Available online at www.sciencedirect.com

ScienceDirect

IFAC PapersOnLine 56-2 (2023) 332–335

Control Education: TC 9.4 Developments and Vision

Antonio Visioli *

* *Dipartimento di Ingegneria Meccanica e Industriale, University of Brescia, Italy*
e-mail: antonio.visioli@unibs.it

Abstract: The covid-19 pandemic has forced all the teachers to rethink control education by exploiting modern technologies. Further, the always increasing availability of computational tools and of resources in the web is a great opportunity for both instructors and students as it facilitates the sharing of best practices and, ultimately, the implementation of personalized learning approaches. Thus, this is really an important time to discuss the future developments of control education. In this paper we outline the different initiatives and discussions of the IFAC Technical Committee 9.4 on Control Education, who has elaborated many ideas in this context. They are related to different concepts involved in the whole control education framework and it is therefore believed that they will be very useful to improve the teaching activities of the IFAC members.

Keywords: Control education, control resources, control curriculum, diversity and inclusion.

1. INTRODUCTION

The covid-19 pandemic has revolutionized the teaching modalities all over the world and forced us to think about new pedagogical approaches to improve the learning of the students. Indeed, there is now the awareness that traditional frontal lectures can be, if not completely substituted, at least enriched in order to provide the students not only with a solid theoretical background, but also with those soft skills (e.g. problem solving, team working, adaptivity, learning capabilities, communication, etc.) that are fundamental to face more and more complex engineering systems. This is also nowadays made much easier by the availability of computational tools that can be fruitfully exploited for this purpose.

In this context, the IFAC Technical Committee 9.4 on Control Education plays a major role in fostering the development of ideas and initiatives to support this change and, in general, to help teachers and students to achieve their educational goals as better as possible. In particular, the technical committee aims at developing new methodologies and tools for teaching control topics effectively at all levels (K-12, high school, undergraduate, postgraduate, continuous learning) and for the promotion of control, of its societal importance, and of its multidisciplinary nature.

In this paper the main initiatives and ideas recently developed in the TC9.4 are outlined and briefly discussed so that the IFAC scientific community can be more involved in education and new contributions can be stimulated. It is worth stressing that the concepts described hereafter have emerged from different sources like surveys, presentations and panels at the last IFAC Symposium on Advances in Control Education and in special sessions organized in other conferences and thanks to the cooperation with the Technical Committee on Control Education of the IEEE Control Systems Society.

2. CONTENT OF THE FIRST CONTROL COURSE

A survey open to the whole automatic control community has been conducted in 2019 and 2020 in order to define which are the main topics that should be addressed in a first and unique control course at a university level. Preliminary results have been described in (Rossiter et al., 2020b, 2019b,a), while a complete presentation has been reported in (Rossiter et al., 2020a). Although it is obvious that different choices should be made depending on the overall career of the student, there is the general feeling that in a first control course the mathematical details should be reduced and the main focus should be on the power of the feedback concept, by giving to the students motivations, examples, etc. In other words, it is essential to broaden the student's horizon by illustrating the many different methodologies and applications in the field, so that the so-called "hidden technology" (Åström, 1999) is revealed. Of course, some mathematical background should be given anyway (for example, Laplace transforms to model the dynamics of simple systems as a transfer function) and it is important that the students be able to design and/or to understand simple controllers. In this context, PID control is thought to be very relevant because it still plays a fundamental role in industry.

Overall, the teaching approach should exploit the use of computational tools in order to help the student to focus on the main concepts rather than on possibly tedious calculations. Further, also thanks to the availability of many resources (see next sections), traditional lectures can be substituted with other teaching approaches that follow best practices already well established in the control education community (Rossiter et al., 2018).

3. CONTROL RESOURCES

In the last years there has been a huge growth of resources that are available on the web and that can be fruitfully exploited as learning tools. A survey has been launched last year with the aim to collect the most relevant ones related to possible topics of the first control course. Preliminary results have been illustrated in (Rossiter, 2021) (Rossiter et al., 2022). In general, these resources can be categorized as shown in the next subsections.

