Smartphone-Based Industrial Informatics Projects and Laboratories

Houcine Hassan, *Member, IEEE*, Juan-Miguel Martínez-Rubio, Angel Perles, Juan-Vicente Capella, *Member, IEEE*, Carlos Domínguez, and José Albaladejo

***Abstract*—The use of IT technologies plays an important role in the training of future engineers. In this paper, smartphones and multimedia technologies are proposed as an innovative way to tackle the formation of students, at different levels, in the Industrial Informatics (II) subject of the Industrial Electronics Engineering (IEE) degree. II instructs future Engineers in the design of IT systems to control industrial processes. In the first level, smartphones are used to display a web-based multimedia tool that is implemented to register the lecture explanations regarding the design of II systems, so as it facilitates student to guide him/her self in the learning process. In the second level, the smartphone is proposed as the control system of a medium size industrial process (e.g., water tank). Since II uses a problem-based learning methodology (miniproject) to instruct the design of II systems, for each lecture, laboratory practices are tackled, and the solutions obtained are embedded in the smartphone to control the corresponding part of the miniproject. An application of the Smartphone multimedia tool is presented to show how students interact with the developed system. The successful evaluation of the proposed tools, by more than 900 IEE students during three years, is shown.**

***Index Terms*—e-learning, industrial informatics (II), process control, remote laboratories, smartphones.**

I. Introduction

THE USE OF new technologies plays an important role in the training of future engineers and the spread of e-learning tools facilitate the teaching and learning process. Education in engineering universities requires a change in its traditional model to adapt to new students of a global knowledge society using new tools and devices for communicating (e.g., smartphones) [1]–[4]. However, the implementation of complete e-learning materials in Engineering, is still far since it involves implementation of laboratories with real processes, which drastically increases the complexity of the e-learning system. To carry out more suitable products to achieve much more effective experiences, new approaches are needed [1], [3], [5]–[8].

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The authors are with the Department of Computer Engineering, Universitat Politecnica de Valencia, 46022 Valencia, Spain (e-mail: husein@disca.upv.es; jmmr@disca.upv.es; aperles@disca.upv.es; jcapella@disca.upv.es; carlosd@disca.upv.es; jalba@disca.upv.es).

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In this paper, smartphones and multimedia technologies are combined to devise an innovative way to undertake the formation of students in the Industrial Informatics (II) subject of Industrial Electronics Engineering (IEE) degree. The proposal implies the use of mobile phones since many of these devices, with which students come to class, have the sufficient graphical and processing capacity to implement the different needed learning tasks. Moreover, all that appears on the mobile phone screen seems to catch immediately his/her attention, hence, it is an excellent tool to guide his/her learning process. This project has been developed in the framework of a global project of the University [9].

The II subject [10] prepares the future Engineers in the design of IT systems to control and supervise industrial processes prototypes of small and medium complexity [11], by using the development environment Nokia Qt and C++ Builder [12] and the Data Acquisition Card (DAQ) PCI-9112 [13]. Smartphones are proposed to tackle the formation of the II students at different levels. In the first level, the mobile phone is used as a platform to implement a web-based multimedia tool, which has been developed to register the most relevant explanations of the lectures, laboratory practices and miniproject related to the development of II systems. Much of the II learning activities, are performed based on software development tools, input/output data acquisition cards and embedded microprocessors, which are essential in the learning process [14]–[17], but sometimes some of the explanations are fleeting and not all the students have the same abilities to follow the class [18], [19]. To overcome this situation, the recording of the explanations in the multimedia tool allows student to guide him/her self in the learning process. The smartphone can access the multimedia tool from Internet with a WIFI or 3G connection.

In the second level, smartphones are used to implement an II system to control a medium size industrial process (e.g., water tank), which is proposed as a project that students have to undertake. They can use the mobile device to monitor in the phone screen the real state of the process through the sensory system (e.g., level) and they can parametrize the process through the actuators (e.g., pump) with mobile phone graphical interface. In this way, students can watch in the smartphone the evolution of the real water tank and verify if the control strategy complies with the design requirements. The water tank is connected through a DAQ card to a gateway. The smartphone communicates with the gateway through Bluetooth to control the water tank and to receive the sensory information of the process.

The II subject uses a problem-based learning methodology [20] to instruct how to tackle the design and implementation of II systems. Therefore, each class is structured in one day of the week (5 h) as: lecture, seminar, laboratory and miniproject. During this day, the lecture (e.g., process interface) is explained and debated in seminar, then the laboratory practices corresponding to this lecture are solved (e.g., digital output Led switch On/Off). Once the most important theoretical and practical concepts are settled, with the help of the above mentioned multimedia tool, the student proceed to the implementation of learned concepts in the miniproject. The previous solution of the lab practice is easily embedded in the smartphone to control the corresponding part of the miniproject that deals with the studied concept.

After the introduction, Section II describes previous work performed on e-learning and remote labs. Section III presents the implementation of the web-based multimedia tool. The use of the smartphones in the development of miniprojects is addressed in Section IV. The PBL II subject is detailed in Section V. In Section VI, the process of applying the smartphone multimedia tool in the II class is shown. Section VII presents the successful student evaluation of multimedia smartphone. The conclusions are summarized in Section VIII.

