A software tool to make primary school students aware of control systems

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Abstract: In this paper we present a simple software tool, designed as a game, that can be used to make (especially primary) school students aware of the importance of control systems. An overhead crane model is used as an effective dynamic system to show the difficulty of applying manual control in some contexts and how a control system can help to achieve the required performance. In addition to the technical details of the tool, which has been developed in Matlab, the overall experience with the students is explained in the paper and some preliminary results of its use with people without expertise in control are discussed.

Keywords: Control education, software tool, overhead crane.

1. INTRODUCTION

The definition of automatic control as the "hidden technology" (Åström, 1999) is well known and clearly gives the idea of the difficulty to make people who are not working in an engineering field aware of the role of control systems in our society. Indeed, people in general are usually familiar with mechanical and electronic components, and they have a clear understanding of computer science, but the importance, or even the existence, of automatic control systems is often not realized. This is of course particularly true for school students, and in particular for primary school students, who have not been yet exposed to many scientific concepts.

Thus, it is important to approach (primary) school students in order to make them aware of the role of control systems in our society by using simple tools and simple concepts. In other words, it is not important to explain complex automatic control topics, but it is important to give to the students a clear idea of what a control system is and why it is useful and to stimulate the students to look for examples in their everyday life. In this way, they might be attracted to study the topic at a university level or, in any case, they are aware of the existence of the automatic control discipline.

In this paper we present a very simple tool that can be used for this purpose. The idea is similar to that presented in (Padula et al., 2017), where a real overhead crane has been employed to show that a control system can significantly improve the performance of a manual control system (Abdel-Rahman et al., 2003).

Overhead cranes are very appropriate systems to be used to demonstrate the usefulness of automatic control systems and also for teaching advanced topics in engineering courses (see, for example, (Horacek, 2000; Lawrence et al., 2006; Lawrence, 2006; Singhose et al., 2008; Carnevale et al., 2019). Indeed, cranes have the following useful features:

- they are widely known systems that can be easily seen in industrial areas and harbours and most of the people (including children) know their usage;
- their dynamics is fairly simple to understand (in particular, the oscillatory mode) but, at the same time, they are difficult to control;
- control strategies (in particular, open-loop ones) that are intuitive for the general audience can be explained at different level of complexity (depending on the background of the audience);
- the advantages of increasing the control performance are evident and relevant in terms of production rate and safety for the user (Cech et al., 2019a,b).

As it is not easy to have a real overhead crane available for demonstrations, we have created a software tool that can be used everywhere with a standard PC. Further, the tool has been created as a game in order to be more appealing to young people. For this purpose, a simple graphic user interface has been developed so that the user can quantify the advantages of the use of the control system (even if it is transparent to the user) in reducing the residual oscillation that typically appears during motions.

Even if different control strategies have been devised for overhead cranes, both in open loop (see, for example, (Padula et al., 2015; Giacomelli et al., 2018)) and in closed loop (see, for example, (den Broeck et al., 2011; Käpernick and Graichen, 2013; Smoczek, 2015; Ermidoroa et al., 2016; Zavari et al., 2014)) the most employed in practical cases is the input shaping one (Singer and Seering, 1990; Potter and Singhose, 2013; Singh and Heppler, 1993; Singhose et al., 1997a, 1994, 1997b; Vaughan et al., 2008; Garrido et al., 2008; Singhose, 2009; Singhose and Vaughan, 2011). It is an open-loop technique (in fact, it can be considered as a motion planning strategy) that has the clear advantage of being simple and easy to implement with commercial off-the-shelf devices. From an educational point of view, the input shaping technique has also the advantage of being intuitive and its rationale can be explained in layman's

terms if the mathematical knowledge of the student is not at a sufficiently high level to fully understand the theory.
For this reason the tool allows the user to virtually move the crane without (manual control) and with the input shaping strategy (automatic control) like in an industrial environment (although, of course, in a very simplistic way) so that the relevance of the control system can be easily understood.
The paper is organized as follows. In Section 2 an explanation of the control problem and of the input shaping strategy that can be done to the students is proposed. The software tool is presented in Section 3 together with some details about its implementation. The opinions of users who have tested the tool are given and discussed in Section 4. Finally, concluding remarks are in Section 5.

