Attractor reconstruction in real time from two electrocardiogram derivations for heart assessment of critical care unit patients

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Abstract

During the care of critically ill hospitalized patients, it is difficult for the specialist doctor to diagnose some life-threatening pathologies (for example, pulmonary thromboembolism), especially when patients present with loss of consciousness, in addition to possibly have nonspecific data of hemodynamic involvement, which is why patients remain connected to devices that monitor the patient's electrical signals continuously, where the most representative is the electrocardiogram (ECG). While the treating physician may interpret changes in the electrical activity of the heart, by seeing the ECG screen constantly, which is impractical. The continuous monitoring activity can be carried out with the device called Holter, but the Holter does not provide information to the doctor in real time. From this problem is derived the formulation of this project, where work has been done on the acquisition and processing of the electrical signals of the heart in real time in order to make them available to the specialist.

Index Terms* — *Attractor reconstruction, cardiac assessment, low cost electronic device.

I. INTRODUCTION

An electrocardiogram (ECG) records electrical activity of human heart normally needed to: assess heart rhythm, diagnose ischemia or a heart attack), evaluate certain abnormalities, among others. In addition to the standard EKG, the Holter test is a portable EKG that monitors and storage the heart electrical for one to two days, 24 hours a day [1]. The electrical signals from the human heart are nonlinear dynamical systems and are problematic to solve even with nonlinear equations, that why scientists rely on visual and qualitative approaches to discover and analyse the dynamics of nonlinearity, such as the attractors [2].

Particularly, in recent developments about attractors of electrocardiographic signal in the Intensive Unit Care (ICU), emphasis is placed to clinical indicators of impending arrhythmic events and sudden death, signal averaged ECG, QT dispersion, ST segment fluctuation, T-wave alternans, QT interval beat-to-beat variability, heart rate variability, and advances in automated arrhythmia detection [3]. In addition, strong evidence has been described about visual information provided from attractors which is substantially valuable in life or dead situations, for example in the ICU [4]. The patients in the ICU are habitually under sedation and mechanical ventilation with no spoken communication. That's why in this paper we propose an alternative way to monitor critically ill patients, which can be rebuilding their attractor in real time and storage it over time to see the patients' improvement or if their condition gets more critical than previous. Attractor reconstruction (AR) analysis has been used before to calculate the changeability in arterial blood pressure (ABP) waveforms. But the ABP monitors are accessible in a smaller percentage of clinical scenarios, that's why in [5], the authors performed the attractor reconstruction on more widely available photoplethysmogram (PPG) signals. They performed AR analysis on simultaneous ABP and PPG signals before, during and after a change in cardiovascular state [5].

In [6], was developed a refined fuzzy entropy (rFuzzyEn) by substituting a piecewise fuzzy membership function for the Gaussian function in conventional fuzzy entropy (FuzzyEn) measure to calculate Heart Rate Variability (HRV) in non-invasive evaluation of cardiovascular function. This method of variability measurement may last 5 min and it can provide almost immediate measurement results and enables the real-time monitoring of cardiovascular function.

In [7], the authors present a novel methodology able to estimate the Lyapunov spectrum of a series of stochastic from the heart events in an instantaneous fashion, in order to effectively and instantaneously track the nonlinear autonomic control dynamics, allowing for complexity variability estimations.

In [8], the authors propose a new algorithm for the classification of life-threatening cardiac arrhythmias including atrial fibrillation (AF), ventricular tachycardia (VT) and ventricular fibrillation (VF). The proposed technique uses a simple signal processing technique for analysing the non-linear dynamics of the ECG signals in the time domain.

Finally, in [4] the authors reconstructed an attractor of the biological electrical signal of electrocardiogram assuming that its evolution is governed by a chaotic dynamic system. They used a Holter Monitor to acquire data from 13 patients to obtain data files which consist of 900,000 rows and three columns of comma separated values (CSV) from 1 hour of registration and we got nonlinear time series. Holter monitoring was performed on each patient every 24 hours for a period of one hour from admission until discharge. The diagnosis of patients was performed from the clinical point of view and confirmed by imaging studies such as computed tomography of the site topologically involved, such as computed axial tomography of the skull, or abdomen.

