult to find an alternative to programmable designers who basically are created as children's education and hobbies.

In the area of programmable design offer now is very high. Institutions of higher education most often use Lego Mindstorms [10; 11] and Fischertechnik constructors [10; 12-15], but in recent years the offer in this field is expanding rapidly. Appeared, such as the Engino, Makeblock, VEX robotics programmable toys, etc.

Next, is described Latvian not too popular, but both in university education and schools, in our view, well suited Fischertechnik constructors. This manufacturer has more than 50 years offers kits for education both robotics and in the manufacturing automation field.

Fischertechnik constructor's basic building blocks were of channel-and-groove design, manufactured of hard nylon. Without these basic elements has been also developed a large number of other elements compatible with them, which allows almost unlimited technical possibilities of fantasy of objects layout design. This cannot be done at any level and with any fictional technical parameters. Constraints has been to the mechanical gear transmission ratio, screw thread steps, shaft diameters and etc. In this constructor can be found almost all traditional mechanical gears: gears, screw, gear rack (rack and pinon), chains and cam gears, cardan drive, worm gear, etc.

With this and other construction toys created models are fully ready to work, but they do not have a particularly high operational stability and precision. This omission has been a number of reasons, but main of them has amount of a union in constructions, which reduces their stiffness. Thus, for example, machine frame structures can be created instead of many small and compatible building blocks, but rather to make them monolithic with a 3D printing technology. Such constructor's users sometimes tries with 3D printing to produce the relatively small mechanical transmission parts. Theoretically it is possible, but practice shows that currently most available FDM 3D printing technology for the time being does not give sufficient accuracy. Mockups work quality sometimes may be improved by guides, axles and shafts, as a material, plastic instead of metal.

Before the electric components report, should be clarified that they can work with either a 9V or 24V direct voltage. A 9V range based on the use Fischertechnik offered electrical components, but without the 24V range Fischertechnik offers can be used for components in a wide range of industrial applications (motors, sensors, control systems). Certainly, those of their own functionality, size, weight, power and design must be suitable for this constructor. Further viewed a 9V at the main components, which are generally cheaper than 24V elements. A 9V system chooses, even if management intends to use Fischertechnik TX or TXT Controller.

Forming model drive can be manual, pneumatic (single acting and double acting cylinders) or powered by DC motors. For seizing metal objects or other purposes can be used electromagnet. Without the drives also available Different lamps and buzzer.

Also Constructor has a quite wide of sensor selection: contact sensor (micro switch), magnetic sensor (reed switch), ultrasonic distance sensor, infrared color sensor, specially developed trail sensor, thermal sensor (NTC resistor), a phototransistor, a photo resistor, a USB camera, are available encoder engine.

Construct objects for automated control can be used in Fischertechnik TXT Controller and the ROBO Pro software. Sensor's and actuator's connection to the both controllers has 8 universal input (digital / analog), 4 high speed numerical inputs, 4 outputs Motor (speed infinitely Controllable) or alternative 8 single outputs for components Such as lighting, etc. The number of inputs and outputs can be increased by linking several controllers at Master-Slave Systems.

Fischertechnik constructive base allows to create models of almost a not limited idea of the range of applications. For example, University of Applied Sciences and elsewhere created flexible production system models in the metalworking field [16]. Using internet can find various automated woodworking equipment mockup images and videos. For example, Fig. 2a shows mockup for sorting timbers length and width. For its part [17] is described the model for automated pig farms. Many researchers and enthusiasts focuses for tractor models creation with different automation functions as it seems in Fig. 2b.

