Research Article

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Design of a web laboratory interface for ECG signal analysis using MATLAB builder NE

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Abstract: An electrocardiogram (ECG) is a noninvasive test, determining any defect in the heart rate or rhythm or changes in the shape of the QRS complex is very significant to detect cardiac arrhythmia. In this study, novel web-ECG simulation tools were proposed using MATLAB Builder NE with WebFigure and ASP.NET platform. The proposed web-ECG simulation tools consisted of two components. First, involved the analyses of normal real ECG signals by calculating the P, Q, R, S, and T values and detecting heart rate, while the second part related to extracting the futures of several types of abnormality real ECG. For calculating the PQRST values, simple and new mathematical equations are proposed in the current study using MATLAB. The Web ECG is capable to plot normal ECG signals and five arrhythmia cases, so the users are able to calculate PQRST easily using the proposed simple method. ECG simulation tools have been tested for validity and educational contributions with 62 undergraduate and graduate students at the Al-Nahrain University-Biomedical Engineering Department, Iraq. The proposed ECG simulation tools have been designed for academic learning to be run easily by a student using only any web browsers without the need for installing MATLAB or any extra programs. The proposed tools could provide a laboratory course for ECG signal analysis using a few buttons, as well as increase and develop the educational skills of students and researchers.

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1 Introduction

Laboratories are the essential support for undergraduate students and researchers with each other as well as courses that lead to improving their skills in solving and fixing practical problems, particularly in engineering laboratories. These laboratories present experiments in evolving students' skills which leads to promoting universities which are the basis for the development of countries [1,2]. An electrocardiogram (ECG) is the chart and map of the heart. The ECG records the electrical activity of the human heart, and the acquired signal is printed on paper. This record is utilized for the early diagnosis of heart disease. The normal and typical ECG wave is composed of a series of positive and negative waveforms, namely, the P wave, QRS complex, and T wave. The ECG is the most frequently used test to assess the heart. This record is significant because it can screen for various cardiac abnormalities. ECG devices are readily available in the majority of medical facilities [3–5]. The heart rate, the rhythm of the heart, abnormality in the muscle of the heart, evidence of a previous heart attack, or the presence of coronary artery disease can be detected from the ECG trace [6,7].

The changes in the electrical pattern of the ECG can offer important clues for the occurrence of syncope or may distinguish heart disease. Thus, clinicians and biomedical engineers who study heart diseases should be trained in interpreting ECG signals [8–10]. Studies on heart diseases have resulted in the remarkable development in the application of computer-assisted learning (CAL) tools widely utilized in medical and biomedical engineering education, especially for physiological data analysis [11–14]. Tools for ECG interpretation and feature extraction are some examples of CAL tools [15–17]. Numerous academic and commercial studies on ECG interpretation and feature extraction tools have been conducted.

McClennen et al. proposed a novel teaching tool for physicians and medical school students. The tool was based on the creation of a web-based ECG system that connects directly with the clinical repository of a hospital [18]. Rodríguez et al. presented a new approach using web service technology to capture, record, and analyze the ECG signals in a personal digital assistant carried by a patient [19]. Nilsson et al. introduced studies on the evaluation of a web-based ECG interpretation program using a diagnostic test to allow medical student users to assess the effect of the program on their skills in ECG interpretation and extraction [20]. Shopov et al. proposed a web-based ECG Personal Health System, which includes a multi-tiered architecture combined with an information system to facilitate the remote examination and analysis of a physician [21]. Islam et al. designed software tools for ECG analysis using MATLAB and LABVIEW programs. The tools included the generation, interpretation, extraction, calculation, and comparison of different ECG signals [22]. Kırbaş and Bayılmış introduced a web-based remote monitoring interface using MATLAB Builder NE with WebFigure, and this interface was applied in medical care using a wireless body area sensor network [23]. Güney et al. designed a new web-ECG simulator using MATLAB WebFigure and included nine types of arrhythmias. In addition, three different noises, namely, baseline wander, power line interference, and random noise, are added to the clear ECG signal in this simulator [24]. Granero-Molina et al. studied the implication of new web simulation curricula in nursing schools and determined the effect of web ECG simulation on strategies and learning styles [25]. AL-Ziarjawey and Çankaya proposed a mathematical algorithm to obtain the P, Q, R, S, and T values, draw these values on the ECG wave, and detect heart rate. The proposed algorithm was materialized by a graphical user interface (GUI) using the MATLAB platform. The software has been devoted to education and scientific research [26]. Ogundepo and Ponnle introduced a model based on the GUI with MATLAB to analyze ECG and detect arrhythmia using a back-propagation neural network. The proposed tools encompass pre-processing of ECG signals and feature extraction [27].

In this study, a novel web-based ECG simulation monitoring system based on MATLAB Builder NE and ASP.NET platform is presented. The web-based ECG simulation tools were designed and developed for educational and scientific research rather than clinical diagnosis. A simple mathematical algorithm for analyzing ECG signal components is proposed to detect the P, Q, R, S, and T values for real normal and abnormal ECG cases. This paper is structured as follows. Section 2 presents a brief review of the ECG signal analysis, which includes feature extraction, and the related works. Section 3 presents an introduction to the architectural layout of the web-ECG simulation tools and design process. Section 4 describes the contents and results of the proposed web-ECG simulation tools. In Section 5, evaluation results of proposed WEB ECG tools are presented. Finally, conclusions and future research directions are drawn in Section 6.

