



Interactive Learning Material for Optoelectronic Devices using MATLAB-based GUI

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Abstract Optoelectronic devices have been a difficult subject to grasp for many university students who undertake electronic engineering. Many students find it difficult to understand the operation principle of the optoelectronic devices, for instance, how a solar cell device converts solar energy into electric energy or electricity, or the difference between types of semiconductor devices in terms of interaction between photons and electrons. Thus, the purpose of this paper is to design and implement an interactive and animated software package to aid students in understanding the concepts of the following optoelectronic devices: solar cell, p-n junction photodiode, p-i-n photodiode, light emitting diode and semiconductor laser. The software package was designed to be user friendly and easy to use requiring minimum learning time. The implementation of the software package was achieved using the MATLAB program which is an interactive software package for scientific and engineering numeric computation. The outcome is a series of MATLAB programs that can be used to help students learn the concepts of optoelectronic devices.

Keywords: Semiconductor devices, optoelectronic devices, MATLAB program, interactive and animated software package.

تصميم وتنفيذ لبرنامج تعليمي تفاعلي للقطع الالكترونية الضوئية باستخدام واجهة المستخدم الرسومية

لبرنامج MATLAB

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المخلص العديد من طلاب الجامعات الذين يدرسون الهندسة الالكترونية يجدون صعوبة في فهم مبدأ عمل القطع الالكترونية الضوئية، على سبيل المثال، كيف تحويل الجهاز الخلايا الشمسية الطاقة الشمسية إلى طاقة كهربائية، أو معرفة الفرق بين أنواع وحدات أشباه الموصلات من حيث التفاعل بين الفوتونات والإلكترونات. تقدم هذه الورقة تصميم وتنفيذ لحزمة برامج تفاعلية ومتحركة لمساعدة الطلاب في فهم مفاهيم القطع الإلكترونية الضوئية التالية: الخلية الشمسية، الثنائي الضوئي للوصلة p-n، الثنائي الضوئي p-i-n، الثنائي الباعث للضوء وليزر أشباه الموصلات. تم تصميم حزمة البرامج لتكون سهلة الاستخدام وتتطلب الحد الأدنى من وقت التعلم. تم تنفيذ حزمة البرامج باستخدام برنامج MATLAB وهو حزمة برامج تفاعلية للحسابات الرقمية العلمية والهندسية. يمكن استخدام حزمة البرامج التفاعلية المنفذة لمساعدة الطلاب على تعلم مفاهيم القطع الإلكترونية الضوئية.

الكلمات المفتاحية: اشباه الموصلات، القطع الالكترونية الضوئية، برنامج الماتلاب، حزمة برامج تفاعلية ومتحركة.

Introduction

Computer-based learning has become a more attractive and modern way of learning. This method of learning moves away from the classroom or lecture theatre, where the presence of a teacher is not compulsory, to the comfort of student's own home or wherever there is a computer with the relevant software package installed. Computer-based learning has many advantages, notably enhanced flexibility and effectiveness of learning process. The flexibility with respect to place and time makes it very appropriate for distance learning; the students can work in their own home, in their own time. The enhanced effectiveness of computer-based learning is mainly the result of extensive sensory stimulation using text, graphics, animations and sound [1-3]. In fact, during the past decade, several notable efforts to develop interactive based

computer animation applied to engineering education related courses are proposed [4-6]. A literature review on characterizing design-based learning in engineering education is presented in [7]. Author in [8] presents the principle of semiconductors devices using interactive MATLAB animations. Authors in [9] describes the design and implementation, of a set of experiments in optoelectronics for first-year engineering students. These experiments are comprised of five inexpensive and transportable modules that provide a hands-on introduction to optoelectronics. these modules include different types of emitters, light-emitting diode (LED) colors, optical voice link, total internal reflection, and wave guiding. Authors in [10] presented a learning environment for an optoelectronic e-course. They focus on the implementation of

