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Modelling and simulation: adaptation of educational processes to epidemic measures

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Abstract

Over the last year, the pandemic of COVID-19 has changed the educational processes immensely, and the studies at the Faculty of Electrical Engineering, University of Ljubljana, are no exception. In the paper, the situation before the winter semester of the academic year 2020-21 is described and also the three expected scenarios concerning the realization of the subject Modelling methods. The experience with the realization of educational processes is analyzed. Despite difficulties, the implemented solutions were positively accepted by the students. Therefore, many of the adaptations introduced will also benefit educational processes in the future.

Keywords: Modelling; Simulation; Blended Learning; Distance Learning; Projects;

1. Introduction

After the introduction of Bologna studies at the Faculty of Electrical Engineering, University of Ljubljana (FE-UL), we have organized the educational processes at three levels, where each academic year is evaluated with 60 credits of the European credit transfer and accumulation system (ECTS). Enrolment in each of the three levels is limited by different rules.

Students can start the Master's program if they have successfully completed undergraduate or higher professional studies of the first degree amounting to at least 180 ECTS credits in the field of electrical engineering or mathematical or technical sciences and have successfully passed the entrance exam. Eight different fields of study are available for admitted students, one of which is *Control systems and computer engineering*. In the first semester of this field of study, all students must also attend the course entitled *Modelling methods*. It is evaluated with 6 ECTS credits which means that it represents a burden for the student of 150 to 180 hours. They are divided into the so-called contact and non-contact hours. The contact hours are organized in the form of lectures in the amount of three hours per week and laboratory exercises in the amount of two hours per week, which means that additional five to seven hours per week must be realized by students through the so-called non-contact hours of study.

Some of the main objectives of the subject *Modelling methods* are:

- to present the interdisciplinary nature of modelling and some of the accompanying activities;
- to present selected approaches to modelling and also to evaluate their effectiveness in relation to various factors;
- to present a systematic approach to the construction, simplification and/or extension, analysis, verification and evaluation of designed models;
- to present the linearization of mathematical models and the appropriate interpretation and use of linearized models in comparison to

corresponding nonlinear models and in comparison with real systems operating in open loop or in closed loop;
- to present model optimization;
- to present/use selected software environments for computer interpretation and solving of models (computation with models, simulation, graphical models interpretation);
- to present professional and research approaches to modelling; and
- to prepare students for independently carrying out research projects and providing appropriate presentation and interpretation of the results.

It is expected that the knowledge acquired will enable the following:

- the application of a systematic approach to solving problems through modelling;
- the application of theoretical, experimental and combined approaches to modelling real systems, which includes the appropriate and justified selection of input signals;
- the application of analytical and simulation experiments with linear and nonlinear models and the performance of mutual comparisons;
- the determination of properties of dynamic mathematical models;
- optimization of mathematical models using conventional methods and global (especially evolutionary) algorithms;
- quantitative and qualitative evaluation of the developed models.

Due to the epidemic, the students are forced to work remotely, which imposes some serious challenges. The paper presents some proven solutions for adapting the educational processes to epidemic measures that have been implemented in the case of the subject Modelling methods, which usually requires a rather hands-on approach. The paper is structured as follows. Firstly, three main scenarios of educational processes are presented in relation to different expected levels of the Covid-19 epidemic in Slovenia. In the third section, the hardware and software equipment is described, indicating also some identified problems and introduced adaptations. In the fourth section, a blended learning approach is presented, where projects introduced at the beginning of a semester enabled the realization of different educational goals. Finally, the conclusions summarize some important observations and point out ideas for improving future work.

2. Different scenarios of educational processes

Regarding the number of infected and hospitalized patients with COVID-19 disease, the government defines the rules every week, which also affect the implementation of educational processes. In September 2020, before the new academic year that starts in Slovenia on October 1, the numbers of infected and hospitalized patients started to increase again. It was clear that different scenarios were possible:

- Normal educational and research processes, where the faculty door is open to all.
- Completely closed faculty, where almost all activities are conducted online.
- Different levels of hybrid work, where some of the staff and some of the students can work at the faculty and the others work remotely. Of course, the number of people allowed in rooms, classrooms, or laboratories is always the variable that depends on the temporary epidemic level.
- Additional issues that are also very important and influence all the decisions in education are the regulatory measures that dictate the operation of public transportation and the opening of dormitories.