2 Methodology and related work

The proposed web-ECG simulation tools are very comprehensive and significant for clinicians and engineers in research and medical students. In current work, a comprehensive, general-goal, user-friendly, graphical user interface ECG signal extraction features tools, which are easy to learn have been developed based on MATLAB Builder NE

This package involved the analyses of normal and abnormal real ECG signals by calculating the P, Q, R, S, and T values and detecting heart rate. The main contribution in the presented work is the calculating of the P, Q, R, S, and T values using simple and new equations with MATLAB. The simple algorithm is tested on the normal ECG and standard arrhythmia database of the MIT-BIH [28], to demonstrate the performance of the proposed algorithm and web-ECG simulation on real ECG data.

2.1 Normal ECG analysis

In this work, a new and simple proposed method is performed to obtain the P, Q, R, S, and T values (Figure 1). This method is based on finding a mathematical relationship between the highest values (peaks and valleys) of the ECG waveform and time. So, the number of samples for one cardiac cycle should be selected in an ECG signal first.

In the proposed method, the normal ECG signal is set to 400 sampling during every 1 cycle (example in our case). The different points are detected by determining the following values:

- R point, which is the maximum amplitude in one cardiac cycle (400 samplings) in an ECG signal;

$$R_{point} = \max(\text{one cardiac cycle in ECG signal}). \quad (1)$$

- Q point, which is the minimum amplitude after shifting several steps (d1) toward the left of the R point at position (R-d1);

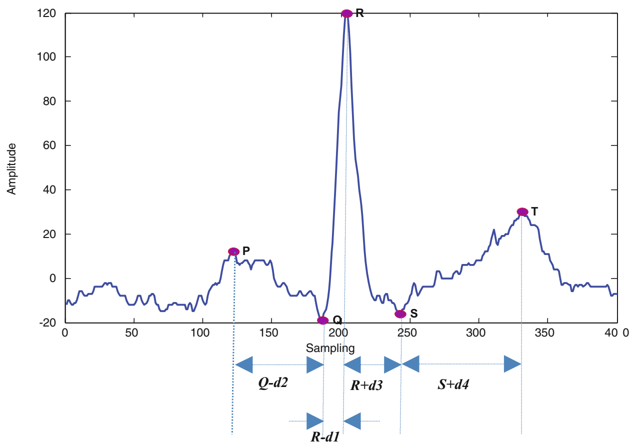


Figure 1: Normal ECG with P, Q, R, S, and T values.

$$Q_{point} = \min(\text{ECG signal till R point}). \quad (2)$$

- P point, which is the maximum amplitude after shifting several steps (d2) toward the left of the *Q* point at position (Q-d2);

$$P_{point} = \max(\text{ECG signal till } Q \text{ point}). \quad (3)$$

- S point, which is the minimum amplitude after shifting several steps (d3) toward the right of the R point at position (Q + d3);

$$S_{point} = \min(\text{ECG signal from R point till (End point of one cardiac cycle in an ECG signal} - \text{Start point of one cardiac cycle in an ECG signal)}). \quad (4)$$

- T point, maximum amplitude after shifting several steps (d4) toward the right of the S point at position (Q + d4);

$$T_{point} = \max(\text{ECG signal from S point till end point of one cardiac cycle in an ECG signal}). \quad (5)$$

Figure 2 shows the length of a normal ECG wave, the length of this wave is with 5,000 samplings. The length of each cardiac cycle is about 400 sampling, so in the proposed method, the length of each cardiac cycle should be defined first, and it can be used easily with the presented tool.

2.2 Abnormal ECG analysis

The second section of the proposed packages provides the same features as in section A for the normal ECG

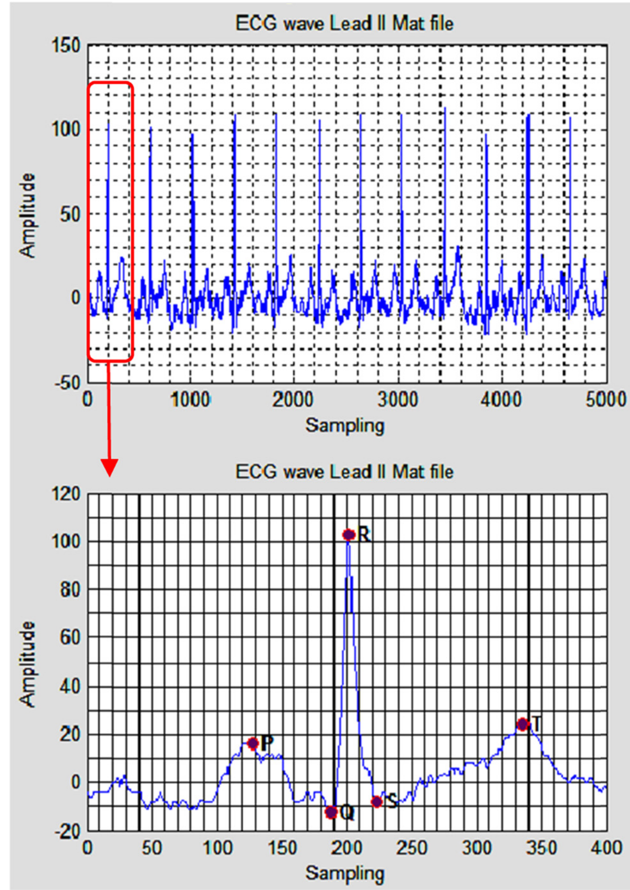
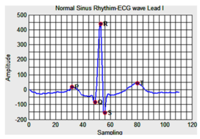
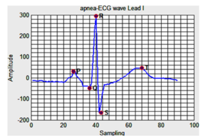
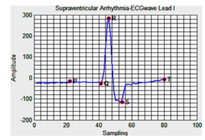
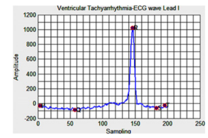
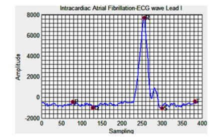


