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Including Sustainable Development in Automatic Control Courses

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ABSTRACT

The automatic control subject has several connections to sustainability and can play an important role in the strive towards a more sustainable society. An example of how sustainability is included in a basic course in automatic control is presented, where the links between the degree requirements, sustainability and the subject are illustrated using The Global Goals for Sustainable Development (SDGs). The key idea is to present real world application examples where automatic control is a vital component and there are clear connections to the SDGs. The examples are inspired and illustrated using videos and images taken from the internet. Several times during the course a part of the lecture time is used to show a video, describe how the control subject comes in, and how the use of feedback control via the application can contribute to the fulfillment of the SDG.

KEYWORDS

Sustainability, SDGs, automatic control

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Introduction

The need for sustainable development is extremely important for the world, and it influences all sectors of the society. Also, within engineering education the topic receives increased attention. The requirements for the various degrees within sustainability the Swedish system for higher education are specified in the Higher Education Ordinance (2024). For the five-year Master of Science in Engineering degree there are twelve learning objectives. The aspects are most visible in objectives 7 and 11, which in translated form say that a graduate should:

- *demonstrate an ability to develop and design products, processes and systems taking into account people's situations and needs and society's objectives for economically, socially and ecologically sustainable development.*
- *demonstrate insight into the potential and limitations of technology, its role in society and people's responsibility for its use, including social and economic aspects, as well as environmental and work environment aspects.*

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Very similar goals can also be found in the requirements for the three-year engineering degree (B.Sc in Eng.). These requirements imply that sustainability should be included in the engineering programs, both in the curricula and in the intended learning outcomes. Somewhat simplified, two main approaches are possible. One approach is to concentrate the sustainability issues to one or several courses focusing entirely on the topic, and the other approach is to integrate sustainability in all courses where it is found relevant. This paper presents an example of the second approach, by demonstrating how to include sustainability aspect in a disciplinary course and show how automatic control can contribute to the fulfillment of the goals. When doing this, it is a challenge to interpret the formulation in objective 7 about society's objectives for economically, socially, and ecologically sustainable development. To operationalize the goals for the society, and to be able to work systematically with the topic, the Global Goals for Sustainable Development (SDGs) is a useful tool which will be explored in this paper.

Automatic control is about using feedback for making a system behave in a desired way. It is used in many sectors of society, such as industrial processes, vehicles and vessels, consumer products, and medical equipment. The objectives are often efficient use of energy and other resources together with the desire to minimize the environmental impact, and the drivers often come from economic factors, safety, or legislations. There are numerous examples in the literature discussing sustainability in engineering education in general, but few are related to automatic control. One example is by Felgueiras et al. (2017), who discuss the connections in general, but also point out that "*automatic control is in the basis of sustainability because it allows to optimize the systems consumption*". An early example of including sustainability aspects in control education is reported by Baglione and del Cerro (2014), focusing specifically on energy efficiency in buildings. A wider perspective is presented by Habib and Chukwuemeka (2019) who discuss the connections between the SDGs and Industry 4.0, where automatic control is an important component, via the areas of cyber-physical systems and automation. Similar perspectives are discussed by Pattison (2017) with emphasis on the information and communication technology field.

One example of a context where the increased importance of sustainability can be observed is the CDIO Initiative. Here the increased focus on sustainable development is seen in the evolution of the fundamental documents of this community. Sustainability aspects have been given more and more attention in each update of the CDIO Syllabus, especially in version 3.0 (Malmqvist et al., 2022). Also, the CDIO Standards have been revised and extended with respect to, among other things, sustainability (Malmqvist et al., 2019).

The paper is organized as follows. A brief introduction is given to the SDGs, which will be used as reference when discussing sustainability in the paper, and the following section then introduces the automatic control subject. Based on this the next section shows how the subject is strongly connected to several of the development goals. In following section, it is described how this connection is introduced and discussed in two courses in automatic control at Linköping university, and this is followed in by a section with results from surveys carried out in the courses. Finally, in the last section contains a discussion of the findings of this work.

