INTERACTIVITY IN AUTOMATIC CONTROL EDUCATION

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Abstract
Looking back thirty years ago, the advances in teaching have accompanied the technology evolution. As soon as the technology progressed, new teaching tools began to appear. This work describes one of these technological advances, Interactivity. Several definitions of Interactivity are presented from different points of view. Afterwards, the influence of Interactivity on teaching is discussed presenting the advantages and drawbacks of this information methodology on education. The Automatic Control Education field is one of the areas where Interactivity has had a major influence. Hence, this work also describes why Interactivity is very important in engineering education, focusing in the Automatic Control field and presenting some interactive tools as examples of this fact.

Keywords: Interactive learning environments, new research environments, simulations, improving classroom teaching, multimedia/hypermedia systems.

1 Introduction

New teaching methods and innovative techniques have lately appeared showing the influences, advantages, and drawbacks that the New Information and Communication Technologies (NICT) have provided to the teaching field. Each time more and more educators teach using new digital techniques (e.g., digital sliders, Flash animations, computer-based simulations), providing documentation on the Internet, creating virtual forums and courses, or performing virtual questionnaires. These great advances in the NICT have been
reflected on teaching in particular, but also in the society in general. Multiple effects can be observed at business level (e.g., remote control, remote management, flexible timetable), socio-cultural level (e.g., mobile telephone, electronic bank, digital television), and as commented above, at teaching level (e.g., digital sliders, distance education, interactive information, virtual and remote labs) opening an innumerable number of possibilities [34, 15]. From an educational point of view, the impact of the NICT have caused the appearance of teaching techniques and methods which facilitate the distribution of information to the students, enhancing their motivation by the use of new learning tools.

In a general context, the main advantages of the NICT are related with teleaccess, teleoperation, telecontrol, and interactivity. Until recently, the exchange of information was done using local networks by several reasons: information safety, narrow bandwidths, limited tools for the exchange of information, etc. Due to the advances of Internet technologies, a new method for accessing the information has appeared, the teleaccess, providing a way to safely access to the information from any part of the world without temporal constraints. Both in the industrial and research/educational fields, high costs are often related to the restricted use of (usually expensive) systems with usage time constraints or to the displacements required to control them. With teleoperation (extension of sensorial capabilities and human skill to the remote place) and telecontrol (specific part of teleoperation whose goal is to send commands to the actuators) technologies, it is possible to control systems remotely through Internet, thus helping to diminish displacement costs and allowing to extend the use of time-limited resources or equipment. On the other hand, the mode in which the information is shown to the users is changing, where data and images are not only presented as static elements, but also as interconnected elements with some specific functionalities. This feature is known as Interactivity which allows enhancing the users’ motivation through a more participating activity [40, 19, 10, 13].

In the educational field, new teaching methods have appeared related with previous advances. These methods allow the teachers to find innovative techniques to enhance the students motivation and improve their education: multimedia tools, hypertext systems, interactive systems, information exchange between teacher and student through the Internet, information access from any part of the world without temporal constraints, etc., where the biggest revolution has been produced by the World Wide Web (WWW). All these advantages are useful for subjects without a relevant practical component, but there exist other subjects with strong experimental contents that require a new element allowing the students to apply the acquired knowledge. Traditionally, this element has been a local simulation tool or a local laboratory, used by the students to perform several practical exercises over real systems but with space and time constraints. Nowadays and thanks to advances in the NICT, especially on Internet technologies, the laboratory environment can be transferred to distance education. By this, two new concepts have appeared within the distance
education framework, virtual laboratories and remote laboratories. The first of them are a new kind of simulation tools much more powerful than the traditional ones, allowing the simultaneous use of remote simulation modules by the students. On the other hand, remote laboratories allow the students to perform the main laboratory activities remotely, without requiring the presence of the students at the place where the hardware is located, in such a way that the students can control and monitor physical devices 24 hours a day at any time and anywhere, interacting with the teacher without having to go to the university. Remote labs help the students to put into practice what they have learned by remotely accessing real systems [40, 39, 19, 10].

