WIRELESS RAY TRACING EDUCATIONAL LAND

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Abstract

Technology has a great impact and influence on the educational process in classroom environments. Students can use the advanced computing and telecommunication technologies, to access different types of information and to communicate with their teachers and colleagues using several types of media. Among the new emerging technologies are online three dimensional virtual worlds (3D VWs). This technology can aid students in understanding and predicting physical behaviour, which would otherwise require interactive simulations and laboratories that may be expensive, time consuming and dangerous. Traditional simulations can help carry out virtual experiments but they are often not very interactive, and are frequently complex and slow. 3D VWs provide a natural interactive exploration environment, where individuals and groups can interact and learn. The prototype Wireless Ray-Tracing Educational Land (WRTEL) was built using the OpenSimulator VWs technology, to improve the learning experience for electrical engineering and physics students studying electromagnetic wireless systems. Instead of using textbooks, pictures, equations and paper examples to understand how wireless signals propagate, signals are visualized in an interactive 3D virtual environment.

This paper presents the prototype WRTEL, where invisible wireless signal propagation is made visible using the VW technology. Students are able to visualize signal behaviour (reflection, refraction, diffraction and scattering) in either two dimensions (2D) or three dimensions (3D), and information about each interaction between signals and the surrounding environment can be displayed. The WRTEL consists of three main regions. In the first region, three educational tools have been implemented to explore the relationship between wavelength and frequency, the electromagnetic spectrum and antennas. In the second region, a free space laboratory had been designed in simulated outer space to allow students to visualize line of sight signal propagation between the transmitter and the receiver antennas. In the third region, students are provided with a selectable two or three dimensional ray-tracing laboratory, to create environments using obstacles made from different materials. Students will be able to visualize how signal behaviour (reflection, refraction, diffraction and scattering) is affected by the surrounding environment. Path loss calculations, received power, angle of incidence and many other values will be provided at any point in space until the signal is received by the receiver antenna. The transmitted wireless signals will be visualized by mapping them into the visual spectrum for display; this makes the invisible rays visible.

A brief technical and educational evaluation indicated that the prototype educational land was both usable and would support student learning activities in laboratories.

Keywords: virtual worlds, wavelength, frequency, electromagnetic spectrum, antennas, Wireless Ray-Tracing Educational Land, OpenSimulator, free space propagation.

1 INTRODUCTION

Technology has a very important role in the classroom today and can be used to teach significant concepts in almost every subject area. Teachers use electronic presentations to integrate video, audio and images to their lecture notes. This helps them to provide students with a better understanding and improve the educational process.

The youth of today know more about technology than any generation before them. They communicate with each other using various communication technologies such as the internet. Most students have profiles in different on-line social networks which they use to share thoughts and exchange knowledge. Web based education is their normal expectation. Students prefer to search for learning materials where the information they need will be found instantly. Recent improvements in information and communication technologies such as powerful processors and broadband connections are available in most universities and schools. This has created the opportunity for developing several web 2.0 [1, 2] based teaching tools which better meet students expectations. Students and teachers
can use the World Wide Web (WWW) [3], to communicate with each other using live chat such as the
Internet Relay Chat (IRC) [4].

E-learning systems provide students with 24 hour online access to educational materials. This plays
an essential role in improving the educational process, especially when the subject discussed in the
classroom is difficult to fully understand or large and couldn’t be finished within the lecture’s specified
time. In other words, a face-to-face class conversation can be shifted to the e-learning systems where
the students can have instant feedback from their teachers and colleagues. However, sometimes the
feedback responses are preconfigured.

Undeniably, a student’s physical presence inside a classroom is an essential part of the educational
process. This is not supported within most web based e-learning systems; on line Virtual Worlds
(VWs) can be used to reinforce the physical presence of users. They provide users with a three
dimensional environment filled with virtual objects. Users can explore the surrounding scenes by
walking, swimming, flying and teleporting using a graphical representation called an avatar [5, 6].

Students can experience inquiry based learning by simply wondering around the virtual learning world
either freely or with some directions. Teachers and students could then perform practical experiments,
which may be expensive or difficult to do in the real world in the VW. In addition, in the VW invisible
phenomena can be made visible. For example, non visible spectrum electromagnetic (EM) signals are
made visible in the Wireless Ray-Tracing Educational Land as shown in Fig. 6.

