Advanced virtual laboratories of electromagnetism using a mobile game development ecosystem

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Abstract. Direct laboratory exercises and observations are a fundamental part of science courses, but the concepts such as distance learning, and open universities, are now becoming more widely used for teaching and learning. However, due to the nature of the subject domain, the use in science and engineering are relatively behind when using online distance learning. We propose a solution developing several advanced virtual laboratories of electromagnetism which is a replica the real lab fully software-based, using a mobile game development with Unity 3D. Unity is a game development ecosystem: a powerful rendering engine fully integrated with a complete set of intuitive tools and rapid workflows to create interactive 3D and 2D content that is considered a tool of artistic expression which joint the art and technology. We argue for this solution since it offers advantages over real labs, which will be elaborated further in this paper.

1. Introduction
Recently we have seen several new ideas in the literature concerned with the future of education and specially for the teaching of Science, Engineering and Technology. Some examples for this kind of study are: e-learning, distance learning, virtual laboratories, virtual reality and virtual worlds, dynamics-based virtual systems, and the overall new concept of immersive education that integrates many of these ideas together[1, 2, 3, 4]. The mentioned topics and the corresponding technologies can open the way to advanced education in Science. The concept of immersive education has been applied to all aspects of education, including: formal-institutional education and informal massive education. Initially, Internet-based distance education appeared as the first response to challenges resulting from the trend of increased globalization of education, but the Magdalena University have already made significant developments in this direction, with the creation of innovative tool in which the learners could interact with movil virtual laboratories of electromagnetism based on the platform Unity that can be used not only on a computer but also in a movil device which open a novel tool to remove all obstacles that limited the access to education, thus making education available to everybody regardless of place, personal disabilities, social status, etc.

2. Virtual laboratories of electromagnetism
The game development ecosystem Unity is a complete of tools and workflows that was used to create interactive 3D and 2D simulations of virtual laboratories of electromagnetism. One
of the most important characteristics of Unity in the development of our physical systems, it supports modeling physical properties, such as objects with mass, collision detection and objects can be assembled, using several kinds of joints. The virtual laboratories is accompanied by a structured guide as follows: Name of laboratory, standard, competences to be developed, problem question, curricular area, achievement to develop, indicators of performance, theoretical foundation, simulation, observation of the phenomenon, calculations, results and analysis. In order that the students recognize relevant variables of the simulated phenomenon, the relation exists between them and the physical laws that explain the phenomenon.

2.1. Positron scattering
This program simulates the dispersion of a set of positrons injected in the direction of an ionic charge nucleus $e^+$ that generates a Coulomb potential of repulsion. In this version the user can select if he wants the dispersion to be by the already mentioned electrostatic potential or by the potential screened by an electron, in this case it is intended to approximate the potential of a hydrogen atom; that is to say in case of screening there is a radius from which the potential is null. In this version the integration of two codes and/or .cpp files is made, one focused on the visualization of dispersion and another focused on a precise calculation of the most relevant parameters as impact parameter and dispersion angle. This program is based on the numerical resolution of Newton's equation of motion, using algorithms of the 4th-order Runge-Kutta-Fehlberg method with self-adapting step.

When all the parameters are entered in the terminal, an automatic display window will be generated that shows the dynamics and behavior of the particles injected by the presence of the scattering ion, showing that some particles alter their trajectory more drastically than others. In the case where the positrons are returned, even in the screened potential, there are particles that do not alter their trajectory. The program also generates files that contain the respective units, the angle of dispersion, energy of the particle, position, speed, cross section and others; It is possible for students to reconstruct graphs as a complement of the study of this phenomenon.

![Figure 1](image)

Figure 1: (Color online) simulation of the dispersion of a set of positrons injected in the direction of an ionic charge nucleus $e^+$ that generates a coulombian potential of repulsion

