e-Toogle: Education Platform for Cyber-Physical Environments

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***Abstract* — A Cyber-Physical Systems (or CPS) is a system that combines and coordinates physical and computational elements. The CPS incorporates the ability to act in the physical world with the intelligence of cyber world to add new features to real-world physical systems [1]. Among the various fields of activity of the CPS, can cite security systems, robotics, education, among others. Educational environments are characterized by being favorable places for the introduction of technologies aimed to facilitate the interaction/mediation between subjects and learning's objects. In this paper, we propose an technological architecture for education, where we identify the main constituents of a cyber-physical learning environment, and their interconnections. The e-Toggle platform is proposed as an implementation for this architecture. It is characterized as being a CPS focused in education and it uses ROS (Robot Operating System) for communication between the real devices and the virtual world.**

Keywords— Cyber-Physical Systems; CPS; Internet of Things; e-Learning;

I. Introduction

In recent years, technological advances are leading to new relationships between individuals and between these and technologies. New environments, digitally supported emerge, allowing different agents (real, virtual) interact in a way before unimaginable to the society. In this new technological landscape arise new theories, methodologies, techniques and tools that come from different areas related to human computer interface.

In this paradigm, different objects, equipped with embedded computing, can interact with each other, sensing and adapting to the environment in a transparent manner, making the human-computer interaction simpler.

Researches in the area called Internet of Things(IoT) [3], in accordance with the ideas of ubiquitous computing, seek to define models for the interconnection of any "thing" (objects, computers, animals, people, etc.) in a network, similar to the devices today already interconnected through Internet. Some of these models are the EPCglobal [4] and the UID architecture [5]. Although there are initiatives in order to create a standard for IoT such as UID Center [6], there is no set standard for this type of system.

More recently, a more specific line of research has emerged, coining the term Cyber-Physical Systems (CPS). A CPS is a system that combines and coordinates physical and computational elements. The CPS integrates the ability to act in the physical world and the intelligence from cyber (virtual) world, adding new resources to real world systems [1]. Among the field of activity of CPS, emerging research areas include security systems, sensors and actuators research, Internet of Things, medical applications, robotics, education, among others.

Research on Cyber-Physical Systems with focus on education is recent and scarce. Some works, like [7] and [8] indicate education as a promising application field for CPSs, but do not present results in this area.

The aim of this paper is to propose an educational technology architecture, where the components of physical and virtual environments become boosters learning. Therefore, it is presented a platform called e-Toggle, which is characterized by being a CPS oriented education.

This paper is organized as follows: first, the research methodology is introduced; then, a discussion about the relationship between education and technology is presented; on chapter 4, a new Cyber-Physical System with focus on educational applications, called e-Toogle, is proposed; on chapter 5, some case studies are presented to validate the proposal; finally, conclusion and future work are presented.

II. Research Methodology

A. Search and choice procedures

The focus on this work is on CPS's related with the Internet of Things (IoT) and with applications on education. Other CPS's research lines, such as security, energy and sensors networks are not discussed in this article. The emphasis of this review is on an empirical search instead of non-empirical explanations.

The empirical search for references was carried out in two phases. On the first phase, we searched for articles on Google Scholar, crossing the keywords Cyber-Physical Systems with keywords Internet of Things and education. On the second phase, we conducted a new search on some citations of papers from first phase. The search on Google Scholar was considered sufficient as it contemplates all major electronic databases.

In may 2013, our search returned 221 papers. After reading the abstracts, 30 were selected for further analysis. These 30 papers were divided in four categories as described in the next section.

B. Data Analysis

The review of these works follows guidelines established by [9], who stated that the purpose of a survey is to summarize the accumulated knowledge base on the topic of interest and highlight issues yet to investigate. Our data analysis proceeded as follows.

Every article found and selected in the empirical search has been read. The categories were not pre-determined before reviewing, but emerged from data instead. Using the constant comparative method [10], the first articles was read and its contents was observed to form a categorization attempt according to the research topic. The results of the first paper were noted. The following article was then selected and read. Its content was matched with the firs article. If it was similar, it was put in the same category as the first one (together with its specificity) and the third article was processed. Otherwise, the second content represented the first entry in a new research category. This process was repeated until all 30 articles have been read and examined. It should be noted that it is possible that a single article produces more than one research category.