II. Related Work

The use of computer-based educational tools has become more commonplace in world-class universities that deliver programs and courses in engineering and technology [1], [3], [21]. Bagnasco [7] proposes a service-oriented middleware to access heterogeneous remote laboratory equipment and experimental settings through the network. The laboratory enables high flexibility and scalability and is applied to education on electronics. Lopez presents [22] a remote laboratory to learn how to program a robot. The system uses free software and allows collaboration among students in design of discrete control systems subject. In [23], an approach to build interactive networked control labs is presented. The work allows not experts in programming instructors to create innovative pedagogical tools to apply the theory of automatic control like the remote control of plants. Matlab and EJS, which require minimum skills on computer programming, are used. The experience with a complete multimedia educational program of DC servo drives for distant learning is proposed in [24]. The program contains three parts: animation, simulation, and Internet-based measurement. This tool permits to describe a dynamic and interactive animation such as the operation of a motor even if students are not good at programming. In [5], a Web-based remote laboratory for automatic control systems that provides user interactive features is presented. The system allows visual algorithm designing, simulation, compilation, real-time monitoring, and supervisory control. Users can carry out experiments without installing any software. Ramos *et al.* [25] describe an Internet-based control-engineering education platform, which allows remote experimentation, mathematical analysis, dynamic simulation, and self-learning. The server is scalable since it is based on general public license (GPL) Linux operating system and Matlab. Vicente *et al.* [26] presents a remote laboratory for industrial automation comprising different programmable logic controller (PLC) manufacturers, which is based on a cluster of virtual machines running on several PCs. This environment allows remote users to learn automation topics while using different PLCs together with several types of sensors, actuators, and industrial communication networks. The aforementioned papers deal with different interesting aspects of the design of remote control environments. However, they do not undertake the integration of smartphones and multimedia technologies to tackle student e-learning as this work does. In this paper, the smartphone is used for II self-learning using the developed web-based multimedia tool, which records virtual teacher explanations and demonstrations. On the other hand, the smartphone is used as a powerful tool to implement II systems to remotely control, without wires through Bluetooth, medium size industrial processes. In other works, Zubia [27], [28] developed a remote lab, WebLab–Deusto that allows students to experiment with real prototypes. The webserver is independent from the instruments and enables the addition of new experiments easily. The webserver uses AJAX to allow mobile devices access. Vargas [29] describes AutomatL@bs, a remote lab that allows the analysis, design, development, and exploitation of web-based applications within the scope of automatic control. They use EJS open-source tool for designing the web-based interactive simulations. Rojko [30] presents a power engineering and motion control remote laboratory shared by 13 partner universities. A mechatronics motion control course, which explains the most important aspects of the design, from modeling, simulations, control and validation is presented. Regarding remote access to the simulators, the work presented in this paper is similar to those presented in [27]–[30], although different GUI are applied. Besides, this work develops Camtasia multimedia units stored in a remote server that allows student self-learning integrated with teacher explanations. Moreover, in [27], mobile devices access to prototypes is performed through the Internet. In contrast, the work presented in this paper allows the smartphone to control the processes through Bluetooth, hence, with no need of the Internet nor wires, which is more suitable for real-time control systems that have to guarantee real-time constraints [31] as is the case of the II subject.

III. Implementation of Smartphone Web-Based Multimedia Tool

In this section, the design of the multimedia tool for the II subject is presented. This tool registers the teacher explanations, laboratory and project videos, and demonstrations of implementations of II systems. The multimedia units are processed in a Relay Server, as shown in Fig. 1. The tool is published in a dedicated Multimedia Server of the University and can be accessed by registered students through the Internet with their smartphones, computers or PDAs. Likewise, students have access to different simulators from a Virtual Lab Server: SimeSeny is a signal simulator and SimProcess is a process simulator developed by the lecturers to help students in the implementation of their project.

A number of factors related to the contents, the functionality, and the design of multimedia web-based tool are analyzed. The challenge is that the tutorial must achieve a rapid student learning to allow him/her repeat the experience successfully [32]. The multimedia tool incorporates some basic functions

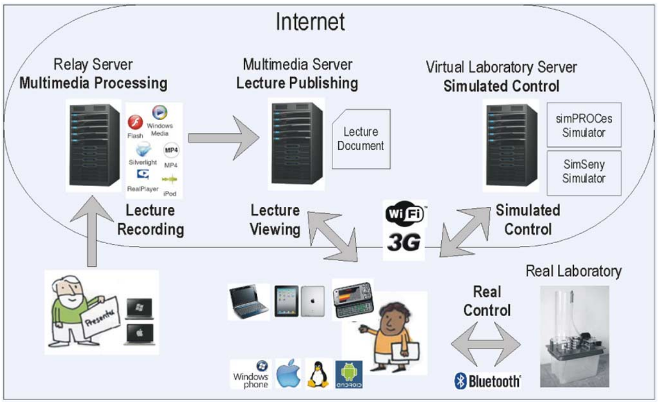

Fig. 1. Remote multimedia server.