From the next figures (Fig1, Fig2, Fig3), we observe the shape of two patients, and confirm the chaos predominates in no-ill conditions.

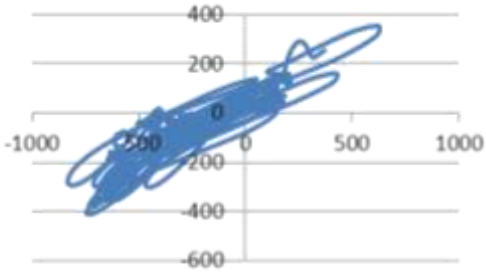

Fig 1. Attractor of healthy patient A [4].

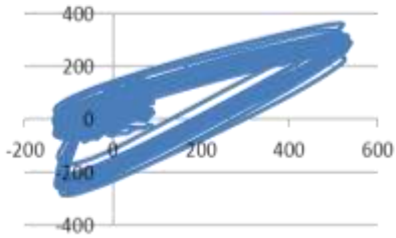

Fig 2: Attractor of a patient B with Colon Necrosis and Septic Shock [4].

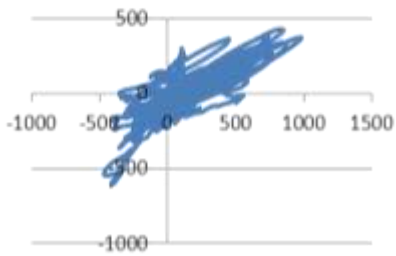

Fig 3: Attractor of a patient B after treatment in the Critical Care Unit [4].

II. METHODOGY

Our main goal is to acquire two channels of electrocardiogram and present them in a two-dimensional chart in real time. We are using two commercial devices dedicated to acquiring signal from cardiac activity. We collect both signals into a microcontroller and send it to a computer to be graph them, in order to display the results to the medic. In the Fig 4, we show the architecture.

The main element of the cardiac sensor is the AD8232 integrated circuit, which filters and an amplifies electrical activity from the heart. We mention some of its features: a) 170 µA supply current, b) Common-mode rejection ratio of 80 dB, c) Two or three electrode configurations, d) High signal gain (G = 100), e) adjustable high-pass filter, f) Single-supply operation: 2.0 V to 3.5 V. See [9] for more information.

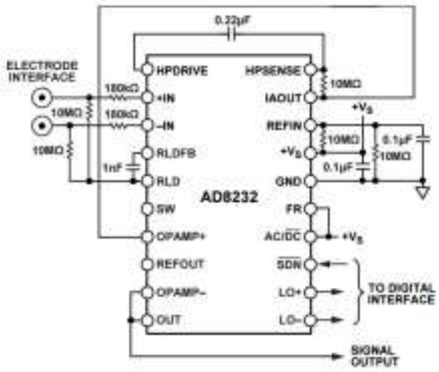

Fig 4: Circuit for Heart Rate Measurement [9].

The microcontroller is the Arduino Nano [10] which main task is to send the signals to a computer, where the signals are assembled into a bidimensional graph. The computer received the data using the serial port and were plotted with MATLAB [11].

Fig 5: Design of the electronic system.