10.1016/j.ifacol.2023.10.1589

3.1 Videos

For obvious reasons, the covid-19 pandemic has caused an increment of videos that are available on the web. There are videos on many topics and they can be roughly subdivided in two categories: video lectures and animated videos. The latter ones, usually, are shorter and deal with a specific topic. It is worth noting that the use of videos allows flipped classrooms (Rossiter, 2020). In general, this large availability makes also self-learning much easier and this poses new challenges to instructors who are called to redefine their activity in order to give a real added value to the students.

3.2 Interactive tools and apps

In recent years, interactive software tools have been demonstrated to be very valuable in helping students to understand many control concepts, such as linearization (Guzmán et al., 2012a), Nyquist criterion (Costa-Castello et al., 2013) system identification (Ávarez et al., 2013; Guzmán et al., 2012b, 2014; Rivera et al., 2015), feedforward control (Guzmán et al., 2011b), dead time compensators (Normey-Rico et al., 2009), fractional control (Dormido et al., 2012). In fact, with such tools, the result obtained when the control system is changed (for example, one controller parameter is modified) is immediately visualized. In this way the physical meaning of the controller parameters can be fully understood by the student and the consequences of different design choices as well as of modifications of the process dynamics can be clearly explained by the instructor (Dormido, 2004; Guzmán et al., 2013). Different software packages can be used to implement an interactive tool, for example Matlab/Simulink (Krasnansky and Kozakova, 2012), Modelica (Zakova and Cech, 2018), SIMIT (Ruiz et al., 2015), Easy Java Simulations (Sánchez et al., 2005) and Sysquake (Guzmán et al., 2016, 2011a).

Moreover, the massive use of mobile phones and portable devices has also stimulated the creation of apps (see, for example, (Pauli et al., 2020)) that can increase the flexibility of the learning process. Most of all, apps allow the instructor, during a lecture, to give simple problems to the students to be solved immediately in the classroom and to have therefore an instantaneous feedback if the current topic has been well understood so that corrective actions can be immediately taken.

3.3 Remote and virtual laboratories

Laboratories are essential in enhancing the learning process for students. Indeed, as the "learning by doing" concept expresses very well, people acquire knowledge and skills if they are also involved in practical experiences, rather than only passively listening to an instructor explaining different notions. This is also summarized by the old adage "Tell me, I'll forget. Show me, I'll remember. Involve me, I'll understand.". Further, laboratories allow students to connect theory and practice. Nowadays, the availability of fast Internet connections has allowed teachers to go beyond traditional hands-on laboratories where students are close to the real plant and the controller is connected to it. In fact, the access to real or virtual (simulated) plants can be shared through the web (de la Torre et al., 2019). The kind of laboratories that are nowadays available are therefore typically classified as local or remote according to the way the resources are accessed (through the Internet in the latter case) and as real or virtual (if they are simulated in the latter case). Regarding virtual labs, the main difference between a local and a remote one is that a remote one allows multiple users to access the resource at the same time. In general, each kind of laboratory has its own advantages and disadvantages. Remote labs (with real instrumentation) can be shared between different institutions and are, in principle, available 24 hours a day and 7 days per week. This implies a reduction of the costs, as the exploitation of the resources can be optimized (although maintenance and safety costs are still present and should be taken into account) (de la Torre et al., 2016). However, the main advantage of remote (and virtual) labs is, of course, that students can avoid travelling to a particular location and save time. Besides, the experiment can be made whenever is needed. Further, people with disabilities can access the environment with personalized interfaces in order to fully learn from the experience. Virtual labs are in general less expensive and, in spite of having the disadvantage that physical issues can be overlooked by students (for example, performing an experiment in the real world might take hours, while in a simulation environments it can take a few seconds), they have the advantage that students can choose the pace to perform the laboratory experience and can analyze signals that are not available in the real world. It is very important that, for virtual and remote labs, the graphical user interface be properly designed for the student to fully understand the results of the experiments. Next steps in the developments of virtual and remote labs are a more intensive use of gamification tools (to make this kind of resources more appealing for the students), the integration of haptic devices to make the virtual experience closer to a real one, and a more extensive use of mobile devices as clients so that the user can really connect to the lab at any time and from any place.