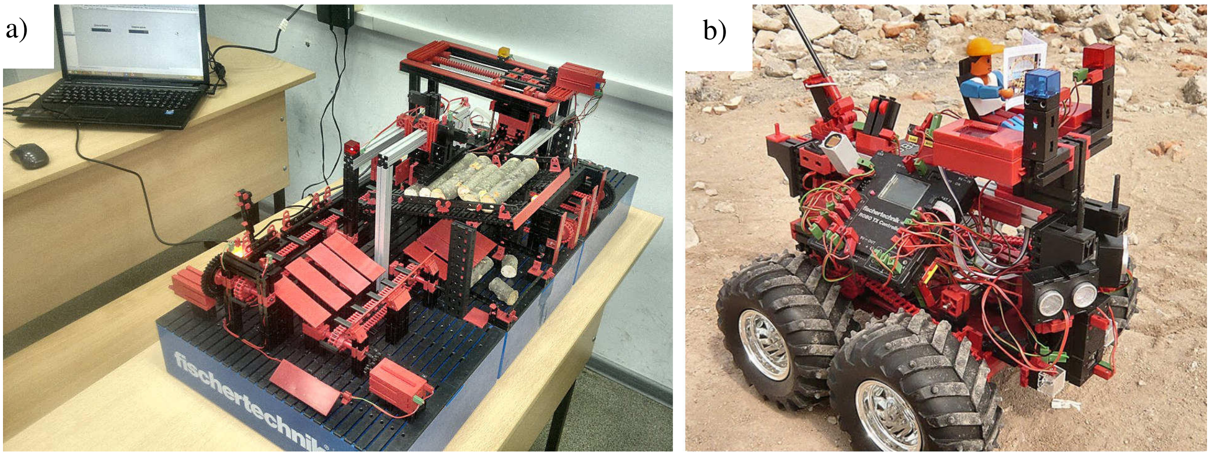

Fig. 2. **Mockups from Fischertechnik constructors equipment elements:** a – automated timber sorting machine; b – autonomous robot/tractor model with GPS Navigation

The current assessment of the situation with regard to the RTU programming languages which could be used in mechanical engineering and industrial design studies in mechatronic mockup control shows that at least initially the most realistic way is to use programmable construction toys packaged with existing graphical programming languages. In the world such programming is used mostly for beginners in pre-university education, but in colleges and universities are often used based textual programming C/C++. It may also be used in Fischertechnik, Lego NXT, etc. programmable of construction toys. Unfortunately, these programming languages are not really suitable for beginners as are essentially our students of mechanics or design programs. At our study plans cannot be found the sufficient time for learning.

Thus Fischertechnik models for programming can be used in visual ROBO Pro software (see. Fig. 3a), which, by its execution is close to the requirements of the well-known and universities used the ISO 5807 standard. For comparison can be mentioned that the Lego Mindstorms graphical programming environment (see. Fig. 3b) is more specific and it seems that at least in visual execution is more focused on a perception to relatively small children age.

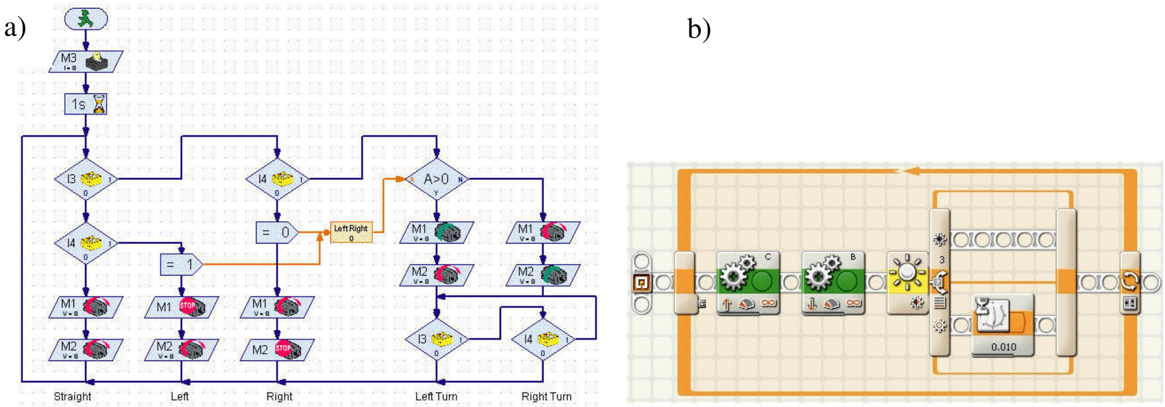

Fig. 3. **Designed graphical programming languages for beginners:** a – Fischertechnik Robot Pro programming language; b – Lego Mindstorms graphic programming language