Figure 2: The length of a normal ECG wave.

signal analysis. In this section, various abnormal ECG signals, namely, supraventricular arrhythmia, apnea, normal sinus rhythm, ventricular tachyarrhythmia, and intracardiac atrial fibrillation, are analyzed. Arrhythmia is detected, and the P, Q, R, S, and T waves are also calculated using the proposed simple method. Moreover, heart rate in the abnormal ECGs is detected. The same mathematical calculations (equations (1–5)) used with normal ECG analysis are the same as that used in the abnormal ECG analysis. The difference in the application between the two analyses is in selecting the number of samples. In the normal ECG analysis, the sampling is set to 400 during every one cycle because it is rhythm; while, in the abnormal ECG analysis, the length of each cardiac cycle is different from one case to another. Also, during the same ECG wave, each cardiac cycle is different in sampling length from another because most cases are irregular as shown in Table 1. So, the length of each cardiac cycle should be defined first as in the normal ECG, and the user/student should enter the starting and end point of each cardiac cycle easily with the presented tool according to each abnormal case.

Table 1: Brief Summary of the Results of the Abnormal ECG signals

Name of abnormality	Normal sinus rhythm	Apnea-ECG	Supraventricular Arrhythmia	Ventricular Tachyarrhythmia	Intra cardiac atrial fibrillation
Rate	96 bpm	73 bpm	53 bpm	125 bpm	125 bpm
Rhythm	Regular	Regular	Regular	May be irregular	Irregular
					
ecg graph with waves characteristic	$P = 19$, $Q = -83$, $R = 439$, $S = -155$, $T = 43$	$P = 31$, $Q = -48$, $R = 294$, $S = -165$, $T = 47$	$P = -15$, $Q = -27$, $R = 283$, $S = -115$, $T = -7$	$P = -29$, $Q = -85$, $R = 1{,}026$, $S = -60$, $T = -25$	$P = -432$, $Q = -984$, $R = 7{,}696$, $S = -1{,}041$, $T = -404$

3 Web-ECG simulation architecture

The design of the web-ECG simulation tools using MATLAB Builder NE and ASP.NET in Microsoft Visual Studio Platform is illustrated in Figure 3.

First, the MATLAB codes reflecting all functions of the proposed web-ECG simulation tools were written as Functions.m files. After compilation of the coding files in MATLAB, a.NET component is created using the deployment tool GUI to build a.NET class. Then, all.m files are added to create.dll files in Ditrib & Src folders as.NET components. Then, web-ECG simulation tools are designed using the ASP.NET Web Site under the Visual Studio program platform. Then, the WebFigure control from the toolbar is dragged to the website page. A reference component to the MWArray and another reference to the deployed components created by MATLAB Builder NE are created. Thereafter, a code for the website page is written using C# in the Microsoft Visual Studio Platform. Finally, the webpage is tested by selecting debug and running the program in Microsoft Visual Studio [29–32].

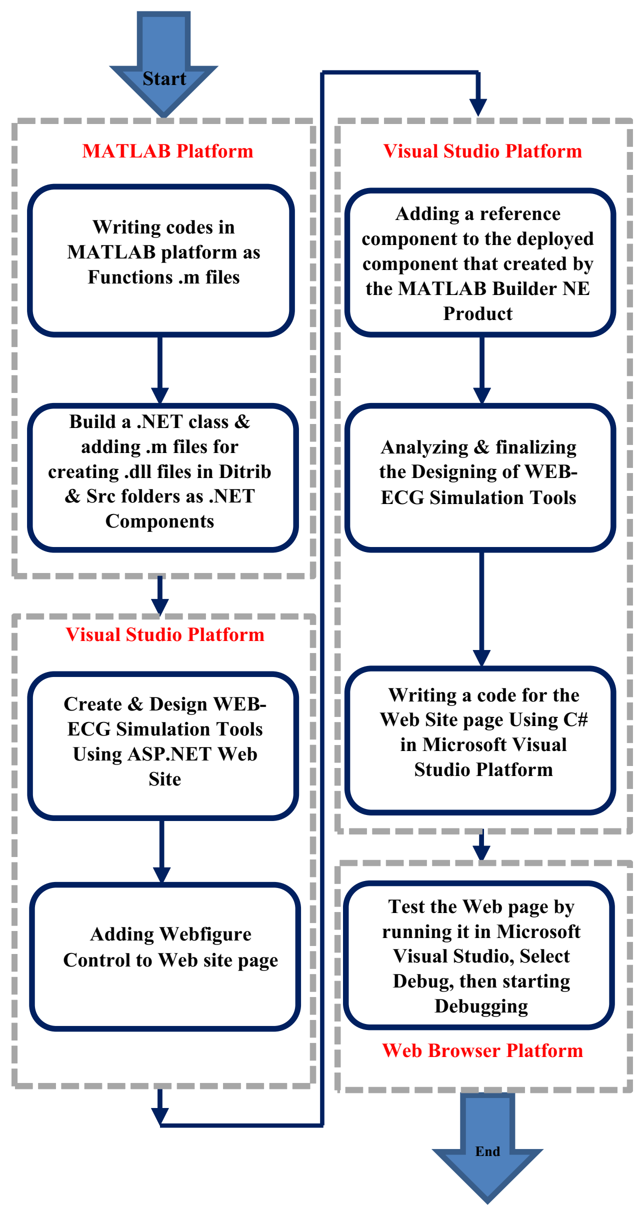


Figure 3: Design of web-ECG simulation tools.