At the faculty level, additional strategy criteria related to educational processes were taken into account: it was, obviously, more important to have laboratory exercises than lectures at the faculty, and also lectures for younger (especially first year) students at the undergraduate level. Thus, special and flexible timetables were also created at the Faculty to take these measures into account.

3. Hardware and software equipment

At the Laboratory of Control Systems and Cybernetics at FE-UL, we have several pilot plants as are presented in Figure 1.

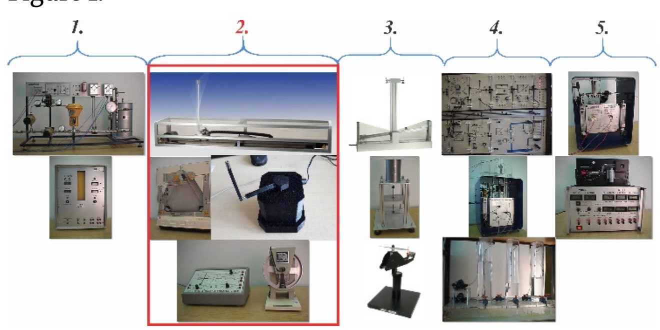

Figure 1. Groups of laboratory pilot plants: 1. Pneumatic systems 2. Electro-mechanical systems (stable-unstable) 3. Electro-mechanical systems (unstable) 4. Hydraulic systems 5. Thermal systems.

They mimic various real-world dynamic systems and are used for educational and research purposes, including modelling. These plants can be divided into different groups (see Figure 1). An important aspect to be considered in education is their time constants, as the duration of laboratory exercises is very precisely limited. Looking at the situation in Figure 1, the fastest group is pneumatic systems (1.), followed by electro-mechanical devices that can operate as stable pilot plants (2.) and those that are unstable (3.). These are followed by hydraulic (4.) and the slowest, thermal systems (5.).

Regarding the course *Modelling methods* we have chosen the 2nd group of pilot plants, not only because they allow a very suitable experimentation time, but also because different modelling approaches can be studied (theoretical, experimental, combined, using electrical equilibrium laws, Newton's laws ...), but also same more advanced (such as Lagrange equilibrium equations (Woods and Lawrence, 1997)), which are not usually treated at the undergraduate level. This is an important aspect, as some of our students have basic knowledge in the field of modelling and simulation (Cellier and Kofman, 2006; Kulakowsky et al., 2007; Ziegler et al., 2000).

It is important to mention that, at the same time, this is also a problem in terms of conducting educational processes, because students have graduated from the first level in different faculties and it is to be expected that some of them are not familiar with simulation and system theory, while the others are. The differences in the knowledge of the students from the first level pose a special and additional challenge every year for the organization of educational processes as well as for the selection of the subject chapters.

All the mentioned pilot plants are connected to a personal computer via A/D and D/A converters (see Figure 2). It is important to mention that we have decided to use MATLAB program (students can also use the campus version installed on their own computers) as it is very suitable for many courses in the field of *Control systems and computer engineering*. Thus, an additional element was added in the Simulink library to enable communication with the converters. In this way, the user can carry out the experiments with the pilot plant in the same way as with the developed models, which significantly shortens the gap between theory and practice and is very time-efficient.

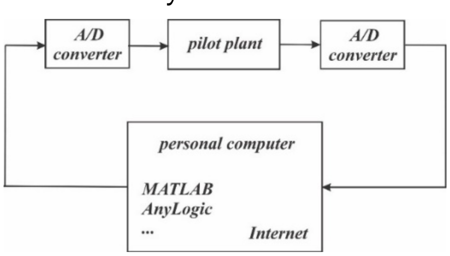

Figure 2. Connection of pilot plant and personal computer.

For *Modelling methods*, AnyLogic (AnyLogic, 2021) (and sometimes Stella (Stella, 2021)) is also used, but students are encouraged to study (as is described below) and to test also other programs that are appropriate for modelling and simulation purposes.