3.4 Take-home kits

In spite of all the previously mentioned benefits of virtual and remote labs, traditional hands-on laboratories are still very important because with them students can better perceive the complexity of the real world, they can build their own setup (thus gaining some experience about the hardware issues) and, in general, they can better understand the role of the instrumentation in a control system. However, this kind of laboratories can be too expensive for a single institution and the space they require might not be available. For this reason simple and inexpensive take-home kits have been recently developed (Hedengren et al., 2019; de Moura Oliveira et al., 2020). They are flexible (namely, they can be used to experiment different control methods) and, although they are not real industrial setups, they pose those technical problems that are encountered in practical applications.

4. BENCHMARK PROBLEMS

In addition to being helpful for the scientific community to test and compare design methodologies, benchmark problems are widely recognized to be a valuable means to engage students and to make them work on real industrial problems (even though only simulated). In fact, benchmark systems are also effective in reducing the gap between theory and practice (Eriksson, 2019). They can be employed to make the students work in team and to stimulate them to design new control solutions, so that their problem solving skills can be improved. Another possible use is to make competitions in international conferences in order to attract the participation of master and PhD students (Morilla, 2012; Bejarano et al., 2018). A wide variety of benchmark problems have been created in the last decades, but there is always the need to make new ones related to different fields of application and with different levels of complexity, so that teachers can select the most suitable one for their specific purpose. Obviously, their online availability is essential to promote their use.

5. EXERCISES

In a learning process, the solution of exercises is also very important. As for the other resources previously mentioned, the availability of a repository where exercises can be collected is therefore highly desirable. Their classification is however really challenging as exercises might differ because of their topic, of their difficulty and also of their kind (for example, they can be quizzes with multiple choices or problems to be solved with paper and pencil, or with a software tool, etc.). There are also different aims for which an exercise can be used. It can be used by the student for self assessing their understanding of a given topic, they can be proposed by the instructor in order to obtain a feedback on the students' comprehension or they can be used for exams at the end of the course.

The examination process also deserves a thorough discussion because, if properly done, it allows the results achieved by the students to be used as a feedback measure in order to improve the teaching process. For this purpose it is useful to investigate the use of taxonomies to assess the different learning outcomes (for example: Knowledge, Comprehension, Application, Analysis, Synthesis, Transfer) (Lichtenberg and Pangalos, 2022). This implies that suitable exercises should be available also for these different levels, which means that the collection of this resource is really complex and deserves to be carefully discussed in the community.

6. DISCUSSION

The control education community is very lively and its members are very aware that education plays a key role in our society. The COVID-19 pandemic has had a great impact on teaching modalities, making students aware that there are other options than the traditional frontal teaching. In this context, students have realized more clearly that there is a great availability of web resources that can be fruitfully exploited. Indeed, this is also a clear advantage for instructors, who have a wide range of tools to improve their efficacy. It is therefore possible to set a new learning paradigm where personalized control courses can be given, depending on the needs of each student. While this is surely positive because the optimal learning process can be applied, in principle, to each student, this also requires that the role of the teachers is rethought because they have to select the best choices in the vast ocean of the available resources (for example by creating "journeys" (Douglas, 2022)). Thus, in addition to continuously creating and improving educational tools, there is the urgent need to organize and classify them (according, for example, to the required background, their goal, etc.) so that they are really usable.

An important remark is that this scenario is really useful from the diversity and inclusion point of view. Indeed, the previously mentioned resources such as videos, remote and virtual labs, and inexpensive take-home kits make possible a significant improvement in the learning process of people with specific learning disorders or disabilities. From another point of view, they can serve as a social elevator for students who have low incomes to have the opportunity of an appropriate education to boost their career.

7. VISION

In the next few years TC9.4 will foster the activities in the fields outlined above in order to support instructors and students in the change from traditional frontal lectures to personalized control education. This means that control courses will be easily tailored to the specific needs of the students and according to the societal challenges they are going to face. In order to make future engineers able to deal with more and more complex systems, the learning process should provide a deep knowledge of the topic but should also include problem solving exercises, team work, and other well-known soft skills. This requires educational tools that can be easily updated and reconfigured, but they should be also classified efficiently so that the most appropriate tool for a specific need can be easily found.

The efforts of the TC will be made in cooperation with the vice-chairs for education of the other IFAC TCs, with the IAC education liaison and with the new Education Structure that is going to be created in order to make education more relevant within the scientific community.

8. CONCLUSIONS

In this paper the main current activities of the IFAC TC on Control Education have been outlined. They give the vision of the TC about the main directions of the future developments of control education. In general, control courses can be redesigned by taking into account the wide availability of resources that facilitates the application of personalized learning paradigms. However, the main challenge is to classify, organize and make these resources easily usable.

