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ViMeLa Project: An innovative concept for teaching mechatronics using virtual reality

Abstract. In this paper, we present joint European project ViMeLa, which is based on a blended-learning method using theory classes and virtual reality (VR) as experimentation tool. The idea to create Virtual Mechatronic Laboratory for learning and teaching students in Mechatronics, came from the University of Technology in Lodz, with participation of the Universities in Skopje, Pavia and Tartu. In the frame of the project, flexible solutions are developed. Three scenarios are part of the project, namely: design, construction and operating principles of electric motors; industrial automation solution for controlling the process of sorting packages in a warehouse; industrial and domestic waste sorting line with belt.

Streszczenie. W niniejszym artykule zaprezentowano projekt Wirtualnego Laboratorium Mechatroniki (ViMeLa) realizowany przez Politechnikę Łódzką, z udziałem uniwersytetów w Skopje, Pawii i Tartu. Projekt opiera się o metodę blended learning, łączącą tradycyjne metody nauczania z rzeczywistością wirtualną. W ramach projektu opracowywane są trzy różne ćwiczenia przedstawiające: budowę i zasady działania silników elektrycznych, wykorzystanie automatyki przemysłowej do sterowania procesem sortowania paczek w magazynie oraz linię do sortowania odpadów. (Projekt ViMeLa: innowacyjna koncepcja nauczania mechatroniki z wykorzystaniem rzeczywistości wirtualnej).

Keywords: Virtual reality, Interactive Environment in VR, Mechatronics, Electric machines, Sensors, Actuators.
Słowa kluczowe: Wirtualna rzeczywistość, interaktywne środowisko VR, mechatronika, maszyny elektryczne, czujniki, aktuatory.

Introduction

Nowadays, traditional education and teaching methods, although with significantly improved teaching techniques, can not keep enough interest of the students that grew up with Internet, mobiles and tablets. Especially sensitive to these issues are students in engineering, in particular, in mechatronics. Modern information technology is rapidly being adopted in Mechatronics Engineering education as a tool for enriching the practical experience of the students. The practical training is a vital part of Mechatronics Engineering education [1]. However, the high cost needed to implement laboratory experiments (for educational purposes) led to development of virtual facilities where physical systems can be virtually controlled via the *Virtual Reality* (VR) simulations. Multimedia and VR technologies offer great potential for presenting theory and laboratory experiments in an enhancing and interesting, but in an economical, way.

Teaching and learning Mechatronics

Mechatronics is synergy and interaction of mechanical, electrical and computer systems as seen in Fig. 1. Hence, it is an interactive combination of mechanical engineering, electronic control and computer technology, with the aim of achieving an ideal balance between mechanical structure and its overall control and performance.
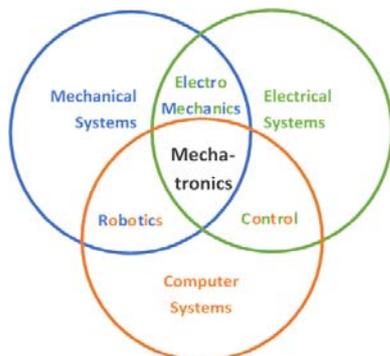

Fig.1. Structure and key elements of mechatronics

Currently, mechatronics classes are divided into two parts: the theoretical lectures and laboratory courses with experiments following the "*learning by doing*" model.

Expensive equipment and limited time for training do not provide sufficient educational platforms [2,3]. In some cases the students conduct based simulations and learn how mechatronic systems and devices operate in reality, despite it may seem abstract and unclear for students, and does not fully reflect the physical phenomena of particular processes.

The described drawbacks of mechatronics study are greatly improved when classroom teaching is supported by VR technology and VR tools. Virtual laboratories are inside these solutions. The students are able to visualize abstract concepts, to observe events at micro or macro scales, to visit various environments and interact with events and devices that usually due to place, time, or safety factor are unavailable. VR laboratory simulations provide an interactive experience. Users can move freely around the environment, interact with objects, carry out tests, and make decisions and mistakes, until they have mastered the subject. As a result, students and graduates are better able to master and apply in practice their knowledge.