C. Search results

We identify four main research categories: (a) System Project, Architecture and Modeling, (b) Survey papers, (c) Frameworks and (d) Applications.

Category 1: System Project, Architecture and Modeling

This category covers a wide range of articles, since it comprises all those which involve the steps of design, architecture and modeling of cyber-physical systems. This section presents only the main works.

[11] presents a research on developing a REST-style architecture for CPS. It is proposed a way to solve the requirements of CPS architecture through RESTful principles.

In [12], a concept lattice-based event model for CPS is introduced. Under this model, a CPS event is uniformly represented by three components: event type, its internal attributes, and its external attributes. The internal and external attributes together characterize the type, spatio-temporal properties of the event as well as the components that observe it. A set of event composition rules are defined where the CPS event composition is based on a CPS concept lattice. A real-life smart home example is used to illustrate the proposed event model.

In [13], a new seven layer sensor modeling approach is presented. The proposed architecture enables one to describe a sensor right from its physical properties to end functionality; where it defines the sensor services to talk with end applications.

Finally, [14] focuses on the challenges of modeling cyber-physical systems that arise from the intrinsic heterogeneity, concurrency, and sensitivity to timing of such systems. It uses a portion of an aircraft vehicle management systems (VMS), specifically the fuel management subsystem, to illustrate the challenges and then discusses technologies that at least partially address the challenges.

Category 2: Survey articles

Similarly to the previous one, this category also covers a wide range of articles, because it is composed of all those articles intended to produce a bibliographic review. This section also present only the main survey articles found in the empirical search.

One of the major references in the case of CPS surveys is “Cyber-Physical Systems: A New Frontier” [15]. This article first reviews some of the challenges and promises of CPS, followed by an articulation of some specific challenges and promises that are more closely related to the Sensor Networks, Ubiquitous and Trustworthy Computing.

[7] presents a future vision for cyber-physical systems and identifies some specific grand challenges, beyond research and educational challenges that must be addressed. It also discusses the resulting societal and economic impact of such advances in CPS.

At [16] the features of CPSs are described, and the research progresses are summarized from different perspectives such as energy control, secure control, transmission and management, control technique, system resource allocation, and model-based software design. After, the research challenges and some suggestions for future work are in brief outlined.

Yet, other important works on CPS surveys deserve to be mentioned as: Advances in Cyber-Physical Systems Research [17], and Cyber-Physical Systems: Close Encounters Between Two Parallel Worlds [Point of View] [8];

Category 3: Frameworks

Several frameworks for different applications appeared in our empirical search. The ones related with the subject of this article are briefly described below.

[18] presents a novel framework, based on CPS concept, for a networked interactive home based intelligent motor rehabilitation system to facilitate functional recovery post-stroke. Patients use proper rehabilitation appliances to conduct continuous, repetitive rehabilitation trainings while wireless sensor networks (WSN) collect data related to the patients' functional activities. Within this framework, it is expected that important information

and resources can be utilized in the rehabilitation stages more efficiently for an individual subject.

[19] involves the design and development of a prototyping platform and open design framework for a semi-autonomous wheelchair to realize a human-in-the-loop cyber physical system (HiLCPS) as an assisting technology. The system is designed to assist physically locked-in individuals in navigating indoor environments through the use of modular sensor, communication, and control designs. This enables the user to share control with the wheelchair and allows the system to operate semi-autonomously with a human in the loop.

In [20], a functional design of an interactive Cyber-Physical System (CPS) for people with disabilities and frail elderly people is introduced as an effective method of proactive service in smart space. In this article, the scenario-based functional design of CPS has been motivated by open issues, concepts, and framework architecture for resolving inter space interaction issues caused by changes in users' location and environment which is one of key issues in adjusting and re-setting smart environments for the target population.

Category 4: Applications

The last category includes studies related to applications utilizing CPSs as basic architecture for the development of specific scenarios. This category has two sub categories as main applications of interest: Persons with Disabilities and Education.