Fig. 2. Final multimedia chapter design presented on a Palm device.

such as: orientation, promotion of self-learning, and self-assessment of learning. The analysis of the characteristics of different tools shows that learning is more effective if it presents information in different formats, which complements each other [33], [34]. Consequently, the following fundamental external factors have been considered in the design of the tool: *Video*, *Audio*, *Text*, *Images*, and *Teacher and blackboard*, to establish the maximum similarity with classrooms. Decisions on the structure, navigation, interaction, and graphic design are taken. The better the prototype is defined at the beginning, the less difficult the development of the multimedia tool chapters. The final prototype includes features such as: *graphic design*, which was decided to have a similar aspect as real classroom and simplicity is prioritized to avoid design becomes more important than contents. *Structure*, based on hypertext with different levels. *Interactivity*, which allows functionality and efficiency and gives the contents an optimal visibility. This organization permits the user to adapt quickly to the tool, which permits access to a large amount of well-structured materials. After having studied various possibilities of how to situate the image of the blackboard and lecturer, the final format displayed in the smartphone of Fig. 2 was selected, which is more appropriate since it resembles more the real classroom.

The learning scenario is divided into two parts perfectly synchronized. The virtual blackboard, containing the video of the lesson to which the teacher refers, is located at the left of Fig. 2, and at the right, a video of the teacher speaking, with a general plan, is presented.

In this work, the smartphone is considered as a minimal user interface. However, desktop computers, tablets, and notebooks are better alternatives to deeply study the concepts of the subject. However, it is becoming common to see students carrying on smartphones permanently, which is not so usual for personal computers. Therefore, a simple format for the lecture viewer that fits easily into the small size of a smartphone screen is developed. About the use of the smartphones as plant controllers, we want that our students learn to develop control programs on mobile platforms. Again, the availability of the smartphones for the students makes these devices good candidates to consider.

The multimedia tool contains 11 chapters of the recordings of the teacher's explanations regarding the lectures, laboratory activities, and videos of the implementation process of II systems to control industrial processes. Each designed chapter has the following order to facilitate the location of the student at any time: *Index*, *Objectives*, *Introduction*, *Required Material*, *Activities*, and *Miniproject*. An index differentiates the parties of the lecture and permits to access each of them directly. In the objectives section, the teacher performs a presentation of the general purpose of the lecture. In the introduction, the conceptual requirements, the attitudes and procedures that student should consider to direct the learning, are presented. The required material section describes all the necessary equipment to carry out the activity. The activities section details the exercises to strengthen the learned concepts. Finally, in the miniproject section, the various guided videos of the process of implementation of the project are detailed to facilitate the development of the II system.

The design of the format of the contents, as well as the fixed screens for each section has been performed with the Photoshop [35]. The assembly and integration of each chapter, has been performed with the Camtasia Studio software [36].

After the whole process, the multimedia tool, by using Camtasia software, is exported as Flash Video (FLV) which is a container file format used to deliver video over the Internet using Adobe Flash Player. The Multimedia FLV unit can be published in a website and optimized for smartphones, hence, it can be visualized more appropriately in mobile devices with Wi-Fi or 3G connections.

Accessing simultaneously the Multimedia Server by the students is not a real limitation since the multimedia tool is saved as a FLV file, hence hundreds of connections are allowed for the students. Regarding the access of the simulators, a classroom composed of 80 students can access concurrently the system with total security. In this case, the Virtual Lab Server creates a new instance of the simulator each time it gets a request from a smartphone client. To this end, the server opens a TCP/IP port in order to serve this instance of the client. On the side of the smartphone client, it has to be specified, the IP address of the Virtual Lab Server and the TCP/IP port to establish safely the connection.

Note that at this first level the students still do not have control of real prototypes through Bluetooth. This aspect is tackled in Section IV.

IV. Smartphone-Based Projects in Industrial Informatics (II)

Besides using the smartphone for reviewing the lessons and for developing the laboratory practices as described above, an

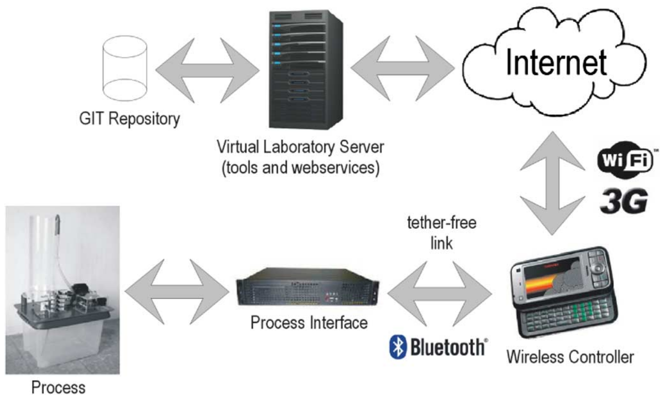

Fig. 3. Smartphone control architecture.

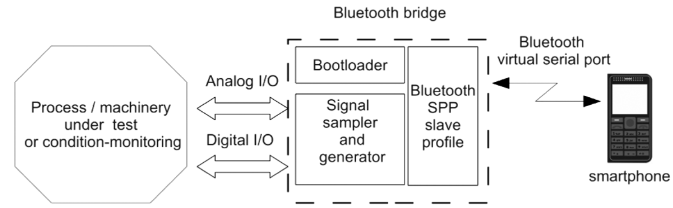

Fig. 4. Bluetooth interface.

important application of these devices is for developing the miniprojects proposed in the II course (e.g., water tank), as it is useful in various stages of the development and because the use of these mobile devices is very attractive to students and gets strong motivation. So, a student can use it to remotely monitor the status of the real water tank and to change its working conditions. In this way, the student has real-time information of the sensors concerning the number of litters in the tank, the temperature of the liquid, the overflow and the overheat sensor values, and the state of the different actuators as the valve, the pump, and the heater. Depending on the specifications of the project, the regulator of the tank analyzes the sensory information and sends control actions remotely to the actuators.