In addition, we have developed a great number of functions and files in MATLAB called LABI, which stands for LABoratory of mathematIcal models of SISO and MIMO systems (Atanasijević-Kunc et al., 2011a; 2011b; 2018; 2020) intending to support educational processes. All files are organized through a user-friendly graphical interface. The starting LABI window for *Modelling methods* is shown in the upper-left part of Figure 3.

This, as well as the other windows of the interface, are similarly organized. The upper part (name of the figure) contains the name of the file that generated the window (in this case *mm_a.m*). Buttons in the lower frame enable to finish work (*end*), return to the higher level (*return*) of the interface (if possible) and to observe information regarding the current level (*info*).

The buttons in the middle part can be active or inactive. Pressing the active buttons performs prepared actions. If the buttons are not active, there are two possibilities: the data needed for the selected action does not exist in the MATLAB workspace or the indicated files are still in the development phase.

The buttons in the first two columns and the first two buttons in the third column are directly related to chapters of the course that are presented through the lectures and the last three buttons of the third column for a very brief introduction to MATLAB, Simulink, and Control System Toolbox, illustrated with several examples. We have also developed the so-called *Analysis Toolbox*, which can be used if a model is defined in the workspace, either as an LTI single-input-single-output (SISO), or a multivariable (MIMO) system (Atanasijević-Kunc et al., 2011a; 2011b; 2018; 2020). This toolbox is divided into four levels (see the first four buttons in the last column in the upper-left part in Figure 3).

The last button in the fourth column (*students*) opens an additional graphical windows with prepared buttons that can be used by students to organize, in a systematic and transparent way, their solutions, prepared through laboratory exercise time or independent work.

4. Blended learning in the form of project work and competition

Although understanding of blended learning is not entirely uniform, it is usually assumed to include e-learning or online delivery methods in addition to established face-to-face forms of education (Kavitha and Jaisingh, 2018; Kintu et al., 2017; Kiran and Dangwal, 2017; Weerasinghe, 2018). But of course, several important factors influence the effectiveness of traditional learning, as well as all variations of blended learning forms (Kintu et al., 2017; Weerasinghe, 2018). In this context, so-called flipped learning approaches are sometimes introduced (Kim and Ahn, 2018; Tsai and Chu, 2019) to increase students' interest and motivation for more engaged work. Many experiences prove (Atanasijević-Kunc et al., 2011a; Logar et al., 2011; Matko et al., 2001) that different levels of competition can additionally increase students motivation to study effectively. Taking into account mentioned possibilities and the uncertain situation regarding the epidemic of COVID-19, we have prepared the following scenarios.

At the beginning of the semester, lectures start, if possible at the faculty, otherwise online, using MS

Teams or Zoom (different combinations of face-to-face and online lectures were also planned). Furthermore, our colleagues at FE-UL have developed an e-learning platform, which is now well accepted by the faculty staff and students enabling many classical forms of education materials delivery, different forms of teaching approaches and realization of exams, etc.

Laboratory exercises are usually postponed for a few weeks to allow sufficient material to be presented. We have decided to organize an introductory and refreshment course in simulation and system theory for the interested students during this time. In this way, the load of study hours is suitable, but it is expected that the differences in terms of prior knowledge will be reduced. As additional support, written materials and a large number of examples were also prepared and arranged in the LABI environment. The interest was very good and allowed to significantly reduce the differences in the knowledge of the students.

In addition, we decided to organize laboratory exercises in the form of project work (see Figures 3 and 4). For motivation purposes, the projects were introduced at the beginning of the semester through lectures, indicating also several aspects of the applicability of the materials presented through lectures.

Laboratory exercises are usually organized in smaller groups, with students working in teams of two to three people. In the current academic year, two cycles of laboratory exercises were realized. Two projects have been prepared for each team, as is illustrated in Figure 3.

4.1. The first project

The first project is related to the modelling of an electro-mechanical pilot plant (see previous section). In both cycles, the same five pilot plants were selected (see Figure 3) with the goal that the modelling results of two teams, one from each cycle, can be compared and discussed. In short, the objectives of the first project were defined in the following way:

Each team has to develop several mathematical models of the corresponding pilot plant suitable for control-design purposes (Egeland and Gravdahl, 2002):

- One mathematical model, a nonlinear one, should be a very good description of the system behavior in the whole operating range.
- Two different operating points have to be chosen and two linearized models have to be designed for the chosen points.
- Appropriate comparisons of the developed models' responses are expected (qualitative and quantitative) with respect to the pilot plant measurements.
- The properties of the observed system must be presented (poles, zeros, time constants, etc.) and how they depend on the operating points.