ViMeLa Project

Recently numerous studies have shown the strengths of virtual reality use in the classroom. The most significant outcome is that students easy learn abstract concepts, as they can experience and visualize them in the virtual environment. Furthermore, VR facilities change the role of the teacher from a deliverer of knowledge into a facilitator who helps the students to explore and learn.

The idea to create a **Vi**rtual **Me**chatronic **La**boratory as an innovative tool for teaching and learning Mechatronics, came from the University of Technology in Lodz, supported by the University Ss. Cyril and Methodius of Skopje, University of Pavia and University of Tartu.

The concept

ViMeLa project is based on a blended-learning method using theory classes and VR as an experimentation tool that is more effective than purely face-to-face classes.

Three scenarios are parts of the project:
- Construction, operating principles and performance of electric motors;
- Industrial automation solution for controlling the process of sorting packages in a high storage warehouse;
- Waste sorting line with belt.

The innovation of the proposed concept lies in developing an original and novel mechatronic learning system, based on VR technology. The IT teams from iCV Lab from Tartu University and IMSI from Lodz University are responsible for development and creation a computer interactive environment – a factory as seen in Fig. 2, where the working spaces for the three scenarios are placed. The student can observe, enter and move through, with possibility to dynamical changes from scenario-to-scenario.

Fig.2. Factory hall created in ViMeLa project using VR

The achievements of project goals are primarily focused to three target groups:
- mechatronics graduates;
- universities and academics;
- business perspective.

## Scenario 1: Construction, operating principles and performance of electric motors

Development and implementation of the first scenario is under responsibility of Ss. Cyril and Methodius University. The exercise is divided in two parts, as described below.

Assembling of electrical motors

In this part of Scenario 1, in created VR environment, students will get familiar with properties of different types of electric motors, as well as their construction. The 3D motor models that are designed are based on authentic devices, according to their technical documentation.

The different 3D parts for various electric motors are placed on a shelf. The user will have a task to assemble a certain type of electric motor based on a selection defined for the exercise. This means that in order to realize the task the student will have to select from the shelf the appropriate 3D motor parts (stator, rotor with shaft, permanent magnets, housing, brushes, rotor bars etc.). After the assembling process is finished, using the VR tools, the completed motor will be checked and a grade will be given to the student. If the electric motor is not regularly put together, the user will have two more attempts to properly assemble the object. For the time being 3D parts are made for the following electrical machines: permanent magnet synchronous motor (PMSM), three phase induction motor, switched reluctance motor, DC commutator motor, permanent magnet DC commutator motor and permanent magnet generator.

The physical look of the major assembling parts, i.e. stator (a) and cage rotor (b), of an induction motor is shown in Fig. 3. The components of a switched reluctance motor created in VR environment, and a partly assembled motor are presented in Fig. 4 (a) and (b).
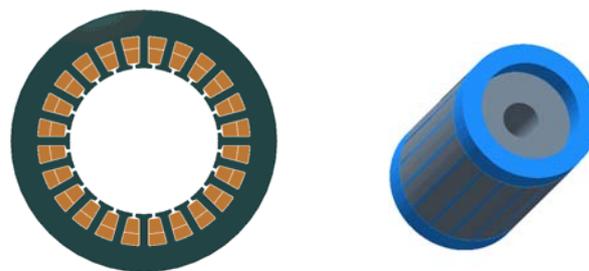
a) stator with windings   b) squirrel cage rotor

Fig.3. Main assembling parts of an induction motor
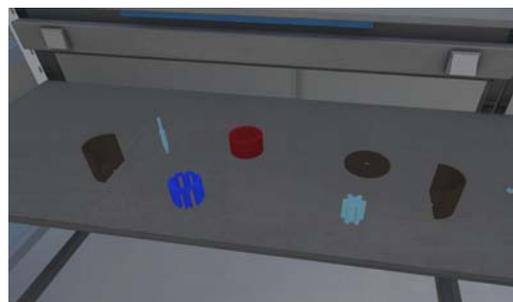
(a) components of the motor parts in VR look