In the same way, the presentation of information by the teachers has been improved along the years, from the classical lectures based on blackboards and sliders to the use of digital sliders and the providing of information through Internet. However, this fact has considerably been improved with the appearance of Interactive Tools (IT). Although Interactivity can be defined in several ways (as will be shown in the next section), from a teaching point of view an IT can be defined as a collection of graphical windows whose components are active, dynamic, and/or clickable; and that is intended to explain just a few concepts. The use of interactive and instructional graphic tools would reinforce active participation of students. For educators, this kind of tools can provide a very useful way to test main ideas and to realize how difficult explaining a particular concept to students is [38].

These advances have had, and currently have, a great impact in education. A good example is the Automatic Control field and mainly the well-known Control Education area, which has been included as a technical committee in IFAC [28] and IEEECSS [25]. Nowadays, it is very common to find sessions dedicated to education at the most important conferences about control (such as IEEE Conference on Decision and Control, European Control Conference, American Control Conference, or IFAC World Congress), symposia and workshops about control education (e.g. IFAC Symposium on Advances Control Education, or IFAC Internet Based Control Education), related European and National projects, special issues about control education in the most important journals (*IEEE Control System Magazine: Innovation in Undergraduate Education, Parts I (2004)[26] and II (2005)[27], or Control Engineering Practice: Special Section on Advances in Control Education, 2006 [29]), or even journals specifically dedicated to these issues (e.g. *IEEE Transactions on Education, Computer Applications in Engineering Education, or International Journal of Engineering Education*).

In the following sections, Interactivity will be described and defined from different points of view showing that it is a complex term which involves multiple disciplines. Then, the influence of Interactivity in teaching is presented remarking its possible drawbacks. Attention is then turned to the Automatic Control field where there exists a great experience about the use of Interactivity for education. Several examples
will be shown by means of a set of Interactive Tools. Finally, some conclusions will be summarized.

2 What does Interactivity mean?

2.1 Definitions and interpretations

Interactivity is an abstract concept which can be interpreted in several ways going from trivial definitions to more complicated ones. Interactivity in a non computer-based framework can be described as follows [36]:

Definition 1. It is some action performed mutually by two or more objects, agents, forces, functions, etc... which allows information exchange between each other.

That is, the conversation between two people can be described as interactive (if both participate into such conversation), a person driving a car is an interactive action (the action is performed by the person and the car functionalities), or even reading a book is also interactive in this sense (the writer interacts with the reader by means of the book). That is, Interactivity is a concept based on the well-known cause-effect relation. For some situation being really interactive, the tasks performed by the people or objects involved in the Interactivity will produce an associated effect. A good background to understand Interactivity is to observe the daily tasks performed by people, where body and senses perceive continuously the world interactions. On an everyday sense, when you drive you are responding interactively with the surrounding environment and traffic. Interaction is an accepted part of our everyday life [23].

Considering the previous definition, Interactivity is something very common and natural. However, the use of this word by people have never been as striking as currently is. Interactivity is a common term that people use frequently. Nowadays, it is very usual to speak about interactive applications, interactive television, interactive mobile phones, etc, associating the interaction between people and technological devices. The inclusion of this phenomenon into the society has been due to the advances on the NICT. That is, this new meaning of Interactivity comes from its use in Computer Science, where people interact with the computer in order to perform some specific task. This definition can be useful from a conceptual point of view, and it may seem an easy and trivial concept. However, some complicated definitions about Interactivity can be found, such as those related with the development of IT or graphical computer-based applications [41]:

Definition 2. It is a compromise between visual aspects, user understanding, creativity, technical support, and direct links with the theoretical or underlying ideas for which Interactivity is required.
In the Computer Science environment, Interactivity is usually wrongly associated to simple menu selection, clickable objects or linear sequencing. It is sometimes confused with its original meaning based on the *cause-effect* relation. That is, following the original meaning of Interactivity, the simple menu selection is really interactive, but this fact does not mean that the application including the menu is interactive. The interactive aspects of an interface are perceived not primarily with the eye, but with our sense for the interactive quality of things. As commented in [41], *this is not a sixth sense with dedicated sense organs, but a faculty of human beings enabling us to perceive, judge, imagine, design, and reason about the behavioral aspects of our environment*. For this reason, the development of Interactivity software can be a little bit complicated and subjective, since what a given person perceives in a given situation is not arbitrary, but depends on the person’s expectations of what is possible. Interactivity involves a wide range of disciplines including software engineering, computational linguistics, artificial intelligence, cognitive science (understanding, thought, creativity), sociology, ergonomics, organizational psychology, mathematics, cognitive psychology, and social psychology [2]. A good description to show the difficulty associated to Interactivity is described in the following definition [44]:

**Definition 3.** Interactivity has gestalt properties. *In the same way as you see a rose, and not a collection of petals; hear a familiar musical theme, and not a sequence of tones; you perceive the interactive behavior of a graphical user interface (GUI) widget no as a collection of action/reaction pairs, but as a meaningful interactive whole.*

On the other hand, the inclusion of Interactivity in a computer application can be seen as a fourth dimension. The representation of 3-D objects into a computer is currently something very usual, corresponding to a *visual component* which allows to show the users wonderful graphical representations. This fact is a very important component, but from a Computer Science point of view, more important elements are required: what can I do with this graphical element?, what kind of information can I get as feedback? That is, this corresponds to the *action component* which describes the available operations to do using a specific element. Although this matter may seem something essential, not many attention has previously put in. We live in a culture where the eye is the dominant sense, and large investments have been made in making the GUIs around people visual appealing [44]. Comparatively the interactive aspects of the interfaces have been less investigated. As commented above, nowadays this fact is changing and the interactive elements are each day more common in our society.

The implementation of Interactivity can be perceived as an art because it requires a comprehensive range of skills, including an understanding of the user, an appreciation of software engineering capabilities, the importance of rigorous instructional design, and the application of appropriate graphical interfaces. The
term *look and feel* is often used to refer to the specifications of a computer system’s interface. Using this as a metaphor, the *look* refers to its visual design, while the *feel* refers to its Interactivity. Indirectly this can be regarded as an informal definition of Interactivity [1].

### 2.2 How old is Interactivity?

The origin of Interactivity in the Computer Science field is very difficult to date. An early effort to use interaction was made in the late 1970s by [4]. They developed *VisiCalc*, which was based on the spreadsheet metaphor. It contained a grid of rows and columns of figures for financial calculations. Its implementation on the *Apple II* was one of the reasons why personal computers started to be used in the office. *VisiCalc* changed spreadsheet from a calculation tool to a modelling and optimization tool. The implementation called *Excel* is now a standard tool in all offices. *Interactive* software includes most popular programs, such as word processors or spreadsheet applications. *Noninteractive* programs operate without human contact such as compilers and batch processing applications.

On the other hand, the term that can be dated is *Interaction Design*. This term dates from the 80s and was developed by Bill Moggridge and his colleagues at the company *ID2* to describe their design work [45]. By focusing on interaction, the term goes to the core of how the design of user interfaces differs from Graphics Design. As this study has illustrated, the interactive dimension of the graphical user interface is fundamentally different from its visual dimension. Interactivity design can be seen as layer-based abstract process. It begins from the idea to show using Interactivity, and the first abstraction layer is created. This process is repeated until a good abstraction is reached [44].

An explanation about the evolution of Interactive Design can be found in [10], where such evolution is associated to the use of Interactivity in the field of Automatic Control. Design involving a human being also benefits from a fast and intuitive approach because it lets the designer understand what is happening. Boring trial and error search from the best set of parameters is avoided. From the control design point of view, the evolution in the use of interactive graphics as an aid can be divided into three phases:

1. **Manual calculation.** This period is previous to the availability of digital computers as a tool in the process design. The procedure consisted in the calculation of a few numerical values. Control engineers developed sets of rules in order to draw graphics by hand.

2. **Computers as an auxiliary tool.** With the advent of digital computers it was possible to make the creation of graphics much easier. Control engineers had the possibility of tuning the design parameters using a trial and error procedure following an iterative process. Specifications of the problem are not usually used to calculate the value of the system parameters because no explicit formula can connect
them directly. This is the reason for dividing each iteration, into two phases. The first one consists in calculating the unknown parameters of the system taking a group of design variables (related to the specifications) as a basis. During the second phase the performance of the system is evaluated and compared to the specifications. If they do not agree, the design variables are modified and a new iteration is performed.

3. Computers as an interactive tool. It is possible however to merge both phases into one, and the resulting modification in the parameters produces an immediate effect. In this way, the design procedure becomes really dynamic and the engineers perceive the gradient of change in the performance criteria given for the elements that they are manipulating. This interactive capacity allows us to identify much more easily the compromises that can be achieved.