4 Web-ECG results

The results of the web-ECG simulation tools are composed of the following components: first, ECG analyses of a normal ECG trace; second, ECG analyses of abnormalities. First of all, a simple user registration form is built in ASP.Net designing using C# to allow the user to register with the website. This step helps the user to enter and utilize the web-ECG simulation tools. The user fills up the registration form with several details, such as username and password. The provided information is saved in the database table connected to this site. Thus, the user should confirm registration to access the website in ASP.Net. The user/student can enter at any time using only his/her username and password on the login page (Figure 4).

The proposed web-ECG simulation tools consist of multiple pages. The confirmed registered user can navigate the pages just by clicking the name of the page. The startup (main) page that will appear after correct login and when the user chooses any page is shown in Figure 5.

From the startup (main) page, the user can navigate five pages, namely, registration page, normal ECG analysis, and abnormal ECG analysis.

4.1 Abnormal ECG analysis

The first section of the proposed package provides the main features of the analysis of a normal ECG signal from the MIT-BIH Database PhysioNet. The steps of detecting P-QRS-T and heart rate are presented in a simple flowchart, as shown in Figure 6. The first step is the selection of the ECG lead (I, II, or III) and the type of file (.mat.txt, or .xlsx file). Then, the proposed algorithm starts to read the ECG data and remove the low- and high-frequency components. Then, the windowing filter and thresholding are used to find the local maxima. Finally, an adjust filter (again windowing filter) is used to detect R–peaks, heart rate, and P-QRS-T waves using a simple mathematical calculation.

The first section of the proposed package provides the main features of the analysis of a normal ECG signal.

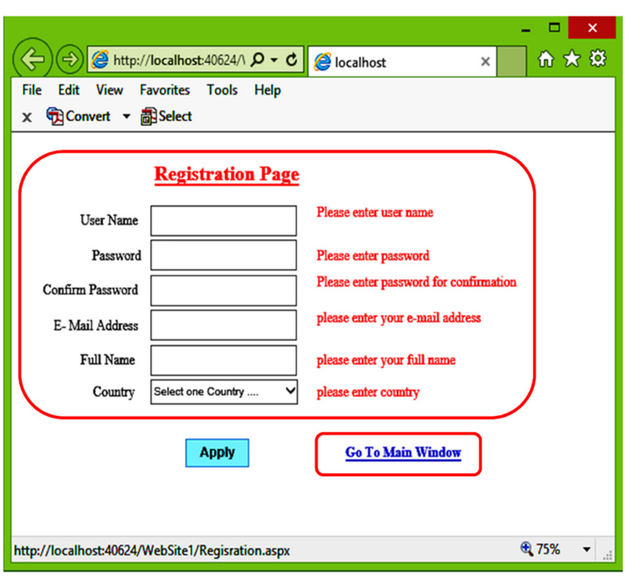


Figure 4: ASP.NET website registration page.

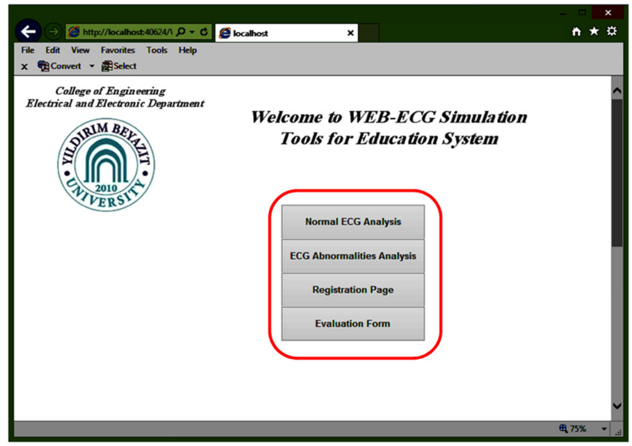


Figure 5: ASP.NET website startup (main) page.

This tool analyzes the ECG recordings to obtain the P, Q, R, S, and T values and detect heart rate (Figure 7), as follows:

1) A full sampling of ECG signal recordings is drawn after the selection of the type of data as an a.mat,.txt, or.xlsx file that matches with the lead I, II, or III.
2) Data are imported from the hard disk or over the network and from any type of data.
3) Selecting the “Detect R-peak & HR” button implements the detection of heart rate proceedings using

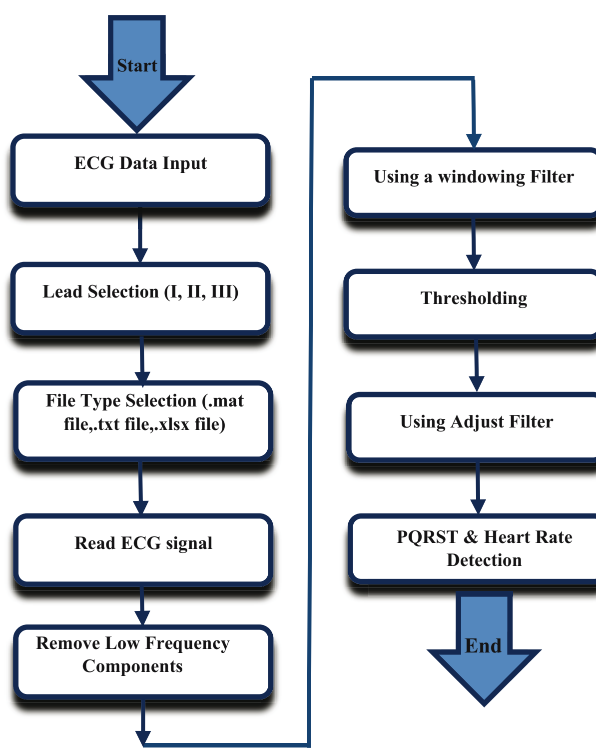


Figure 6: Detection of P-QRS-T and heart rate.