Here it is important to distinguish between two scenarios. If the exercises are carried out in the laboratory, the students have direct access to the pilot plant. Their task is to define and generate suitable input signals so that the output signals can support the theoretical modelling results. However, we also need to consider the other situation where the students cannot come to the faculty. Therefore, we have prepared a set of measurements for each of the pilot plants and included them in the LABI environment, which is the starting point of the combined modelling approach. An example, namely for the pilot plant that can operate as a crane (imitating a loading bridge) and as an inverted pendulum, is shown in Figure 4. Two sets of measurements were prepared for this plant. The first one was performed without the pendulum, and the second one with the pendulum, which also indicates gradual model development. Some of the prepared measurement results are described below.

4.1.1. Experiment 1.1

When *Experiment 1* is pressed in the first group, the measurements are plotted as shown in Figure 5. In the upper part of the figure, the input voltage signal applied to the crane motor is presented, while in the lower part, three responses of motor movement are illustrated. In addition, the average value is calculated and shown with red colour. It is clear that the repeatability of the experiment, in this case, is very good, but it is important to mention that this is not the case in all pilot plants. Furthermore, the crane rail has a limited length, which is also evident from the presented experiment. All important facts regarding each of the prepared experiments can be accessed by pressing the *info* button at the observed experiment level.

4.1.2. Experiment 2.1

When the button *Experiment 1* in the second group is pressed, the results are plotted as shown in Figure 6. The same input signal is used as in the experiment 1.1, but in this case, two responses are measured: cart displacement $x(t)$ and pendulum angle $\Phi(t)$.

4.1.3. Experiment 2.2

When the button *Experiment 2* in the second group is pressed, the results are plotted as shown in Figure 7. Here, both system responses to pendulum initial condition are illustrated (Φ_{IC}=90°).

4.1.4. Experiment 2.3

When the button *Experiment 3* in the second group is pressed, the results are plotted as shown in Figure 8. Also, in this case, the identical input was realized three times and corresponding responses are presented in the bottom two figures. The input signal influenced the pendulum through the cart movement in such a way that the pendulum rotated for 360° around the equilibrium point seven to eight times. The repeatability was slightly worse in this experiment.