2.3 Measuring Interactivity

Another important aspect related with Interactivity is that, once a computer-based application has been developed, how can its degree of Interactivity be studied? This fact may become something subjective, and the associated Interactivity could be analyzed from several perspectives. Different authors have given some recommendations in order to study the interactive features of a given application [3, 37, 31, 41]. Some Interactivity features extracted by the study of several instructional programs are outlined in [3] where the most important ones are summarized in the following:

- Immediate response means that the user is able to access information (a graph, text, or video) with a mouse click. It is compared to the difference between face-to-face conversation and communication through non-electronic mail. Immediate feedback as opposed to waiting.

- Non-linear access to information. One needs to compare two models of instruction. Model A involves a step by step hierarchical presentation of information, with no questioning or discussion. In model B instruction responds to the level of knowledge of each individual learner. The ability to customize the response to the user’s level of knowledge is called adaptability.

- There is no Interactivity without feedback, the user must know if the objective has been achieved. Responses along the lines of simply “wrong” or “right” are not adequate; the user needs to know how to improve and progress.

- Adaptability and feedback should allow for a sufficient number of options. If the users’ only option is to turn electronic pages then the program is not extracting enough information from the user and so providing for limited instruction.
Grain-size refers to the length of time required before allowing the user to interrupt or initiate an action. If the user, for example, has to wait for a fifteen-minute video or for ten minutes of credits before interaction occurs, then Interactivity is compromised.

Learner control involves handing some degree of responsibility to the user. If the user can control some aspects of the process such as the pace and sequence of instructions, then motivation and learning are likely to increase. Total learner control is not recommended for it can lead to the too-much-rope-syndrome, an imbalance of Interactivity with the instructional focus shifting to the user. This is only beneficial for users who are specialist in particular areas or who are generally high-achievers.

3 Interactivity in Teaching

The use of Interactivity in teaching involves the different definitions described in the previous section. In a typical lesson, the teacher must motivate the students and enhance their participation in class, trying to obtain some feedback from them. In the same way, work groups may be promoted, where students can discuss and solve problems all together exchanging ideas and information. That is, the aim is to create an interactive environment where, as definition 1 sets, students and teachers can perform actions influencing on each other. In a non-interactive lecture the teacher will talk and the students will listen. In an interactive lecture the teacher invites questions and comments from the students and a discussion ensues. Interactivity in learning is a necessary and fundamental mechanism for knowledge acquisition and the development of both cognitive and physical skills. From this point of view, Interactivity in education has two possible ways:

- **Interactive teaching** is a two way process wherein the teacher modifies his or her approach in response to the needs of the students. The interactive teacher is keenly aware of the students and their different learning styles. All good teachers are interactive teachers. To teach effectively is not possible without interaction.

- **Interactive learning** is also a two way process but the student may be interacting with the teacher, with peers, with resources, or with all three. For example, to envisage the following key skills lesson in which the teacher aims to develop students ability to solve problems.

Another inclusion of Interactivity in teaching comes from the point of view described by definition 3. This is also known as interactive multimedia or interactive software. These are a new kind of computer software that mixes multimedia capabilities (text, pictures, sound, videos, ...), together with interactive
features (the multimedia elements allows performing multiple actions and providing some kind of feedback to the user). That is, it consists in IT with high abstraction levels allowing the teachers to show theoretical concepts in an easier way, and the students to better understand theoretical concepts observing their practical applications.

Traditionally, all the information was presented as static text and formulas. In this way, the student motivation was difficult to enhance, being necessary turning to exercises or general questions in order to keep the student attention. Based on a traditional saying which expresses "an image is worth a thousand words", the information presentation has been improved along the years, first with the use of slides, and after that using digital transparencies. These new elements are a great support to traditional education, being possible to improve by means of visualization; that is, the way of acting with explicit attention to potential specific representations in order to explain abstract concepts. As commented above Interactivity can be defined as a fourth dimension from a Computer Science point of view. In this way, the previous traditional saying could be changed by "Interactivity is worth a thousand images" [23].

