# ViMeLa: Interactive Educational Environment for Mechatronics Lab in Virtual Reality

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Chapter 18

# ViMeLa

Interactive educational environment
for the mechatronics lab in virtual
reality

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## Introduction

Traditional education and teaching methods, although with significantly improved teaching techniques, cannot sufficiently keep the interest of the students that grew up with Internet, mobiles and tablets (Heradio, de la Torre, & Dormido, 2016). Especially sensitive to these issues are students in engineering, in particular, in mechatronics (Abulrub, Attridge, & Williams, 2011). 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 (Piovesan, Passerino, & Pereira, 2012). However, the high cost needed to implement laboratory experiments (for educational purposes) led to development of virtual facilities in which physical systems can be virtually controlled via Virtual Reality (VR) simulations (Brown & Green, 2016). Multimedia and VR technologies offer great potential for presenting theory and laboratory experiments in an enhancing and interesting but economical way (Anbarjafari, Haamer, Lüsi, Tikk, & Valgma, 2019; Kamińska et al., 2019).

Mechatronics is synergy and interaction of mechanical, electrical and computer systems (Wikander, Torngren, & Hanson, 2001), as seen in Figure 18.1. 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.

Currently, mechatronics classes are divided into two parts: 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 (Petrović, Nikolić, Jovanović, &
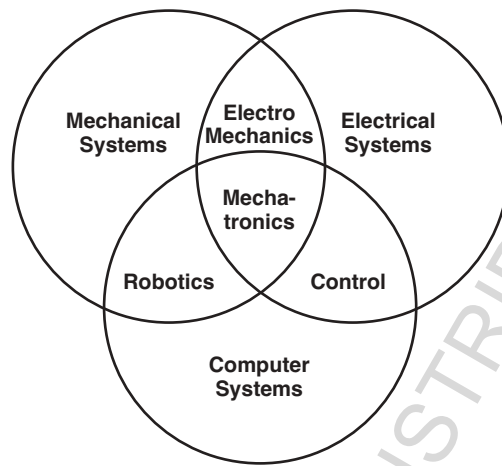
*Figure 18.1* Structure and key elements of mechatronics.

Potkonjak, 2016; Popescu, Stoian, Petrisor, & Popescu, 2015). In some cases, students simulate scenarios on the computer and only later learn how mechatronic systems and devices operate in reality. For some students this approach appears too abstract 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 a large part of 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 factors 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 their knowledge in practice.

## Use-cases of ViMeLa

The ViMeLa project proposes a solution for this problem by giving future students the opportunity to learn mechatronics concepts in an engaging and cost-effective environment. The project is based on a blended-learning method combining theoretical classes and VR as an experimentation tool that is more effective than purely face-to-face classes. The project consists of three unique scenarios:

1.  Construction, operating principles and performance of electric motors
2.  Industrial automation solution for controlling the process of sorting packages in a high storage warehouse
3.  Construction and tuning of an automatic waste sorting line

The innovation of the proposed concept lies in developing an original and novel mechatronic learning system, which is based on VR technology in a factory, as seen in Figure 18.2, where the working spaces for the three scenarios are placed. In these scenarios, students will be able to observe, enter and move around, with a possibility to make dynamical changes in each scenario.

The project is primarily meant for three target groups:

•   students of mechatronics
•   universities and other academic institutions
•   businesses seeking trained personnel

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

*Assembling of electrical motors:* In this part of Scenario 1, in a created VR environment, students will become 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 the task of assembling 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.).



*Figure 18.2* Factory hall created in ViMeLa project using VR.

After the assembling process is finished, using the VR tools, the completed motor will be automatically assessed, giving the students appropriate feedback. If the electric motor is not correctly put together, the user will have two more chances 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 components of a switched reluctance motor created in VR environment and a partly assembled motor are presented in Figure 18.3 (a) and (b).

*Investigation of operating principles of PMSM:* In the second part of Scenario 1 the user will be able to observe the working principles and to perform various investigations of a pre-defined model of PMSM.

First, the student will have to place the tested motor on the testing bench and make appropriate connections with a power supply, control and adequate instrumentation. When the connections are realized, the user will receive information on whether the wiring is properly done. 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 perform an even more hazardous investigation, such as an overload of the motor, for which the user will get a certain signalization of the problematic working condition.