It is worth stressing that only some aspects have been analyzed (for example, educational tools related to robotics have been neglected) but it is believed that this paper can be useful to stimulate a discussion in the control community, because the societal impact of education is also important in addition to the relevance of scientific research.

ACKNOWLEDGEMENTS

The author is grateful to the vice-chairs and to all the members of the IFAC TC9.4 as well as to all the other colleagues involved in control education, for all the discussions and the initiatives carried out on the topic, which are always a source of inspiration for the automatic control scientific community.

REFERENCES

Åström, K.J. (1999). Automatic control - the hidden technology. In P.M. Frank (ed.), *Advances in Control: highlights of ECC'99*. Springer, London.

Ávarez, J., Guzmán, J., Rivera, D., Berenguel, M., and Dormido, S. (2013). Perspectives on control-relevant identification through the use of interactive tools. *Control Engineering Practice*, 21(2), 171–183.

Bejarano, G., Alfaya, J.A., Rodriguez, D., Morilla, F., and Ortega, M.G. (2018). Benchmark for PID control of refrigeration systems based on vapour compression. *IFAC-PapersOnLine*, 51(4), 497–502. 3rd IFAC Conference on Advances in Proportional-Integral-Derivative Control PID 2018.

Costa-Castello, R., Guzmán, J., Berenguel, M., and Dormido, S. (2013). An interactive cad tool to teach and learn nyquist criterion. In *IFAC Proceedings Volumes (IFAC-PapersOnline)*, volume 10, 55–60.

de la Torre, L., Sánchez, J.P., and Dormido, S. (2016). What remote labs can do for you. *Physics Today*, 69, 48–53.

de la Torre, L., Chacon, J., Chaos, D., Dormido, S., and Sánchez, J. (2019). A master course on automatic control with remote labs. *IFAC-PapersOnLine*, 52(9), 48–49. 12th IFAC Symposium on Advances in Control Education.

de Moura Oliveira, P., Hedengren, J.D., and Rossiter, J. (2020). Introducing digital controllers to undergraduate students using the tclab arduino kit. *IFAC-PapersOnLine*, 53(2), 17524–17529. 21st IFAC World Congress.

Dormido, S. (2004). Control learning: present and future. *Annual Reviews in Control*, 28, 115–136.

Dormido, S., Pisoni, E., and Visioli, A. (2012). Interactive tools for designing fractional-order PID controllers. *International Journal of Innovative Computing, Information and Control*, 12(7), 4579–4590.

Douglas, B. (2022). Resourcium. `https://resourcium.org/`.

Eriksson, L. (2019). An overview of various control benchmarks with a focus on automotive control. *Control Theory and Technology*, 17, 121–130.

Guzmán, J., Costa-Castello, R., Dormido, S., and Berenguel, M. (2011a). Study of fundamental control concepts through interactive learning objects. In *IFAC Proceedings Volumes (IFAC-PapersOnline)*, volume 44, 7286–7291.

Guzmán, J., Costa-Castello, R., Dormido, S., and Berenguel, M. (2012a). Interactive tools to learn basic concepts of nonlinear systems linearization through a case study. In *IFAC Proceedings Volumes (IFAC-PapersOnline)*, volume 9, 66–71.

Guzmán, J., Costa-Castello, R., Dormido, S., and Berenguel, M. (2016). An interactivity-based methodology to support control education: How to teach and learn using simple interactive tools [lecture notes]. *IEEE Control Systems Magazine*, 36(1), 63–76.

Guzmán, J., Dormido, S., and Berenguel, M. (2013). Interactivity in education: An experience in the automatic control field. *Computer Applications in Engineering Education*, 21(2), 360–371.

Guzmán, J., Hagglund, T., Aström, K., Dormido, S., Berenguel, M., and Piguet, Y. (2011b). Feedforward control concepts through interactive tools. In *IFAC Proceedings Volumes (IFAC-PapersOnline)*, volume 44, 6361–6366.

Guzmán, J., Rivera, D., Berenguel, M., and Dormido, S. (2014). ITCLI: An interactive tool for closed-loop identification. In *IFAC Proceedings Volumes (IFAC-PapersOnline)*, volume 19, 12249–12254.