The control of the water tank is performed by the smartphone through Bluetooth based on the architecture of Fig. 3. Bluetooth has been chosen because it is well suited for hard and soft real-time industrial applications [31], which is the kind of applications that are used in the II subject and in more advanced subjects of the EE degree as real-time systems subject in the fourth year. Bluetooth is a master/slave approach where slaves follow the frequency hops of the master and can only communicate when polled by the master, at least in the associated minimal piconet (a master and up to seven slaves). This approach provides a near zero probability of collision.

The smartphone is the central piece of the system, which executes C++ control programs that collect sensory information from the process under control, and send control actions to change its behavior through Bluetooth interface. Smartphone controllers can be cross compiled by accessing a remote request service of the Lab web server through wifi, consequently, the software of the controller can be easily adapted to control other processes (i.e., greenhouse, elevator).

A. Hardware Components

Smartphones cannot be directly connected to the process, hence, the Bluetooth process interface of Fig. 4 between the smartphone and the real process is designed. This flexible tether-free hardware can interface physical and electrical signals between the mobile device and the process. This component must be cheap, transparent to the system, and highly reconfigurable to suit different needs. The remote server provides the control software for the smartphone depending on the process being controlled. Following industry standards, this service is likely to be provided through a web service request. The Firmware is maintained in GIT repositories as source code [37] and, if required the smartphone can access a web service that can commit the appropriate repository, cross-compile the source code and provide the compiled result for the smartphone.

The Bluetooth interface allows interaction between the smartphone and the process in both directions, so that in addition to monitoring, it can interact with the process and modify its operating parameters. The main parts of this interface are the following.

- A signal sampler and generator that generates and samples electrical signals and connects with the monitored or tested device.
- A Bluetooth module that handles the transfer of signal information between the sampler/generator and smartphone.

The choice of the hardware elements to build the prototype has been made with a view to minimizing the hardware design effort and avoiding the need of closed proprietary software tools. The signal generation/sampling module is based on an LPCXpresso NXP LPC1343 module [38]. This popular and low-cost module integrates a highly featured ARM Cortex-M3 processor and provides sufficient processing power to solve the required evaluation requirements. The development tool chain is based on the open GNU GCC compiler and can be integrated at no cost into the platform. For the Bluetooth link, a FlexiPanel Linkmatik2 module was selected [39]. This module provides a Bluetooth SPP serial profile that is easy to use from the microcontroller. Basically, the microcontroller accepts commands through a Bluetooth virtual serial link. The current set of commands to read/write simple signals is based on the CheapDAQ project [40].

B. Software Architecture

A fundamental criterion at the moment of deciding how to perform the implementation of applications based on mobile devices has been the selection of the mobile Operating Systems and the software development platform. The criteria that have been considered, in order of importance were the following.

- Multiplatform: the development should be able to take advantage in different platforms, including netbooks and computers.
- Free tools: to facilitate that others could take advantage of our work without need to pay for the development tools.
- Facility of development: to use a development environment that facilitates the implementation work.

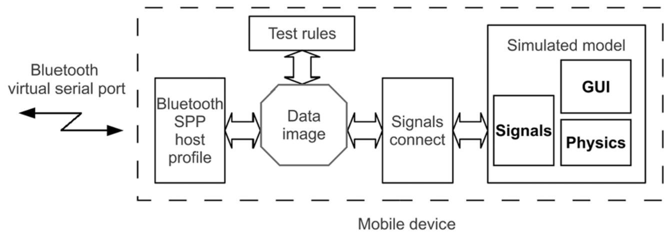

Fig. 5. Block diagram of smartphone application.

Nokia Qt (C++) and Builder C++ based environments that allow the easy development of multiplatform applications is selected. Most of the mobile OS permits application development based on this language (iOS, Android,webOS, Windows Mobile, BlackBerry OS, Symbian,Maemo, MeeGoBada).

The block diagram of a smartphone application is shown in Fig. 5. The logical modules containing a smartphone application are the following.

- An SPP Bluetooth logical connector that transfers information between the real process and a local representation of the state of the process (i.e., image of the process). This link is bidirectional, that is, the smartphone is able to change the state of the process by generating control actions.
- An image of the state of the process that is updated by the information gathered by the Bluetooth link and the information generated by the simulation model. The representation of magnitudes is independent of the acquisition card.
- A simulation model and the physics and/or electrical behavior equations—incorporating submodules for graphical representation in the mobile device.
- A module of logical signal connection that relates the simulated model signals with the signals stored in the image of the process.
- Test rule controller, which implements a control strategy, and based on the sensory information and on the state of the process, it provides control actions to satisfy the requirements of the system.