practical remote work on light emitting diodes. The development of MATLAB -based learning tools has also been a subject of great interest in the signal processing and control engineering education. The authors in [11] suggest to use MATLAB Live Scripts for building exercise material to support control engineering learning and based on the obtained student feedback, the implications of visual learning material in the course development can be analyzed in brief. To improve the quality of electromagnetic education by utilizing computer, the authors in [12] described the development of a MATLAB-based GUI for visualization plane wave polarization, electromagnetic wave propagation, plane wavefronts and spherical wavefronts. The authors in [13] proposed MATLAB Based Learn FFT tool for Constructive and Graphical Understanding of FFT.

In this paper a set of simple animated solutions is proposed, offering a simple and graphical platform to aid students to understand the concepts of the optoelectronic devices. The proposed interactive and animated software package address the following objectives: 1) provide quick and better learning capabilities to aid students in electrical and electronic engineering in understanding the concepts of the following optoelectronic devices: solar cell, p-n junction photodiode, p-i-n photodiode, light emitting diode and laser diode; 2) enhance learning by exposing students to hands-on manipulation of tasks using animation; 3) provide intuition and complementary information about optoelectronic devices, this information is displayed at the beginning of each task.

The rest of this paper is structured as follows. Section 2 and Section 3 cover the details of the design and the implementation of the proposed software package, respectively. Section 4 presents the evaluation and results process. Conclusions are drawn in Section 5.

The design of the proposed interactive and animated software package

The main step in the design stage of the proposed software is to define the design guidelines and methods that can be used to design the software package. With these methods it could be ensured that the final product would satisfy the requirement specifications. So, the software engineering principle must be used to build a "Well engineered software", that is software which does what the user wants. It also should be maintainable, reliable, efficient and user friendly [14,15]. Design guidelines are a set of strong, reasonable suggestions that should be followed throughout the design and implementation of the software package. It helps the designers stay on the right track and not be easily swayed away from the goals. The list of guidelines that were followed in proposed software system are be consistent, get user's attention, provide information to help user, use animation more than text, provide easy to start or stop animation, and speed of animation can be controlled. There are many software development models that can

be used to develop a software package; such as Waterfall, Exploratory programming, Prototyping models, the detailed description of these models can be found in [15]. "Waterfall model" is the initial and classic approach for software engineering. This approach consists of five stages that are the requirements collection where the information is processed and converted into a design that translates requirements for software into a set of representations that describe data structure, architecture, algorithms and interface characteristics. In the implementation stage the software design is translated into a program in machine form. The testing stage is used to test the programs to ensure that they function correctly and meet the demands of the software requirements. The maintenance stage may be used to adapted the software to meet change in environment, or because the customer required extra functional requirements.

In the proposed software package, the requirements and details of input, processing and output can be identified explicitly. For this reason, the Waterfall model was chosen as the approach to develop the software package.

1. Logic flow diagram of design structure

The block diagram shown in figure 1 provides an overview of the design structure of the proposed software package that is composed of the main user interface and seven tasks. These tasks are p-n junction, solar cell, schema of light emitting diode, energy band of light emitting diode, p-n junction photodiode, p-i-n photodiode and laser diode. As shown in Figure 1, each task consists of three stages. The first stage is to display information about the task in order to help a user to understand the concept of the task. The second stage is to draw the schema and the energy band of a device. The third stage is to create animation to illustrate the operation of a device. Animation is used in task 1 to show the basic principle of the p-n junction, and in particular to show the effect of increasing the depletion region width and the corresponding changes of the energy band diagram. In task 2 animations is used to show the operation principle of a solar cell in terms of how electrons and holes can be generated in the junction space charge region and how they are separated by the built junction field to produce the photovoltaic effect. Also, animation is used in task 3, which is the energy band of light emitting diode in order to show movement of electrons from n side to p side and the movement of holes from p side to n side. Also, animation shows the recombination of the electron and hole that may cause the radiation of light. In task 4 animations is used to show how light emission can be produced when a current pass through the light emitting diode. Animation is used in tasks 5 and 6 in order to show how absorption of light can create electron-hole pairs and how the drift of these charge carriers generates a photocurrent. In task 7, which covers the principle operation of laser diode, animation shows recombination of an electron and a hole to produce light. The main

user interface is used to link the tasks and to

allow users to select a task from the main menu.