The Global Goals for Sustainable Development

Sustainable development is a very wide topic, as it concerns most aspects of human life. It can therefore be perceived as vague and difficult to make concrete, for example in education situations. The Global Goals for Sustainable Development (SDGs) offer a useful frame of reference for a more systematic treatment of the topic. Keeping in mind that this is just one way to do this, the SDGs will be the basis

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for the paper. There are several thorough descriptions of the background and contents of the SDGs (see for instance UN, 2024). The graphical illustration of the SDGs is given in Figure 1.

Figure 1: Graphical illustration of the Global Goals for Sustainable Development.

For each of the goals there are Targets at a more detailed level, but even on this sub-level the Targets are rather wide, and it would hence be naive to think that a single action or subject is enough to tackle the Target under discussion. The approach here is instead to look at examples where applications of automatic control can contribute to some extent. Many companies have a clear strategy for how to deal with sustainability aspects, and one illustrative view of how the company's activities connect to the SDGs is found in ABB's Sustainability report (ABB, 2022).

Automatic Control

The field of automatic (feedback) control has a very long history. The first examples of feedback mechanisms described in the literature date back to names such as Ktesibios and Heron of Alexandria, who were active around two thousand years ago. There are several excellent surveys of the history of automatic control, such as those by Bissell (2009) and Bennett (1996). The development of the field has had different drivers during the centuries, including the industrial revolution and the use of the steam engines, the development of long-distance telecommunication lines, and the exploration of space. An early example of the use of mathematics for analyzing the properties of automatic control systems is Maxwell (1868), who analyzed the properties of the feedback mechanism in a steam engine. Automatic control is a key enabling technology in many engineering products, processes, and systems. The task for an automatic control mechanism is to make a product, process, or system behave in a desired way. The field has been called The Hidden Technology (Åström, 1999) since its presence in the different applications is seldom visible. Instead, the effects can be observed indirectly via the operation of the object under control. Automatic control can be found in many applications, ranging from process industry, aerospace applications, passenger cars and trucks, power systems, consumer products like mobile phones and computers, biomedical engineering equipment, etc. The objectives for using feedback control mechanisms depend on the application, but they involve aspects like quality,

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productivity, safety, efficient use of energy and other resources, comfort, etc. One of the fascinating features of the subject is that the creation of a real-world control systems includes several disciplines, including mathematical models and tools, process knowledge, hardware and software technology, sensor, and measurement technology, etc.

A block diagram, consisting of boxes and arrows, is a useful abstraction when studying an automatic control problem. Figure 2 shows an abstraction of the real problem and how the involved quantities are related. There are often several steps to take before the problem can be described in this form, including choosing the system border, and selecting the most important inputs, outputs, and disturbances. Outputs represent properties or behaviors of the system that we want to behave in a desired way, where low emissions from a car engine is one example. The inputs represent ways the system can be affected, for example, the air-fuel ratio in a combustion process. Finally, disturbances represent factors that affect the system but cannot be chosen, and one example is the ambient air temperature around the combustion process.

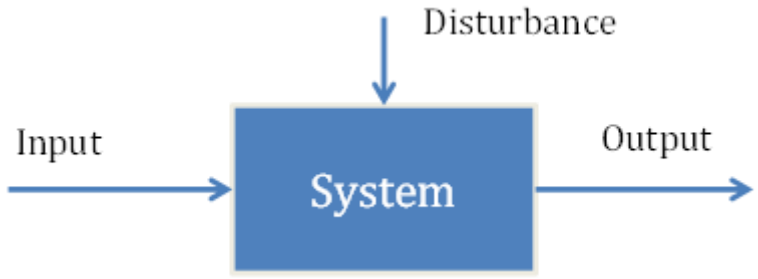

Figure 2: Block diagram description of the system to be controlled.