Practical works in RTU Mechanical Engineering and Industrial Design study programs where would be used Fischertechnik Constructor has not yet been introduced. Teaching staff have a large, but functionally varied Fischertechnik number of components. In such way is assessed labor-intensive of planed students tasks, different ideas realization probability, often used structural elements types, approximate number of established structural strength etc. In addition to carrying out demonstrations and students' participation in the execution of some minor projects, it is planned to get students' views on such works. The acquired student feedback in this area are positive.

In the last years 3D printing options and limit the field of our students and teaching staff has accumulated some experience, because of this technology is increasingly being made different product models in a diploma projecting process. This experience allows to predict the use of 3D printing capabilities from Fischertechnik constructors developed by mockup.

Programmable constructors, however, is not a cheap product, so the mass use in different subjects and study programs of RTU currently seems unlikely. Initial it use seems real in industrial design study program, teaching the subject of “Fundamentals of Mechatronics”, because this specialty is being taken relatively small number of students (about 15 students).

Discusses an example that shows the way how Fischertechnik constructor with a simple CAE software can be used in both industrial design and mechanical engineering studies. An example is on a digital mixer topic. This is a product that is often used both at home and in restaurants and in the food industry and other enterprises. For each application area are used different structures, the size and complexity of the mixers. In general, they form is a relatively compact where is possible to find enough variety for both mechatronics and manufacturing automations characteristic elements.

Many of stationary mixers are based on a planetary mechanism, which threshing blade provides the desired planetary motion trajectory. In studies, looking at the theory of planetary pinion gears and mechanisms basic principles are showed the analytical relationships that determine the planetary gear mechanism, for gear rotational speeds, etc. These issues are much easier to understand by supplementing an explanation with visually easily perceived simulations. One of the easiest CAE programs, which includes how to make simulation is a Working Model. To master this program is very easily and in a short time. Although this is not a 3D program, its capabilities in the field of mechanics is quite large.

Fig. 4. shows that in the Working Model are made two different calculation schemes of planetary mechanisms and modeling acquired for them the corresponding mixer blade motion trajectory. Mixer blades simplified form here as a rectangle. Upper scheme might be appropriate so-called double planetary mixer and the lower planetary mixer with a one blade.

The Planetary mixers can also create mockups from Fischertechnik constructor’s components. Working on these topics, students could ask from the technical literature to get acquainted with industrial mixer structures and to create a mockup that is close to one of them or to create their own construction. If there is not enough time for full design creation, may modify any pre-construction. For example, in one of the constructor standard sets (Mechanic + Static) are given detailed instructions for creation simplified planetary mixer standard model. This model planetary mechanism is similar to the large industrial mixer (Double Planetary Mixer) construction, otherwise it looks more like a kitchen stand mixer. Mentioned planetary mechanism is simulated with Working Model (see. Fig. 4 above).

In Fig. 5 previously mentioned mixer mockup modification is shown. For the mixer blade drive is saved the construction upper illustration in Fig. 4. It added with the blender jar (mixer bowl) lifting / lowering mechanism that fitted from a DC motor through a screw transmission. This mechanism could also be used for other transmissions such as rack and pinion transmission. Students may ask to draw up planetary mixer blade drive mechanism as in Fig. 4 – the lower picture or any other schemes. Blade drive kinematics gear train can be supplemented with a simple manual gearbox and make further changes. Different variations of the model creation functioning independent can substantially strengthen the knowledge and skills in mechanics that are obtained in theoretical studies.

There are some issues in this exercise as the drive mechanism part that is discussed. Can find out the differences between the blade rotation speed setting, switching speeds with the gear box, or by changing the DC motor shaft revolutions with Pulse Width Modulation (PWM) method, which is realizable with Fischertechnik constructors. Mixer bowl lifting/lowering mechanism can also be operated with pneumatic cylinders.