(b) Partly assembled motor

Fig.4. Switched reluctance motor in VR environment

Investigation of operating principles of PMSM

In the second part of the Scenario 1 the user will be able to observe the working principles and to perform various investigations of a pre-defined model of permanent magnet synchronous motor – PMSM. In Fig. 5 the main parts of a permanent magnet synchronous motor are shown.
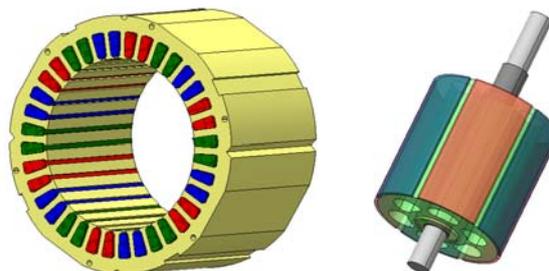
a) stator with windings   b) rotor with PM

Fig.5. Permanent magnet synchronous motor assembling parts

First of all, the student will have to place the tested motor on testing bench and make appropriate connections with power supply, control and adequate instrumentation. When the connections are realized, the user will get information whether the wiring is properly done or not. Here the user will also have two more attempts to realize the correct connections. After the connections are properly done the user can proceed to the investigation of operating principles of the studied PMSM at different working conditions, by changing voltage, frequency and load. The measured values of voltages, frequency, input currents, input power, speed and torque are presented on a display.

The VR testing environment will enable the user to also perform even a more hazardous investigation of the motor, such as an overload of the motor, for which the user will get a certain signalization of the problematic working condition. A proposed view of this testing bench is presented in Fig. 6.

Fig.6. The proposed testing bench for VR environment

Scenario 2: Industrial automation solution for controlling the process of sorting packages in a high storage warehouse

Lodz University of Technology is responsible for creation of an exercise presenting control in an industrial automation solution for sorting packages in a high storage warehouse. The goal is to familiarize the end users with the functional principles of industrial automation and the details of most important components necessary to control the process of sorting packages in a high storage warehouse. Through the course of this scenario, the students will learn about pneumatic actuator construction, rules for selecting proper pneumatic actuators for a particular task, and will be able to master the fundamentals of PLC programming.

The VR environment in this exercise, is a representation of the final part in the process of production and distribution of electric motors. The high storage warehouse (see Fig.7 and Fig. 8) where the motors are stacked, consists of: racks, lift platform, roller-belt conveyor, pneumatic cylinder for transferring the packages on the racks, device with electric drive for stacking and retrieving pallets on/from shelves, PLC controller with power supply board, several different sensors, actuators, and pneumatics components.
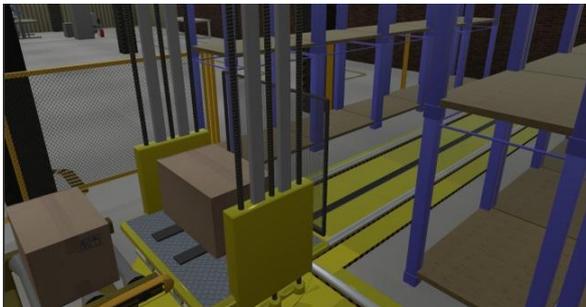

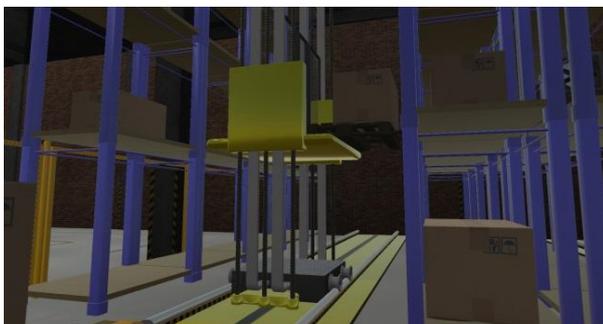Fig.7. Pulling off the package from roller conveyor to lift platform

Fig.8. Pushing the package from lift platform to warehouse shelf

Through the use of VR, students have the opportunity to interact with each element of the controlling line, learn about the construction of pneumatic actuators, operate the

sorting line, select proper sensors and assemble the sorting line from partial elements, while "being present" in a simulation of an actual working environment. Every actuator used in this exercise can be disassembled providing the possibility for the students to get acquainted with its construction. Each part has an attached description (containing the name, purpose, type of material, etc.) and can be viewed from any side or angle.

