A computer-aided ECG diagnostic tool

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ABSTRACT

Jordan lacks companies that provide local medical facilities with products that are of help in daily performed medical procedures. Because of this, the country imports most of these expensive products. Consequently, a local interest in producing such products has emerged and resulted in serious research efforts in this area. The main goal of this paper is to provide local (the north of Jordan) clinics with a computer-aided electrocardiogram (ECG) diagnostic tool in an attempt to reduce time and work demands for busy physicians especially in areas where only one general medicine doctor is employed and a bulk of cases are to be diagnosed. The tool was designed to help in detecting heart defects such as arrhythmias and heart blocks using ECG signal analysis depending on the time-domain representation, the frequency-domain spectrum, and the relationship between them. The application studied here represents a state of the art ECG diagnostic tool that was designed, implemented, and tested in Jordan to serve wide spectrum of population who are from poor families. The results of applying the tool on randomly selected representative sample showed about 99% matching with those results obtained at specialized medical facilities. Costs, ease of interface, and accuracy indicated the usefulness of the tool and its use as an assisting diagnostic tool.

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1. Introduction

Electrocardiography is a non-invasive investigatory method that provides information for the detection, diagnosis, and therapy of cardiac conditions [1]. The shape and size of the electrocardiogram (ECG) wave, the time duration of each of its constituent parts may contain helpful information about the nature of diseases affecting the heart [2]. The use of ECG for detecting heart problems in asymptomatic adults during routine clinical examinations may lead to a large number of ECGs to be analyzed.

In the past, cardiologists were asked to perform visual ECG analysis. To reduce the workload for physicians, computer programs for ECG analysis have been developed and used. Pibberger et al. [3] were cited by [4–6] as the first who attempted to differentiate between normal and abnormal ECGs by a computer program (designed to recognize and measure the wave components of the digitized ECG signal) in the late 1950s. Since the first commercially available programs were introduced in the early 1970s [4,6] computerized ECG analysis systems have become more sophisticated and less expensive with an increasing number of available programs.

The use of computerized ECG analysis has increased rapidly in health care over the last 30 years [4,6–11]. The ECG analysis is accomplished through a sequential examination of the heart electric events. An ECG signal consists mainly of a P-wave, a QRS-complex, and a T-wave. The amplitude, direction and duration of the waves, and their morphological aspects are analyzed. The information obtained is also used to detect and diagnose normal and abnormal cardiac
There are many variations and combinations of ECG features or parameters, which must be measured, studied, analyzed, and correlated one with another and with other available data before a definite ECG analysis is made. Each of the waveforms has its own sensitivity and specificity for detection of particular various abnormalities and may be influenced by many pathological and pathophysiological factors. The same ECG pattern can be recorded in individuals who have different structural and pathophysiological states. Therefore, ECG analysis requires a systematic approach that includes knowledge of the patient's age, sex, and race and presenting complaints/symptoms. The abnormalities observed must be correlated with the data collected from the individual's medical history and physical examination and from other tests performed.

Patients considered at risk for heart disease currently go through a series of non-invasive exercise stress tests that can identify ischemic heart disease but not risk of arrhythmia. As a result, only a small fraction of patients at risk for ventricular arrhythmia presently receive invasive but definitive electrophysiology (EP) testing and go on to preventative treatment. However, several findings may be present that cannot be considered sufficient for a diagnosis but that, nonetheless, are suspicious, and may be predecessors of a structural heart disease that will become apparent only with time. In these cases, although an initial diagnosis of idiopathic ventricular fibrillation (IVF) may be acceptable, a careful follow-up of the patient is necessary. Even in the absence of symptoms or of arrhythmia recurrence, all patients should probably receive a comprehensive clinical evaluation every year. Also, repeat echocardiograms and ECGs and Holter monitoring are recommended every year.