## Scenario 2: Industrial automation solution for controlling the process of 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 the most important components necessary to control the process of sorting packages in a high storage warehouse. Through
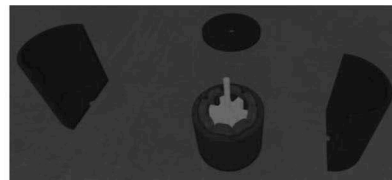


(a) components of the motor parts in VR look          (b) Partly assembled motor

*Figure 18.3* Switched reluctance motor in VR environment. (a) Components of the motor parts in VR look. (b) Partly assembled motor.

the course of this scenario, the students will learn about pneumatic actuator construction and 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, where the motors are stacked, consists of racks, a lift platform, a roller-belt conveyor, a pneumatic cylinder for transferring the packages on the racks, a device with electric drive for stacking pallets on and retrieving pallets from shelves, a PLC controller with power supply board and several different sensors, actuators and pneumatics components.

Through the use of VR, students have the opportunity to interact with each element of the controlling line, learn about the construction of pneumatic actu-ators, 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 an 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 elem-ents such as logic functions, slope detection, time blocks, counters, etc.). The sorting line will be launched according to the user's programming. The stu-dents will be able to individually assess the correctness of the created program-ming and experience full-scale effects of potential errors or misconfiguration. Additionally, this scenario includes states of emergency that may lead to equipment damage.

After learning the basics (e.g. principle of operation, construction, types of components), students start to arrange the whole process by

- selecting appropriate components for particular process;
- Programming the PLC controller (i.e. to ensure appropriate package sorting according to colour, size, etc.) and avoid collisions or uninten-tional stopping of the sorting line.

It is assumed that the students should experience positive and negative outcomes while programming the controlling line. Negative outcomes include wrongly programed PLC controllers or component selection. In such a case, packages can fall, stack, push each other etc. In addition, to emphasise learning to react to

states of emergency, the VR environment provides controls similar to those in the real world (i.e. buttons and switches 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

This scenario is composed of two sub-scenarios: Scenario A, domestic waste sorting line and Scenario B, industrial waste sorting line. The user can choose, at the beginning of the VR tutorial session, to sort domestic waste or industrial waste. Figure 18.4 illustrates the overview of scenario 3.

Scenario A aims to build and use a waste sorting line able to segregate materials like plastic, glass and organic waste. In Scenario B the user can sort other kinds of materials (e.g. the ferromagnetic and the conductive materials).

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 set their positions along the belt. The user has to set the position of the containers for various materials.

There is one magnetic actuator and two kinds of sensors (inductive and capacitive). The user can set their properties (e.g. frequency and magnitude of current or voltage). In order to make the Scenario work, the characterization of the sensors and actuators in terms of input–output transfer function is modelled with Finite Element Models.



*Figure 18.4* An overview of the waste sorting scenario for the ViMeLa project.

## Field models of sensors and actuators

The developed scenario has two types of sensors: an inductive sensor for ferro-magnetic and conductive objects and a capacitive sensor that senses dielectric permittivity. The former must be implemented with a frequency between 50Hz to 100kHz. When a conductive objective is in front of the sensor, the impedance of the coil becomes lower. In turn, when a ferromagnetic object-ive is in front of the sensor, the impedance of the coil becomes higher. The sensor in VR mimics these sensing lines using three basic 3D shapes. The resulting sensor field is not completely realistic, but in terms of the scenario it performs enough like real-life to be used as a realistic approximation.

The capacitive sensor is able to sense objects with different dielectric per-mittivity. The capacitive sensor consists of two electrode plates: one grounded and the other fed by 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.

As with the inductive sensor, the capacitive sensor uses three detection fields in order to mimic realistic detections. The fields are spaced out based on size and model detection areas for 20%, 50% and 100% actual capaci-tance. The capacitive sensor has three changeable parameters:

- the applied voltage of the electrode (V)
- the frequency of the source (f)
- the number of electrode plates (m) m=1,2,3.