The theory can be learned through textbooks, inspiring lectures, and active study. The ability to solve practical problems relies on good skill in using theory and in breaking down large problems into manageable subproblems. One of the important tasks for teachers in engineering is to transmit to the students not only the formal and logic structure of the discipline, but also, and certainly with much more emphasis, the strategic and intuitive aspects of the subject [24]. These last aspects are probably much more difficult to make explicit and assimilate for students, precisely because they lie very often in the less conscious substrata of the experts activity. IT are considered a great stimulus for developing the students intuition. These IT attempt to demystify abstract mathematical concepts through visualization for specifically chosen examples.

In essence, an IT is a collection of graphical windows that are manipulated by just using the mouse. Students do not have to learn or write any sentences. If students change any active element in the graphical windows an immediate recalculation and presentation automatically begins. In this way, they perceive how their modifications affect the obtained result. IT cannot only be effective in presenting theoretical concepts in the classroom, but also beneficial in extending student experience in analysis and design assignments.

This strategy causes students to think small and simple. This is justified by a frank assessment of our limited knowledge for designing educational software as well as by practical considerations about how to manage incremental innovation. As IT are fairly easy to create and deploy, they provide a means for rapidly prototyping and testing theoretical ideas. In particular, they can be used as sharp tools for investigating precisely what it takes to make a theoretical concept known to students. In this way, the virtue of simplicity becomes an issue in learning research on the design and use of this kind of tools [9].
A good summary describing the main reasons for which IT are useful for teaching are the following can be found in [16]:

- They facilitate student-focused learning, allowing choice in the pathways for learning and the rate at which new material is introduced.
- They can address several learning styles and modalities – providing a rich variety of instructional approaches which can teach in most of the ways what students learn best.
- They motivate students interaction, experimentation, and cooperative learning.
- Students often work together in computer projects as they never did on paper-and-pencil projects.
- They facilitate storylines or thematic learning – where a pathway for exploration can easily be woven around a particular concept dynamics.
- They promote the constructivist view of learning.

However, these advantages don’t indicate that it is necessary to create IT in a discriminated way for all kind of theoretical ideas. It must be kept in mind that IT are presented as support for the teaching. Some outlines to identify teaching problems where IT may be suitable to use are the following [16]:

- Material which is hard to visualize, such as microscopic processes.
- Material which is three-dimensional, which is difficult to visualize using traditional two dimensional media such as books and blackboards.
- Dynamic processes, which require an understanding of the relationships between moving objects.
- Material which covers broad contexts, where a number of ideas need to be linked to gain an understanding of the whole, not just the parts.
- Simulations of expensive or complex processes, where understanding may be hindered by the process mechanical details, or where there is no possibility of using real equipment.

Therefore, the presence of Interactivity in teaching takes a high pedagogical value. It is reflected at teaching methods level, in the form of interactions between teachers-students and students-students. It is also presented as practical support, where IT help to improve the abstraction of theoretical concepts and motivate the students’ participation. Some results provided along this work are aimed on the development of IT to be used in the teaching of Automatic Control.
3.1 Warning of Interactivity in Teaching

It can be very helpful in education but there is a danger: *students try to learn and solve problems by manipulation without understanding*. The tools should challenge the students and encouraging them to make observations and relate them to theory in order to develop a broader and deeper understanding.

A simple view of the idea of interactive learning is that activity promotes learning. The power of the IT sometimes provokes the user’s temptation to play with the different dynamic objects forgetting the real meaning of such graphical elements. Teachers must make clear to the students that IT are abstractions of the theoretical concepts, and the full learning must be complemented as a mixture of both. In the same way that mathematical books are accompanied with exercises in order to understand the theoretical concepts, IT should be used as support to the traditional lectures [22].

However, the danger underlying in teaching with IT not only comes from the risk that students forget the theoretical component of the subject, the great reputation that this kind of tools are currently taking, can lead teachers to rapidly develop IT loosing the correct abstraction levels. That is, although there exist development environments to facilitate the creation of IT (such as Sysquake [35], or Easy Java Simulations [12]), their development requires a long time, specially during the design phase. As commented in previous sections, the design of interactive modules can be seen as layer-based abstract process. It begins from the idea to be shown using Interactivity, and the first abstraction layer that is created. This process is repeated until a good abstraction is reached. This fact is even more critical from an educational point of view, where the abstraction of theoretical concepts must be thought and re-thought considering the students’ perspective.