The key component in automatic control is feedback, which means that the properties of interest are measured and compared with the desired properties, and that the input is selected based on this difference. In some control problems there are several, and sometimes contradictory, objectives and one must find a trade-off between these objectives.

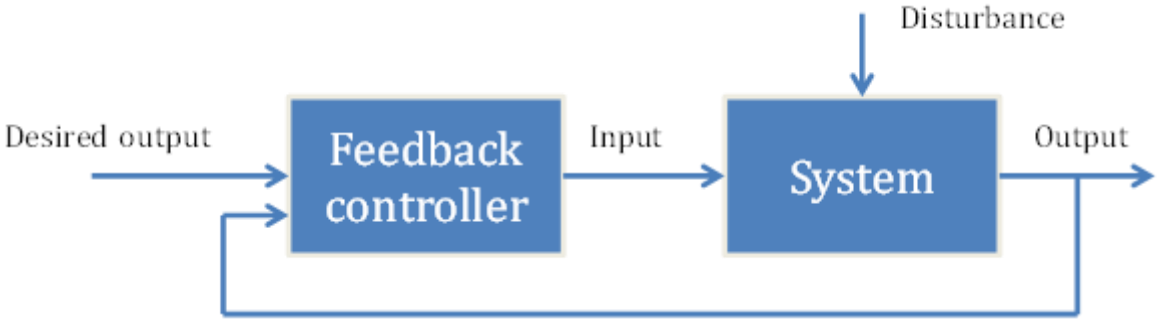

Figure 3: Block diagram description of the feedback control system.

The block diagram description in Figures 2 and 3 is a convenient way to describe systems and their interaction on a more abstract level, and the subject can hence help students to develop their *systems thinking*, which is an important skill in both engineering and other fields. The terminology in the figures has an engineering touch, but it can be generalized to by replacing input with *action*, replacing output with *obtained result*, desired output with *desired result*, and disturbance with *external factors.* With this more general terminology the representations in Figures 2 and 3 are applicable in many areas outside the engineering field. To determine an action based on the difference between a desired and

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obtained result is a natural process in numerous fields. The measurements of the obtained results typically include data of various types, representing the behavior of the object under study, and the feedback mechanism can hence, with other words, be rephrased as *from data to decisions.*

In addition to the requirement that the feedback control system in Figure 3 must be *stable*, which can be characterized using mathematical tools, there are three *fundamental limitations* that always are present and must be considered in the *decision process*, which means the feedback controller in Figure 3. The limitations are:

- The capacity for actions is always limited, and the actions must be used in an efficient way, given the resources available.
- The obtained result can normally not be measured with arbitrary accuracy. The challenge is to be able to measure the relevant things and to measure the relevant things accurately enough. There is always a trade-off between seeing trends and risking being fooled by random variations. A careful analysis and interpretation of the collected data is hence very important.
- The properties of the system, to which the actions are applied, are not exactly known, and the knowledge about the properties of a complex system can sometimes be partly subjective. The more uncertain the knowledge about the system is, the more cautions the decisions and actions must be.

Connecting Automatic Control to the SDGs

In the long history of the automatic control subject, the research and practical applications have in many cases been in line with several of the SDGs long before the word sustainability came into use and the world realized the need to work for a sustainable society. As always, however, it is important to keep in mind that achievements within engineering and new technical solutions can be used in both positive and negative ways, and this is true also for automatic control. In the following, the connections between automatic control and the SDGs are illustrated by considering the goals 3, 6, 7, and 11. There is no doubt that these goals are related to numerous disciplines and aspects of society, and the fulfillment of the goals requires a combined effort from most sectors of the society including the political systems and authorities of various types. The aim of this paper is to illustrate that also a typical engineering subject, such as control, can contribute to some extent. It should be strongly emphasized that the intention is not to convey a simplified and naive impression of the importance of the automatic control subject, but that it can be an enabling factor in many cases.