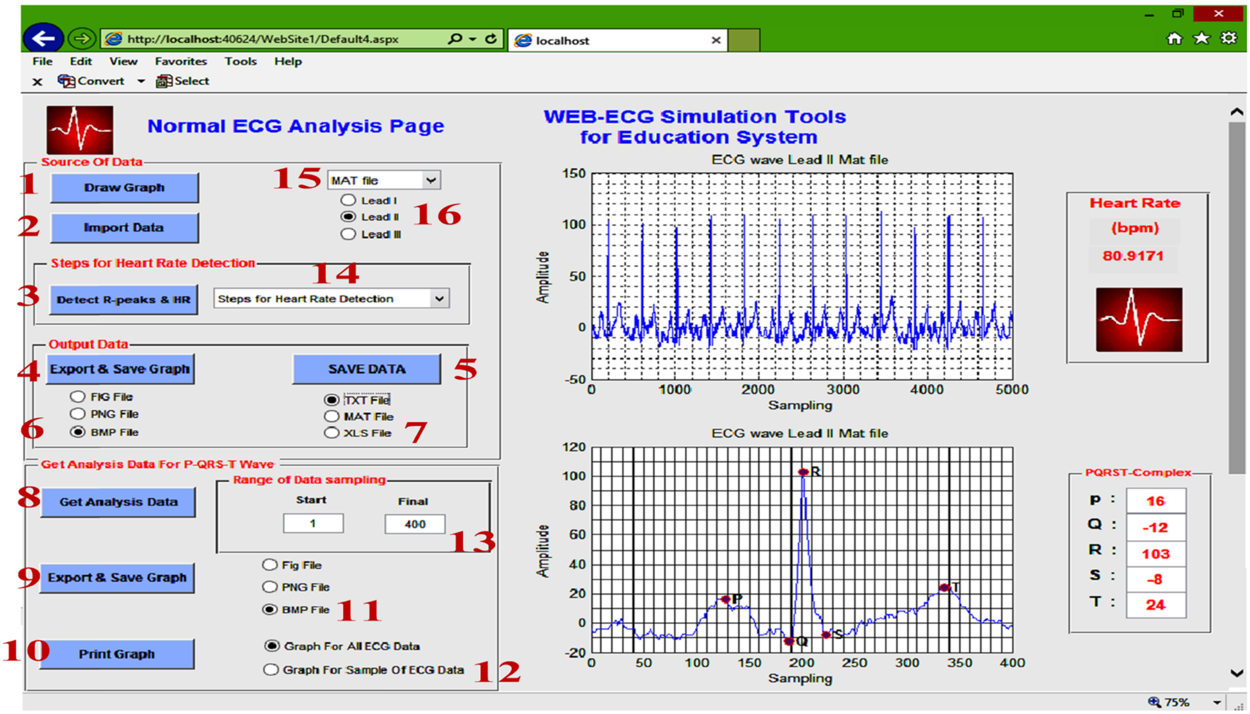


Figure 7: Web-ECG simulation tools to analyze normal ECG signals.

a windowing filter twice to find the local maxima of the R-peak after removal of the low-frequency components. Then, the filter size is adjusted.

4) The user can save the graph in any of three types of files (.fig, .png or .bmp) when the “Export & save Graph” button is clicked.
5) The user can save data as .txt, .mat, or .xlsx file.
6) The program can save different types of images (figures).
7) The program can also save different types of data.
8) Clicking the “Get Analysis Data” button will run ECG data analysis to calculate the P, Q, R, S, and T values. The number of samples for one cardiac cycle in an ECG signal of the P-QRS-T waves should be set to 400 samples.
9) The user can save the graph displayed at the bottom in any of the three types of files (.fig, .png, or .bmp) when this button is clicked.
10) The user can print out each figure.
11) Different types of images are available.
12) The user can select whether to print all or specific samples.
13) The range of sampling data is entered.
14) The “POP-UP” menu is used to select steps to detect R-peaks and heart rate.
15) The type of data (.mat, txt, and xlsx) is selected.
16) The user selects data for any lead of the ECG that the user wants to be drawn.

4.2 Abnormal ECG analysis

The other section of the WEB-ECG Simulation tools packages provides the same features as the previous section. The main different features in this part are the ECG abnormality analysis. This analysis includes (supraventricular arrhythmia, apnea, normal sinus rhythm, ventricular tachyarrhythmia, and intracardiac atrial fibrillation) which analyzes the abnormalities of ECG recordings. The objective of this analysis is to detect arrhythmia and calculate P, Q, R, S, and T waves; as well as to detect the heart rate of ECG abnormalities. Therefore, Table 1 and Figure 8 provide all abnormal ECG signals and a summary of the results of these abnormalities.