Therefore, IT can be very powerful in teaching, but they must be used with control.

4 Interactivity in the Automatic Control Field

4.1 Why is Interactivity very important in Control Education?

As commented in the introduction, during the last years the research in the field of Automatic Control education is taking a large interest, Interactivity being one the main factors of attention [10, 32, 38, 18, 22]. Several decades ago, it was possible to find several works which have attempted to provide teaching innovations related with Interactivity. Some examples of these works are [11], [14], and [7] in which basic IT were developed, where the interaction between the user and the computer was mainly done by keyboard or light pen.

In the previous sections, abstraction has been set as one of the most important features for IT. In this context, abstraction refers to associate theoretical concepts with graphical elements. That is, visualizing the
concepts with graphical and dynamic pictures, knowing this as visualization. In order to design technical systems or simply to understand the physical laws that describe their behavior, scientists and engineers often use computers to calculate and graphically represent different magnitudes. In control engineering, these quantities include among others: time and frequency responses, poles and zeros on the complex plane, Bode, Nyquist and Nichols diagrams, phase plane, etc. Frequently these magnitudes are closely related and constitute different visions of a single reality. The understanding of these relationships is one of the keys to achieve a good learning of the basic concepts and it enables students to accurately design control systems [10].

Automatic control ideas, concepts, and methods are really rich in visual contents that can be represented intuitively and geometrically. These visual contents can be used for presenting tasks and handling concepts and methods, and manipulated for solving problems. Control specialists have visual images, intuitive ways of perceiving concepts and methods that are exceedingly important for effectively carrying out their creative work and mastering the field in which they work. Using visual images and intuition, they are able to relate constellations of facts that are frequently highly complex, and the results of their theories in an extremely versatile and varied way. Furthermore, via these significant networks, they are able to naturally and effortlessly choose the most effective strategies to attack and solve the problems facing them.

The basic ideas of automatic control often arise from very specific and visual situations. All experts know how useful it is to go to this specific origin when they want to skilfully handle the corresponding abstract objects. The same occurs with other apparently more abstract parts of Automatic Control. This way of acting with explicit attention to potential specific representations to explain the abstract relations that are of interest to the control expert is what we name control visualization.

The fact that visualization is an especially important aspect in the control experts activity is something completely natural if we bear in mind the applied mathematics feature of control theory. Broadly speaking, mathematics tries to explore the structures of the reality that are accessible using this special manipulation that we call mathematization, which could be described as follows. The first perception is that tangible things have certain similarities and we recognize from these perceptions what is common and can be abstracted. We then subject this information to rational and symbolic detail in order to handle more clearly the underlying structure of these perceptions.

People feeling is primarily visual and it is thus not surprising that visual support is so present in the daily work. Control experts very often make use of symbolic processes, visual diagrams, and other forms of imaginative processes in their work and they acquire what could be called an intuition of what is abstract. Visualization thus appears to be something deeply natural both in the origins of automatic control and the discovery of new relations between mathematical objects, and also of course in the transmission and
communication of our control knowledge. One of the important tasks for teachers in control engineering is
to transmit to students not only the formal and logic structure of our discipline but also, and certainly with
much more emphasis, the strategic and intuitive aspects of the subject. These strategic and intuitive aspects
are probably much more difficult to make explicit and assimilate for students, precisely because they are
very often in the less conscious substrata of the experts activity. Given the nature of visualization, it will
have many highly subjective elements.

The ways of visualizing and making Automatic Control ideas closer and intuitive in order to implement
them in certain situations, and apply them to specific problems, depends a lot on each individuals mental
structure. The degree of visual support certainly varies considerably from one analysis to another, and
what for a person is helpful, for another person is possibly a hindrance. Yet, these differences must not
hamper our attempts to generously offer those instruments that are so useful for us in our work and without
which our work would be much more difficult, abstruse, and boring. The mathematical language used by
control specialists is a mixture of natural language and formalized language, a strange jargon consisting
of natural language elements, more or less esoteric words, and logical and mathematical symbols. In this
strange language reference is explicitly made, or not so explicitly, to scientific conventions that have been
established in the course of time and that are laden with intuitive, visual, and implicit connotations. It is not
surprising that mathematical and communication work using this tool produces mistakes, confusion, and
obscurities that may lead to error.