The availability of follow-up data on a large number of IVF patients will be most valuable to allow the assessment of those individuals initially diagnosed as having IVF who will eventually develop structural heart disease; indeed, this is one of the major goals of this paper. To provide a simple yet inexpensive diagnostic tool that allows medical doctors registering and following up different normal and abnormal features extracted from their ECG machine, a PC-based diagnostic tool is designed.

Typically, a commercial ECG system with signal analysis capabilities represents a financial challenge in many developing countries. In Jordan, an ordinary unit costs about US$ 4000. Given the fact that ECG monitors are widely available locally, this proposed system entails adding a PC and a signal conditioning circuitry, which requires an extra investment of less than US$ 650. As far as the use of MATLAB is concerned, the MATLAB could be run from a main server located at the Directorate of Biomedical Engineering in the Ministry of Health to which the 1000 local public clinics (medical facilities) throughout the country are connected. Alternatively, the MATLAB compiler 4.3 gives the possibility to setup the software as a stand-alone executable program.

The proposed system provides doctors with different ECG analysis techniques in both time and frequency domains and a simple tracking mechanism for the patients' history and analysis of different possible risk factors. The objectives of introducing such a system may be summarized as follows:

To reduce the analysis time needed for the busy physician especially when there are multiple diagnoses, and in cases of large numbers of ECGs to be analyzed.
To assist the physician in ECG analysis and improve his/her diagnostic accuracy.
To facilitate handling of large numbers of ECGs.
To simplify ECG storage and retrieval in a database.

2. Materials and methods

To evaluate the tool, the MIT database was used, which provides the possibility of selecting a random sample that includes both normal and different arrhythmias cases. The proposed tool in this study has the capability of a range of sampling frequency known in this kind of application. However, a sampling frequency of 333 sample/s had to be chosen to be compatible with MIT database, which was sampled at 333 sample/s. Furthermore, the ANSI/AAMI signals were also utilized to assess the tool performance. The analyses mentioned above were implemented using the MATLAB software and the benefits offered by the Graphical User Interface Development Environment were also utilized. To take the tool evaluation a step further, a sample of 100 cases diagnosed by a physician (normal and with arrhythmias) was matched with the tool output.

3. ECG analysis

To use this tool, any case study is analyzed by inserting patient's name, gender, age, family history, activity, blood pressure, cholesterol level, diabetes, stress, fat levels, triglycerides, tobacco use and smoking, and weight. Time and frequency windows are then popped up. The ECG signal is acquired using the proper sampling frequency of 333 Hz. This frequency spans 165 Hz of the ECG spectrum which is necessary for diagnosis. The doctor has the option to change this frequency to higher values enabling late potential detection. An on-line monitoring and saving of the signal is permitted. Doctor has the option to zoom in the segment of interest for analysis. The following ECG algorithms are available:

Signal analysis in time domain: It includes an automatic detection of signal characteristic points, amplitudes, and durations (P-wave, PR segment, QRS complex, ST segment, T-wave, and QT interval). An accurate QRS detection was performed by processing the raw ECG signal through a bandpass filter to remove unwanted noise, followed by non-linear transform to provide coarse detection for R locations. An adaptive thresholding followed to determine coarse limits of QRS complex. The filtered signal was then passed through a differentiator to determine QRS slope information and the peaks and notches of the QRS were determined using the zero crossing of the differentiated signal. Once the QRSon and QRSoff were determined, an accurate T-wave detector was applied. To detect the T-wave, the ECG signal was pro-
Processed through filtering and differentiation stages, T-wave window: minimum and maximum search, finding T-shape and thresholds, then finding characteristic points of T-wave including T_on, T_off, and T_peak. P-wave detection was then applied. In a similar fashion, the P-wave was detected. However, thresholds are lower and low-pass filtering was performed at a cutoff frequency of 30 Hz.