2. TEACHING ACTIVITY

The proposed activity with the students (which of course has to be adapted depending the kind of audience) can be done according to the following points:

(1) an explanation of what an overhead crane is and how it is used in industry for material handling should be given; in this phase it is important to recall to the students that these systems are widely employed, they can be seen easily in many industrial areas and their usage has a relevant impact in the society. A figure like Figure 1 of a real industrial should be shown to the students;
(2) the dynamics of the crane should be explained by considering the most relevant aspect, that is, the oscillatory mode. Even if the students have not any knowledge about dynamic systems, it can be easily understood that the motion of the cart induces oscillations of the payload that might impair significantly the safety of the operations and, in any case, it might result in very long time intervals for the movements as it is necessary to wait for the vanishing of the residual oscillation before removing the load;
(3) at this point the control problem, that is, moving the payload without oscillations, should be understood by the student. It can be further clarified that manual control is difficult, by taking into account that the operator can only move the cart backwards and forwards at a constant velocity by means of command buttons;

Fig. 1. A generic overhead crane picture that can be shown to the students to understand the control problem.

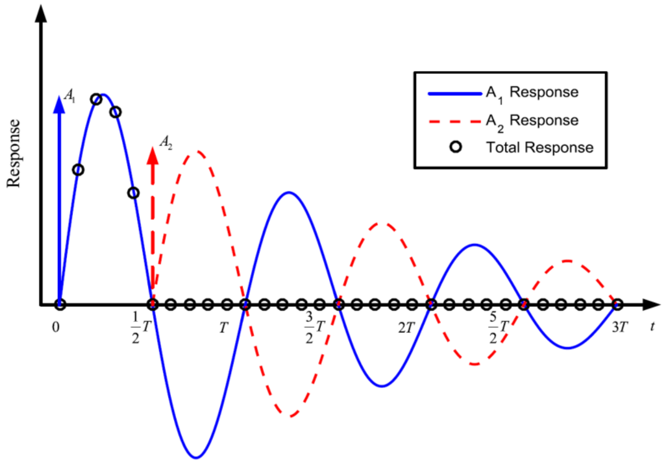

Fig. 2. A picture showing the main concept of the input shaping approach.

(4) the input shaping approach can be now introduced by highlighting the rationale of the approach. A figure like Figure 2 can be effectively used to show that an impulse causes an oscillation but this oscillation can be compensated by another one caused by a second impulse with the right amplitude and applied at the right time instant. The parameters of the second impulse are indeed difficult to determine manually and this calls for the need of an automatic control system.

3. SOFTWARE TOOL DESCRIPTION

Although there are many very effective software packages to implement interactive tools, like Easy Java Simulations (Saenz et al., 2015) and Sysquake (Guzman et al., 2009), we have chosen to use Matlab for our application, mainly because it is more known by instructors, who can therefore possibly better exploit their expertise and integrate this teaching experience with other ones. In any case, it is worth stressing that applications built in Matlab can easily be exported into executable files, meaning that the instructor only needs a PC and does not need licences for proprietary programs.

The Graphic User Interface (GUI) has been built using the *appdesigner* tool. The (linearised, undamped) dynamics of the crane is described by the following linear difference equations:

$$\begin{cases} x_1(k+1) = x_2(k) \\ x_2(k+1) = u(k) \\ x_3(k+1) = x_4(k) \\ x_4(k+1) = -\dfrac{gx_3(k)}{L} - \dfrac{u(k)}{L} \end{cases} \tag{1}$$

where x_1 is the cart position, x_2 is the cart velocity, x_3 is the payload angular position, x_4 is the payload velocity, g is the gravitational constant, L is the length of the rope and the input u is the acceleration of the cart.
Equation (1) is cyclically solved by a function called by a Timer Object. It has to be noted that, due to the computational effort that the GUI encounters when plotting graphs, the plot showing the crane can be refreshed with a frame rate of approximately 10 fps. If the solver function were to be run with a sample time of $T_s = 0.1s$, problems could arise, in particular when the length of the rope is small, as the crane would exhibit a fast oscillatory dynamics that could not be followed by a discrete