Guzmán, J., Rivera, D., Dormido, S., and Berenguel, M. (2012b). An interactive software tool for system identification. *Advances in Engineering Software*, 45(1), 115–123.

Hedengren, J.D., Martin, R.A., Kantor, J.C., and Reuel, N. (2019). Temperature control lab for dynamics and control. In *2019 AIChE Annual Meeting*.

Krasnansky, R. and Kozakova, A. (2012). State space control design: An interactive tool for control education. In *IFAC Proceedings Volumes (IFAC-PapersOnline)*, volume 9, 78–83.

Lichtenberg, G. and Pangalos, G. (2022). Constructive alignment by portfolio exams for an advanced control master module. *IFAC-PapersOnLine*, 55(17), 194–199. 13th IFAC Symposium on Advances in Control Education ACE 2022.

Morilla, F. (2012). Benchmark for PID control based on the boiler control problem. *IFAC Proceedings Volumes*, 45(3), 346–351. 2nd IFAC Conference on Advances in PID Control.

Normey-Rico, J., Guzmán, J., Dormido, S., Berenguel, M., and Camacho, E. (2009). An unified approach for DTC design using interactive tools. *Control Engineering Practice*, 17(10), 1234–1244.

Pauli, P., Koch, A., and Allgöwer, F. (2020). Smartphone apps for learning progress and course revision. *IFAC-PapersOnLine*, 53(2), 17368–17373. 21st IFAC World Congress.

Rivera, D., Guzmán, J., Berenguel, M., and Dormido, S. (2015). Understanding closed-loop identification with ITCLI. In *IFAC-PapersOnLine*, volume 48, 739–744.

Rossiter, A., Serbezov, A., Visioli, A., Zakova, K., and Huba, M. (2020a). A survey of international views on a first course in systems and control for engineering undergraduates. *IFAC Journal of Systems and Control*, 13.

Rossiter, J. (2020). Blended learning in control engineering teaching; an example of good practice. *IFAC-PapersOnLine*, 53(2), 17252–17257. 21st IFAC World Congress.

Rossiter, J. (2021). Resources to support a first course in feedback, dynamics and control. In *Proceedings of the 2021 European Control Conference, ECC 2021*, 1739–1744.

Rossiter, J., Pasik-Duncan, B., Dormido, S., Vlacic, L., Jones, B., and Murray, R. (2018). A survey of good practice in control education. *European Journal of Engineering Education*, 43(6), 801–823.

Rossiter, J., Visioli, A., Serbezov, A., Douglas, B., Hedengren, J., and Zakova, K. (2022). Open access resources to support learning of control engineering. In *Proceedings of the 2022 European Control Conference, ECC 2022*, 1902–1907. London, UK.

Rossiter, J., Zakova, K., Huba, M., Serbezov, A., and Visioli, A. (2019a). A first course in feedback, dynamics and control: Findings from an online pilot survey for the IFAC community. In *Proceedings of the 12th IFAC Symposium on Advances in Control Education, ACE 2019*, 15–20. Philadelphia, USA.

Rossiter, J., Zakova, K., Huba, M., Serbezov, A., and Visioli, A. (2019b). A first course in feedback, dynamics and control: Preliminary findings of a survey for the IFAC community. In *Proceedings of the 18th European Control Conference, ECC 2019*, 3065–3069. Naples, I.

Rossiter, J., Zakova, K., Huba, M., Serbezov, A., and Visioli, A. (2020b). A first course in feedback, dynamics and control: Findings from 2019 online survey of the international control community. In *Proceedings of the 21st IFAC World Congress*, 17264–17275. Berlin, D.

Ruiz, A., Jimenez, J., Ruz, M., Dormido, S., and Visioli, A. (2015). Interactivity-based control education: Some experiences at the University of Cordoba. In *IFAC-PapersOnLine*, volume 48, 37–42.

Sánchez, J., Dormido, S., and Esquembre, F. (2005). The learning of control concepts using interactive tools. *Computer Applications in Engineering Education*, 13(1), 84–98.

Zakova, K. and Cech, M. (2018). Design of control education interactive examples via web service for openmodelica. In *Proceedings 13th APCA International Conference on Control and Soft Computing, CONTROLO 2018*, 242–246.