Moreover, it is possible to run a simple simulation of particular actuators working in a pneumatic system with solenoid valves and damping valves. During this simulation, the students have the possibility to adjust the force and speed of the piston and model the operation of the actuator with incorrect connection of the pneumatic system.

As mentioned before, all elements of the exercise are created in VR as interactive models. Including the PLC controllers. The user will be able to program the controller in VR using a ladder diagram (containing basic elements such as logic functions, slope detection, time blocks, counters, etc). The sorting line will be launched according to user's programming. The students will be able to individually assess the correctness of created programming and experience full scale effects of potential errors or misconfiguration. Additionally, this scenario includes states of emergency which may lead to equipment damage.

After learning the basics such as principle of operation, construction, types of components, students start to arrange the whole process by:
• selecting appropriate components for particular process;
• programming PLC controller i.e. to ensure appropriate packages sorting according to the certain conditions (color, size, etc.) and avoid collisions or unintentional stopping of the sorting line.

It is assumed that during learning process the students should experience positive and negative outcomes, while programming the controlling line. Negative outcomes assumed wrong programed PLC controllers or components selection. In this case, packages can for example fall, stack, push each other etc. In addition, to emphasise learning reacting to states of emergency the VR environment provides controls similar to the real world, i.e. buttons and switches are used for emergency shutdown or for manual mode, e.g. reversing the belt conveyor or the lift platform.

Scenario 3: A waste sorting line with belt

The University of Pavia is responsible for the creation and implementation of the Scenario 3, which consists of the model of a sorting line with belt.

This Scenario is composed of two sub-scenarios: Scenario A, domestic waste sorting line and Scenario B, industrial waste sorting line, respectively. The user can choose, at the beginning of the VR tutorial session, if sorting domestic waste or industrial waste.

The proposed Scenario A aims to build and use a waste sorting line, which should be able to segregate materials like plastic, glass and organic waste. On the other hand, in the Scenario B the user can sort other kind of materials like e.g. the ferromagnetic and the conductive ones.

The system is composed of sensors, actuators and a single belt, whose velocity is set *a* priori. The waste is assumed to exit from an automatized dispenser and falls on the belt. At the beginning of the tutorial session, the user has to design the sorting line, by choosing the sensors and actuators available in the library, and setting their position along the belt. The user has to set also the position of the containers for the various materials.

There is one magnetic actuator and two different kinds of sensors (an inductive one and a capacitive one). The user can set their properties like e.g. frequency and

magnitude of current or voltage. In order to make the Scenario working, the characterization of the sensors and actuators in terms of input-output transfer function is modelled by means of the Finite Element Models (FEMs).

Field models of sensors and actuators

The inductive sensor is able to detect conductive and ferromagnetic objects. The sensor is made of an iron-cored coil and a conducting screen [4]. The coil is supplied by AC voltage, with frequency ranging from 50 Hz to 100 kHz. When a conductive objective is in front of the sensor, the impedance of the coil becomes lower. In turn, when a ferromagnetic objective is in front of the sensor, the impedance of the coil becomes higher. The shape of the inductive sensor is shown in Fig. 9 (a) while in Fig. 9 (b) the flux lines obtained by means of FEM are represented.
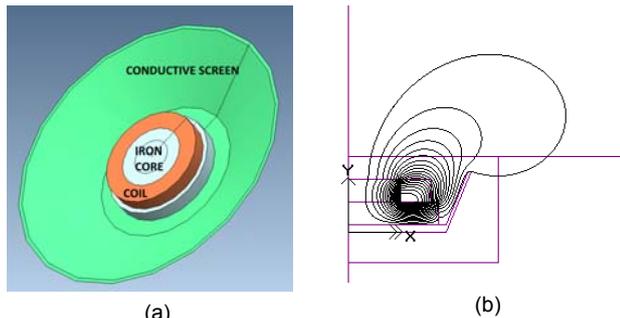

(a)　　　　　　　　　　　(b)

Fig.9. Inductive sensor: 3D geometry (a), magnetic flux lines (b).

