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Open access resources to support the first course in feedback, dynamics and control

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Abstract: The Technical Committees for Control Education of IFAC and IEEE have started a collaborative initiative to collect, curate, and disseminate high quality freely available resources that support instruction of the first control course for undergraduate students in engineering and applied sciences programs. An initial survey with limited distribution provided 64 resources that cover all topics in a typical introductory control curriculum. This paper gives an initial glimpse of the resources collected thus far. It also suggests possible ways for categorization and dissemination.

Keywords: Engineering education, Automatic control curriculum, E-learning in control engineering, Open access resources in automatic control, Automatic control virtual learning environments.

1. INTRODUCTION

In many engineering programs the first course in feedback, dynamics and control is the only one on the topic. Its numerous objectives present a significant challenge for teaching. Instructors must strike the right balance between fundamental theory and practical application, such that students are equally well prepared for subsequent advanced control courses or entry-level industrial positions. Even though the first control course varies in its specifics between engineering disciplines, a common core of topics was identified in a recent large-scale survey of the international control community, (Rossiter et al. 2019, 2020a, 2020b). The survey was conducted by the Technical Committees for Control Education of IFAC (2021) and IEEE (2021). The common core topics and their suggested depth of coverage are shown in Table 1.

In addition to content, course design and delivery methods are essential for good learning outcomes, Rossiter et al. (2018). The control education community has come to a consensus long time ago that interactive computational or modeling tools as well as virtual or remote laboratories significantly improve student learning, e.g., Dormido et al. (2012), Brinson (2015), de la Torre et al. (2016), Rossiter (2017), Moodley (2020). Another instructional tool that has become widespread in recent years is video in various forms: screencasts, lecture recordings, animations. Videos were the backbone of remote instruction during the COVID pandemic. Pre- and post-pandemic, videos have been used in a variety of blended learning environments and indeed have become an expected resource in all lecturers' provisions, Kirkley and Kirkley (2005), Eryilmaz, (2015), Dart et al., (2020).

A number of individual instructors and university groups have produced high quality resources to support the learning and teaching of control related courses and many of these are freely available to share e.g., MIT (2021), Douglas (2021), Albertos (2021), Staehle, (2017), Khan (2012). Nevertheless, despite the availability of these resources, one impediment to their wide-spread adoption and use has been the lack of an organized repository where users could search for and obtain the resources easily.

A centralized and well-organized repository of learning resources promotes benchmarking and provides impetus for instructors to reevaluate their own courses. It stimulates the adoption of best teaching and learning practices by allowing instructors to share and reuse tried and tested tools. Benchmarking works for students as well. They are encouraged and motivated to go beyond the content of their own course curriculum in their quest to match the skills of their peers around the globe.

The benefit of a curated repository of free online resources extends further than academia. It serves practicing engineers to refresh on fundamentals or prepare for licensure examinations, such as the PE Control Systems Engineering exam, NCEES (2021).

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Table 1. Common core topics in the first control course.

- Signal Processing
  - Signal processing and impact of measurement (Awareness Only)
  - Delays and dead time (Awareness Only)
- Identification and Modelling
  - Modelling of simple systems, 1st and 2nd order (Fine Detail)
  - Laplace and transfer functions (Fine Detail)
  - Block diagrams (Minimal Detail)
  - State space models (Minimal Detail)
  - Modelling from real data (Awareness Only)
- System Analysis
  - Stability (Good Detail)
  - Frequency response (Minimal Detail)
  - Bode diagrams (Awareness Only)
- Control Design
  - Feedback loop concepts, definitions, and hardware components (Good Detail)
  - PID (Good Detail)
  - Control loop requirements (Awareness Only)

The need for a repository of learning resources is well accepted, but how to produce and maintain one is still an open question. An IFAC project over the 2017-2020 triennium looked in more detail at how a repository could be developed and maintained, unfortunately with the conclusion in IFAC council that this was unaffordable in any format that they were comfortable to own. It is likely that the high cost was linked to a desire to host all the resources themselves. In an alternative and much cheaper model the resources are hosted by their original authors and the repository simply provides curation and pointing, Douglas (2021)

While alternatives for curation and distribution of resources are being sought and discussed, the IFAC and IEEE Technical Committees for Control Education are continuing to collect high-quality resources to support the instruction of the first control course. This paper discusses the latest progress towards this goal and gives a summary of the resources that have been gathered so far through a survey of the international control community. Section 2 provides early results from the survey. Section 3 describes the interim management of the identified resources. Section 4 gives additional details for selected resources.

