USING THE SUSTAINABLE DEVELOPMENT GOALS (SDGs) IN AUTOMATIC CONTROL COURSES

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ABSTRACT

An example of how sustainability aspects can be treated in a basic course in automatic control is presented. This is done by connecting the subject to some of the Sustainable Development Goals (SDGs) and giving examples of how automatic control can contribute to the fulfillment of these goals. The examples are inspired and illustrated using videos and images taken from the internet, showing various examples of applications where feedback control plays a crucial role. On several occasions 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, Standards: 1, 2

INTRODUCTION

The need for sustainable development is of increasing importance for the world, and it influences all sectors of the society. Also, within engineering education the topic receives increased attention, and one of several aspects is how to incorporate sustainability aspects in engineering education in a suitable way. One approach is to treat the subject in courses entirely dedicated to the field. A second approach is to include sustainability aspects in regular courses when it is suitable, and this is the approach presented here, i.e., to present automatic control as an enabling technology for sustainability. 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 or legislations. The aim of this paper is to show how sustainable aspects have been incorporated in a basic course in automatic control using the UN Sustainable development goals (SGDs). This is done by presenting examples of practical applications of the subject and to show and discuss how the examples relate to one (or several) of the SDGs, and how feedback control can contribute to the fulfillment of the goal.

Within the CDIO Initiative the increased focus on sustainable development can be seen in different ways. For example, in version 2.0 of the CDIO Syllabus sustainability aspects are much more emphasized than in the first version. In e.g., Malmqvist et. al. (2019) the need for revision and extension of the CDIO Standards with respect to, among other things, sustainability is discussed. In addition, there are several other examples in the literature where the connections between sustainability, engineering education, and automatic control are discussion. Felgueiras et.al. (2017) discuss the connections in general, but also point out that, see Section 3, "*automatic control is in the basis of sustainability because it allows to optimize the systems consumption*". A comparatively early example where sustainability aspects are included in control education is Baglione and del Cerro (2014) where the focus is on energy efficiency in buildings. A wider perspective is presented in Habib and Chukwuemeka (2019) where the authors 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 in Pattison (2017) with emphasis on the ICT (Information and Communication Technology) field.

The paper is organized as follows. Initially, it is discussed how the requirements concerning sustainability are expressed in the overall goals for the engineering education, and that leads to the discussion of how the SDGs can be used to express the society's goals for sustainable development. In the following section the fundamental ideas and concepts within the automatic control subject is introduced, followed by brief outlook over how sustainability and the control subject meet in both academic research and industry. Next the connections between the subject and some of the SDGs are discussed followed by a description how the discussion of these connections are brought into the course. In the following section some additional aspects, valuable in for understanding of some sustainability issues are discussed. Finally, a summary and some conclusions are given.

SUSTAINABILITY IN THE HIGHER EDUCATION ORDINANCE

The requirements for the various degrees within the Swedish system for higher education are specified in the Higher Education Ordinance (2021). For the five-year engineering degree there are twelve goals, and the sustainability aspect is most visible in goal seven, which in translated form says that a graduate should.

show the ability to develop products, processes and systems considering the society's goals for economic, social, and ecological sustainable development.

A similar goal can be found in the requirements for the three-year engineering degree.

To some extent the topic is also visible in goal eleven, which says.

show insight into the possibilities and limitations of technology, its role in the society and man's responsibility for the use of it, including social, economic, and environmental aspects.

These requirements imply that sustainability should be included in the engineering programs. Somewhat simplified, two main approaches can be used. One approach is to concentrate the sustainability issues to one or several courses focusing on the topic, and the other approach is to try to integrate this aspect in all courses where it is found relevant. This paper presents an example of the second approach, i.e., and attempt to include sustainability aspect in a disciplinary course.