C. Users Access

A classroom is composed of 80 students. Teams of 2 students develop the miniprojects, hence 40 groups have to check on the real prototypes if their solution is correct. Five real water tanks are available in the lab, therefore, 8 groups per tank per day can perform the validation of the developed smartphone application. Each miniproject session lasts for 2 h/week, then 15 min are the available time for each team to validate its application. This time is enough for the validation with the real process, since the miniproject application is already tested in the PC with the process simulators.

Once a process is granted to a smartphone team, none of the rest of the smartphones can access this process until the former team releases it, hence no simultaneous smartphone accesses are allowed. Regarding the implementation of the communication protocol, each tank is a different Bluetooth *piconet* with its corresponding *master* node. A smartphone is connected to a given piconet of a tank, by requesting the connection through the *id* number of the tank. This *id* has to be published to the smartphone clients. To control the simultaneous accesses, the piconet master is configured to accept only one *slave* at a time. An *access manager* of the tank is developed to control the mutual exclusion access of smartphones to the tank based on the Bluetooth MAC address. In this way, first the students should register their smartphones with the pair "*name*, *MAC address*" and when a tank is granted to the smartphone, the MAC address of this latter is sent to the requested tank node. If another smartphone tries to access the tank node, the manager checks that it has a different MAC and hence the connection is refused. After 15 min use of the tank by a smartphone, the access manager finalizes its session.

The Bluetooth bandwidth (maximum application throughput of 2.1 Mbits/s for the BT version 2 that we are using in this project) has proved to be enough to control systems like the water tank, where simple and slow data exchange is required between the GUI of the Smartphone and the controlled plant. Note that only some basic sensor and motor variables are transferred. The connection latency has not been either relevant in this applications due to the slow dynamics of the level and temperature variables in the water tank. Control through the Bluetooth ensures good performance in general allowing plotting and monitoring on the smartphone the measurements of all the sensors of the processes, including those invisible magnitudes to the webcam as temperature or humidity. This solution is cheaper and more complete than using a web-cam for the needs of the subject.

D. Plant Security

One of the advantages of the wireless control of the plant is that students do not handle it physically. This prevents them to be hurt because of burns, cuts, electrical shocks, and other typical risks in a laboratory with potentially dangerous systems, even though the plant (water tank) obviously incorporates all the normalized active and passive safety elements. It includes, for example, electrical protective devices to prevent a current shunt to ground when an isolation failure happens. In addition, it is possible to operate the plant in even safer conditions; for example, the system incorporates a microcontroller that can simulate the water heating process bypassing the water temperature sensor. So, if the instructor considers it convenient, the students can test their temperature controllers using water flow, which is actually at the same temperature as the laboratory room. Moreover, since the students are still learning about the design and implementation of digital controllers, there are a lot of variables that could run out of control putting the plant itself in danger. To prevent the most common failure situations, the plant incorporates sensors to detect the limit conditions for the level and the temperature variables and actuators to reactively stop dangerous processes. Additionally, just in case the water level protection system fails, the plant has been designed as a closed loop water flow to prevent a water dropping.

V. Industrial Informatics in IEE

II is a compulsory subject that represents 25% of the mandatory credits of the second year course of IEE. Fig. 6 shows the organization of the different thematic units sequence, detailing the smartphone miniproject sessions and the smartphone multimedia units. The II subject is organized through a Problem-

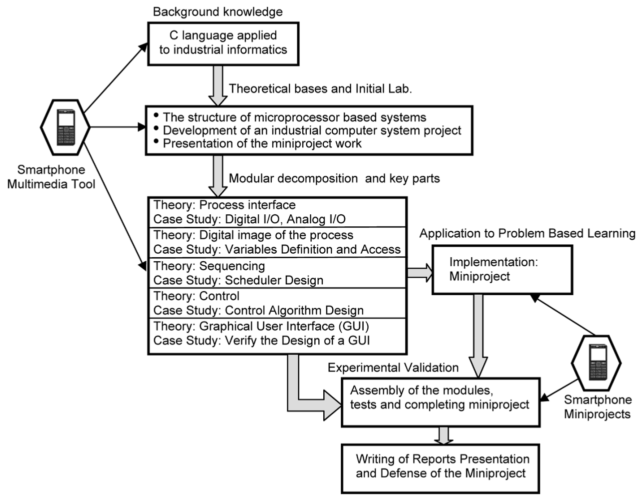

Fig. 6. Smartphone-based II course.

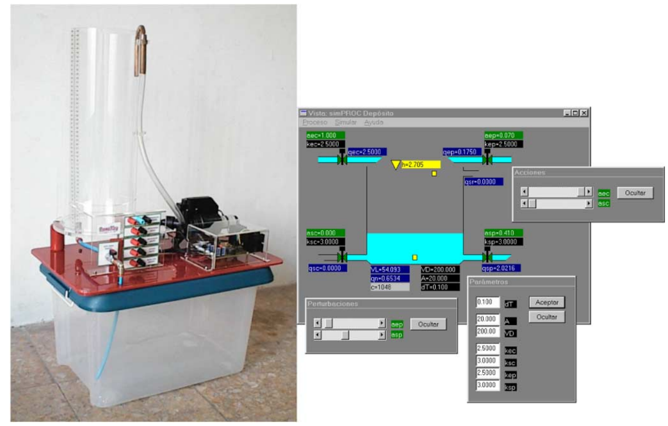

Fig. 7. Water tank: real and simulation prototypes.