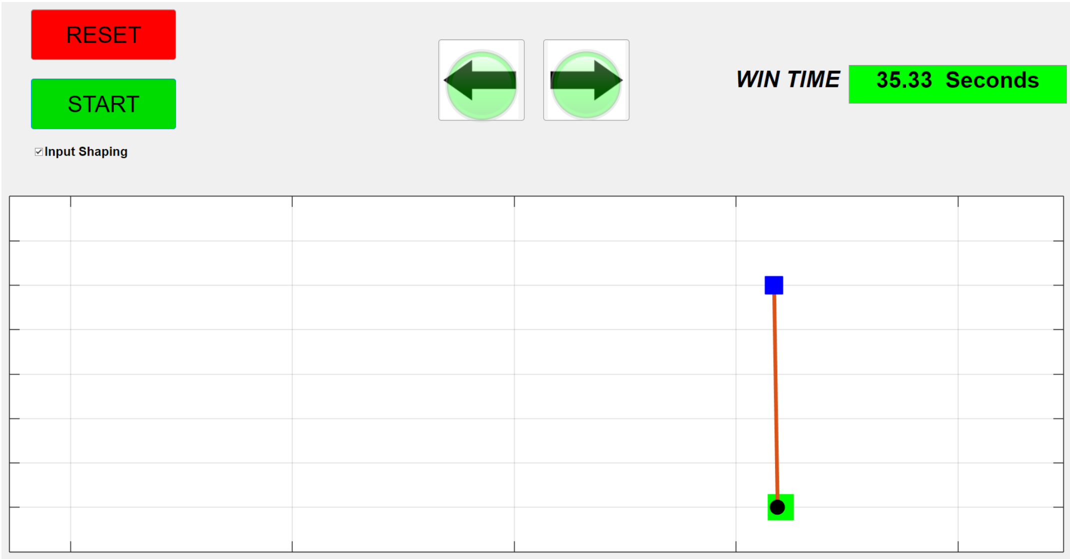

Fig. 3. The Graphic User Interface of the tool

model running at a low sampling rate. In order to respect the constraints posed by the limited frame rate and the faster sampling time required for the solution of the discrete solver, the solver function called by the timer runs a function that, in turn, calls the solver ten times with a sampling time ten time smaller then timer time, that is $T_{s_{solver}} = 0.01s$.

The input u, that is the acceleration of the cart, is managed by a function that detects the keyboard input of the user (left and right arrows) and set the acceleration properly in order to obtain a three traits law of motion for the cart. The values of the maximum acceleration and of the maximum velocity of the cart are fixed and cannot be changed by the user.

If the input shaping is activated, the three traits law generated by the function is filtered by a second function that, according to the Zero Vibration (ZV) input shaping (Singer and Seering, 1990), produces as output immediately half of the input and delays the other half by half of the oscillation of the period. The half of the oscillation period can be calculated as:

$$T_{delay} = \frac{1}{2}\sqrt{\frac{L}{g}}. \tag{2}$$

The GUI is shown in Figure 3. When the user clicks on the start button, a red square shows the target position of the payload. The user has to move the cart in order to bring the payload at the target position. When the payload is inside the target box, the box becomes green. Once the payload has stationed inside the box continuatively for 3 seconds, another target box appears in a different position, and this is repeated for a total of three target positions. Once the payload has stationed for 3 seconds at the last target position, the GUI freezes and the total positioning time is shown in the *WIN TIME* box.

The choice of imposing a 3 seconds time for which the payload must remain inside the boxes makes the task difficult to accomplish, as it difficult to succeed when the payload arrives with a strong, undamped oscillation. In any case, by doing the task without and with the input shaping technique, the user can compare the times taken in both cases and therefore he/she can experience the usefulness of the control system.