SDG 3: Good health and well-being

One example is the use of autonomous aerial vehicles for delivering blood and medicine in areas with poor communication facilities on the ground. There are many efforts and projects in this area, both within research and commercially, and one of the many companies doing this daily is called Zipline (2024a, 2024b). An autonomous aerial vehicle needs feedback control to maintain the desired height, course, and velocity, plus the related functionality for navigation.

Also, humans have a built-in feedback control function that adjust the breathing frequency depending on the need for oxygen (very simplified). When this function does not work, for example, due to an accident, assistance is needed, and that can be achieved via a so-called ventilator. The task of a ventilator is to blow air into the patient so that a desired oxygen level is obtained, but this is in reality a difficult task. One reason is that the characteristics, such as volume and elasticity, of the lungs are very different between a premature baby, a 25-year-old athlete, and a 90-year-old person. Therefore, the feedback control algorithms must be able to adapt itself to the conditions of the patient under treatment. There are many companies delivering ventilators, among them Getinge (2024).

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SDG 6: Clean water and sanitation

Humans need clean fresh water, and one aspect of this need is efficient wastewater treatment. This is a complicated control problem, and modeling of that type of systems, which involves the use of subjects like fluid dynamics, biology, and chemistry, typically leads to sophisticated mathematical models. Another complicating factor is that it is not always possible to measure all quantities of interest. One company in the area is ABB, offering systems and products for various kinds of water processes (ABB, 2024). Another example is Cantoni et al. (2007) dealing with large scale irrigations systems, where it is shown that considerable improvements concerning the use of water can be obtained using modern methods for modeling and control.

SDG 7: Affordable and clean energy

Access to affordable and clean energy is a crucial challenge for the entire society. This involves both development and introduction of fossil-free energy and ways to reduce the negative impact of fossil-based energy systems. Feedback control is a key technique in energy systems on all levels. For example, on national level the management of the electrical power grid is a control problem, where the key reference value, corresponding to the Desired output in Figure 3, is the frequency in the grid (50 Hz). In the Swedish system the performance of this control system can be seen in real-time via the website of Svenska Kraftnät (2024). From the national level, via various types of power plants, to climate control in individual buildings, automatic control is necessary to use resources efficiently and minimize the negative impact on the climate and the environment.

SDG 11: Sustainable cities and communities

Transportation of goods and people, in the air, on the ground, and on the oceans is a big and important area for a sustainable society. The area is related to several of the SDGs, and in addition to goal 11, discussed here, it also relates to, for example, goal 3 about Climate action. The main trend within transportation is the rapid electrification based on electro-chemical drivelines, using, for example, batteries or hydrogen-based fuels cells, and here decisions based on data from the system is crucial for efficient operation. In addition, the development within drivelines based on combustion engines continues, with more sophisticated control methods and introduction of alternative fuels.

These examples show that there are strong connections between automatic control and several of the SDGs, and that the subject plays an important role in the efforts to reach these goals.

Implementation

The key idea for including sustainability in the control courses has been to use the vast source of information that is available on the internet via films and images illustrating real world examples of the use of automatic control. A few minutes of some of lectures is used to present the examples as follows: (i) Showing a video or images of the application. (ii) Discussing why feedback control is necessary in this application. (iii) Connecting the application to the SDGs. The discussion of why automatic control is necessary can include basic aspects such as: Which are the overall objectives for using feedback control? Which are the input(s), output(s), and disturbance(s) in the example? What is the desired behavior, and are there any contradictory requirements in the problem? At this stage, the assessment is done by e.g. including a question in the exam where the students are asked to give a practical example of how feedback control can contribute to sustainability.

The approach is used in two different versions of a basic control course at Linköping University. One target group is the students in the course *TSRT22 Automatic Control* given for the programs in Industrial engineering and management and Energy, environment, and management respectively,

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which both are five-year programs. This is a mandatory course in both programs, and there are approximately 250 students in the course.

The second target group participate in a corresponding basic course *TSIU61 Automatic Control* for the students in the second year of the three-year engineering programs in Mechanical engineering and Electronics, respectively. This course has approximately 90 students. Both courses encompass 6 ECTS credits.