Based Learning (PBL) methodology, which deals with the specification, design, and development of the IT systems for controlling an industrial process. The main focus is that all the learning activities are instructed based on the water tank case study application. To develop the project, students have to apply the knowledge acquired from the lectures and the laboratory practices. To this end, one day of the week is dedicated to teach one lecture unit (5 h). The structure of a class is the following.

- *Lecture*: the lecturer presents the main ideas of the lecture contents showing some application examples in 1 h. Before the session, the students have access to the smartphone multimedia application to review the lecture.
- *Seminars*: a panel discussion with student teams lasting 45 min is proposed, consisting generally of solving a problem with the help of the multimedia tool.
- *Laboratory session*: in this session (1 h 15″) students implement a practical problem (e.g., analog input) that has been previously presented during the lecture. Students have the multimedia tool that guides them for solving the practice.
- *Miniprojects*: this part of the class is dedicated to the planning, design, and development of II system for the water tank. Each team is composed of two students and each session is performed in 2 h. To complete the project, the team applies the knowledge acquired from the previous sessions. Each week, the project is advanced progressively.

Fig. 6 shows how thematic units are focused on the student work related to the miniproject within a modular decomposition way. The smartphone is helpful to support the learning process and their use is directly related to the different thematic units. The smartphone is used both for displaying the multimedia units and for the development of the miniprojects. The students implement in C++ a project containing five modules, including a Process Interface (i.e., sensory and actuators manager), Controller (i.e., PID), Scheduler (i.e., Task Sequencer) and a Grapical User Interface (i.e., Parameter adjusting). The project is cross-compiled and embedded in the smartphone to control the real water tank. In addition to the water tank miniproject presented in this paper, in previous years, the students have worked on other II projects like the control of temperature and humidity of a greenhouse, the control of an irrigation system or the control system of an elevator.

For example, the sequencing of a one-week class for the process interface lecture using the Smartphone multimedia tool is: the analog to digital conversion (A/D) is explained in the lecture session based on the simulation prototype of the water tank (see Fig. 7). In the seminar, a problem of programming the A/D converter to read the liquid level of the water tank is analyzed. After this session, students get a first draft of the solution of the problem. In the Lab session, the groups implement the necessary code in C++ for reading the liquid level with a simulator of the DAQ card that includes input analog bars that simulates the level (see Fig. 7 right).

In the previous three sessions, the students have used the multimedia tool in the smartphone, in an iterative way, to review either the theory or the steps to reach the solution of programming the A/D conversion for monitoring the liquid level. Once the solution is completed, during the miniproject session, students have to include the previously developed A/D module in their miniproject and test it remotely in the real water tank with their smartphones. For instance, to test the level A/D conversion with the smartphone, the A/D module is cross-compiled and the executable code is embedded in the smartphone to permit the monitoring and control of the liquid level through a graphical user interface. Each week, this process is repeated in the different sessions for the different lectures, and the required functionalities of the water tank control system are progressively built and incorporated to the miniproject. At the end, a final version of the smartphone controller is obtained.

VI. Smartphone Multimedia Industrial Informatics Application Course

This section describes first, how the smartphone multimedia application is used to solve a practical problem and, secondly, how this solution is embedded in the mobile phone to tackle the specific part of the control of the water tank miniproject. Student can switch in the Smartphone, from the multimedia tool to the controller and *vice versa* to review the lessons and hence tune conveniently the controller of the water tank.

Fig. 8. Smartphone display of button creation demonstration.

A. Web-Based Multimedia Laboratory

The PCI-9112 DAQ of Advantech is an Input/Output DAQ widely used in process control of industrial applications and in the different subjects of engineering degrees such as Industrial Informatics, Electronics, etc. To acquire the sufficient skills of this DAQ, students are formed on how to develop C++ programs to carry out acquisitions/generation of data with the Analog to Digital (A/D) and Digital to Analog (D/A) converters of the DAQ card and how to manage the Digital input/output to control industrial processes. To show how students learn to program the input/output of the card, by interacting with the web-based multimedia tool, the Digital Output chapter is selected.

The practice consists of programming several buttons of the Windows Graphical Interface so as a LED (Light-Emitting Diode), connected to the PCI-9112 card, switches on when student clicks on an ON button of the windows interface, and the LED switches off when he/she clicks on the OFF button. When the ON/OFF buttons are activated, they send a positive/negative signal to the PCI-9112 through the digital output line of the card and the LED is illuminated/darken. First, the student has to make the appropriate hardware connections of the LED to the DAQ, explained by the teacher in the multimedia unit. Second, throughout the multimedia tool, the student receives real-time explanation in his/her smartphone together with the animation of how the buttons are created with the properties of the Object Inspector of C++ Builder. Each button has associated a code that implements the actions to execute when the button is activated/deactivated. Therefore, the teacher shows in the multimedia tool which parts of the code to modify to implement the buttons functions (see Fig. 8). Later on, the student must create his/her own project following the explanations of the multimedia class and he/she has to check that his/her solution meets the specified requirements, otherwise, he/she has to return to review the multimedia course to correct the mistakes that he/she has performed until he/she gets a correct solution. Finally, the practice is complemented with activities that the student should undertake. For this chapter, the creation of a timer to make the LED intermittent every 500 ms is proposed.