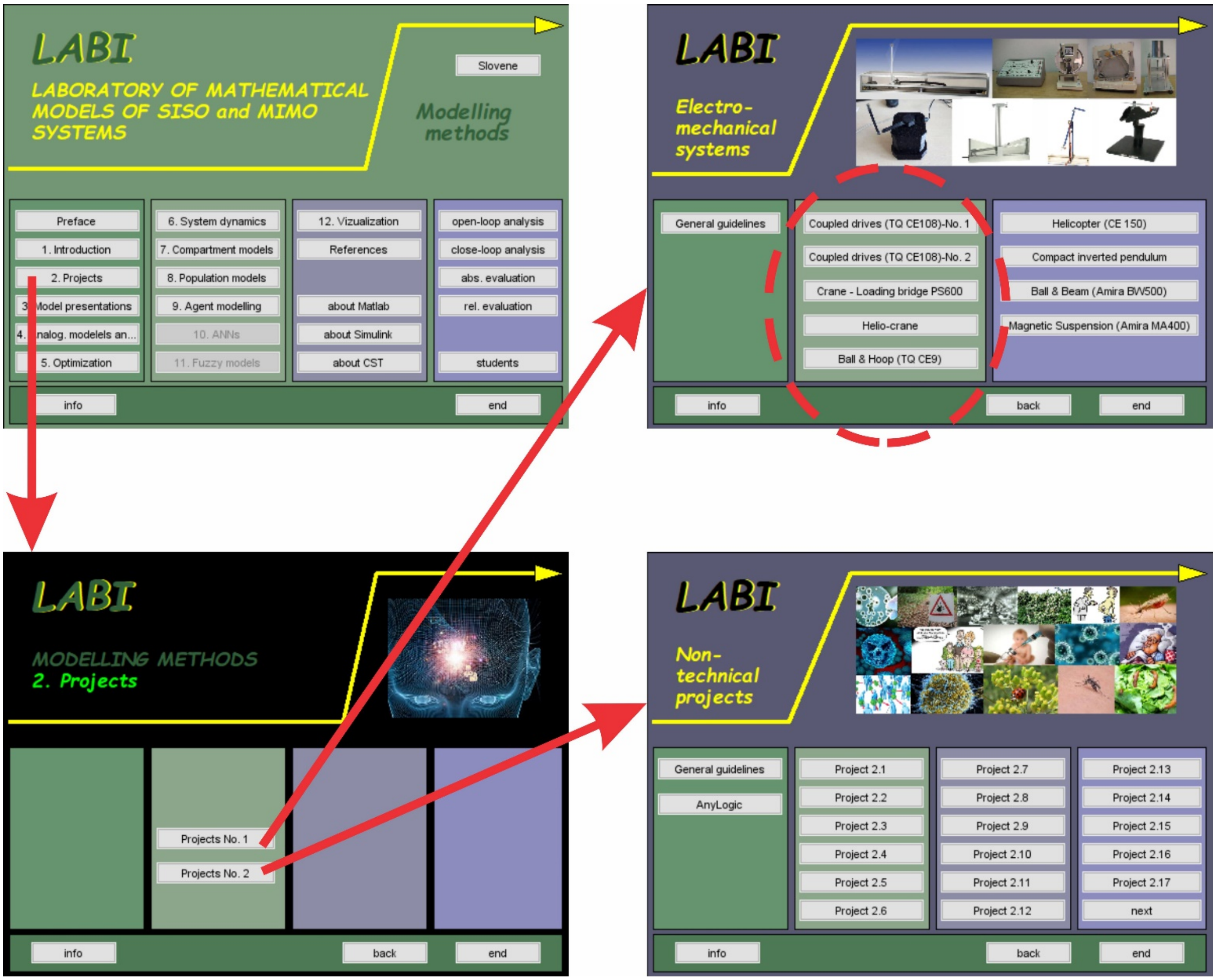

Figure 3. Access to information regarding two groups of students' projects: Electromechanical system modelling and Nontechnical system modelling.