This sensor can be described using a linear transfer function shown in (1). In it, the three aforementioned variables are defined by the user while the rest are defined by the scenario. This allows the sensing current (eqn. 1) to be derived based on the capacitance of the detected material.

$$I = \frac{V}{\left|\frac{1}{j\omega C}\right|} = V2\pi fC[\text{A}]. \tag{1}$$

The current that capacitive sensor is capable of detecting should be in the following range (eqn 2):

$$50[\mu A] \leq I \leq 10[mA]. \tag{2}$$

By considering that the capacitance in our project is changing in the range $[1.64 \times 10^{-12}, 9.31 \times 10^{-12}]$ [F] and the voltage is changing from 100 mV to 20V, the current will be in the range of 10.33 mA to 23.4 mA. By consid-ering the feasible range of current based on (2), for output current in the range of 10.33 mA to mA, the current is not in the detectable range, so no

output signal is generated. In the range of 10 mA to 23.4 mA, the sensor will experience overcurrent and can be damaged in real life. To mimic this the virtual sensor first trips an alarm and over time will cease to function. This means only a current in the range of will be detected and sent forward to the actuators. To accommodate for the wide ranges and magnitudal differences in the adjustable ranges, the scales in the scenario are logarithmic.

Scenario 3 is based on a tangible task of sorting waste into different containers. The scenario is set up as a mini factory with a waste conveyor belt, electric actuators, capacitive and inductive sensors as well as a waste generator. The main task for the student is to set the parameters for the sensors (current, frequency, voltage) determining the sensor field, delays between detections and the travel time of the detection signal to a specific actuator. This exercise provides a basic understanding of capacitive and inductive sensor parameters along with an applied overview of how a simple sorting line functions. During the VR tutorial session, a user may choose to practice on Scenario A or Scenario B, but during tasks these will be predefined by the instructor.

## Development

The most relevant concern during discussions for the scenario were centralized around the differences between real and virtual worlds. These issues were primarily centred around hardware limitations and general optimization questions: Do we have realistic detection fields, proper theoretical current calculation models, photorealistic visuals and component-accurate models?

For any given exercise, a far more important task was a realistic detection algorithm. It is possible to develop a VR world without a realistic setting and physical parameters. For instance, if there is glass bottle, then the object could just have a tag that indicates it as such. Passing this in front of a sensor would then yield a binary detection that would travel to an actuator, which pushes the object. This would heavily optimize the application side but would not be realistic enough for the given environment. The detection should instead be dependent on capacity, inductivity, distance, sensor frequency, voltage, orientation and so on. Thus, the largest portion of the workload was devoted to developing a close to real life approximation of different material parameters and sensor functionalities.

As in the real world, students need to configure sensors and parameters with the utmost care in the virtual one. The main difference in the two is that in the virtual one, overloading sensors or causing edge case scenarios will not result in a costly mistake and can instead be used for learning.

## Platform

The project was developed in the Unity3D game engine. This choice provided several advantages in the visual aspects as Unity already contains an optimized rendering engine. Despite the advantages, the models still had to be developed externally. The hardware that we used is the HTC Vive headset with two standard controllers. This limited our means of interaction with the scenario, removing the sense of weight and touch. The student would thus lose the ability to tell components apart solely based on how they felt in their hand and would instead have to rely on the visual appearance of the object alone.

In an ideal case, the factory would look as close to realistic as possible with correct models, textures, lights and ambiance, but are all of these required to perform and learn a task? Modern students have grown up with high quality games with stunning visuals, and this can create expectations for any virtual world, even those meant for learning. In the scope of the exercise it has low importance, which means it is not wise to spend too much energy on visuals, but the application still has an obligation to leave a good first impression. From the point of view of completing an exercise, it is essential to create an intuitive enough system for a student to instantly understand it and enter intended values for a given setup or to tune the parameters of a conveyor system. In the end a balance was found between the realistic nature of the scenario and its intuitive user interaction system.

## Scene components

The system is composed of sensors, actuators, sorting bins, a conveyor belt, a waste dispenser and the waste itself. Each of the components has its own custom models and behavioural logic. The waste is comprised of domestic and industrial components. Each kind of waste contains appropriate capacitive and inductive information the sensors can detect.

The waste will be placed on the belt by the automatic dispenser and will be removed from the scene if it enters one of the sorting bins. The scenario starts with the user being given a task of designing the general structure of the sorting line. This consists of sensor and actuator placement as well as the setting up of their interconnections. These components will be available on a virtual shelf and can be created at will if any of them is lost in the scenario.

The actuators in the scenario serve the purpose of moving trash items from the belt into the trash bins. The actuators have configurable push distances and speeds, but these will not play a huge roll in the scenario setup. The main functionality stems from the signal delay between the sensor and actuator.