Table 1 lists the data from several abnormal ECG signals from the MIT-BIH Database Arrhythmia PhysioNet. The first case is normal sinus rhythm, in which the heartbeat is normal at 96 bpm (between 60 and 100 bpm). The rhythm is healthy with a normal and regular heartbeat. The shape of this case shows three clear deflection waves, namely, P, QRS, and T.

The second signal shows an apnea ECG, which may be misinterpreted as normal because of the regular rhythm and normal heart rate of 73 bpm (between 60 and 100). The shape of the wave also embodies the three deflections. The third case is supraventricular arrhythmia, which shows an abnormality in the timing or pattern of the heartbeat.

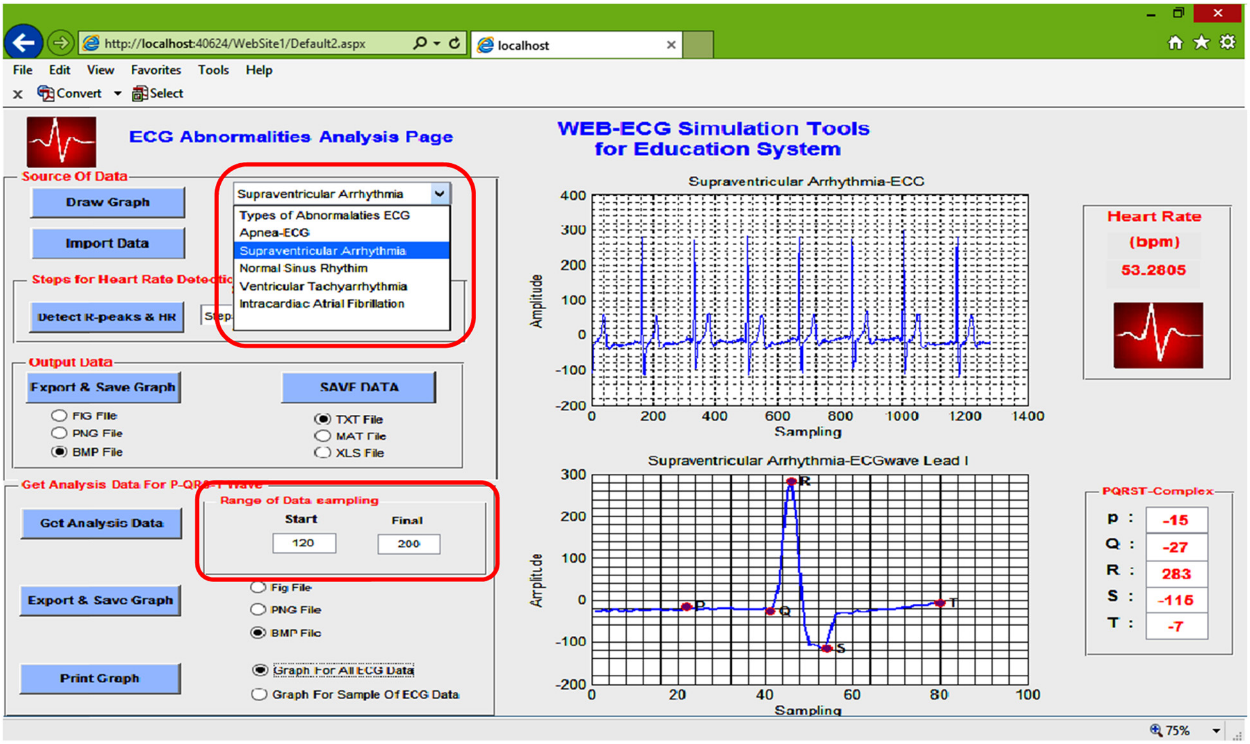


Figure 8: Third main page of the proposed web-ECG simulation tools for analyzing abnormal ECG signals.

Arrhythmias lead to very rapid, very low, or irregular heartbeat. In supraventricular arrhythmia, the heartbeat is very low at 53 bpm. The fourth case is ventricular tachyarrhythmia, which shows irregular rhythm and very rapid heartbeat at 125 bpm (over 120 bpm). The fifth case is intracardiac atrial fibrillation. This condition is activated in the atria which leads to an irregular rhythm. The heartbeat is very rapid at 125 bpm (over 120 bpm).

5 WEB-ECG assessment

Web ECG simulation tools have been tested for validity and educational contributions, by considering these tools as a supplement for medical practitioners or biomedical engineers and as an efficacious educational tool for learning and analyzing ECG. Web ECG system is evaluated at the Al-Nahrain University in which nearly 62 students in biomedical engineering in both undergraduate and graduate studies participated to assess the WEB-ECG system in terms of educational contributions and validity. WEB ECG system tools were designed with an automatic evaluation form (Figure 9) on the main page of this system in which several questions are presented about the efficiency and flexibility of this system. The evaluation form was designed to rank the WEB ECG system with eleven questions, by using a scale of five points (excellent = 5, very good = 4, good = 3, fair = 2, and very poor = 1). The evaluation form is filled out by students after using the WEB ECG system tools and submitted to the serve under the ASP.NET platform.