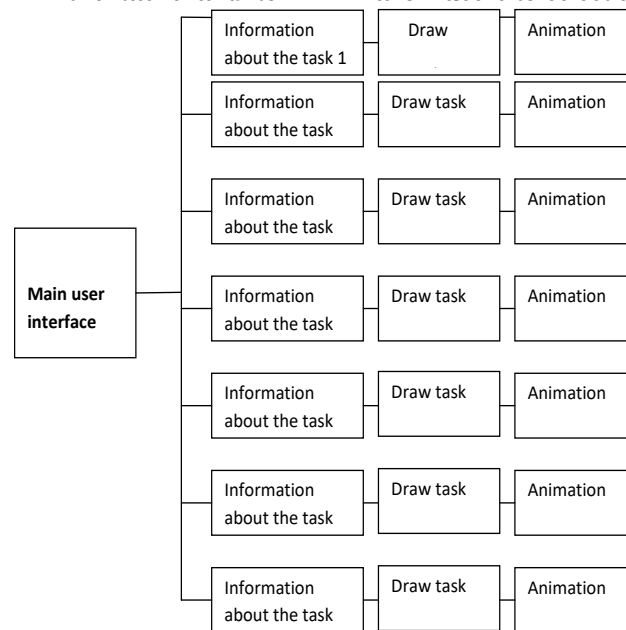


Fig. 1: Block diagram of design structure of the proposed software package

2 Logic flow diagram of a task

As shown in Figure 2, the logic flow diagram of a task describes the steps of the design of a task that will be implemented using the MATLAB program. The first step is to display information about the task; this information will be displayed as text on the screen, then a schematic and energy band of a device will be displayed on the screen, and third step allows a user to select to start animation or to close the task. The last stage is to play the animation and change the speed of it. Animation also can be stopped and started at any time.

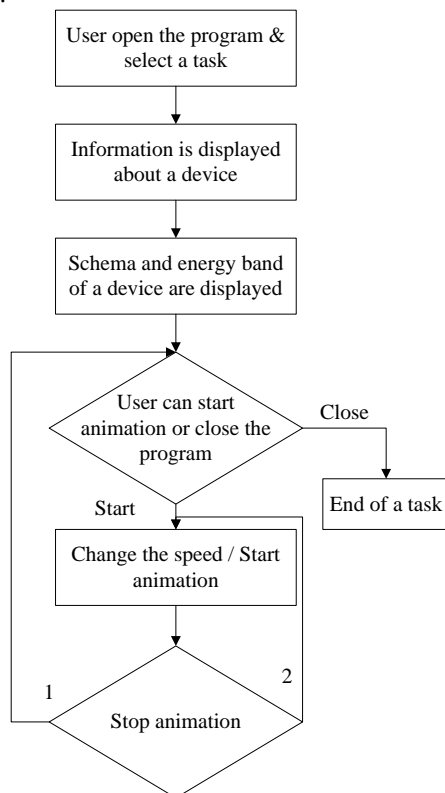


Fig. 2: logic diagram of a task

3 The Main user interface

The main user interface is designed to make the software package easy to use. It is designed to be a graphical user interfaces for all operations and composed of the main window, the list box that contains the list of tasks to allow a user to select a task from this list, the start button that is used to run a program that has been chosen from the list box and the close button which is used to close the software package. Figure 3 illustrates the main user interface design.