Fig. 9. Open valve.

B. Smartphone Based Project

Once the laboratory practice of the Digital Output is completed, the student tackles the part of the miniproject, which corresponds to this Lab. In the water tank project, the valve is considered as a digital output actuator. Therefore, the control of the valve is proposed. After having programmed successfully the Digital Output of the DAQ card in the above example following the explanations of the multimedia tool, now the generated code is used by students, in the smartphone, to control the valve digital actuator. The button created previously for illuminating/darken the LED, now it is used to Open/Close the Valve, without any additional change in C++ code. On the other hand, the code related to the Open/Close button and controlling the valve has to be slightly changed to incorporate the graphical evolution of the liquid in the tank, the color of the valve (changes to red when open) and the exit of the liquid from the tank when the pump is open. Since student has practiced designing graphics from the first lab session this exercise is not difficult to tackle. To plot the evolution of the liquid in the tank, the student has to read the level sensor variable that gets the current tank level and adapt the blue rectangle to the corresponding dimensions. The code related to the level sensor is provided by the lecturer, as an object file, since it is related to the Analog to Digital conversion, which is not yet studied.

In this miniproject session, the student has to focus only on the control of the valve and monitoring of the water tank, the rest of the code is provided by the lecturer avoiding distracting student in concepts that are not important for the moment. A smartphone valve control example is proposed, which consists of opening the valve until reaching 5000.0 L, and at this moment the valve should be closed. After cross compiling the application and embedding it in the smartphone, the student has to check that the application works as expected. When the Valve On/Off button is On, a signal is sent through Bluetooth to the real water tank, which is connected to the DAQ card, to open the valve, and to the Bluetooth gate to communicate with mobile phone. Fig. 9 shows that the color of the valve changes to gray (ON) and the exit of the tank liquid is plotted in white when this action is taken, as it was required.

When the student detects that the level is reaching 5000.0 L, he/she changes the Valve On/Off button to Off, then the digital signal is sent to the real tank valve through the Bluetooth to close the valve. In the Fig. 10, the real value of the tank liquid

Fig. 10. Close valve.

1. Were the Smartphone multimedia tools effective and easy to use?
2. Have the tools given you the feeling of being in a classroom?
3. Has these tools permitted you to progress in your learning more than if you only worked in the classroom?
4. The Smartphone tool helped me to understand the Industrial Informatics courses.
5. Was the work effort in the proposed activities appropriate?
6. Would you recommend the use of the Smartphone multimedia tool to students for the next course?

Fig. 11. Questions of Smartphone multimedia survey.

TABLE I
MARKS SIGNIFICANCE

MARK	MEANING
A	Strongly disagree
B	Disagree
C	Unsure
D	Agree
E	Strongly agree

variable is plotted in white in the mobile phone screen, likewise the valve is plotted in white, which represents its closed state (OFF), as was required in the specifications.

In summary, during the laboratory and miniproject sessions, the student first has used the web-based smartphone multimedia tool to implement an application related to the digital output lecture by emulating with the Led a digital actuator. After having understood the practice, the solution has been embedded in the Smartphone to control the tank real valve. Although, more concepts (e.g., analog input) are intrinsically included in this session of the miniproject, they are hidden to the student to allow him/her to focus on the important part, which is the current lecture of the digital output.

VII. SMARTPHONE MULTIMEDIA TOOLS EVALUATION

ETSID students attending II subject have evaluated the Smartphone multimedia tool. During three years, four groups per year of 80 students/group have been using the platform during the development of their courses. At the end of the year, they answered the questions contained in the query of Fig. 11.

The answers were rated from A to E marks. Table I shows the meaning of each mark.

The results of this assessment are shown in the Fig. 12.

In global, ETSID students have rated the Smartphone multimedia tool with great success. Most of them do not have difficulties in using the tools (86%). The results of the question 2

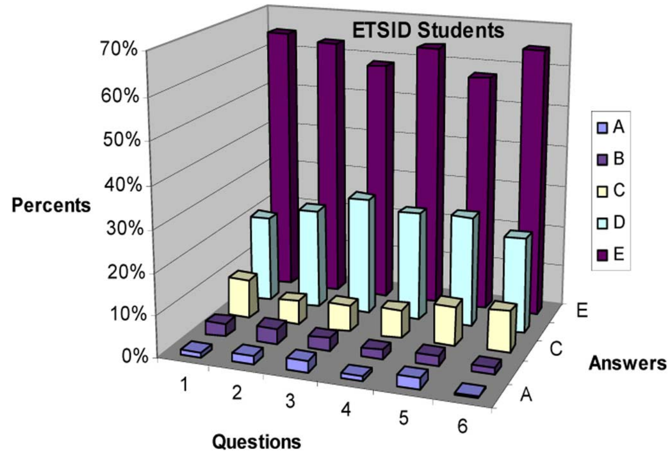

Fig. 12. ETSID student opinion.

shows that both the contents and the designs of the web-based multimedia tool allow students (87%) to work autonomously. In question 3, the results remain quite good (86%), although it is detected that some of the students are not sure that the tools allow to learn more than in front of the teacher. This can be explained due to some students use of new technologies with certain hesitancies, and give more importance to the face-to-face contact. Question 4 shows that students tackle the activities and implement the miniproject with success (90%). Regarding question 5, we can see that most of the students (84%) consider that the level of complexity of the proposed activities is adapted to the contents of the lectures. Only 4% of the surveyed students would not recommend the Smartphone multimedia tools.