Category 4.1: People with Disability

A common theme that appeared in the searches under the category applications, was related to applications involving systems for people with disabilities. Among the major works, stand out systems for motor rehabilitation after stroke [18], for Semi-Autonomous Wheelchair Navigation [19] and for people with disability and frail elderly people [20].

Category 4.2: Education

The search of this empirical study showed that the use of Cyber-Physical Systems for educational purposes is very new and scarce. Some works like [7] and [8] identify education as one of the promising fields of application for CPSs, but do not focus or present results in this area. Thus, to complete this research, we have searched for articles that use similar concepts to CPS in education, even if does not present nomenclature and references for this type of system.

In [21] the author documents real-world experiences of innovators in higher education who have redesigned spaces for learning and teaching, including physical, virtual, formal, informal, blended, flexible, and time sensitive factors.

The reference [22] proposes a research model that examines the determinants of student learning satisfaction in a blended e-learning system (BELS) environment, based on social cognitive theory. The empirical findings indicate that computer self-efficacy, performance expectations, system functionality, content feature, interaction, and learning climate are the primary determinants of student learning satisfaction with BELS. Interaction has a significant effect on learning climate.

Yet [23] aimed to investigate the effect of experimenting with physical manipulative (PM), virtual manipulative (VM), and a blended combination of PM and VM on undergraduate students' understanding of concepts in the domain of Light and Color. Results revealed that the use of a blended combination of PM and VM enhanced students' conceptual understanding in the domain of Light and Color more than the use of PM or VM alone.

Last, [24] explores blending virtual and physical learning environments to enhance the experience of first year by immersing students into university culture through social and academic interaction between peers. The social network Facebook is used in parallel with the classroom to assess student performance.

III. Education and Technology

The fast speed on which new technological devices are introduced creates new necessities and imposes different modes of interaction. Some technological artifacts, like analog and digital photography, movie pictures, television, computers and videogames are technological resources developed with different ends and that have been improved along the years, contributing more intensely to construct what today we call digital culture.

In this new technological reality our brain is filed with images, movements and sounds, conducting a new mode of learning the world. The computer (which began been developed on 1946) has become an essential tool for any sector of society: throughout the web, millions of people have access to information, education and entertainment.

Furthermore, social relationship networks like Facebook, constitute a way of interaction characterized by the sharing of information and knowledge previously nonexistent among humans. For this extensive use of technology, the effects of changes arising from developments in the sector are being increasingly perceived in contemporary society.

The presence of so-called Information and Communication Technologies (ICTs) in Education is providing new ways of teaching and learning, where there are new ways to serve and access a large volume of information and knowledge [25].

Virtual learning environments (VLEs), according to [26] are computer systems that allow integrate different media, languages and resources, present information, develop interactions; perform and socialize productions, regardless of time and space for each participant. With the spread of the world wide web, education gains new perspectives. In this context, VLE are being used for distance learning, teleconferencing and scientific events [27].

In recent years, Cyber-Physical Systems (CPS) have emerged and, shyly, permeated work related to learning environments. These systems intend to integrate objects from the physical world and information systems, making interconnections as well as the sharing of information. Among the various fields of activity of the CPS, it can be cited education as the most promising. Thus, it has started to emerge the first Virtual-Physical Learning Environments.

All this progress in information technology and communication meets the theories of Piaget. For him, the behavior of living beings is not innate, neither the result of conditioning, and yes, the behavior is built on an interaction between the environment and the individual. This epistemological theory is characterized as interactional. The intelligence of the individual, as an adaptation to new situations, therefore, is related to the complexity of the individual interaction with the environment [2]. In other words, the more complex this interaction, the more "intelligent" is the individual. We realize that there are technological tools nowadays that offer such ease of interaction between subjects and the means that surround them, are others available content or learning objects differentiated.

Thus, we see that the CPS's can provide a computational model which can provide an interaction between subjects and media, more natural, at any time, by anyone and in different places, playing as catalyst role for a new education.