When doing this, it is a challenge to interpret the formulation in goal seven about the *society's goals for economic, social, and ecological sustainable development*. On the national Swedish level, the goals for the society are not specified very clearly, and to be able to work systematically with the topic the UN Sustainable development goals (SDGs) can be very useful.

THE UN SUSTAINABILITY GOALS

There are several thorough descriptions of the background to and contents of the SDGs. See for example UN (2021). The graphical illustration of the goals 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 the control subject can contribute to some extent.

AUTOMATIC CONTROL

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 is sometimes 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 automatic control mechanisms depend on the application, but they involve aspects like quality, 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.

The starting point when studying an automatic control problem is a problem description of the type depicted in Figure 2, which is an abstraction of the real problem. There are often several steps to take before the problem can be described as in Figure 2, including how to choose the system border, selecting the most important inputs, outputs, and disturbances. Outputs represent properties or behaviors of the system we want to behave in a desired way, e.g., low emissions from a car engine. The inputs represent the ways that the system can be affected, e.g., the air-fuel ratio in a combustion process. Finally, disturbances represent factors that affect the behavior of the system but cannot be chosen, e.g., the ambient air temperature around the combustion process.

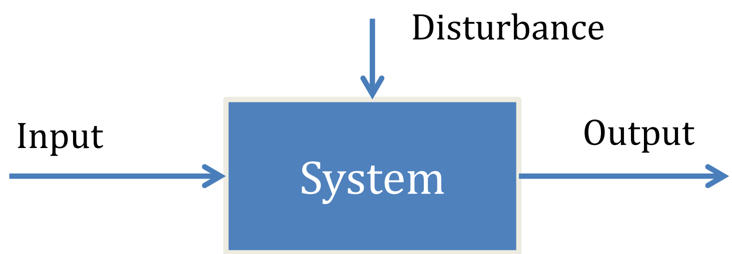

Figure 2: Block diagram description of the system to be controlled.

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 the properties of this difference. In some control problems there are several, and sometimes contradictory, objectives and one must find a trade-off between these objectives.

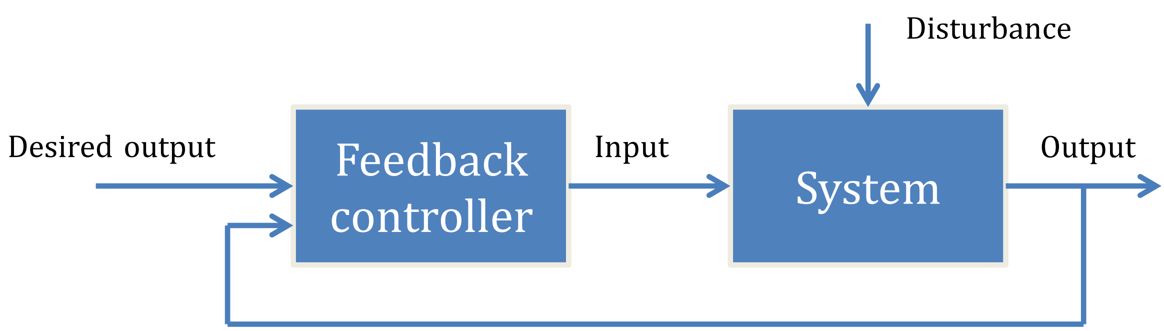

Figure 3: Block diagram description of the feedback control system.

There are many examples of academic research and business activities within the field, aiming at contributing to the fulfillment of the SDGs. One excellent example is Cantoni et. al. (2007) dealing with large scale irrigations systems, where it is shown that considerable improvements concerning the usage of water can be obtained using modern methods for modeling and control. Many companies have a clear strategy for how do 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, see ABB (2021a).