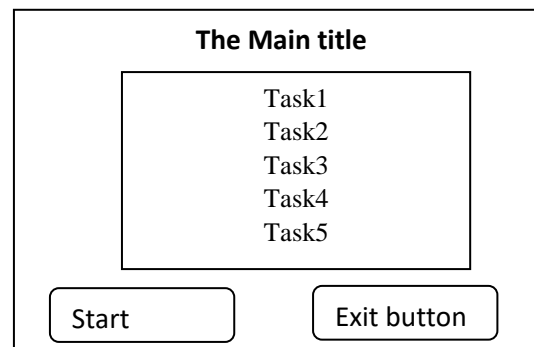


Fig. 3: The main user interface design

4 The Screen0 design of a task

This screen was designed for all tasks in order to show the result of the execution of the task. It contains the main title, which describes the task, and three control buttons that are start, stop and speed; these buttons are used to control the animation. Also, it contains graphs that illustrate the energy band and schematic of the device. When a user clicks the start button, animation will play to show the behavior of the device. The speed of animation can be changed at any time using the speed button; animation can be stopped using the stop button. The close button is used to allow a user to close the task and return to the main user interface. Figure 4 shows the screen design of a task.

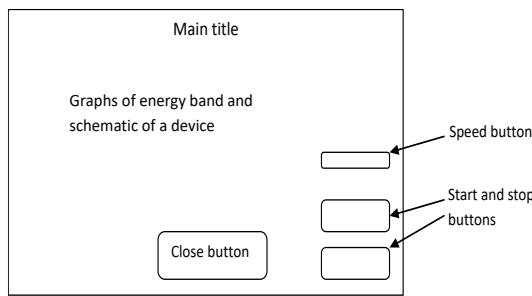


Fig. 4: The screen design of a task

Implementation of the propose interactive and animated software package

In the implementation stage, the design is transferred into a programming language. In the propose software system, the MATLAB program was used to develop the software package, which is divided into models that are the main program and several functions; the aim of the main program is to make an interface between a user and the functions; each function is used to implement a task in order to illustrate the energy band and schema of a device. Also, animation is used to show the operations of devices. For example, the movement and the recombination of an electron and hole are shown by using animation. There are three ways that can be used to create animation using the MATLAB program. These are Erase mode method, creating movies and using AVI files. The second and the third are suited to situations where the frame is fairly complex and cannot be redrawn rapidly [16].

In the propose software package, the animation is required to show the movement and recombination of electrons and holes so, the first approach was chosen to implement the animation because it allows faster redrawing for an electron and hole.

As shown in Figure 5, the main user interface was designed and implemented to be easy to use. It is composed of the main title, list box, start and stop buttons.

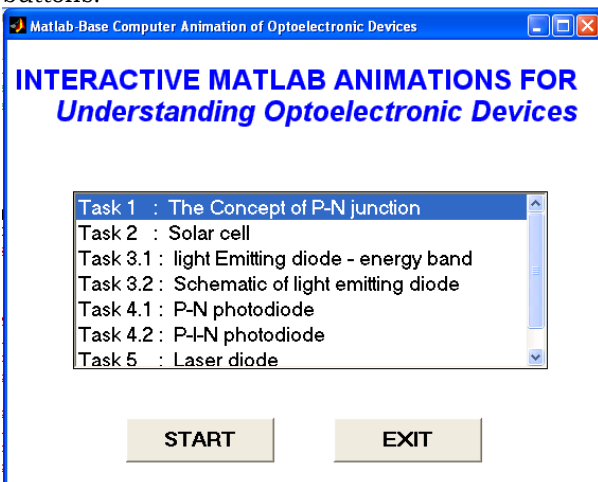


Fig. 5: Main user interface

The figure 6,7,8,9,10 show the implementation of solar cell, Energy band of light emitting diode, p-n photodiode and p-i-n photodiode, Laser diode

tasks, respectively. The implementation of Solar cell task illustrates the behavior of a solar cell. It is composed of the energy band and the schematic of a solar cell in order to show the operation principle of it, and in particular, to show how diffusion of light can generate electrons and holes. Also, it consists of three control buttons, which are the start button which is used to start animation, the stop button which is used to stop animation and the speed button that is used to control the speed of animation.