2. EARLY RESULTS FROM THE SURVEY

2.1 Survey Questions and Participation

The survey is created with Google Forms. It is deliberately concise with the aim of capturing only high-level information. For each submitted resource, the survey requests the following information:

1) Title for resource

2) URL address

3) Topic (from a provided checklist)

4) Type of resource (laboratory, video, notes, code, etc.).

5) Language

6) Rules for usage (free, registration, etc.).

7) Additional information.

As of December 2021, information on 64 resources has been submitted.

2.2 Types of Resources

The intent of the "Type of Resource" classification was to facilitate the curation of the resources The following choices were provided:

- Virtual, remote, or take-home laboratory
- Simulation, animation, interactive example
- Video presentation
- Lecture notes, tutorials, student assignments
- Computer code for student use
- Other

The survey responses for the resource type are summarized in Figure 1. Unfortunately, as for simplicity, the survey did not provide specific definitions for the types. Consequently, many entries received more than one classification. For example, interactive simulation resources were frequently also classified as virtual labs. Figure 1 suggests that the survey produced 14 resources for virtual, remote, or take-home labs, but upon inspection, only 2 of the resources truly fitted that category. Thus, Figure 1 is not a true representation of the content of the submitted resources. A better classification of the resources is provided in Section 4.

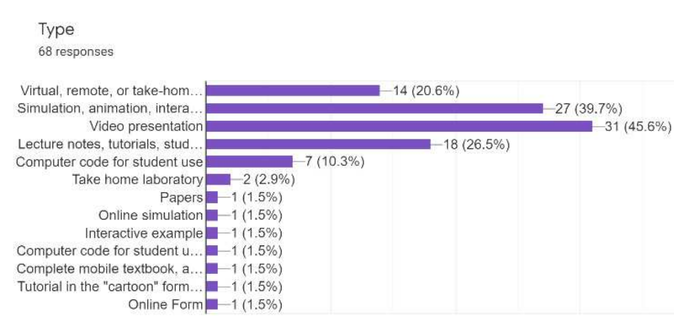

Figure 1. Types of resources (Dec. 2021).

2.3 Control Topics

A pictorial map of control theory topics is shown in Figure 2. A boundary separates the common core topics listed in Table

1 from the other, more advanced topics. A green check mark indicates availability of at least one free access resource for the corresponding topic. A red X mark denotes a lack of resources.

Figure 2 shows that all topics from the introductory material are covered by at least one resource, which is a great achievement of the collaborative effort of the international control community. However, the coverage is very thin, with limited choices of examples, applications, interactive options, and media variety. The goal is to have each topic covered by various types of resources, such as videos, interactive examples, labs, etc. Additional work is needed to augment the resource collection. The control community is encouraged to continue submitting information through the survey portal.