IV. E-TOOGLE PLATFORM

The e-Toogle platform is proposed as an implementation of a technological architecture for education applications. It is a CPS targeted on education. It uses ROS (Robot Operating System) for communication between real devices and the virtual world. Moreover, it uses Blender 3D rendering software as object visualization tool and Moodle as virtual-real learning environment.

The e-Toogle is a version of Toogle platform specially projected for education purposes.

The Toogle platform is composed by several objects that can be grouped on the following categories:

- Real elements with no processing, perception or actuation capacity, referred in this work as “things”.
- Computational nodes with processing capacity.
- Graphical and simulation technologies with virtual representation capacity.
- Communication technologies capable of integrating different elements.

The Toogle system has been developed as a cyber-physical environments editor and navigator. Through Toogle, one can create any simulation scenario with 3D visualization and configure sensors and actuators on the lowest level for this scenario. With this environment, we have a relationship between the virtual and real world, which allows real objects to execute tasks, while simultaneously simulating them in the Toogle virtual environment. The opposite is also possible: simulate tasks in the virtual environment and forward the simulation parameters for real objects.

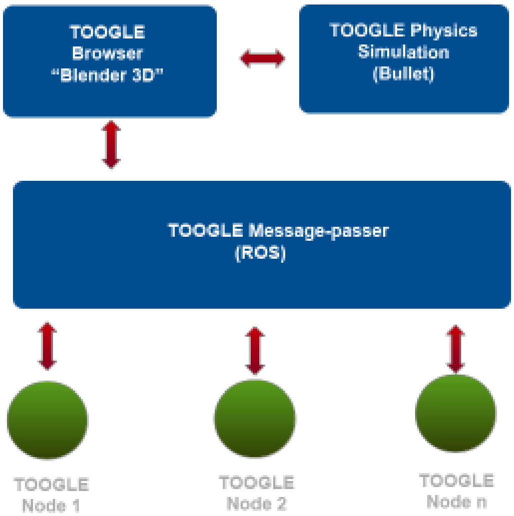

Figura 1. Toogle’s Architecture

Figure 1 shows the modules that compose the system architecture. This modules are described below, but for a better understanding, we first describe the two main systems used to create Toogle.

ROS: is the Robot Operating System consisting of process (called nodes). These processes can run in different machines. The nodes use two types of communication to send messages to the system: the first is synchronous and is called service; the second is asynchronous, where topics are published on nodes.

Blender: the Blender development tool offers tridimensional graphical resources for object visualization and information representation. Blender has been adopted as visualization tool for ubiquitous environments due its open source and multi-platform characteristics. Moreover it supports stereoscopy, multiprojection and physics simulation.

A. Toogle Nodes

The system nodes are a representation of all objects perceived by the system. These objects can have its own processing capacity (like robots, computers and cell phones) or have no processing capacity (objects, vehicles, people). The CPS nodes represent physical and virtual objects within the system. The node configuration is saved in a xml file hosted in the network server. In this file, it is possible to configure the attributes of each node. In execution time, the attributes of each node can be modified by information received from sensors that are connected with them. Depending on the node processing capacity, actuators can be activated to control and supervise the function of nodes in the system.

The nodes can be created directly in Blender or imported from other pieces of software. The system allows the importing of several types of files. The 3D models can be rendered directly in Blender by a procedural technique that generates high resolution images without the necessity of importing external images.

B. Toogle message/passer

The Toggle message-passer is the middleware responsible for communication between nodes and the system. It is composed by the ROS system. In Toogle system, the nodes can publish topics (messages) with information about the object that they represent. This messages contain information about sensors and actuators that will be used by Toogle Navigator/Editor. For example, a topic can represent the position of a student in a classroom or the state (activated/deactivated) of a sensor in this classroom. These topics are accessed by Toogle Navigator/Editor that uses the topics information to virtually simulate the real object. In this example, a student avatar.

C. Toogle Navegador/Editor

It allows to build and edit cyber physical environments, providing navigability and interaction with the information provided by nodes. The Toogle editor allows creating, editing, biding and removing information within a given scenario. An analogy with internet pages can be drawn: a hypertext consists of an aggregate of information and their connections while the hyper-environments (physical-virtual environments) consists of an aggregate of "things" on a given scenario and their connections. Therefore, the editor is able to create and represent the different pieces of information provided by the nodes and making connections / links between them. For each hyper-environment it is possible to create and add new objects, track them, add pre-existing objects, insert sensors and actuators for these objects and enable its connections with other objects. In addition, the editor allows the visualization of messages exchange between objects. Figure 2 shows the Toogle Editor/Navigator.