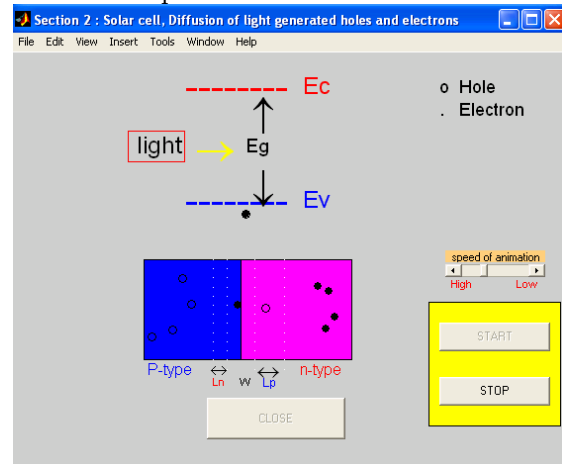


Fig. 6: Task of Solar cell

The implementation of the behavior of the energy band of the light emitting diode (LED) is shown in figure 7. The user can start animation by clicking on the start button or stop animation by clicking on the stop button. When animation is started a few electrons in the n-region will move into the p-region and a few holes will move into the n-region; recombination of the electrons and holes may cause the radiation of a photon. The speed of animation can be control to be low or high using the speed button.

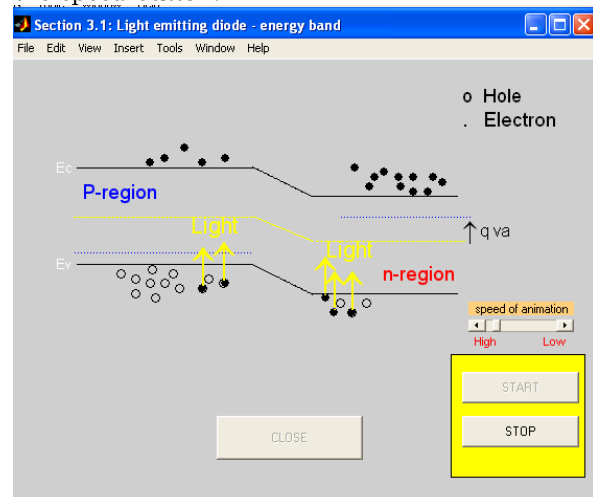


Fig. 7: Task of Energy band of light emitting diode4

Figure 8 shows the implementation of the p-n photodiode task, in which the operation principle of the p-n junction photodiode is illustrated. It consists of the energy band and schematic of the p-n photodiode. As shown in Figure 8, blue indicates the p type whereas red color indicates n

the type. Three control buttons are used to control the animation; these buttons are start, stop and speed. The task shows how a light can be converted into a signal current. When a light is absorbed by the device, electron-hole pairs are generated within the junction; electrons drift to the n-region and holes to the p-region, consequently a signal current will be generated. Animation is used in this task to show the movement of electrons and holes that are generated as a result of the absorption of light. Also, animation shows a photocurrent that flows from the n type region to the p type region of the device. This photocurrent can be measured related to the amount of light absorbed by the detector.