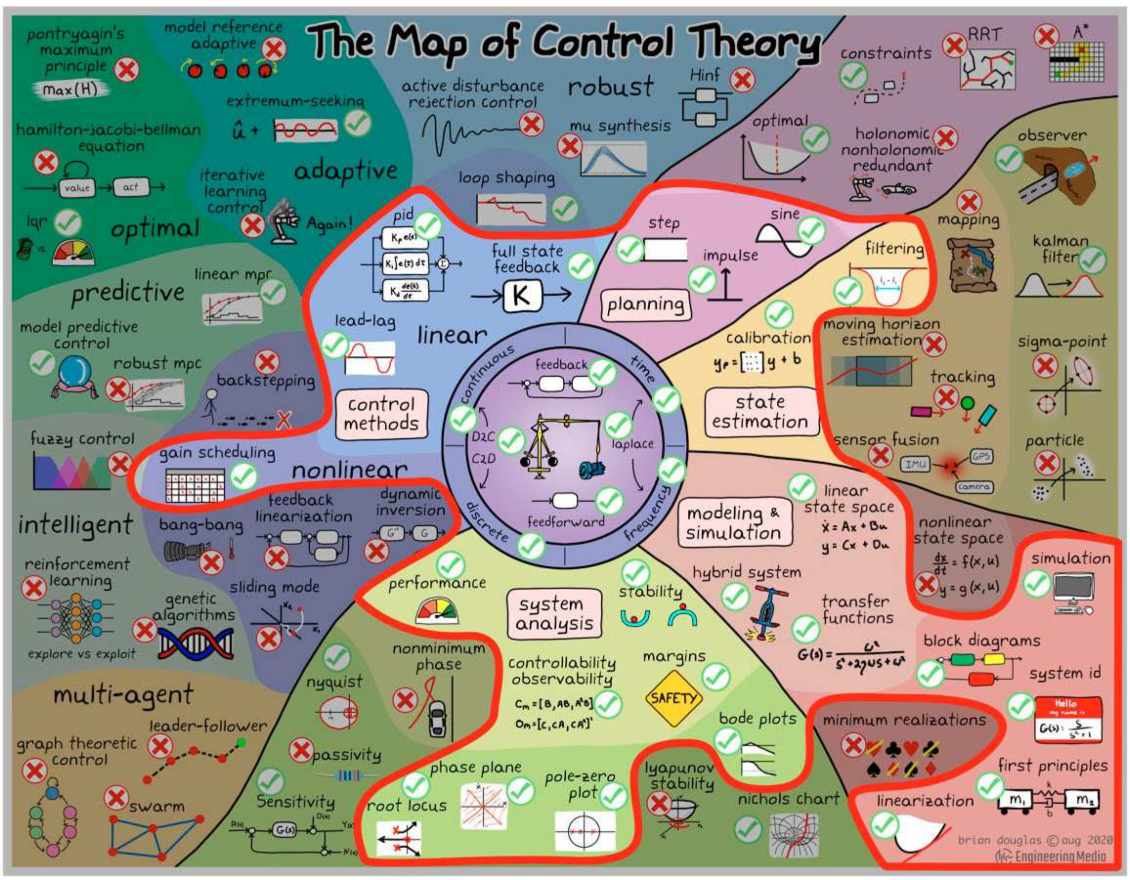

Figure 2. Pictorial map of control theory topics with a boundary separating the introductory from the advanced material.

3. INTERIM ORGANIZATION OF THE RESOURCES

At present, the collected resources are listed on the Resourcium web site (Douglas (2021)), Figure 3. For each resource, the following information is provided, Figure 4:

- Title and link
- Short description
- Classification based on type, difficulty, and content

The plan for the future development is to engage the control community and provide ordered lists representative of typical progression patterns in the first control course. The arrangements could be made by individual instructors and shared with the community.

4. OVERVIEW OF RESOURCE CONTENT

In this section we provide an initial discussion of the resources collected thus far from the survey.

4.1 Collections

Two of the submitted sites summarized in Table 2 are collections of references. “Resourcium” is a compilation of control and automation resources which can be combined to create order lists called journeys. The site is maintained by Brian Douglas, a member of the control community, but it is set up such that other users can add and maintain the content. As of December 2021, Resourcium contains over 600 resources.

“Computer Aids for Chemical Engineering” is maintained by the CACHE Corporation, a not-for-profit organization for development and distribution of computer-related and/or technology-based educational aids for the chemical engineering profession, CACHE (2021). The collated resources target primarily applications in the chemical process industries.