To determine the ST segment information, baseline wandering and motion artifacts were removed by estimating the baseline and removing low frequency contributions of the motion and electrode movement artifacts. ST information (locations, slope, and shape) depends on the heart rate to determine the onset of ST segment. Rates over 60 beat/min put the start point at 0.06 s from QRS_off, otherwise it would be at 0.08 s. After determining the ECG characteristic parameters, the doctor has the ability to intervene if some portions are not in conformance with his judgement. In this case, manual intervention is advised. The data are then normalized and compared with normal values. Computations are made to determine possible diagnostic procedures. Diagnostic results enable the doctor to determine the best follow-up procedure and help him/her to make quick decisions.

Frequency analysis: It enables the doctor to perform spectral analysis techniques to isolate different noises and artifacts of the acquired ECG segment and project denoised segment for time analysis.

Heart rate analysis algorithm: It is based on spectrum analysis of the heart rate series. Results are stored in tables and kept in the patient’s records. If the patient already has a record, data are automatically compared and suggestions are given for possible reasons of change.

Other digital signal processing algorithms such as power spectral density, autocorrelation, coherency, and covariance are available for further analysis. These algorithms are built-in in the MATLAB signal processing toolbox. In addition, the system allows for the possibility of writing any other algorithm in the textbox available in the GUI. The data obtained after applying these algorithms can be compared with normal data available from recently published results targeting ECG analysis.

3.1. Description of the tool

Signal diagnosis tool consists of two windows. These are:

Signal diagnosis window: This window contains time signal and frequency spectrum axes. Current cases can be displayed using a pop-up menu that gives the user the choice of picking up the case based on his/her name or serial number. Information about the current active case will also be displayed. Lower and upper frequency limits of the spectrum can be determined using custom controls. Default time division spacing is 3 ms corresponding to a sampling frequency of about 333 Hz. Hence, frequency spectrum of the signal will be located in a range from the dc up to about 165 Hz in which normal ECG and many arrhythmias are present. The default sampling frequency of 333 samples/s can be easily changed any time to match the frequency content of the acquired data. The operation of such tool is done via several push buttons: Load Cases, New Case, Edit Case, Diagnose, Frequency Content, Exit, and Info.

Case information window: Clicking the new case button the user adds a new case or edits a current one. This new window contains editable text boxes where patient name, age, gender, notes, and ECG raw data file name are given. Via this window’s buttons the doctor is able to browse for the ECG raw data file, add a new case, save the edited current case, cancel without saving any changes, and display help. Typing help Caseinf will also yield the same result. It is important to note that any push button comes up inactive when appropriate. Also unacceptable values will be self-corrected.

4. Results

To ensure the validity of the proposed diagnostic tool many tests have been performed. One of the tests applied was on an ECG signal as may be seen in Fig. 1. This ECG signal was downloaded from the MIT-ECG database, previously diagnosed as having atrial fibrillation (AF). AF is the most common arrhythmia and it is characterized by having no obvious P-wave and most of its frequency spectrum is in the range of 0-30 Hz.

Fig. 1 – A downloaded ECG time-domain signal with an atrial fibrillation used for system evaluation (upper part) and its frequency spectrum obtained by applying the proposed software (lower part).

Fig. 2 – Portion of the downloaded signal shown enlarged (upper part) and its corresponding frequency content (lower part) demonstrating the zooming capabilities in the proposed software.
Relative to the common practice in local public clinics where the GP has to see and diagnose a large number of patients using traditional techniques, the tool allows the physician to easily investigate the time-domain signal by simply dragging the mouse on the desired signal portion to zoom selected area and thus allows him/her to discriminate more accurately the heart defect as demonstrated in Fig. 2. Consequently, the tool provides several benefits including time saving and quality of patient care.

When the physician decides to investigate the frequency spectrum seeking extra valuable information that are not clear from the time-domain signal, all he/she needs to do is to choose the upper and lower frequency limits by means of the available sliders, and then press the frequency content button (Fig. 2). The chosen range will be plotted on the frequency spectrum axes and its corresponding time-domain signal sites will be marked in red (Fig. 3). Fig. 4 shows the benefits of using such a tool in determining the heart conditions. No obvious P-wave in the frequency range 0–30 Hz was observed. Fig. 5 illustrates that similar results can also be obtained for an ECG signal recorded from v1.