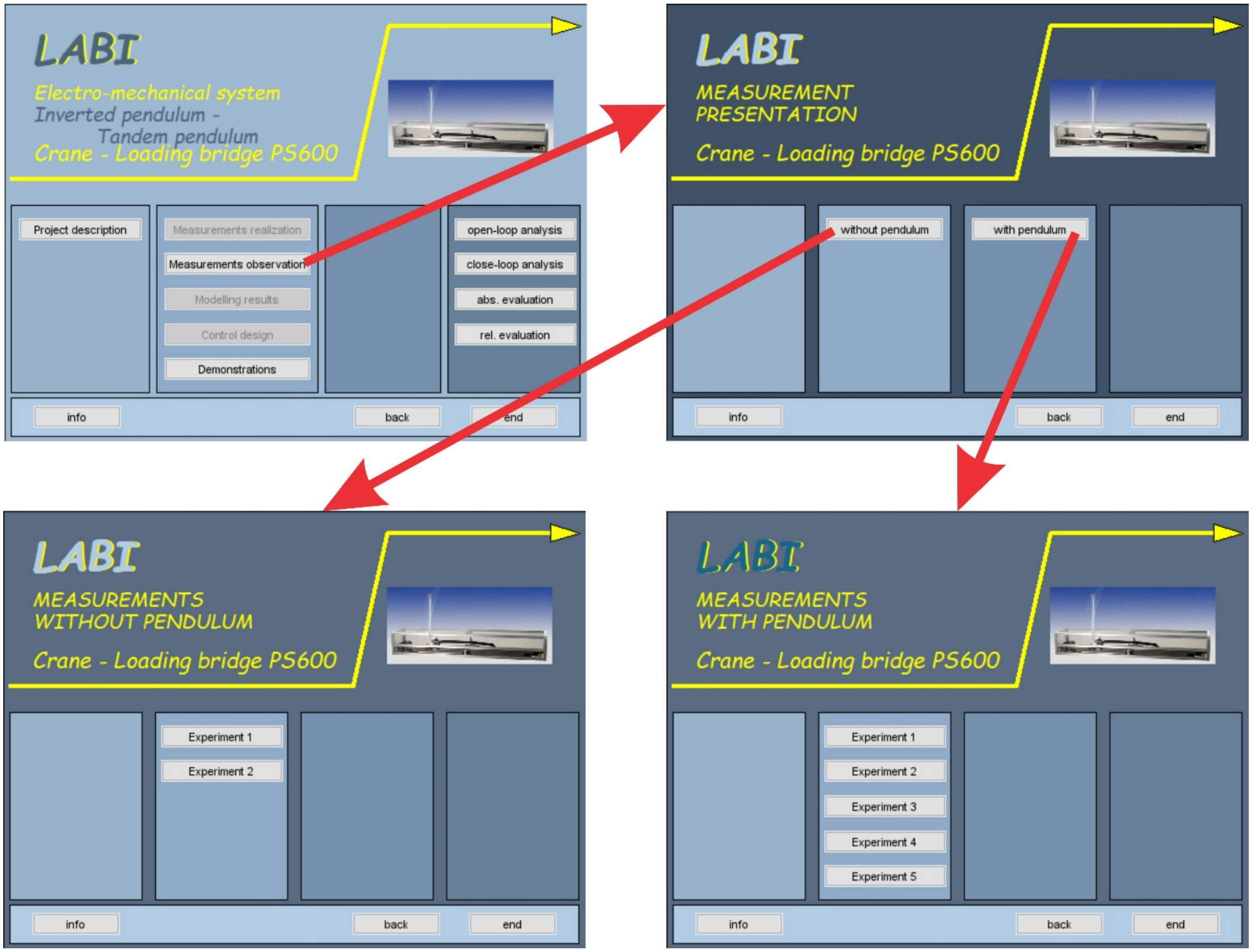

Figure 4. Prepared experiments for the pilot plant Inverted pendulum – Crane can be observed by pushing corresponding buttons in LABI environment windows.

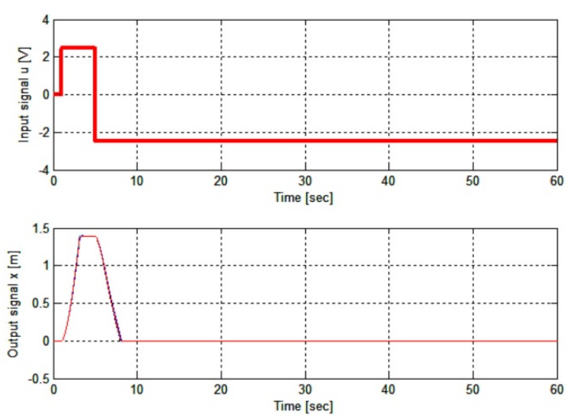

Figure 5. Experiment 1.1.

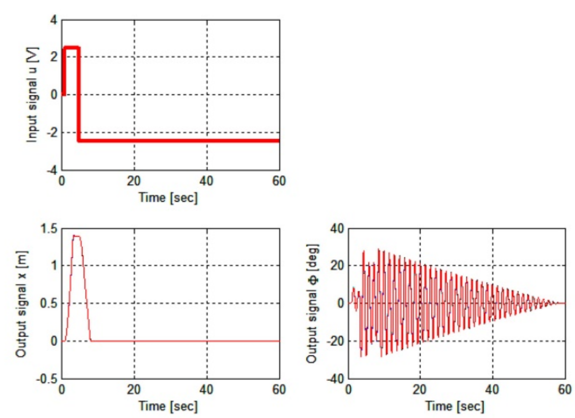

Figure 6. Experiment 2.1.

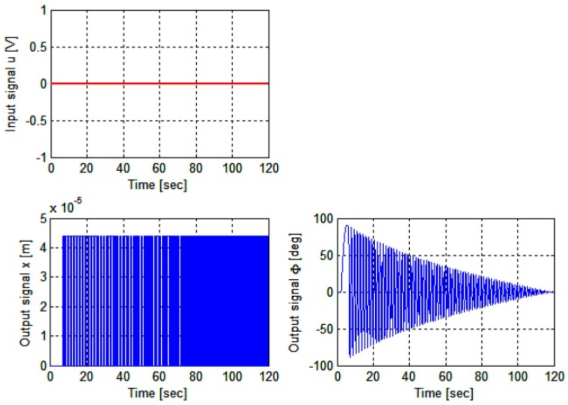

Figure 7. Experiment 2.2.