EM signal propagation and interactions between these signals and the surrounding environment is an
example phenomenon, which cannot be easily visualized within real classrooms and many e-learning
systems. Teachers and students find it difficult to perform any practical experiments to visualize the
propagated signals in the real world. For some cases, instruments can measure parameters such as
signal strength at a given location. These measurements are difficult to be achieved everywhere and
are even more difficult to visualize and compare. As a result, students find it hard to predict how
signals propagate and interact with the surrounding environment. In the VW, students should be able
to visualize and understand the behaviour of the propagated signals such as their reflection, refraction,
diffraction, and scattering easily.

The Wireless Ray-Tracing Educational Land (WRTEL) which is developed using the OpenSimulator
virtual world [7] technology aims to introduce students to several concepts in a flexible and easy-going
way. Firstly, students will become familiar with the signal’s wavelength and frequency properties.
Secondly, they are introduced to the EM spectrum, to understand frequency ranges. Thirdly, students
can use pre-configured antennas or can create, view and check their own antenna geometry.
Understanding antenna radiation is aided by generated, displayed and/or compared near/far-field
radiation patterns in either 2D or 3D [8]. At the current stage this is considered as future work, as the
implemented prototype only provides students with information about antennas and one pre-
configured antenna implementation. Fourthly, students are provided with a simulated free space
propagation laboratory where the line of sight (LOS) signal between the transmitter and the receiver
antennas is visualized. The laboratory is placed in outer space to give students the indication that free
space propagation only occurs in an environment, where no interactions with the surroundings occur,
and only the LOS signal is received by the receiver antenna. Free space path loss and received power
calculations are provided to students at each point along the LOS signal. Finally the main part of the
WRTEL is the two dimensional (2D) and three dimensional (3D) wireless ray-tracing laboratory. It
allows students to visualize the propagated signals between the transmitter and the receiver antennas
in 2D and 3D modes. In 2D mode, signals are emitted from the transmitter antenna in a horizontal
plane only, and in 3D mode signals are emitted in all directions. In the VW, students can create
different environments and assign various materials to the obstacles presented in the scene in order to
visualize how the signal propagation behaviour is affected by the obstacles. Each time obstacles
change in shape or material the results will change. Calculated information about the path loss,
received power, angle of incidence, refraction angle and many other values are provided to students.
Students can test their understanding at any time as the WRTEL provides them with a self-test
functionality.

The educational land is designed to in future adapt based on the student’s age range, background
knowledge and learning preferences. This will allow students to take full advantage of the educational
experience. Before students enter the land, teachers should be able to specify which concepts
students should already understand and which new concepts they should aim to achieve by
configuring a concept map. The information displayed and self-test questions asked by the system will
change to utilize understood concepts in extending understanding to new concepts. As students
explore the VW their activities will be monitored to change the concept map as knowledge is
expanded and tested. Comprehension of each concept and the relationships between concepts can change to represent both increasing and decreasing understanding. The concept model supports adaptive positive reinforcement based learning alongside more challenging learning extension experiences.

Students obtain new knowledge and achieve the required concepts by traversing from one area to another in the WRTEL world. The path followed will differ from one student to another, even though the system aims for the concepts learned through the experience to be the same.

Section 2 of the paper discusses the design and implementation of the WRTEL. Section 3 gives a brief description of the interactive demonstrations within the land. Finally section 4 concludes the paper.

2 DESIGN AND IMPLEMENTATION

This section introduces the design and implementation work undertaken in the prototype WRTEL.

2.1 Implementation environment

Virtual worlds like many computer games provide users with a 3D environment filled with virtual objects. Users can explore the surrounding scenes by walking, swimming, flying and teleporting. The VW is an “Internet virtual community” [9], where people from all over the world can interact with each other in real time using a graphical representation of themselves, their avatar. Virtual worlds have been simulated in massively multiplayer online (MMO) games, which support thousands of users simultaneously. Most MMO games had been created statically by the games producers, players have no privilege to modify or create contents while playing. In 2007 OpenSimulator (OpenSim) was developed under the Berkeley Software Distribution (BSD) license. It is an open source project which aims to provide users with an open and extensible platform. Virtual worlds within OpenSimulator can run on a user’s own computer. For all the reasons mentioned above OpenSimulator had been chosen as the implementation environment of the WRTEL.