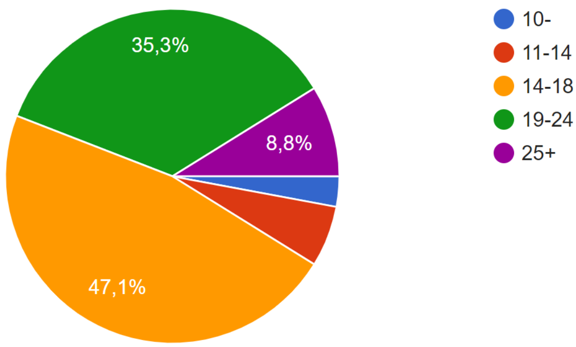

Fig. 4. Age of the participants.

4. FIRST EVALUATION

The experience with the software tool (after the explanation outlined in Section 2) has been offered to visitors of the European Researchers' night held at the University of Brescia on September 2019.
The participants were asked to try the challenge first without the use of the input shaping. Then, the input shaping filter was activated. A brief explanation of the technique as outlined in Section 2 was performed at the beginning, and the participants were warned of the position drift caused by the filter delay (2).
In particular, 34 people have participated to the initiative and, after that, they have been asked to fill a simple questionnaire, in order to evaluate the effectiveness of the tool. The pool of participants was composed by individuals with different ages as shown in Figure 4. The questionnaire was composed by 9 statements:

(1) Before this experience, I had a perception of what a control system is.
(2) After this experience, I have a perception of what a control system is.
(3) I think that automation is increasingly pervasive in everyday life, and it is therefore essential to have a basic knowledge of it.

(4) Now I want to know more about the presence of control systems in everyday life.
(5) The automatic control technique improved the performance of the system.
(6) Moving the crane WITHOUT the automatic control technique has been easy.
(7) Moving the crane WITH the automatic control technique has been easy.
(8) The GUI is satisfactory from a graphical point of view.
(9) I enjoyed playing with the software.

The possible answers for all the statements range in a scale from 1 to 5, where 1 stands for *I totally disagree* and 5 stands for *I totally agree*.

The answers to statements (1) and (2) are shown in Figures 5 and 6. From them, the effectiveness of the tool in giving to the users an idea of what a control system is can be evaluated. While the majority of the participants had no idea of what a control system is (64.7%), after testing the tool the participants begin to understand the concept of control system as 73.5% answered positively to statement (2), and only 2.9% answered in a negative way, while the remaining 23.6% remained neutral. The answers to statement (3) are shown in Figure 7. They show that participants agrees that automation is pervasive in everyday life and a knowledge of this field is important. This results somehow seems to be in contrast with the one obtained by analysing the answers to statement (4), shown in Figure 8. While these answers are more positive than negative, 58.8% of the participants are not interested in deepen their knowledge on control systems or are neutral. The reason for this scarce interest is to be searched on the very diversified pool of participants, most of which have already undertaken specific careers on topics that strongly differ from the engineering field. A test of the tool on a more specific pool of participants coming from primary schools should be carried out in order to verify this assumption.
The improving in performance resulting from the application of the input shaping technique to the control of the crane is confirmed by the answers to statement (5), shown in Figure 9, to which the totality of the participants have answered positively. The positive approach to the control technique is also demonstrated by answers to statements (6) and (7), shown in Figures 10 and 11, where the trends of the answers show that the participants perceived the use of the input shaping filter as non-invasive and user-friendly.
The answers to statement (8), shown in Figure 12, highlight that the graphics of the tool is sufficient for its aim and the reduced frame-rate does not affect the fluidity of the graphics and the playability of the tool.
The vast majority of the participants (97.1%) enjoyed playing with the tool, as shown by the answers to statement (9) in Figure 13. For a tool such this one, aimed to primary school students, this positive response is very important as at that age the user must see the tool as an enjoyable game in order to be attracted and to fully pay attention to it.

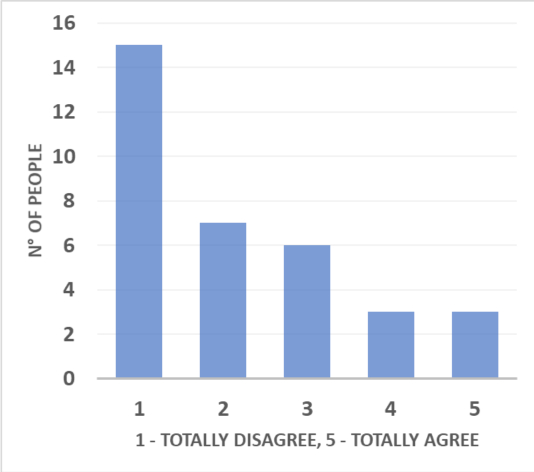

Fig. 5. Answers to the first statement.