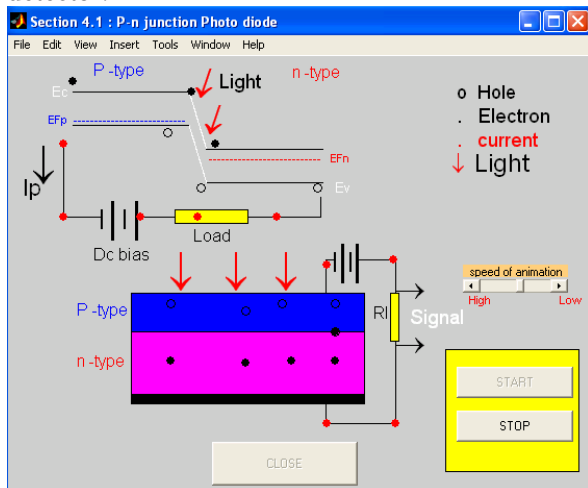


Fig. 8: Task of p-n photodiode

As shown in Figure 9, the p-i-n photodiode is made of the p region, n region and i region. The i region is sandwiched between the p and n region. Three types of colours are used to draw the schema of the device: red for the n region, blue for the p region and white for the i region. Animation is used to show the movement of electron-hole pairs that are generated within the i region. When radiation is absorbed, electrons drift to the n region and holes drift to the p region under the reverse bias, adding to the reverse signal current.

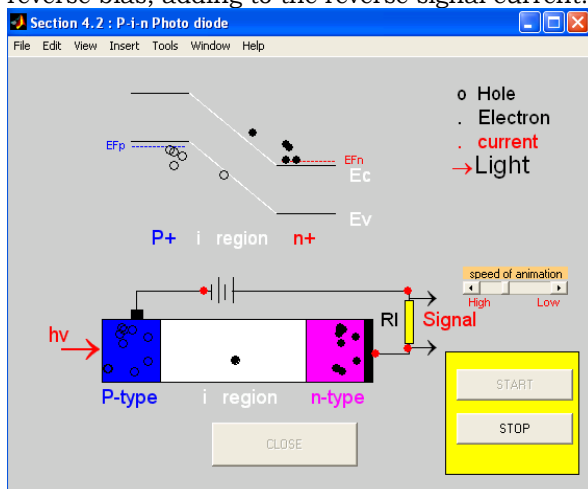


Fig. 9: Task of p-i-n photodiode

Figure 10 shows the stimulated emission and schematic of a semiconductor laser diode that consists of a thin layer of active material which is sandwiched between the p-region and n- region of the p-n junction. Animation in this task can be controlled by using the start, stop and speed buttons. When the animation starts, it will show the recombination of electrons and holes that cause radiation of light.