2.2 2D/3D Wireless Ray-Tracing Educational Land

Fig. 1 shows the wireless ray-tracing educational land layout. The land has no restriction on what, where and when students should start or stop learning in any of the regions. This helps because students have different educational backgrounds and can choose to start leaning in any of the regions.

WRTEL designed and implemented in this project consists of three main regions. Sections 2.2.1, 2.2.2 and 2.2.3 present the A, B and C regions. Each region is associated with an information box and a set of self-test questions; students can use the information to learn about each region and the questions
to test their understanding at each stage during the learning process. The information displayed and the selection of the test questions depends on the student age, background knowledge, education preference and progress during the educational task as represented in the concept map introduced in section 2.2.1.1. Students are free to start exploring and learning in any of the regions, even though sign posts are provided to help them learn in an incremental manner. The following sections briefly describe how each region is designed and implemented.

2.2.1 Region A

In this region three prototype tools have so far been developed; the frequency-wavelength converter tool, the electromagnetic spectrum tool and the antenna tool. By using these educational tools, students will be made familiar with the frequency, wavelength, the EM spectrum and antennas.

2.2.1.1 Frequency-wavelength converter tool

The concept that should be achieved in this tool is “relating wavelength and frequency”. This is shown in Fig. 2 which presents a prototype concept map. The tool is used to find the frequency when the wavelength is entered by students and vice-versa. The frequency-wavelength converter tool provided to students is shown in Fig. 3. It consists of two white buttons which are used to determine whether the student wants to convert frequency to wavelength or vice-versa. The red “Q” letter presents the self-test functionality to students and the blue information box, provides instructions about the tool usage and the equations used for conversion. The instructions accessed via the blue information box and the questions asked via the “Q” letter use the concept map. The understanding of “frequency”, “wavelength” and their conversion changes depending on a student’s responses to questions which themselves also change to present appropriate numerical questions based on a student’s knowledge of “fractions” and “decimals” which is also adapted to the responses the student gives.

![Fig. 2 Concept Map](image-url)
2.2.1.2 Electromagnetic spectrum tool

The electromagnetic spectrum tool will provide students with information about different types of EM radiation such as radio, microwave and visible light. Students will be made familiar with the range of frequencies and the practical usage of each type. The concepts achieved in this tool are shown in Fig. 2. The tool which is shown in Fig. 4 consists of coloured boxes which represent the types of EM radiation. Each box is responsible for listening to the student’s requested frequency or wavelength and providing an appropriate description currently using the in-world loading of web pages facility. In future this information will be adaptive using the in-built concept model.

2.2.1.3 Antenna tool

This tool shown in Fig. 5 will allow students to select and/or create and generate different types of antenna in the WRTEL. The tool’s use will let students see how the achieved propagation differs with different kinds of antennas. Students will be able to select a pre-existing antenna or create their antenna and then use it in both the free space propagation (section 2.2.2) and the 2D/3D wireless ray-tracing laboratories (section 2.2.3).

The antenna tool introduces students to different kinds of antennas used in wireless communication systems. Students will be able to distinguish between the purely theoretical isotropic antenna, omni-directional antennas and directional antennas. The prototype’s antenna tool, which is shown in Fig. 5, consists of three white buttons that currently present information about one of the antenna kinds. The information currently provided includes the gain and the directionality of the chosen antenna. The Fig. 5 shows the information displayed when the isotropic antenna button was touched.
2.2.2 Region B

This region contains the free space propagation laboratory shown in Fig. 6. In this laboratory, students will become familiar with free space propagation and the free space path loss terms. The laboratory exists in simulated outer space to give students an indication that the LOS free space propagation occurs in an environment where signals do not interact with any surrounding environment and only the LOS signal is received by the receiver antenna, in other words there is no reflection or other interactions. Within the laboratory, students are able to visualize the free space EM waves and clearly see that the power of EM waves is proportional to the inverse of the distance squared from the transmitter antenna \( \frac{1}{\text{distance}^2} \). As stated earlier, calculations of the free space path loss, the transmission power, and the received power are provided to students at each point along the LOS path between the transmitter and the receiver antennas.