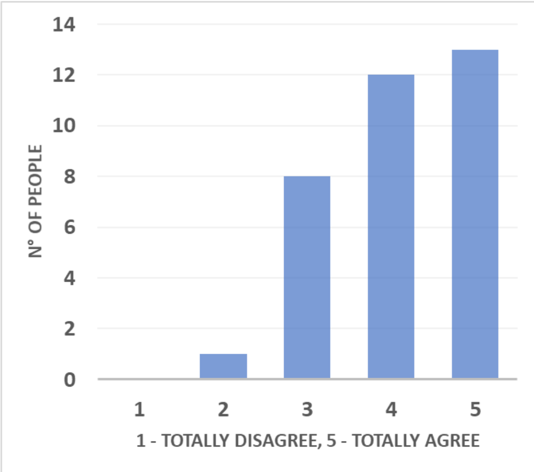

Fig. 6. Answers to the second statement.

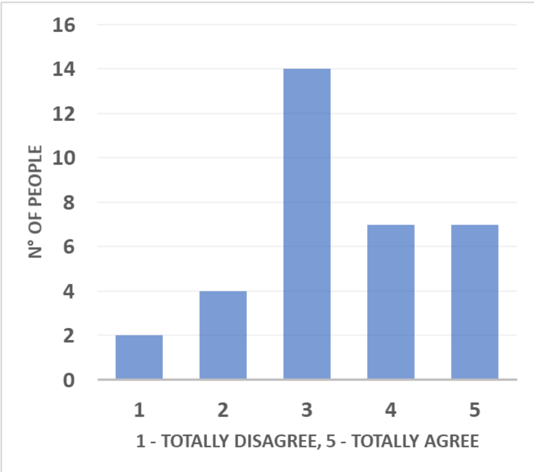

Fig. 7. Answers to the third statement.

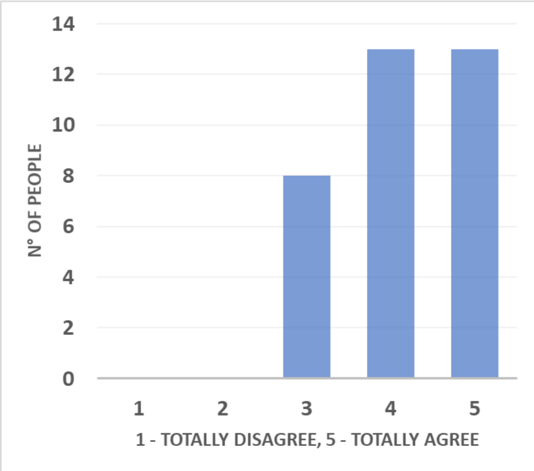

Fig. 8. Answers to the fourth statement.

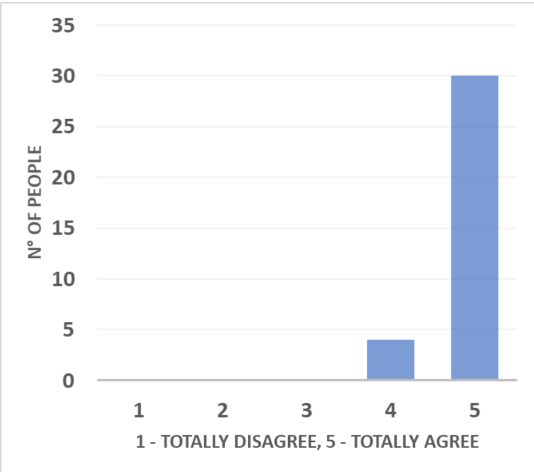

Fig. 9. Answers to the fifth statement.