The Toogle navigator allows the access and visualization of information that has been created in Toogle Editor. It is a tridimensional scenario visualizer, where a replica of a real world scenario can be seen, according to the connections created in editor. The Toogle Navigator/Editor uses the Blender developing tool to create, edit and visualize the tridimensional scenarios. An interface for multiprojection in a CAVE visualization environment is also available. This interface allows an immersive visualization of objects and information from Toogle.

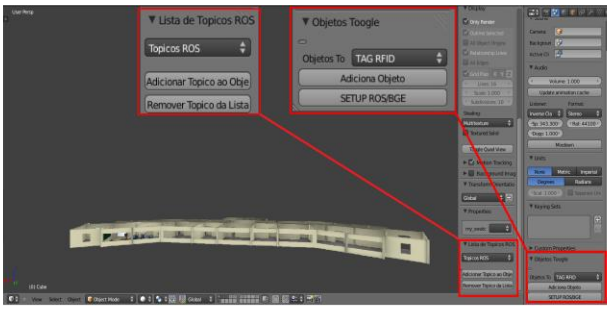

Figura 2. Toogle Editor/Navegador

The advent of HTML5 has enabled the development of tools for 2D/3D visualization for Web browsers without the need to use plugins. Thus, it was possible to build visualization and interaction Toggle realtime accessed remotely by the user. For this we have two main components: the server-side and client-side. On the server side we have the middleware ROS, it is integrated to the WebSocket server through the Java Script library "ROS BRIGDE". The middleware responsible for communication between server and client sides is the WebSocket (that is a feature provided by Html5). On the client side, we have the web browser with its java script libraries, web socket, responsible for communication, and libraries responsible for rendering the scene and their interactions.

D. Toogle Physics Simulation

This module is responsible for physical simulations, allowing realism and high performance computation. It uses Bullet open source library, which uses OpenGL for real time rendering. It has mechanisms for collision detection and rigid body dynamics. The physical simulator makes it possible to simulate objects that can fall, roll and collide with other objects, all with a very realistic appearance. Aspects of scene lighting make use of GLSL and Pixel Shaders techniques.

E. Education Module

As the e-Toogle is a version of Toogle platform designed for education, the last module we present is the Education one. The e-Toogle has an unique module for learning applications, with different pre-existing objects available, as described below:

● Moodle – The platform allows web pages to be incorpored as textures for objects in the scenario. This is possible mainly because Toogle Navigator is implemented using HTML 5 standard. Thus this module enables the insertion of Moodle black boards, where a rectangular object, with panel style, displays the contents of a registered course in Moodle. The course can be chosen according the object configuration.

● Attendance book – Virtual object associated with real sensors to detect the presence of students in the classroom and record their attendance. As the student enters the classroom carrying a RFID tag, he is detected by a RFID reader. This reader sends (through the message/passer module) the student ID to the system, which logs into the student's Moodle account, and register the student in the cyber physical environment.

● Virtual-Physical Blackboard – this object can be inserted wherever we want the virtual environment presents the contents simultaneously with the contents shown in classroom. Once the e-Toogle is installed on teacher's computer and this object is inserted in the scenario, the content displayed in classroom will be simultaneously presented in the virtual blackboard. If the teacher goes to the next slide in a presentation in classroom, the virtual environment will also reflect this change.

● Course calendar – object that contains class calendar, exams schedule, assignments due date, etc.

● Message tool – provides communication between students' avatars in the virtual environment. This tool is integrated with Moodle messaging system, which records all exchanged messages.