2.2. Velocity Selector
The code simulates the dynamics of three electronic beams injected at three different speeds in the presence of an electric and a magnetic field, uniform and mutually perpendicular. The simulation and visualization consists of three key regions, the first is the injection region on
the x axis, it is a free region, that is, the beam does not interact with any force, once this region is overcome, the beam enters the region of Crossed fields already mentioned, where the electric field is generated by two parallel metal plates separate a distance of 6 cm, the magnetic field is produced by two Helmholtz coils. The last region is again a free region where you can see the final deflection of each beam. One of the three beams is injected at a speed exactly equal to the $E/B$ ratio and this is considered a reference beam because at this speed the electric field effect compensates for the magnetic field effect, resulting in a net force equal to zero. Another of the beams is injected at a speed $3E/B$ and finally the last at $0.7E/B$ called make fast and slow down respectively. This program is based on the numerical solution of the relativistic Newton-Lorentz motion equation under the Boris-Buneman scheme. Once the

previous instructions are followed, a dialog box will appear in the terminal asking the user for voltage values between the plates and current in the coils. These values of potential difference and current will be given in volts and amperes respectively. Once the requested information has been entered, the program can generate the simulation and its respective visualization. In the terminal information of the fields and the speed of the reference beam will be thrown. When all the parameters are entered in the terminal, a visualization window that recreates the simulation will be generated, in which the path of the beam is evidenced when passing through the three previously mentioned regions. The program also generates in the directory or folder containing the program, the files ((Fast electron.txt)), ((Slow electron.txt)) and ((Electron reference.txt)) that contain the position information in each axis for each instant of time, being possible to reconstruct the trajectory in an external plotter if the user wishes it.

2.3. The Cyclotron

This code bases its lines according to the $C++$ programming language, where it is compiled and executed in a LINUX environment. This program simulates the acceleration of an electron in a cyclotron type mechanism, starting with a constant velocity $1\times10^7\, cm/s$ in the direction of the $x$ positive axis. Cyclotron acceleration occurs in a curved path directed by a magnetic field in a direction perpendicular to the path of the electron, an electric field accelerates the electron in two regions, which are in the curved path of the electron.
Figure 3: (Color online) A charged particle having a velocity vector into a cyclotron that has a component perpendicular to a uniform magnetic field. The blue curved line represent the path of the particle.

Once the instructions are followed, a dialog box will appear in the terminal asking the user for the potential value \([kV]\) that he wants to use in the simulation and then the magnitude of the magnetic field \([\mu T]\). Once the requested information has been entered, press the ((enter)) key once more so that the program can start calculations. It is worth mentioning that the recommended values to appreciate the phenomenon is between 1\(kV\) and 2\(kV\) for the potential between the plates and between 300\(\mu T\) and 1000\(\mu T\) for the magnetic field. When all the parameters are entered in the terminal, an automatic display window that shows the dynamics and behavior of the injected particles will be generated, verifying that there is an acceleration when the path is between the electric field region. In each file there is a header informing of the data that each file contains and the respective units, among these data there is information of the simulation time with its respective position and speed; It is possible to reconstruct graphs to complement the study if the user so wishes.

2.4. Equipotential surfaces
The code allows to determine the electrical potential of a two-dimensional region, generated by a distribution of electrodes subjected to the same difference of potential with respect to the rectangular contour that contains them. This version allows the user to enter one of 6 distributions, based on the combination of three different geometries for the electrodes. This program is based on the numerical resolution of the Laplace equation for the electrostatic potential, using iterative algorithms that converge in solving the problem. Once the previous instructions are followed, a dialog box will appear in the terminal asking the user for the distribution of electrodes that he wants. Once the requested information has been entered, press the ((enter)) key once more so that the program can generate the results. In the terminal, information on the execution status will be displayed: 1- Finding an electric potential function, 2- Creating an image, 3- Program compiled and executed successfully. When the terminal indicates that the code has been compiled and executed successfully, a figure containing the map of the lines of contour of the distribution of electrostatic potential generated by the chosen electrodes. This figure allows manipulation of size and can be saved in various formats. The program
Figure 4: (Color online) Equipotential surfaces for different distribution of electric field produced by two electrodes with the following shapes (a) rectangle-semicircle, (b) semicircle-semicircle, (c) oval-oval and (d) rectangle-oval.

also generates in the directory or folder containing the program, the file ((Potential.txt)) that contains the electric potential function in a matrix format, giving thus the freedom to generate the figure already obtained in another plotter if the user so wishes.

3. Conclusions

We present virtual laboratories in advanced topics of electromagnetism as a proposal to support in science and Engineering in order to be applied in formal-institutional educations as well as in informal massive education. Using a mobile game development ecosystem with Unity, we simulated the positron scattering, velocity selector, cyclotron and equipotential surfaces. The authors are aware that virtual lab systems and simulators are often used only as an initial step in a student’s engineering education and training, followed by more in-depth hands-on experience with real authentic equipment.

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