According to [42], a control designer (teacher, engineer, or student) must fulfill the following procedure
in order to design a suitable control system for a plant [38]:

1. Study the plant to be controlled and obtain initial information about the control objectives.
2. Model the plant and simplify the model, if necessary.
3. Analyze the resulting model; determine its properties.
4. Decide which variables are to be controlled (controlled outputs).
5. Select the control configuration.
6. Decide on the type of controller to be used.
7. Decide on performance specifications, based on the overall control objectives.
8. Design a controller.
9. Analyze the results and if the specifications are not satisfied, modify it or the type of controller.
10. Simulate the resulting controlled system, either on a computer or pilot plant.

11. Repeat from step 2, if necessary.

12. Choose hardware and software and implement the controller.

13. Test and validate the control system, and tune the controller on line, if necessary.

It can be observed that if the design of the control system leads to unsatisfactory results of the simulations, it would be forced to go back to step 2 and proceed to repeat steps 2 to 10, analyzing them one-by-one. The previous approach to design a control system using traditional tools can be considered a non-interactive approach (see Figure 1 (a)). This is due to the fact that it is not possible to know the consequences of the decisions taken during the design process until we are very near the end (step 11), just before the final implementations. This situation produces that the same steps must be repeated over and over in order to correctly tune the design parameters, making this a very time-consuming activity. This is a direct consequence of the non-existence of a real-time link between the design and the analysis phases, avoiding the designer from appreciating the gradient of change in the performance criteria given for the elements he/she is manipulating.

![Non-Interactive approach versus Interactive approach.](image)

Figure 1: Non-Interactive approach versus Interactive approach.

If there were such a real-time connection or link between the decisions taken during the design phase and the results obtained in the analysis phase, both phases could be merged into one. In this new approach, decisions taken in some steps would show on-the-fly the differences between the simulation results and the original control specifications fixed in step 1. It would not be necessary to iterate so many times across every step trying to tune the parameters. But this proposed link to merge analysis and design can be brought to existence giving Interactivity the central role that it deserves in the development of new software tools for control education. So, this would be an interactive approach (see Figure 1(b)).

In such a high-interactive system, several graphic windows are updated immediately, reflecting the value of every active element, and the constraints among them. This lets us establish a reactive behavior among all active components of the system, hiding the underlying mathematical basis. Every change in the values
of system parameters has a dynamic effect on the system response. Since a good design usually involves multiple control objectives using different representations (time domain or frequency domain), it is possible to display several graphic windows that can be updated simultaneously during the manipulation of the active elements [38, 10]. Furthermore, interactive design with instantaneous performance display let us go further. In many cases, it is not only possible to calculate the position of a graphic element (be it a curve, a pole, or a template) from the model, controller, or specifications, but also calculate a new controller from the position of the element. For instance, a closed loop pole can be computed by calculating the roots of the characteristic polynomial, itself based on the model and controller; and the controller parameters can be synthesized from the set of closed loop poles if some conditions on the degrees are fulfilled [5].

Many tools for control education have been developed over the years incorporating the concepts of dynamic pictures and virtual interactive systems [46]. Nowadays a new generation of software packages has appeared, based on objects that admit a direct graphic manipulation and that are automatically updated, so that the relationship among them is continuously maintained. The early programs were useful but their implementation required a substantial effort which significantly limited their use in education. Advances in computers and software have made implementation easier. Matlab has been used in several projects, where two successful efforts have resulted in ICTools [30] and CCSdemo [46] developed in the Department of Automatic Control at Lund Institute of Technology. The programs are, however, strongly version dependent which has made support and future development cumbersome. Yves Piguet at the Federal Institute of Technology in Lausanne (EPFL) developed a Matlab-like program Sysquake which has strong support for interactive graphics [35]. Projects based on Sysquake were developed at EPFL and elsewhere [18, 22, 8, 6].

Therefore, the role of this new interactive computer learning experience in control engineering curriculum is twofold:

- To provide a new method for delivering classroom material whereby real-world control system engineering concepts are introduced via an interactive package, and
- to provide an opportunity for innovative laboratory assignments where students can analyze, design, and modify control engineering systems via IT.