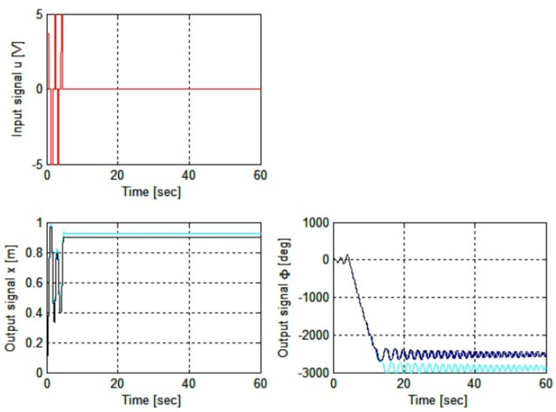

Figure 8. Experiment 2.3.

4.2. The second project

The second, nontechnical project was introduced to showcase also the modelling challenges, where data is usually not as dense as in the technical domain. Hence, analogies can be very helpful. In such situations, approaches presented through System Dynamics (Forrester, 1961) are frequently proposed. A large number of different titles were prepared and described from which problems could be selected (see Figure 3), but each team was also allowed to propose their own topic. Unlike the first project, the title of the second one was different for each group. In addition, students had to find all the necessary information necessary for chosen modelling problem, keeping in mind the principles of obtaining reliable data. Some very interesting problems were addressed among which are the following:

- Influence of COVID-19 on the study of electrical engineering;
- The impact of climate changes on coffee production;
- COVID-19 epidemic and its impact on employees in various industries;
- Environmental impacts on the beetle population in Slovenia;
- Bacterial resistance to antibiotics and some worrying consequences.

In the middle of the semester, all teams were required to prepare a short presentation of their findings, problems and likely additional experiments and/or additional information needed. The comments and discussions of teaching staff and peers provided an important guide for improving future work.

4.3. Students' presentation of the results

At the end of the semester, all teams were required to prepare a written report of both projects, accompanied by the designed files, and orally present their solutions, where also theoretical questions regarding the treated materials could be expected.

In addition, the quality of nonlinear models of the teams working with the same pilot plant was compared to pilot-plant responses acquired by the staff using a representative input signal according to predefined criteria. The team that designed a better model was rewarded with additional points contributing to a better final exam mark.

It had turned out that the faculty was to be closed during the whole semester. Therefore, teaching was realized using MS Teams for communication and presentation purposes, while access to additional experiments with the pilot plants was realized through VPN –communication, remote desktop applications (Tight VNC) and additional assistance from the staff.

It is important to mention that the best teams were invited to further improve their work and participate in the conference entitled Automation in industry and economy which was organized in Maribor in Slovenia. There, a student session was organized and the response was very good, as three teams (Černe et al., 2021; Kodele and Trampuž, 2021; Langerholc and Ljubi, 2021) took part in the mentioned competition session. Unfortunately, due to the epidemic, this conference also needed to be realized online.

5. Conclusions

Due to COVID-19 epidemic, all educational processes regarding the subject *Modelling methods* were realized online. We implemented e-learning FE-UL support, MS Teams, Matlab and the developed LABI Toolbox, including a large set of demonstration examples, measured signals describing the operation of the pilot plants used, Analytic Toolbox, AnyLogic, along with VPN connection and remote desktop applications (Tight VNC) allowing additional experiments with selected pilot plants. The laboratory work was organized through project work. The key advantages of these projects are:

- they enable (self)-verification of the students' knowledge and the presented materials;
- they motivate students to learn important aspects of professional and research work;

- and they teach students how to present the results of their work in written and oral form.

If the results of projects are very good and innovative, students are invited to participate in various conferences. This contributes to the educational process and additionally motivates qualitative study.

In the future, additional efforts will be given to different possibilities of remote experiments with pilot plants. Moreover, several solutions that were forcedly implemented due to the epidemic were proven quite successful and were favourably accepted by the students. Therefore, such solutions can benefit educational processes in "normal" times as well.

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