The automatic control course makes extensive use of "boxes and arrows", as shown in Figures 2 and 3, which is a convenient way to describe systems and their interaction on a more abstract level. The course hence helps the students to develop the systems thinking, which is an important skill, see the CDIO Syllabus, Section 2.3, 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*, replacing desired output with *desired result* and replacing disturbance with *external factors.* With this more general terminology the representation in Figures 2 and 3 is applicable in many areas outside the engineering field. To determine an action based on the difference between a desired and obtained result is a natural process in numerous fields. The obtained results typically include data of various types, representing the behavior of the object under study, and the whole feedback control mechanism can hence with other words be rephrased as *from data to decisions.*

In addition to the fundamental requirement that the feedback control system in Figure 3 must be *stable* there are three fundamental limitations that always are present and must be considered in the *decision process*, i.e., 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 challenges are 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.

Since decision making takes place in many areas, like e.g., the sustainability field, it is important to have these limitations in mind, and hopefully does the course in automatic control contribute to the understanding of these limitations.

CONNECTING THE AUTOMATIC CONTROL SUBJECT TO THE SDGs

In this paper the connections between the control subject and the SDGs will be illustrated by considering the two goals given below. In the course additional goals, e.g., Goals 11 and 12, are treated in similar ways.

- Goal 3: Good health and well-being.
- Goal 6: Clean water and sanitation

It should be emphasized that these goals cover many disciplines and aspects of society, and that the fulfillment of the goals requires a combined effort from most sectors of the society including the political systems, authorities of various types, etc. 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 naïve impression of the importance of the automatic control subject, but that it can be an enabling factor in many cases.

For Goal 3, i.e., *Good health and well-being*, the following examples are used:

- 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 the company Zipline. See Zipline (2021a, 2021b). An autonomous aerial vehicle needs feedback control to maintain the desired height, course, and velocity, plus the related functionality for navigation.

- 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, e.g., due to an accident, assistance is needed, and that can be achieved via a so-called ventilator. The task of the ventilator is “simply” 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, e.g., 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. For this application there are normally no videos available, so the case is described using images. There are many companies delivering ventilators, and one example is Getinge (2021).

For Goal 6, i.e., *Clean water and sanitation*, the following example is used:

- Humans need clean fresh water, and one aspect of this need is efficient wastewater treatment. This is a very tricky control problem, and modeling of that type of systems, which involves the use of subjects like fluid dynamics and chemistry, typically leads to non-linear and multivariable models. Another complicating factor is that it is not always possible to measure all quantities of interest. One example of a commercial actor in the area is the company ABB, and an example of a solution from that company is shown in ABB (2021b).

IMPLEMENTATION

The activities to connect automatic control to the SDGs have been applied during the fall semesters of 2019 and 2020. Both years, one target group was the basic course in automatic control (TSRT22) for the students in the second year of the program in Industrial engineering and management plus students in the third year of the program in Energy, environment, and management. Both are five-year programs, and this is a mandatory course in both programs, which gives that there are approximately 250 students in the course. In 2020 the second target group was corresponding basic course (TSIU61) 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.

In 2019 the course was given in the conventional format, which means thirteen lectures, thirteen exercise sessions, and three laboratory sessions using real physical hardware. In each lecture approximately five minutes are used to discuss a practical application of the subject using images or short video clips from the huge amount of such material on the internet. In four of them the application is presented using the SDGs as background, and this is done by first showing the video/images, then discussing how the contents connect to the SDG and how the automatic control subject comes in. This corresponds to the I-step in the sequence Introduce-Teach-Utilize, which is used in the CDIO framework. See pages 96 – 97 in Crawley et. al. (2014). It also means that, at this stage, there is no assessment connected to the sustainability questions. The main reason is that a deeper study of some of the application examples would require substantial domain knowledge. Also, since the approach is used in a course with 250 students the volume of the course also has impact on which learning activities that are possible to implement.