V. CASE STUDY: COMPUTATIONAL ALGORITHMS CLASS USING E-TOOGLE

This case study is a prototype of a physical-virtual course with e-Toogle. The prototype was developed according to the steps described below:

Step 1: 3D modeling of physical building: we use the Toogle Editor to create a 3D model of the Center for Computational Science building at Federal University of Rio Grande (FURG). This building has classrooms, teachers offices, labs and bathrooms. The modeling is still a prototype, and several improvements ought to be made. Greater attention was given to classrooms explored in this case study.(Figure 3).

Figura 3. Modelo 3D do prédio do C3 - Sala de Aula

Step 2: Physical adequation (sensors and actuators): The classroom used in this case study was prepared. A computer with e-Toogle has been installed and RFID readers where connected to this computer. The RFID equipment undertaken was: reader L-RX201 and active tag DOMINO L-TG100, shown in Figure 4.

Figura 4. RFID reader and active tag

Step 3: Communication: This step consists on providing data communication from sensors to Toogle plataform, through Toogle Message/passer, which uses middleware (ROS). The library used for integration was ros.h. This communication can be better understood through the use of the object Attendance Book, which uses RFID technology to record student attendance. The communication between the RFID reader and the Toggle platform was over serial port and used the library boost-asio. The communication is done with the software sending the command to the reader to start reading the tags. The tag detected by the reader (attached to the student) is sent to the program that interprets the data received through the serial port, and publishes, on a topic of ROS, the desired data (tagsLidas topic). The data sent by the detection can be, for example, signal intensity, the tag ID, the reader ID. In our experiment, only the detected tag ID is published. Figure 8 shows the topic "tagsLidas" listing the codes of detected tags.

Step 4: Toogle-Editor: The hyper-environment was created using the Toogle-Editor. A virtual scenario was modeled, biding the information from sensors and virtual objects. The Toogle-Editor interface is shown in Figure 5.

Figura 5. Toogle Navigator/Editor

Step 5: Toogle-Navigator: the last step performed was to run the Toogle-Navigator. It enables the access to information related to hyper environment through a 3D environment. The presence of an element or its absence can be noticed through the radio frequency reader. In other words, the RFID reader emits Radio Frequency and if the label attached to the student is close enough to this reader it will produce a response signal. By detecting the signal sent by the reader, the tag sends its unique ID to the reader, wich, introduces into the system Toggle (step 3). The Toogle system manages the information and makes the updating of information in the virtual 3D environment in real time, in this case, putting the avatar corresponding to the student in the specific classroom. When running the Toogle-Navigator, the objects that were associated with the corresponding code tags (step 4) will simulate the presence of the student in the virtual environment, inserting the avatars when the reader reader detect the approach of the relevant tag (Figure 5). This is possible because the object "attendance book" has a function capable of receiving the topic of ROS with the tags's code read and identify which object (one of the nodes tags) has the property with the same code, placing, at this moment, the avatar in the correct environment. Finally, it can be viewed in figure 5 the objects Moodle and Virtual-Physical Blackboard, both from Education module, in the environment while the user navigates through it.

VI. CONCLUSION AND FUTURE WORKS

It was presented in this paper, a platform called e-Toggle, version of the Toogle platform designed for education. It was proposed as an implementation of an educational and technological architecture, being characterized by a CPS using the ROS for communication between the real and virtual world. Software Blender 3D was used as viewer for the system objects. Finally, Moodle was presented as a virtual-real environment for learning in this platform.

The architecture of e-Toggle was presented with 5 modules: Toggle Nodes, Toggle message / passer, Toggle Browser / Editor, Toggle physical simulator and Education Module. Finally, we presented a use case to validate the platform and use the results as feedback.

As future work, we intend to improve the education module, enabling new virtual/physical objects to be developed. It is important to emphasize that the focus from the present moment, where the platform is implemented and tested, becomes the creation of learning objects that provide greater interaction among individuals and the environment, providing an environment that, according to Piaget, provides learning of higher quality.

We also aim, at a second moment, the deployment of the prototype in some courses offered at the Center for Computational Sciences at Federal University of Rio Grande, so that new actual tests can be made, and the results can be used to determine new platform requirements.

Finally, it is also the intention of this work to create a Non-Restrictive Module, where the focus will be the development of objects that seek to minimize the restrictions of space-time, sensory and performance found by people with needs or not, at the educational environments.

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