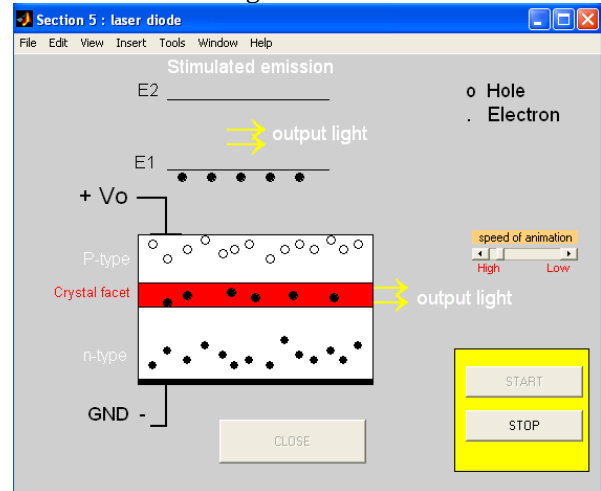


Fig. 10: Task of Laser diode

Evaluation process and results

Evaluation is a process of systematic data collection to shed light on some aspects of a project. It is required in order to ensure that the final product meets the user’s requirements. Any software product should be evaluated according to many aspects: correctness, accuracy, reliability, maintainability, readability, understandability, testability, expandability, usability, and design cost [15]. Evaluation can take place in many stages of the development of the design. It can either be made during the early design stage in order to predict the usability of the final product and user’s requirements or it can be carried out during later design stages where the result of it can be used for further modifications. The evaluation of the proposed software package was carried out by users who were asked to use the software and try to note their opinions about it. The users had to complete the questionnaire. The measurement scale of this questionnaire was from 1 to 7 where 1 represents a negative view and 7 represents a positive view. The questions of the questionnaire were divided into three sections. The first section measured the overall impression of the users about the software; the second section measured their impression about the screen design and layout of the software package, and the third section measured contents. Twenty students who have an electronic background or science background with certain knowledge about electronic science were asked to evaluate the software package. In general, users were satisfied with the software package, and they suggested some adjustments to be made to it. The proposed suggestions were implemented to improve the software package were: increase the font size of the text to 13; adding a button to control the speed of animation;

modifying the colors; adding buttons to start or stop animation. The results of each section of the questionnaire are shown in the following charts: Figure 11 shows the results of the questions about overall impression of the software package. It can be seen that the users in general had a good impression about the software package and their scores users over 5 out of seven in questions 1 and 3, and over 4 in question 3.

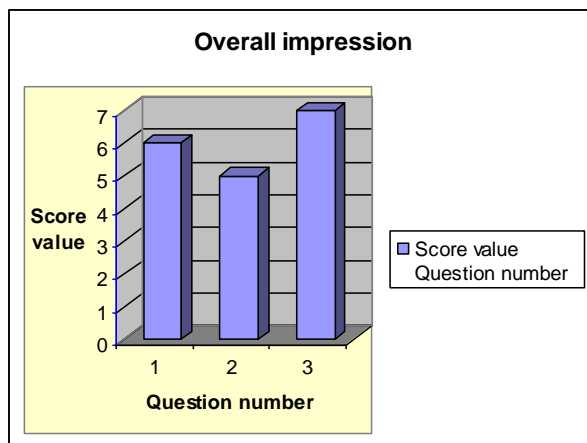


Fig. 11: The average scores for the questions in section 1

Figure 12 shows the result of the questions in section 2 that are about screen design and layout. The chart shows the users were satisfied in general with the screen design and layout. However, the users noted that the size of the text was not appropriate. Also, some users noted that the speed of the animation was fast and some of them noted the speed was slow. The first suggestion was implemented by increasing the font size. The second suggestion was implemented by adding a button to control the speed of the animation so users can select appropriate speed for the animation.

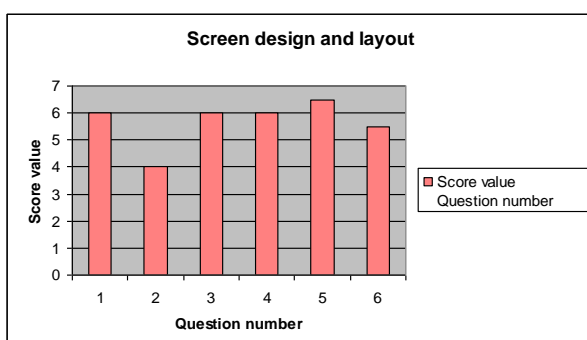


Fig. 12: The average scores for the questions in section 2

Figure 13 shows the result of the questions in section 3 that are about contents. As can be seen from chart, the users were satisfied with contents of the software package and they believe that it will help students to understand the operation principle of optoelectronic devices.