The information of evaluation is saved in the database table connected to this site, then authors can analyze these data to convert them into a statistical report (bar graph) (Figure 10) that reflects how the students are evaluated by this system. The statistical report is beneficial in examining the skills gained by students after utilizing the WEB ECG system as well as providing feedback information about the extent of WEB ECG success and meets the requirements of distance learning. The results of the statistical report are shown in Figure 10. The questions in the evaluation form can be classified into five sets. The first four questions are concerning in the facilitating the education success as well as learning how to calculate heart rate and P, Q, R, S, and T values with WEB ECG tools. There are at least 81% of students were said that the WEB ECG system has a positive response regarding the ease of using this system. The second set includes questions (five, six, seven, and eight) that are related to ease of use as well as to purpose to get feedback on the use of the WEB ECG system, and most of the

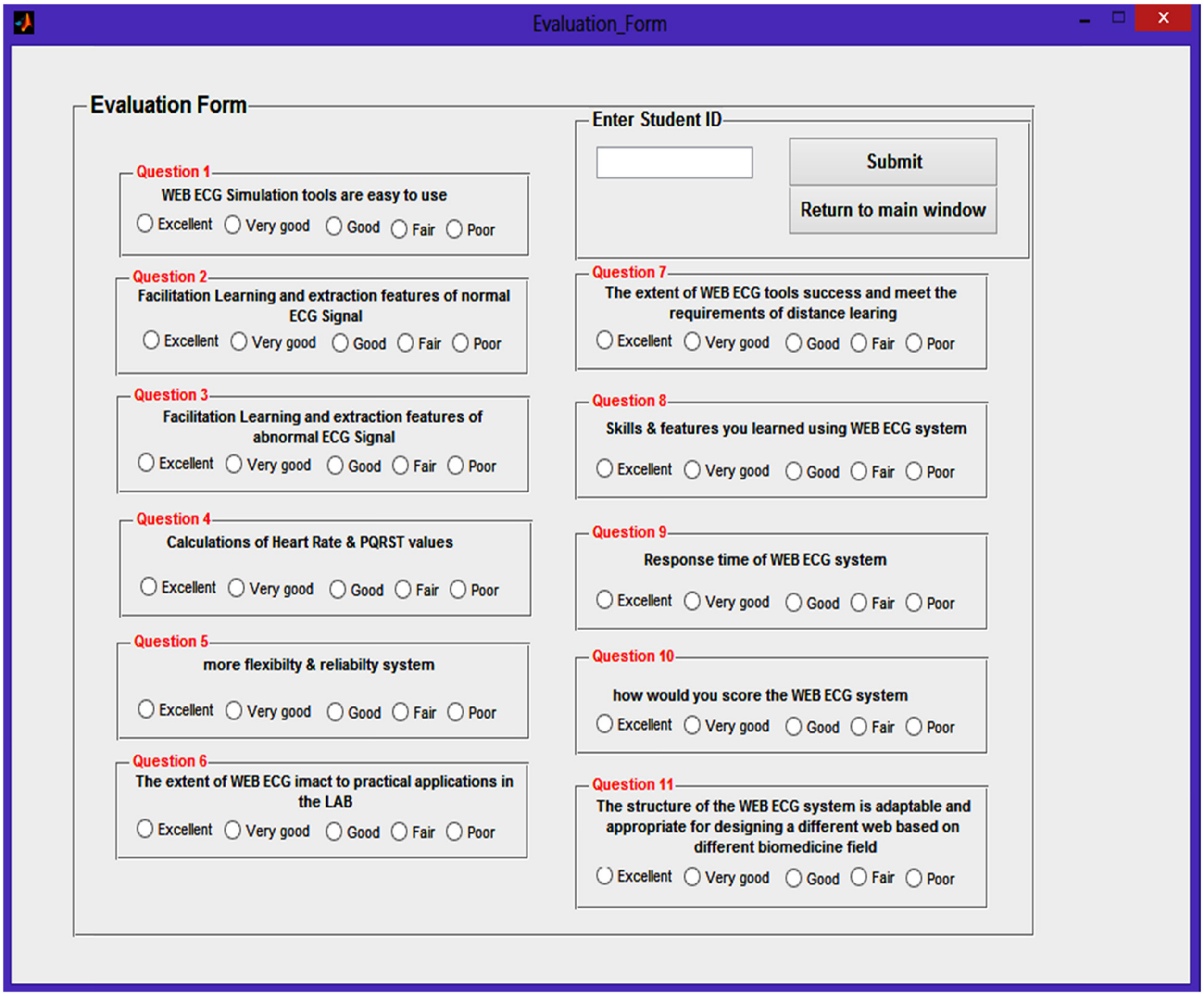


Figure 9: Evaluation form.

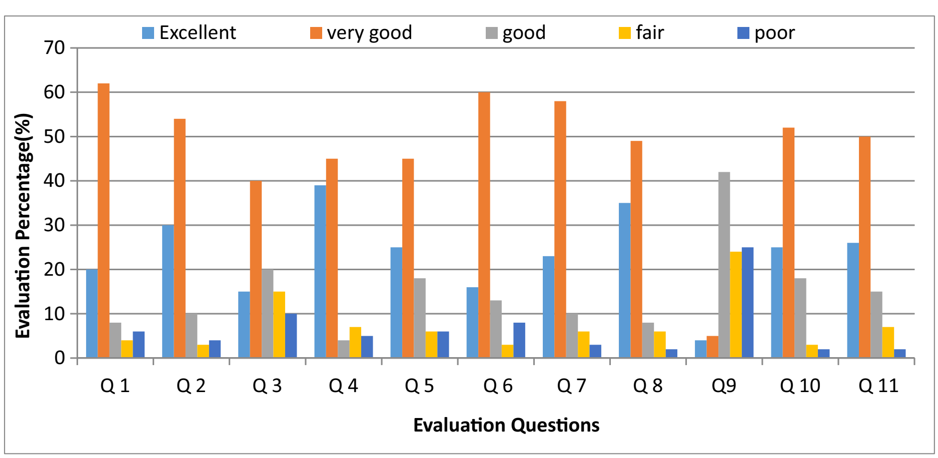


Figure 10: Evaluation results.

students were believed that the WEB ECG system is very useful and very easy to use as well as user-friendly tools, as a result, the average is increased to 85%. The third set has only the ninth question, related to the response time of WEB ECG simulation tools. There are at least 80% of students who said that the WEB ECG system has a negative response regarding the time response of using this system, because students have to wait for around in sometimes more than one minute for getting the result because of the connection between the student (client) and server need some time, so the average is decreased to 42%.