The activities to connect automatic control to the SDGs were initiated during the fall semester 2019 and have been used since then. In 2019 the courses were given in a conventional format for this university, which means thirteen lectures, thirteen exercise sessions, and three laboratory sessions using real physical hardware. In 2020 and 2021 almost all learning activities were carried out in distance mode due to the pandemic, but from 2022 the courses were back in its conventional on-site format again.

Evaluation

The approach to including sustainability in the automatic control courses via the SDGs was evaluated by adding some extra questions to the regular web-based course evaluation system. Details about this can be found in Gunnarsson and Erlander Klein (2021), and only the main findings are presented here. The students were asked to consider the following three statements:

A. The automatic control subject has natural connection to several of the SDGs.

B. The connections to the SDGs have increased my motivation for the subject and the course.

C. The connections between the subject and the SDGs have given new insights in possible future jobs.

They were asked to express their opinion according to the following scale: 5 – totally agree, 4 – partly agree, 3 – neutral, 2 – partly disagree, 1 – totally disagree.

For TSRT22 Automatic Control there were around 250 students in the course, and the response rate was 32 %. For statement A, this gave the following results. 5 – 29 %, 4 – 23 %, 3 – 32 %, 2 – 11 % and 1 – 5 %, which indicates that the connection between the subject and sustainability is apparent for most students.

One difficulty connected to the interpretation of the evaluation results is that data were collected when the course was given in distance mode. The theory parts of the lectures were pre-recorded, and the students were assumed to have watched the corresponding films before each scheduled time for the lectures. The scheduled lecture time was used for quizzes, Q&A, and presentation of application examples, including connections to the SDG. The format led to that seemingly all students watched the recorded presentations of the theoretical contents, but only a subset of the students attended the scheduled online lectures where the connections to the SDGs were discussed. Therefore, when it was time for the course evaluation the discussion about the connection to the SDGs was new for this group, and it was difficult for them to have any opinion. Keeping this aspect in mind, the interpretation is that the idea has been received positively by the students.

For TSIU61 Automatic Control the evaluation was done using a separate questionnaire, and the response rate was 28 % in this case. %. For statement A, this gave the following results. 5 – 17 %, 4 – 37 %, 3 – 43 %, 2 – 0 % and 1 – 3 %, i.e. more than half of the students answering the questionnaire agreed with statement A, totally or partly.

Discussion

The paper has illustrated that automatic control has strong connections and can give valuable contribution to sustainability in several ways. The paper has also described how this connection can be included in the education situation in a straightforward way, and that the connections seem to be understood and appreciated by the students.

As mentioned previously, it is important not to have a too simplified and naive understanding of the use of automatic control, and like many other technologies it can be used in many ways. The exploration of space was one important driver for the development of the subject, but a rocket can be used for launching satellites for research and communication purposes as well as for carrying nuclear warheads, and this, so called, dual use of technology must always be kept in mind.

Automation using, for example, industrial robots offer an excellent opportunity to get rid of jobs that are dirty, dull, and dangerous and increase productivity, but at the same time it means that some people risk losing their livelihood. While automation normally involves physical objects such as, for example, production systems, the term autonomous systems is much wider and includes situations where the decision-making is done entirely in software. The question of how much of the decision-making that should be handed over to the software and how much that should be supervised by humans is extremely important and challenging.

It is also not always evident that high-tech solutions represent the best way to face a challenge related to sustainability. Implementing and maintaining high-tech solutions is often costly, and requires access to people with adequate education, support organization, energy, etc.

One observation from the example shown by ABB (2024), is that all persons in their video appear to be male. From an engineering viewpoint it is an excellent illustration of the importance of automatic control, however showing this to students can give a very biased impression of that field of engineering. This could be used for a critical discussion in the classroom.

Matters and observations such as these are important and relevant, and hopefully they can be picked up for continued discussion also in other courses and contexts.

Declaration of Interest

There are no conflicts of interest related to the paper.

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