The capacitive sensor is able to sense objects with different dielectric permittivity. The capacitive sensor consists of two electrode plates: one is grounded, the other is fed by an AC voltage. The piece of waste to be detected and sorted, should pass through these plates. When a dielectric objective is in the middle of the plates, the capacitance of the sensor becomes higher. The capacitive sensor has the aspect shown in Fig. 10 (a) and the relevant field map is shown in Fig. 10 (b).
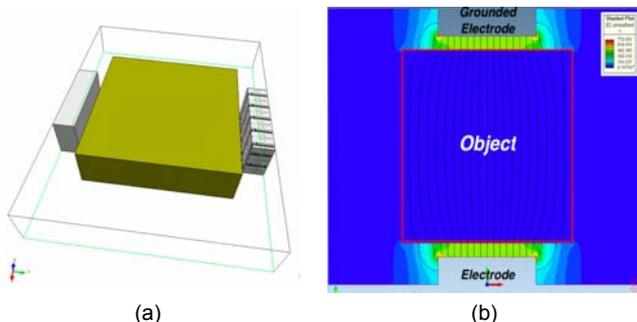

(a)　　　　　　　　　　　(b)

Fig.10. Capacitive sensor: 3D geometry (a), electric field map (b).

The actuator used in the sorting line with belt is an electromagnetic actuator. It is composed of a magnetic circuit and a coil. The cross-section of the 3D model of the cylindrical electromagnet along with the magnetic flux lines shown in Fig. 11 (a) and 11 (b), respectively.

When the current flows in the coil, the movable part of the actuator (in red in Fig.11a) is pulled inside the actuator (movement bottom-up in Fig. 11a) and hence the anchor (in green in Fig. 11a) pushes the piece of waste. In contrast, when the current is off, the movable part exits from the actuator (movement from up to down in Fig. 11a) and the anchor is retained inside it. The current pulse exhibits a trapezoidal shape and the user can set its rise time, duration, decay time and amplitude.

Once the behavior of sensors and actuators composing the sorting line is characterized by means of field models, it

is possible to identify the transfer function of each device, eventually helping the computer engineers of the IT team in programming the sorting line within the virtual mechatronics laboratory.
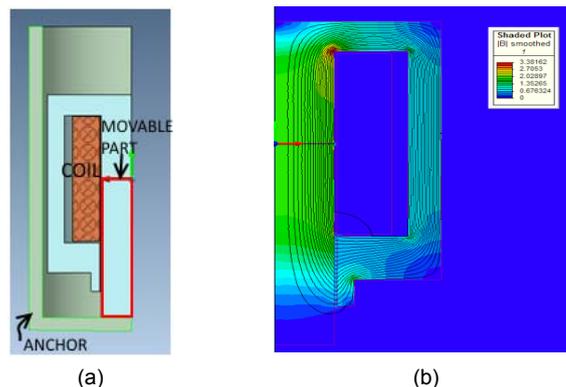

(a)　　　　　　　　　　　(b)

Fig.11. Electromagnetic actuator: cross-section (a), magnetic flux lines (b).

Conclusions

In today's digital world, finding new ways to teach students is more difficult ever. When technologies such as mobile phones, tablets and games consoles are highly advanced, finding educational engagement with modern technology in the classroom can be even harder. Hence, virtual reality has become an important and useful tool in engineering education.

The use of VR in teaching mechatronics provides a unique opportunity to create a truly exciting and engaging learning experience for students.

In the paper are presented main features of ViMeLa project, which intends to introduce an innovative concept of teaching mechatronics using virtual reality and to bring industry into classroom. *Entering* in an environment of a virtual factory, students will learn basics of mechatronics, experiencing three scenarios created in the frame of the project.

 Virtual Mechatronic Laboratory
http://vimela.p.lodz.pl/

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