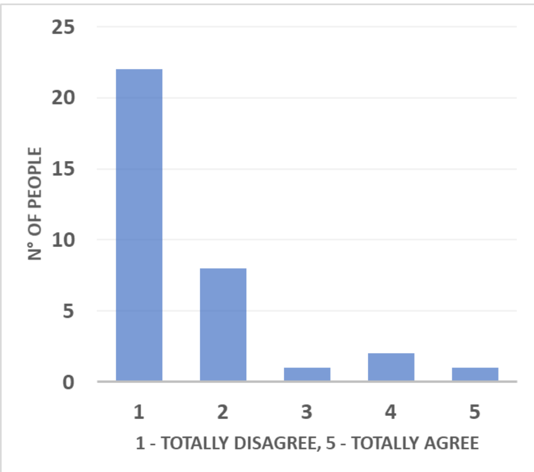

Fig. 10. Answers to the sixth statement.

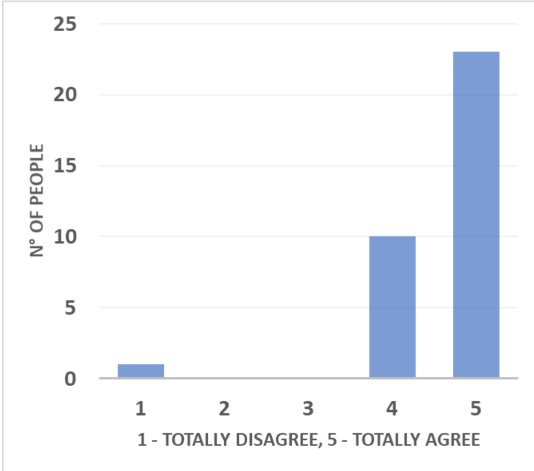

Fig. 11. Answers to the seventh statement.

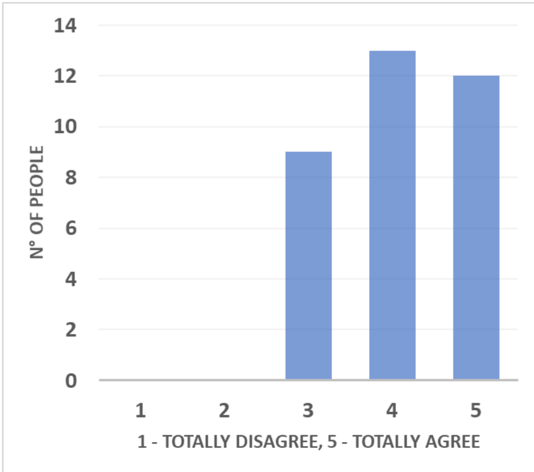

Fig. 12. Answers to the eighth statement.

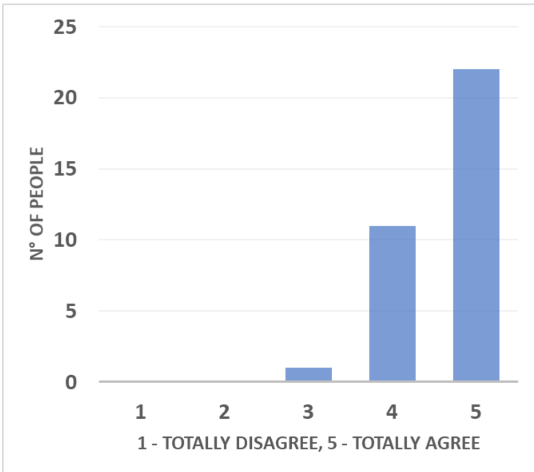

Fig. 13. Answers to the ninth statement.

5. CONCLUSIONS

In this paper we have presented a simple tool to show to (primary school) students the benefits of using control systems. In particular, a simple game consisting in the control of an overhead crane has been implemented. The user can try with manual control and then with the insertion of an automatic control system based on an input shaping approach. The tool aims to encourage students to ask themselves about the role of control systems in everyday life and to perceive their usefulness.
The tool has been tested with people of different age and background and a positive evaluation have been obtained in general. Future work will therefore consists in a massive use of it in primary schools in order to disseminate the knowledge of the "hidden technology" among people.
The tool is available to anyone upon request to the authors.

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