The fourth set has only the tenth question that is related to the overall success and score of WEB ECG; the majority of students, nearly 83%, have believed the WEB ECG system is very acceptable and successful. The fifth set has only the eleventh question, which relates to whether the structure of the WEB ECG system is adaptable and appropriate for designing a different web-based on different biomedicine fields. There are 80% of students who have thought that the structure of WEB ECG is suitable to design and perform another WEB system for another application course in the biomedical field for improving the practical skills of students.

6 Discussion

Laboratories are the essential support for undergraduate students and researchers with each other as well as courses that lead to improving their skills in solving and fixing practical problems, particularly in engineering laboratories. These laboratories present experiments in evolving students' skills which leads to promoting universities which are the basis for the development of countries.

There are different literature that introduced a description of the development of the ECG simulator on various platforms, but still, all the presented work was limited to a specific type and number of ECG signal cases. Software tool using MATLAB and LABVIEW programs has been introduced for analyzing different ECG signals [22]. A web-based using MATLAB Builder NE with WebFigure was applied in medical care using a wireless body area sensor network [23]. Another web-ECG simulator using MATLAB WebFigure has been introduced to deal with nine types of arrhythmias and three different noises [24].

The presented ECG software package is designed to extract features for any shape of ECG signal and classify the ECG signals for detecting arrhythmia according to the analyzed signals. Actually, our tool has many structures, and the main contribution to this work is the implementation of a new and simple proposed method to obtain values of P, Q, R, S, and T. This method is based on finding a mathematical relationship between the highest values (peaks and valleys) of the ECG waveform and time.

In the presented tool, the clinicians are capable to import data (any type of ECG signal) from any place (inside the computer, outside computers like hard disk or any storage as well as from internet website). However, the equipment utilized in these laboratories are still so costly, so the suggested WEB ECG tools in current work are presented as cheap educational interface way as well as user-friendly tools for students and researchers. This tools package enables the opening of a new approach for researchers and undergraduate and graduate students about how they can use ECG signals and be familiar with other biosignals in the future by using similar tools for processing and extracting features of it. As a result, the aim of designing WEB ECG tools is to improve the learning of students and understanding of how can find some features extraction of ECG.

7 Conclusion and future works

The proposed current work is very necessary and has vital significance, especially in countries that suffer from a lack of financial resources which lead to raising the criterion of the education level profession. It should promote sharing medical consultation in the field of cardiology between medical centers in different governorates inside the country and also between centers in other countries.

The presented simulation tools are essential for academic instruction by clinicians, engineers, and researchers, as well as for the training of medical students. This package is beneficial as a supplement for medical practitioners and as an efficacious educational tool for learning and analyzing ECGs. The proposed web-ECG simulation tools can be utilized to train clinicians and engineers working in fields related to the study of heart disease. The proposed web-ECG simulation tool package is a simple and authoritative method to detect the P, Q, R, S, and T values of normal and abnormal ECG cases.

Therefore, the package provides the following main features:

1) Detection of R-peaks and measurement of the heart rate in real normal and abnormal ECG signals.
2) Detection of P, Q, R, S, and T values in real normal and abnormal ECG signals.

3) Classification of ECG signals to detect arrhythmia according to the analyzed signals. These cases included supraventricular arrhythmia, apnea, normal sinus rhythm, ventricular tachyarrhythmia, and intracardiac atrial fibrillation.
4) Differentiation of the shape of normal from abnormal ECG signals by analyzing these signals and extracting the features of both types of ECG traces.
5) Building a web-ECG simulation tool package without installing any program (MATLAB) such that users who do not have MATLAB can use this package directly using a few buttons.
6) Web ECG can be used in laboratory environments as well as for distance learning by running only a web browser without the need to install any other program.
7) Web ECG can be operated across different computer platforms such as Windows, Linux, UNIX, and son.

In summary, the proposed WEB-ECG Simulation tool is more beneficial for academic students as a supplemental course. Moreover, the installation of MATLAB is not necessary to use the package. Only MATLAB Compiler Runtime (MCR) and a web browser are required. Web-ECG system is very easy to run and maintain. The package is robust and flexible. The tool is very easy to grow and develop.

For future work, the method can be developed further by applying it to telemedicine. Cardiac arrhythmia detection through remote access to ECG diagnosis is highly effective and beneficial for medical practitioners and patients. The remote access control is performed between the patient and the hospital or research center by transmitting ECG information of a patient for 24 h a day, especially from one clinic or patient's home for chronic patients to a remote site. Thus, this service facilitates the feasibility of a homecare service center for telehomecare and creates a link between nurses and specialist doctors when an abnormality is found in the patient. Future studies related to ECG diagnosis using telemedicine applications are very significant. Moreover, other techniques, such as artificial neural networks, can be used to process ECG signals.

Conflict of interest: Authors state no conflict of interest.

Data Availability Statement: PhysioBank Databases. https://physionet.org/physiobank database.

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