The laboratory shown in Fig. 6 consists of two white spheres representing here omni-directional isotropic antennas, which represent the transmitter and receiver antennas. Students can set the frequency and transmission power parameters in the transmitter antenna and the receiver sensitivity parameter in the receiver antenna. This allows them to later visually compare how the received power, path loss and reception is affected each time these parameters change. For example, setting the sensitivity parameter in the receiver antenna allows students to understand that the received signal should be above the sensitivity level to receive an error free (correct) signal. Students can see the result of insufficient received power or not having enough receive sensitivity when the receiver sphere colour changes from white to red if the received power is lower than the sensitivity level as shown in Fig. 11.

Students are also able to visualize the propagation path loss using traditional graphs. The transmitter calculates the path loss between the transmitter and the receiver, and produces a graph which will be loaded on the screen.

The yellow sphere with a square hollow around the transmit antenna as shown in Fig. 6, represent the inverse square relation of radiation intensity (power) with distance from the radiation source. When the transmitter emits the signal, the yellow sphere grows in size; a square is drawn on the surface of the sphere to enable students to easily see how the same power in the area representing the square is spread more thinly because it is spread over an increased area as the sphere and the square on its surface grow.

Students can leave the laboratory and return to earth using the window which is the teleporter to the real world.

2.2.3 Region C

The third main region in the WRTEL is the 2D/3D wireless ray-tracing laboratory. After students are introduced to signal frequency, wave length, EM spectrum, antennas and free space propagation, the 2D/3D ray-tracing laboratory allows them to understand how the propagated signals behaviour is affected by obstacles in the surrounding environment. This laboratory currently allows students to visualize the LOS, reflected and refracted propagating signals. Students are also provided with information about each emitted ray such as; the angle of incidence, the refraction angle and the power remaining after each interaction between a ray and the surrounding environment.

The 2D/3D wireless ray-tracing laboratory, seen in Fig. 7 provides students with a default environment which consist of two perpendicular walls with a floor and two isotropic antennas represented by white spheres. The walls and floor represent obstacles that reflect radio waves. The laboratory supports additional user configured spherical and cuboid obstacles, which students can use to change the surrounding environment dynamically by adding and removing them and changing their location, size and the virtual material they are made from.
The laboratory is controlled using the remote control component shown in Fig. 7. The remote control is used to determine the mode of visualization (2D/3D), the number of reflection and refraction interactions drawn between the emitted rays and the surrounding environment and the LOS path if one exists between the transmitter and receiver antennas.

In this laboratory a signal propagation experiment is performed according to a study, which has been done on the effects of wall parameters on wireless propagation at 900 MHz and 2.4 GHz frequencies and 44 dBm transmission power [10]. Three different wall materials (wood, cement, and iron) were used and the refractive index for each material was calculated.

The ray tracer in the project is currently implemented in OSSL [11] using the brute force method. Each emitted ray from the transmitter antenna is traced in a specified direction. If no intersection between the obstacles and the ray occurs, the ray will be discarded and a new ray will be emitted and traced. Once an intersection has occurred, the ray splits into a reflected ray and a refracted ray and a check is made to determine if one of the rays is received by the receiver antenna. During ray-tracing detailed information about each ray received by the receiver antenna is calculated and stored. The information includes:

- The number of reflections and refractions the ray is involved in until it reaches the receiver.
- The intersection points with obstacles.
- The incident and the refraction angles of each reflected and refracted ray with the obstacles it encounters.
- The material and the refractive index of each obstacle the ray intersects with until it reaches the receiver.
- Finally the reflection coefficient, refraction coefficient and return loss.

The ray tracer is very inefficient and a more efficient one is currently being written. However, it will always be necessary to limit the number of rays emitted in this experiment as the number of rays can rapidly become large, for example 1 ray per degree in 2D is 360 rays and in 3D is 129,600. When rays encounter obstacles, some of the power is reflected and some passes through the object, doubling the number of rays. When rays are diffracted or scattered the number of rays can multiply. Thankfully, in our case, normally, not many rays are needed. Too many rays rapidly become very difficult to visualize clearly so constraining the number of rays and interactions with the environment that are rendered is a necessary and sensible constraint.