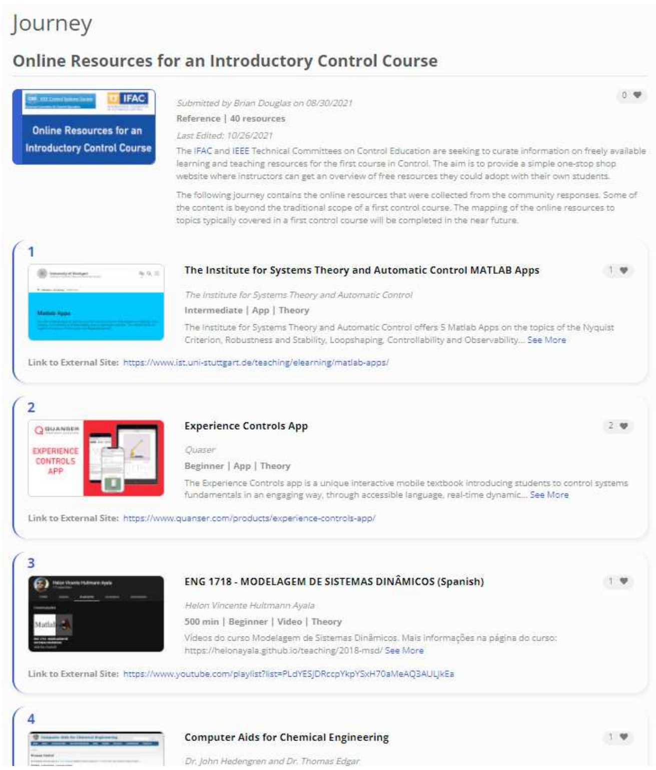

Figure 3. Home page for the collected resources on the Resourcium web site (https://resourcium.org/journey/online-resources-introductory-control-course)

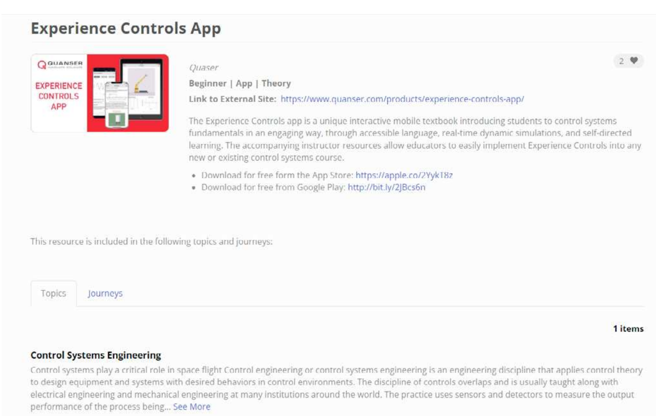

Figure 4. A typical starting view for an individual resource on the Resourcium web site.

Table 2. Resource collections.

Title / URL
Resourcium / https://resourcium.org/
Computer Aids for Chemical Engineering / https://cache.org/teaching-resources-center/process-control

4.2 Holistic Resources

The holistic resources listed in Table 3 cover a broad range of topics that are part of the common core. Most of these resources are being used as companion sites for introductory control courses. They are developed by the course instructors who have made the content accessible to everyone.

"Modelling, Dynamics and Control" is a website intended to be used like a textbook, either as a reference for checking specific topics or to learn topics from scratch. It is made up of PDF files with basic notes summaries, video lectures, tutorial sheets with worked solutions, questions to test progress, and MATLAB files for core engineering problem analysis.

"Process Dynamics and Control Course" focuses on a complete start to finish course for physics-based modeling, data driven methods, and controller design. Similar content is provided by the other resources in Table 3.

Table 3. Holistic resources.