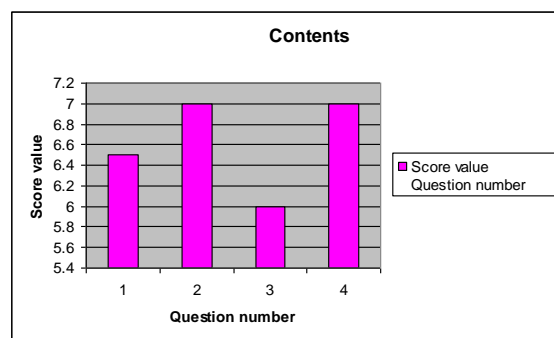


Fig. 13: The average scores for the questions in section 3

Conclusion

This paper presents the design and implementation of an interactive and animated software package using the MATLAB program in order to aid Electrical and Electronic Engineering students to understand the concept of optoelectronic devices. The software package was designed and implemented to be user friendly. It may be used as a part of a lecture or as self-study material to aid students. The software package is composed of a series of MATLAB programs that cover the principal operations of several types of optoelectronic devices using graphic and animation. Based on the student feedback, the implications of visual learning material can enhance the teaching process and help students to understand the relevant concepts better. Naturally, the same principles can be adopted for other electronic devices and applications of optoelectronic devices to promote the interactive learning material.

Further investigation for increasing robustness by using adaptive embedding strength a depending on blocks characteristics is on the way.

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References

- [1]- D. Gillet, Toward flexible learning in engineering education. Redding, CT: Begell House, pp. 95–102, 2003.
- [2]- D. Magin and S. Kanapathipillai, "Engineering students' understanding of the role of experimentation," *Eur. J. Eng. Educ.*, vol. 25, no. 4, pp. 351–358, 2000.
- [3]- A. V. Nguyen, D. Gillet, and S. Sire, "Sustaining collaboration within a learning community in flexible engineering education," in *Proc. World Conf. Educational Multimedia, Hypermedia and Telecommunications*, pp. 21–26, 2004.
- [4]- Kok-Meng Lee, Wayne Daley and Tom McKlin, an interactive learning tool for dynamic systems and control, *Proceedings of the ASME Dynamic Systems and Control Division, IMECE* pp. 71-76, 1998.
- [5]- Andreas Spanias, and Venkatraman Atti, Interactive Online Undergraduate Laboratories Using J-DSP, *IEEE Tras. on education*, Vol. 48, no. 4, pp. 735-749, 2005

- [6]- P.Bauer, E-learning for power electronics in future power systems, International Conference on Future Power Systems, pp. 1-6,2005
- [7]- S.M. Gómez Puente, M. van Eijck and W. Jochems, Towards characterising design-based learning in engineering education: a review of the literature, European Journal of Engineering Education, Vol. 36, no. 2, pp.137–149, 2011.
- [8]- S. Dimitrijević, Understanding Semiconductor Devices, Oxford University Press, 2000.
- [9]- S. M. Lord, "Optoelectronics experiments for first-year engineering students," IEEE Trans. Educ., vol. 44, no. 1, pp. 16–23, 2001.
- [10]- S. Rebiai, N. E. H. Toudjien, S. Mouissat, Implementation of Online Optoelectronic Devices Course and Remote Experiments in UC1 iLab, Int. Conf. on Interactive Mobile Communication Tech, vol. 9 (2), pp. 17- 21, 2014.
- [11]- N. Nevaranta, P. Jaatinen, K. Gräsbeck and O. Pyrhönen, "Interactive Learning Material for Control Engineering Education Using Matlab Live Scripts," 2019 IEEE 17th International Conference on Industrial Informatics (INDIN) pp. 1150-1154, 2019.
- [12]- S. Y. Wong and S. Yong Lim, "Towards a Livelier Electromagnetic Education with an Interactive MATLAB-based GUI," 2019 IEEE Asia-Pacific Conference on Applied Electromagnetics (APACE), pp. 1-4, 2019.
- [13]- S. Satavlekar, V. Keskar and V. Dahake, "Development of MATLAB Based LearnFFT Tool for Constructive and Graphical Understanding of FFT," 2019 IEEE Tenth International Conference on Technology for Education (T4E), pp. 284-285, 2019.
- [14]- Preece, J., Yvonne, Helen, David, Holland and Carey Human Computer Interaction, Addison-Wesley, 1994.
- [15]- Software engineering tutorial, Tutorials Point (I) Pvt. Ltd 2014. Available: www.tutorialspoint.com
- [16]- TheMathWorks, 2017, Available: <https://www.mathworks.com>