3 OVERVIEW OF INTERACTIVE DEMONSTRATIONS IN THE WRTEL

This section introduces some of the free space propagation and the 2D/3D wireless ray-tracing laboratories interactive demonstrations.
3.1 Region B: Free Space propagation laboratory

As mentioned before, students are able to visualize the free space path loss (attenuation) between the transmitter and receiver antennas in 2D and 3D. Fig. 8 is a 2D graph of the loss against distance. Fig. 9 shows the LOS ray which is presented in a 3D perspective, note the colour changes from dark blue to green representing the attenuation with distance visually. In Fig. 9 the student decided to touch a specific point (circled) on the LOS ray and a pop-up box then appeared showing the received power and path loss at that point. Fig. 10 shows a yellow sphere which shows here the signal’s power and distance relation at a 1 meter distance between the transmitter and receiver antennas. The sphere expands like a wave until it reaches the receiver antenna. Finally in Fig. 11 the receiver antenna colour changed from white to red after the student set the transmission power and the receiver’s sensitivity parameters so there is not enough signal strength to understand the signal at the receiver.
### 3.2 Region C: 2D/3D wireless ray-tracing laboratory

Within this laboratory, students can add, remove, resize and change spherical and cuboid obstacles and materials. Fig. 12 and Fig. 13 show the information displayed to students when they touch the intersection point of a reflected ray for a wooden and then a cement obstacles. The information presented in the dialog box includes the angle of incidence, the reflection coefficient (proportion of incident power reflected), the reflection loss (how much incident power is absorbed by the material), the transmission coefficient (proportion of incident power transmitted through the obstacle) and the refractive index (the ratio of the speed of light (SOL) in the medium to the SOL in a vacuum and also the change in direction of the ray in the medium).

![Fig. 12 Region C Ray Trace Showing Only 2D Horizontal Rays With One Reflection. The Student Has Requested Information At the Circled Reflection Point With A Wooden Wall](image1)

![Fig. 13 Region C The Same As Fig. 12. The Material Of The Wall At The Reflection Point Has Been Changed To Cement Giving Different Results.](image2)

### 4 CONCLUSIONS

In conventional learning environments students face challenges in understanding how signals propagate and interact with the surrounding environment. It is difficult for them to predict how signal behaviours (reflection, refraction, diffraction and scattering) are affected by the various obstacles geometry, construction and position in space. Our prototype WRTEL demonstrator allows students to visualize wireless signal propagation behaviours in different environments. The prototype provides students with an immersive 2D/3D wireless ray-tracing educational environment to learn different aspects related to signals and signals propagation. The tool allows students to learn in a number of different styles [12]. Those who prefer to read descriptions and examples can do so using the provided information points. Students who learn more effectively from visual examples are provided with these.

Adaptation to modern expectations via the provision of interactive rather than static demonstrations is designed to hold the inquisitive for longer in order to try out different configurations. Those who need directed incremental learning can be directed around the regions and their laboratories. Students who wish to learn more freely by exploring the world or who are capable of making intellectual jumps can simply explore and try things out. Assessment can be either formative or quantitative and can to some extent be achieved by simply monitoring student’s actions when they are presented with problems to solve using the laboratories. However, preparation for and formal assessment are supported via written questions in either short answer or multiple choice format.

Teachers should be able to specify concepts and levels of attainment they would like their students to achieve in WRTEL and be provided with their student’s progress information. We are currently working to integrate WRTEL with the Moodle [13] Virtual Learning Environment (VLE) using the Sloodle
integration project [14, 15]. This will allow monitoring of student actions and answers which teachers can use for assessment, guidance and which we will use to test the effectiveness of the learning environment.

The educational tools developed within the WRTEL prototype are static and don’t consider students background knowledge, learning preferences (visual or text), behaviour and performance during each task. An obvious enhancement would be to consider these, in order to generate appropriate information, examples, laboratories and tests which adapt to different types of student. We are also currently working to integrate our concept models into WRTEL and to program the generation of adaptive learning materials into the system. This will then have to be tested and evaluated to assess its effectiveness.

REFERENCES