The tool was locally tested on randomly selected 100 subjects. Indications of cardiac problems were diagnosed on 22% of tested subjects who had no history of cardiac risks. Twelve percent of subjects were diagnosed with heart blocks while 55% were found to be normal without cardiac risks. Eleven percent were diagnosed with arrhythmic problems. Patients who were diagnosed with cardiac problems were admitted to the hospital. The test results showed about 99% matching with those obtained at specialized medical facilities. Table 1 shows the results of the analysis tool compared with results obtained from a certified cardiologist. These results further demonstrate the accuracy of the proposed tool.
used for computerized ECG analysis have been recognized to rise rapidly over the past decade. Although the programs

The interest in using computer programs to analyze ECGs has increased rapidly over the past decade. Several computer systems for analyzing ECGs have been developed and the use of computerized ECG analysis has increased worldwide. Computerized ECG analysis systems are currently operational in inpatient hospital and emergency departments, outpatient clinics, primary care, and other clinical settings, and are used to detect health problems during routine clinical examinations or to diagnose and monitor suspected cardiac conditions.

The use of the proposed system does not equal or surpass the diagnostic accuracy of the expert human ECG analyzer. Instead, the system goes hand in hand with the physician to achieve the accurate diagnosis. With current systems, cardiologists usually use the time-domain ECG signals, which are recorded on strip-charts to analyze ECG signals. Pathological condition may not always be quite obvious in the original time-domain signal. It can sometimes be diagnosed more easily when the frequency content of the signal is analyzed.

This proposed user-friendly tool helps in better discriminating heart arrhythmias through three types of analyses: the first, the time-domain analysis, by which several types of arrhythmias can be visually discriminated; the second, the frequency-domain analysis, by which abnormal frequencies not well inspected by the time-domain analysis can be viewed and investigated; the third, the relationship between the time-domain and the frequency-domain signals. The latter analysis allows the physician to determine in which part of the time-domain the frequency-domain signals. The latter analysis allows the physician to determine in which part of the time-domain the frequency-domain signals. The latter analysis allows the physician to determine in which part of the time-domain the frequency-domain signals.

The inexperienced physicians in their routine practice may be imperfect, their use has become accepted as providing the less experienced physicians with an almost immediate, reasonably accurate analysis to assist them in achieving more accurate analyses.

This proposed computer-aided ECG diagnostic tool in this work has made a contribution to reducing the load of analysis of the many ECGs recorded routinely. Its use actually increases physician’s accuracy in ECG analysis, saves physician time, and improves quality of patient care and leads to a reduction in the costs associated with ECG analysis. The results of applying the tool on randomly selected representative sample shows 99% matching with those results obtained at specialized medical facilities.

The inexperienced physicians in their routine practice may benefit from the proposed diagnostic tool to get reasonably accurate diagnosis and informative backup to improve the accuracy of their analyses. The reading by an expert is recommended when dealing with uncertain and indefinite diagnoses of normality and suspected abnormalities.

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REFERENCES


Table 1 – Comparison between detected values using the system and the cardiologist

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<th>Interval</th>
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<th>Quality control observer</th>
<th>Standard deviation</th>
<th>Mean difference</th>
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<td>955.4</td>
<td>2.1</td>
<td>2.9</td>
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</tbody>
</table>

* All values are in millisecond.

5. Discussion

During the past decade, several computer systems for analysis, storage, and retrieval of ECGs have been developed and the use of computerized ECG analysis has increased worldwide. Computerized ECG analysis systems are currently operational in inpatient hospital and emergency departments, outpatient clinics, primary care, and other clinical settings, and are used to detect health problems during routine clinical examinations or to diagnose and monitor suspected cardiac conditions.