In 2020 almost all learning activities were carried out in distance mode due to the pandemic. The only exception was one laboratory exercise, that was carried out in the lab using physical hardware. The structure of the lectures was that the presentations of the theoretical contents were pre-recorded and posted on internet, and that the students were expected to watch the films in advance before the scheduled occasions, leading to a flipped classroom format. The scheduled lecture time was used somewhat differently in the two courses. The lectures were carried on using Zoom, and they included quizzes, a Q&A (questions and answers) part, and a longer presentation of examples of real-world applications of automatic control. For several of these application examples there were natural connections to the SDGs, and these were discussed.

EVALUATION

In 2019 the approach was evaluated qualitatively via discussions with the students during the regular course evaluation meeting, and the ideas were received positively by the students. For the program Energy, environment, and management the sustainability topic is close to the scope of the entire education program, and the curriculum contains several courses related to sustainability. The students within the Industrial engineering and management take the course Corporate Sustainability Management parallel to the automatic control course, and the topic and the use of the SDGs is well known from that course. There can hence be some synergy between these courses.

For 2020 the students' view on the connections between the subject and the SDGs was evaluated as part of the regular web-based course evaluation system, and a set of additional questions were added to the regular ones. The new statements read:

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.

The students 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. There were around 250 students in the course, and the response rate was 32 %. The results are summarized in Figure 4.

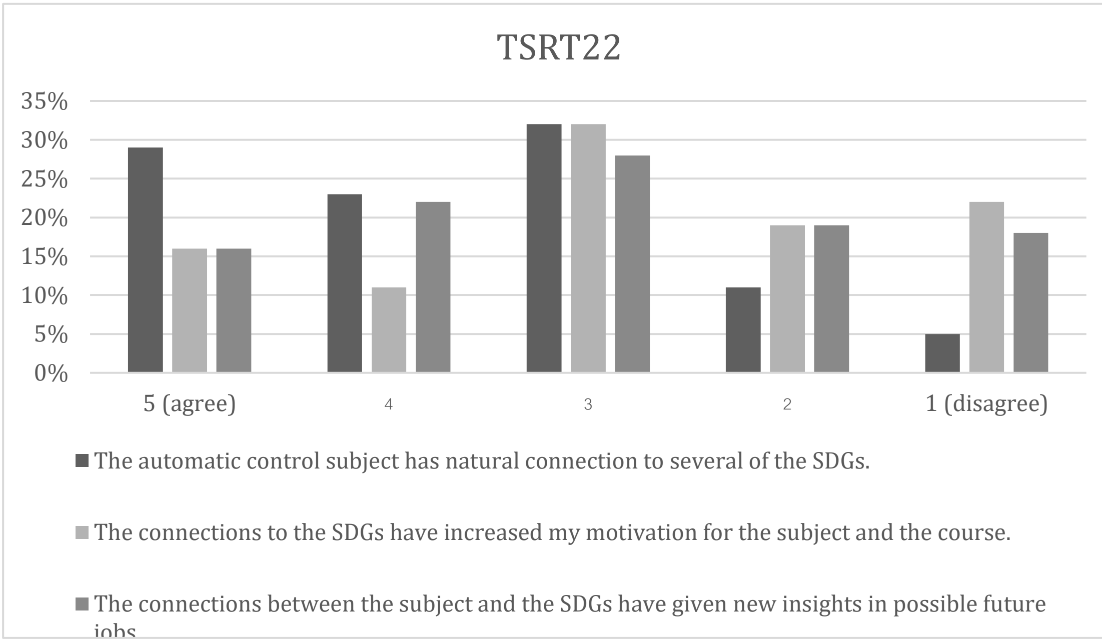

Figure 4: Answers to statements A – C in % for the course TSRT22.

The figures for statement A are overall positive, and a clear majority of the students agrees that the subject has natural connections to some of the SDGs. For statement by the answers are more towards the lower values, i.e., more students disagree than agree. However, since the statement ask about if the connection has *increased* the motivation it does not say anything about the motivation to start with. Other questions in the evaluation indicate that the motivation is rather high to start with, and that the course and the subject is motivated in general. For statement C the opinions are balanced, with a slight shift towards the positive side, i.e., that the students agree with the statement that the connection to the SDGs as given new insight into future jobs.