Title / URL
Modelling, Dynamics and Control / http://controleducation.group.shef.ac.uk/mainindex.html
Process Dynamics and Control Course / https://apmonitor.com/pdc
Interactive Course for Control Theory / https://icct.cafre.unipi.it/
edX course: Dynamics and Control / https://www.edx.org/es/course/dynamics-and-control
Basic Course of Control Theory / https://www.aut.bme.hu/Pages/ResearchEn/ControlTheory
Systems modeling and representations (French) / https://modelisation.cs-campus.fr/
What's a Control System and Why Should I Care? / https://dabramovitch.com/pubs/what_is_ctrl_n_why_college_stem_1.pdf

4.3 Videos

Videos are more engaging than text and allow for asynchronous learning and flipped classrooms. In general, the video resources collected by the survey fall into two broad categories: animated and narrated examples and video lectures. The first category is more difficult to produce, and only one resource was collected, "Understanding Control Systems Playlist", Table 4. The video lectures category is represented by several entries in the survey, two of which are listed in Table 4.

Table 4. Video resources.

Title / URL
Understanding Control Systems Playlist / https://www.youtube.com/playlist?list=PLn8PRpmsu08q8CE0pbZ-cSrMm_WYJfVGd
Introduction to Classic Control Theory (Japanese) / https://youtube.com/playlist?list=PLQPJtAInj5HnI0oJsp4jCwLoYmNd9BfEw
Video Lectures on Automatic Control / https://www.youtube.com/playlist?list=PLkq3XsX6LXRLJQVJvg_5YQkvsai5BiY1i

4.4 Interactive Tools

Interactive tools develop engineering intuition by challenging students to explore and test a variety of scenarios. Good pedagogy has recognized these tools as essential elements for improving student learning. The interactive tools resources collected in the survey are listed in Table 5.

Table 5. Interactive Tools.

Title / URL
IST Matlab Apps / https://www.ist.uni-stuttgart.de/teaching/elearning/matlab-apps/
Interactive Tools for Control Purposes / https://w3.ual.es/personal/joguzman/material_docente_itools.shtml
Various Games for Learning Controller Design / https://www.ist.uni-stuttgart.de/teaching/elearning/educational-games/
Toys for Control Education / https://maruta.github.io/toy4edu/
Nyquist Stability Criterion (Mobile App) https://www.ist.uni-stuttgart.de/teaching/elearning/policy-nyquist/
Experience Controls (Mobile App) / https://www.quanser.com/products/experience-controls-app/

"IST Matlab Apps" and "Interactive Tools for Control Purposes" are developed in the MATLAB environment and cover a broad range of control applications. "Various Games for Learning Controller Design" and "Toys for Control Education" are developed in an engaging game-like setting. Of particular interest are the mobile app resources "Nyquist Stability Criterion" and "Experience Controls". The latter one is developed by Quanser and includes a free interactive mobile textbook.

4.5 Laboratories

Laboratories prepare students for practice but accessibility to lab facilities is not always available. Virtual, remote, and take-home labs provide lab experience in a cost-effective manner.

Despite the proliferation of virtual and remote laboratories in the past decade, (Dormido et. al, 2011, 2012), only two resources have been submitted in the survey, as seen in Table 6. This is an indication that additional channels for the distribution of the survey need to be explored in the future.

Table 6. Laboratory resources.

Title / URL
Temperature Control Lab (TCLab) / http://apmonitor.com/pdc/index.php/Main/ArduinoTemperatureControl
Virtual Labs for Control Education / https://w3.ual.es/personal/joguzman/material_docente_labs.shtml

5. CONCLUSIONS

This paper reports the preliminary results from a collaborative initiative to collate high quality freely available resources for instructional use in an introductory control course. The project is still in the collection phase. To date the survey has yielded 64 resources that cover all topics in a typical first course in control. However, more resources are needed to enhance the selection and to provide more options. The survey is still open, and readers are encouraged to participate, https://tinyurl.com/control-resources.

The next phase of the initiative will be collation of the resources. This paper has given only the very briefest summary of the collected content, and it is clear that important challenging tasks are resource categorization and a decision on the most appropriate hosting environment.

We should finish by emphasizing that the initiative is collaborative in nature and the authors, who are also the current coordinators, would appreciate advice, support, and volunteers from the control community to take this project forward. Critically, we want a sustainable and affordable model for how to share these resources.

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