The combinations of an interactive environment plus animation bring visualization to a new level and aid learning, and active participation by control engineering students. Automatic Control teachers are at the threshold of a new era in which advanced information technology is finding its way towards effective and efficient applications in control education [33].
4.2 Interactive Applications for Control Education

During the last years, the authors have collaborated actively in several projects dedicated to the development of IT for Control Education and associated areas [22, 21, 23, 18, 17, 10, 8, 6], where Sysquake has been used as development tool. In this section some of these IT are briefly described. It must bear in mind that the main characteristic of the IT - the Interactivity - is difficult to be reflected in a written text, and the reader is cordially invited to visit the Web site http://www.calerga.com (section User Contributions) to experience the interactive features of the tools.

4.2.1 SISO-GPCIT and MIMO-GPCIT

SISO-GPCIT (Single Input Single Output Generalized Predictive Control Interactive Tool, Figure 2) and MIMO-GPCIT (Multiple Inputs Multiple Outputs Generalized Predictive Control Interactive Tool, Figure 3) are two IT dedicated to help the students to learn and understand the basic concepts involved in Generalized Predictive Control (GPC) for monovariable and multivariable systems. Using this tool the students can put into practice the acquired knowledge on this control technique using simple examples of unconstrained cases, effect of plant/model mismatch and robustness issues, disturbance rejection, effect of constraints in the design and performance of the controller, stability issues, etc. It is possible to analyze how the closed loop system response is affected by changes in different design parameters such as weighting factors $\delta$ (on tracking errors) and $\lambda$ (on control effort), the prediction ($N_1$ and $N_2$) and control ($N_u$) horizons, the sample time, the T-polynomial, etc. At the same time, different constraints related to physical limits or security issues, desired performance or stability can be selected and activated to see their effect on the performance of the controlled system [18].

The tools have been used in process control courses during the last two years, receiving a great attention and acceptance by the students, as indicated in surveys and tests provided to them when finishing the courses. In fact, the combined use of IT with classical programming lab sessions (using Matlab) has been very successful, as the IT have become a way to test the correctness of the algorithms and calculus performed by the students. The repercussion of the IT in the classrooms has been such that we have been almost forced to developed new tools for the different courses covered by the Automatic Control unit of our university [21, 22].

4.2.2 MRIT

MRIT (Mobile Robotics Interactive Tool) is an IT aimed at facilitating the understanding of the algorithms and techniques involved in solving mobile robotics problems, from those that model the mechanics of
Figure 2: The user interface of the module *SISO-GPCIT*.

Figure 3: The user interface of the module *MIMO-GPCIT*. 
mobility to those used in navigation, showing how the modification of a certain element of the system affects to the other components. Different parameters involved in the general robot navigation problem can be selected and/or modified using the interface of the tool, such as those associated to the navigation algorithm, the initial and goal positions of the mobile robot, the robot kinematics and associated dimensions, the number, morphology and position of different objects in the environment, etc., and the user can interactively visualize (in one run or using a step by step procedure) the effect that these modifications have on the selected trajectory to navigate from the initial to the goal position (see Figure 4) [20].

The tool has been used by the students during the last years both to understand the concepts and also to test the algorithms in many different (and even atypical) conditions. Students also use the tool in order to analyze and compare the results with laboratory sessions.

5 Conclusion

In this work a deep reflection about the Interactivity has been accomplished. It has been seen that Interactivity can present multiple meanings depending on the context in which it is defined. It can be found as something very easy and common as part of our everyday life, as a new technological term that people use in relation to human-device interactions, or as a more complicated element inside of the Computer Science field. On the other hand, Interactivity has been situated in the last context, where the Interactivity influence
in the teaching field has been analyzed.

The use of Interactivity on education provides a wide range of possibilities to both teachers and students. Teachers can use interactive presentations where not only the meaning of the concepts is provided, but also how these concepts are related with others, or how such concepts are affected by some input modifications. On the other hand, students can use interactive web sites or interactive computer-based tools, as a way to study theoretical concepts abstracted by means of interactive elements.

The role of Interactivity in Automatic Control education has been discussed in order to show the powerful of this element in Teaching, where several Interactive Tools, which have been successfully used by students during the last two years, have been briefly described.

In the personal experience of the authors, Interactivity is an excellent element as support to teaching and learning which allows to enhance the motivation and participation of the students. Authors animate to the readers to test these new interactive features in education.

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