The belt speed will determine the time it takes different objects to pass by the sensors and actuators; this is important as, without trial and error, the belt speed will determine the delays the students will have to design. In
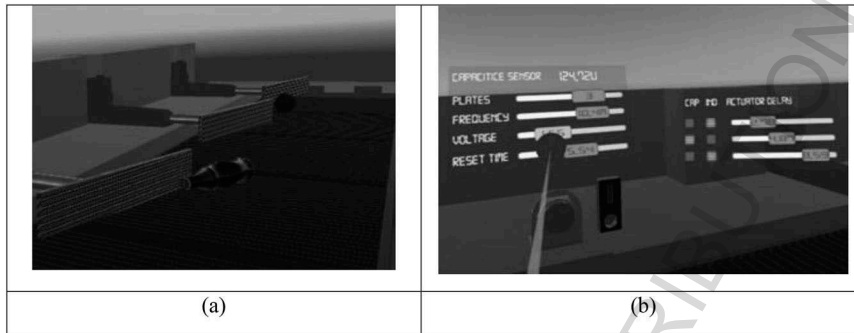
|      (a)      |      (b)      |

*Figure 18.5* Actuators on the conveyor line. (a) Capacitive sensor with adjustable parameters (b) Framework of the Evaluation tool Results of the evaluation.

order to further solidify this fact, the speed of the belt as well as the trash dispensing speed will vary between exercises. During training, however, both the dispensing and belt speeds will be adjustable by the user.

Due to their complexity, the actuators and sensors come with their own parametrized logic. The task for the user is to adjust the parameters for each of these components to complete the provided sorting task. The user will have to adjust not only the sensor to actuator signal timings, but also the exact voltage and frequency levels for each sensor. Incorrect parameter initialization can cause unintended actuator activations, detections to not occur or damage to the virtual sensors, which will incur a fail state. Figure 18.5 illustrates the actuator and sensor adjustment views.

The waste containers serve the purpose of waste removal from the scene as well as a grading mechanism based on the number of correctly sorted objects. Their locations will be adjustable by the user but can also be predefined in order to increase the complexity of a given scenario.

## Conclusions

In today's digital world, finding new ways to teach students is more difficult than ever. When technologies such as mobile phones, tablets and game consoles are highly advanced, finding educational engagement with modern technology in the classroom can be even harder. Hence, VR 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. The chapter presents main features of the ViMeLa project, which intends to introduce an innovative concept of teaching mechatronics using VR and to bring industry into

the classroom. In a virtual factory, students will learn the basics of mechatronics, experiencing three scenarios in the frame of the project.

## Acknowledgements

## References

Abulrub, A. H. G., Attridge, A. N., & Williams, M. A. (2011, April). Virtual reality in engineering education: The future of creative learning. In *2011 IEEE Global Engineering Education Conference (EDUCON)* (pp. 751–757). IEEE.

Anbarjafari, G., Haamer, R. E., Lüsi, I., Tikk, T., & Valgma, L. (2019). 3D face reconstruction with region based best fit blending using mobile phone for virtual reality based social media. *Bulletin of the Polish Academy of Sciences: Technical Sciences. 67*(1), pp. 125–132.

Brown, A., & Green, T. (2016). Virtual reality: Low-cost tools and resources for the classroom. *TechTrends*, *60*(5), 517–519.

Heradio, R., de la Torre, L., & Dormido, S. (2016). Virtual and remote labs in control education: A survey. *Annual Reviews in Control*, *42*, 1–10.

Kamińska, D., Sapiński, T., Wiak, S., Tikk, T., Haamer, R. E., Avots, E., Anbarjafari, G. (2019). Virtual reality and its applications in education: Survey. *Information*, *10*(318), 1–20.

Petrović, V. M., Nikolić, B., Jovanović, K., & Potkonjak, V. (2016, June). Development of virtual laboratory for mechatronic systems. In *International Conference on Robotics in Alpe-Adria Danube Region* (pp. 622–630). Cham: Springer.

Piovesan, S. D., Passerino, L. M., & Pereira, A. S. (2012). Virtual reality as a tool in the education. *International Association for Development of the Information Society*.295–298.

Popescu, D., Stoian, V., Petrisor, A., & Popescu, R. (2015). Virtual engineering for mechatronics laboratory. In *2015 Proceedings of 6th International Conference "Computational Mechanics and Virtual Engineering" (COMEC)* (pp. 316–322). 15–16 October 2015, Braşov, Romania.

Wikander, J., Torngren, M., & Hanson, M. (2001). The science and education of mechatronics engineering. *IEEE Robotics & Automation Magazine*, *8*(2), 20–26.