In this exercise do not need particularly complex sensors. Could be enough with two limit switch or light barrier sensor mixer bowl lifting/lowering mechanism for position control. The sensor part can be supplemented by a temperature measurement sensor that is also used in such products.

The control algorithm for such equipment is usually pretty simple. Basically only need to set different modes of operation, including a variety of mixer blade rotation speed and operating duration, to manage container lifting/lowering mechanism, as well as measuring and transmitting information to the operator about the temperature in the working environment. From actoric, sensoric and the control algorithm complexity point of view this could be an entry-level task or mechatronics basic of production automation.

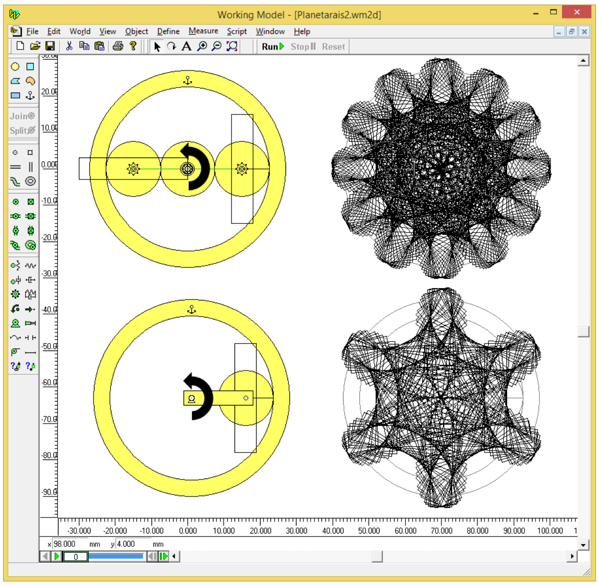

Fig. 4. **Planetary mechanism of computer simulation with Working Model**

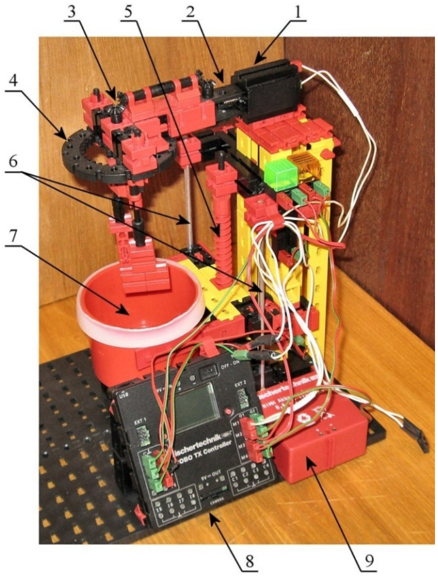

Fig. 5. **Industrial mixer mockup from Fischertechnik element:** 1 – DC motor; 2 – reduction gear unit; 3 – bevel gearing; 4 – planetary mechanism; 5 – screw gearing; 6 – cylindrical guide; 7 – mixer bowl; 8 – TX controller; 9 – rechargeable accumulator

Conclusions

For best results in learning mechatronics and manufacturing automation basic, is not enough with to individual institutions or their structural efforts. In the mechatronics and in its close areas is very important to have the group STEM subjects with serious learning methods in pre-university education.

Our experience shows that in the current conditions mechanics and design specialties students with insufficient background in IT and electronics fields of mechatronics basic learning would be essential to a new and not very complicated equipment implementation in the learning process, which could make the learning process more creative and interesting for students. The best learning outcomes can be achieved with laboratory equipment management programs using graphical programming languages. Working with Festo Didactic developed educational laboratory stands it is good to use it for programming software FluidSIM and EasyPort interface device opportunities. The great creative freedom for students in practical classes can be achieved by using programmable construction toys, for example, the Fischertechnik offer. Creating models quality on this technical basic can be improved by including elements created with 3D printing technology. Beginners for such programming mockup can be used ROBO Pro software visual programming environment.

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