A difficulty with the interpretation of the evaluation results comes from how the course was organized and executed in distance mode. As mentioned above, 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 films with the presentations of the theoretical contents, but only a subset of the students attended the scheduled Zoom-lectures where the connections to the SDGs were discussed. A consequence of that was that when it was time for the course evaluation the discussion about the connection to the SDGs was new, 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.

The evaluation for TSIU61, which means the course in the three-year programs, was done using a separate questionnaire, and the results are summarized in Figure 5. The response rate was 28 % for this course.

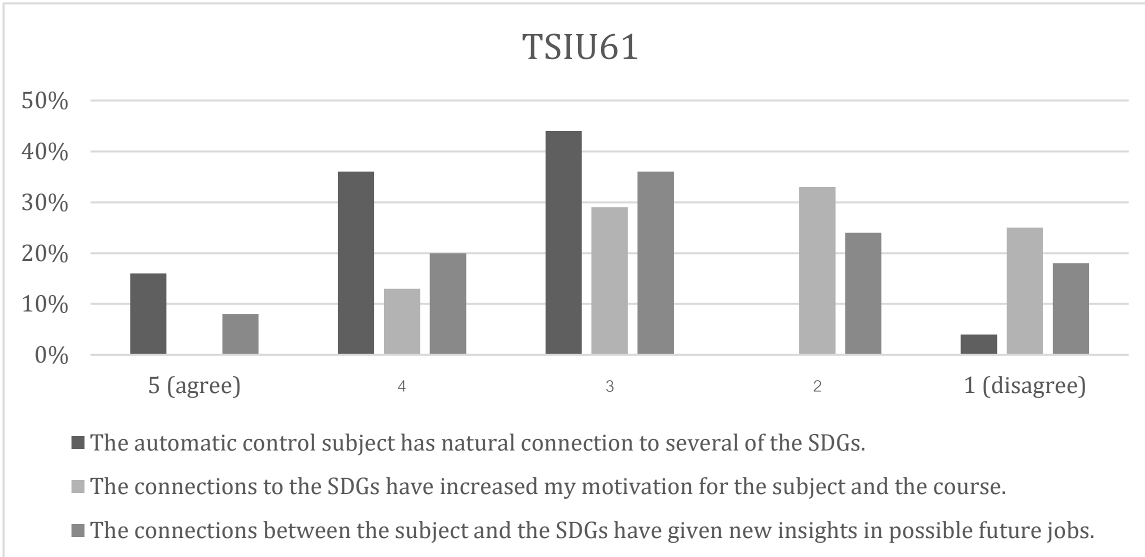

Figure 5: Answers to statements A – C in % for the course TSIU61.

The organization of this course was to a large extent similar to TSRT22 with pre-recorded lectures and the application examples, with the connections to the SDGs, presented at the scheduled Zoom lectures. A common, and positive, observation is that there is a clear and positive opinion among the students that the automatic control subject has a clear connection to the goals for sustainable development. For statement B there is a shift towards the negative side, i.e., no immediate increase of the motivation for the subject, and for statement C the opinions are rather equal. Both these observations agree with what was found for TSRT22.

CONCLUSIONS

An example of how sustainability aspects can be treated in a basic course in automatic control has been presented. The approach is to connect the subject to some of the Sustainable Development Goals (SDGs) and giving examples of how automatic control can contribute to the fulfillment of these goals. The examples are inspired and illustrated using videos taken from the internet, showing various examples of applications where feedback control plays a crucial role. On some occasions during the course parts of the lecture time are used to show a video, describe how the control subject comes in, and how the use of control via the application can contribute to the fulfillment of the SDG. The approach has been evaluated with positive results, even though the distance mode during the fall of 2020 have made both the execution and evaluation of the activity somewhat complicated.

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