Throughout the academic year, statistics about the access to the smartphone multimedia tool are recorded, showing that over 97% of students repeatedly have agreed to the contents continuously available. Regarding the use of the smartphone for the development of the miniproject, each team of two students used the platform 15 min each week during 26 weeks. The last four weeks when they have to assemble the different modules and to test the whole project, the five prototypes of the lab are available 8 h/day, hence the 80 students spend a maximum of 1 h per group per day. Around 94% of the teams have used the system to implement their project.

VIII. CONCLUSION

A Smartphone multimedia learning environment to instruct II subject regarding the design and implementation of II systems to remotely control industrial processes, has been presented. On the one hand, the smartphone has been proposed to review the theoretical and solve practical problems by displaying at anytime anywhere in the mobile device a developed web-based multimedia tool. The videos of the demonstrations and teachers' speech have been synchronized with Camtasia software to produce the chapters of the multimedia tool. Aspects as to the functionality, and the design of the multimedia tool to maximize the self-learning process, have been discussed. On the other hand, the smartphone is used to tackle remotely the control of a medium size industrial process such as the water tank, which is used as the II PBL miniproject. Different implementation criteria regarding programming platform and communication models, to support the development of mobile phone applications has been examined. To show how students learn the lessons using the Smartphone multimedia tools, first, Digital Output programming using C++ Builder programming tool and the Data Acquisition Card PCI-9112, has been described. Secondly, the process of adapting the solutions obtained in the first part to the corresponding module of the miniproject that controls the digital output valve with the smartphone device has been detailed. The evaluation of the smartphone multimedia tools has been performed by 4 groups of 80 students each year during three consecutive years. The results show that the students, which they use to help them in their formation, have successfully accepted the mobile phone web-based based multimedia tool.

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Houcine Hassan received the M.S. and Ph.D. degrees in computer engineering from the Universitat Politecnica de Valencia (UPV), Valencia, Spain, in 1993 and 2001, respectively.

He has been an Associate Professor with the Department of Computer Engineering, UPV, since 1994, where he is presently participating in several research projects. He is coauthor of more than 50 papers published in international refereed conferences and journals, and has been a scientific committee member of a number of IEEE and ACM International Conferences and Journal Editorial Boards. His research interests focus on real-time systems, embedded computers, multicore processor architectures, power savings, and industrial informatics.

Juan-Miguel Martínez-Rubio received the B.Eng. degree in electrical engineering and the M.S. and Ph.D. degrees in computer engineering from the Universitat Politecnica de Valencia (UPV), Valencia, Spain, in 1986, 1993, and 1999, respectively.

He has been with the Department of Computer Engineering, UPV, since 1986, where he is currently an Associate Professor. He has been involved in different projects in innovation in higher education since 1990. His research interests include Industrial Informatics, power saving, deadlock handling and congestion control mechanisms for computer interconnection networks.

Angel Perles received the M.S. and Ph.D. degrees in computer engineering from the Universitat Politecnica de Valencia (UPV), Spain, in 1994 and 2003, respectively.

He has been an Assistant Professor with the Department of Computer Engineering (DISCA), UPV, since 1997. He is a member of the Fault Tolerant Systems Research Group. His research interests include discrete-event-based modeling and simulation, real-time systems, microcontroller-based systems, and industry-applied computers.

Juan-Vicente Capella received the Degree in computer engineering from the Universitat Politecnica de Valencia (UPV), Valencia, Spain, in 1998. He joined the Fault Tolerant Systems Research Group, UPV, where he received the M.S. degree in 2000 and Ph.D. degree in 2010.

He has been an Assistant Professor with the Department of Computer Engineering (DISCA), UPV, since 2001. He has been involved in different innovation projects in higher education since 2001. He is a member of the editorial committee of two international journals. His main research interests are distributed systems design, fault tolerant systems and networks.

Prof. Capella is a member of the program committees of several international conferences organized by IEEE and ACM.

Carlos Domínguez received the M.S. degree in electrical engineering from the Polytechnic University of Valencia (UPV), Valencia, Spain, in 1991.

He has been an Assistant Professor with the Department of Computer Engineering, UPV, since 1992. He has been involved in different projects in the Industrial Informatics Group since 1989. His research interests include the development of intelligent agents for mobile robots, real-time systems, and planning and scheduling integration.

José Albaladejo received the M.S. degree in fundamental physics from the University of Valencia (UV), Valencia, Spain, and the Ph.D. degree in computer engineering from the Polytechnic University of Valencia (UPV), Valencia, in 1984 and 2003, respectively.

He has been an Assistant Professor with the Department of Computer Engineering, Polytechnic University of Valencia, since 1989. He joined the Fault Tolerant Systems Group in 2000. His research interests are fault injection, hardware and software codesign, and reconfigurability.