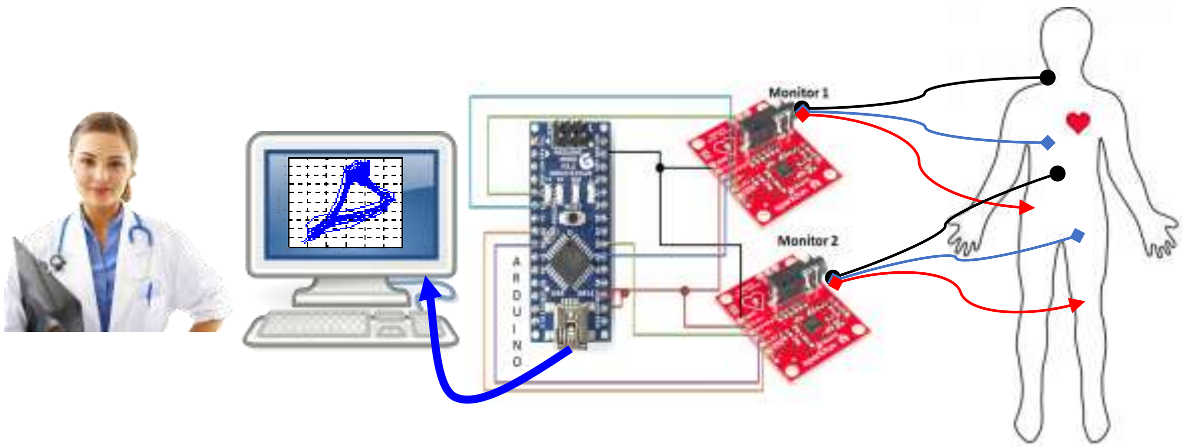

Fig 6: Model of the electronic system.

III. RESULTS

For the results, we connect three electrodes for each derivation (e.g. DI and DII), each sensor was plugged to the Arduino and then to the personal computer. The MATLAB program received two values, one for each sensor, which was converted into a graphic as shown in Fig7 and Fig10.

For the we chose to probe in a stable patient in the Critical Care Unit in the Hospital Regional "Lic. Adolfo López Mateos", which identity is reserved. And we referred to the results as *NO ILL patient*. The next Fig7 represents the attractor reconstruction, obtained from one EKG channel (Fig 8) and a second EKG channel (Fig 9).

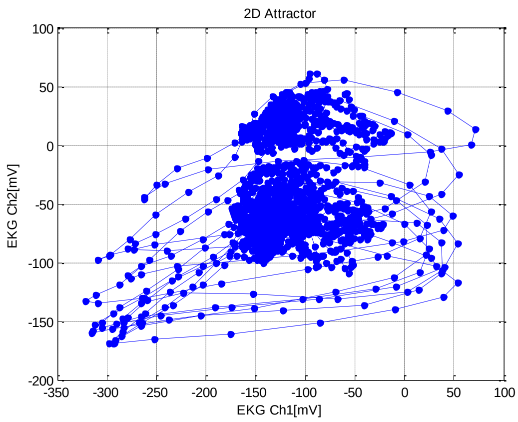

Fig 7: Results NO ILL patient.

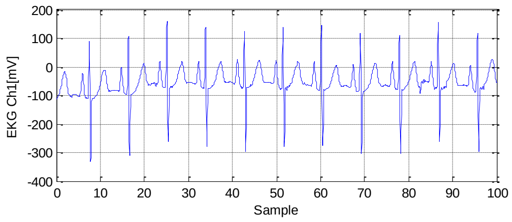

Fig 8: Results NO ILL patient.

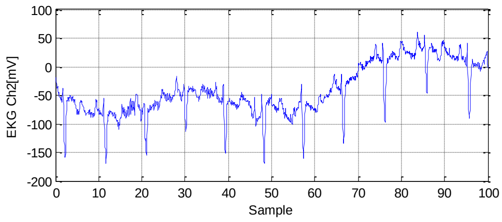

Fig 9: Results NO ILL patient.

In the other side, we connected the system to a person with diagnosis of *pulmonary thromboembolism*, also the identity is reserved, but we referred the results as *ILL patient*. The next Fig 10 represents the attractor reconstruction, obtained from one EKG channel (Fig 11) and a second EKG channel (Fig 12). We search for two patients with similar age and sex.

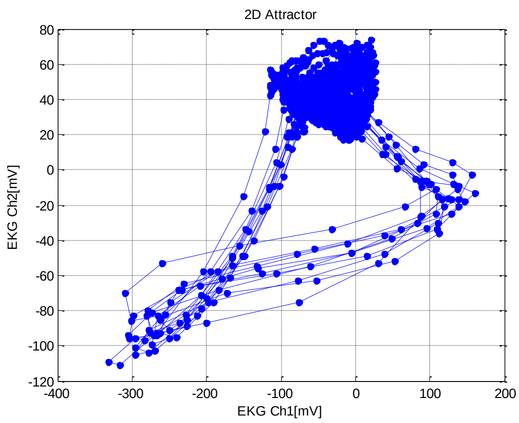

Fig 10: Results ILL patient.

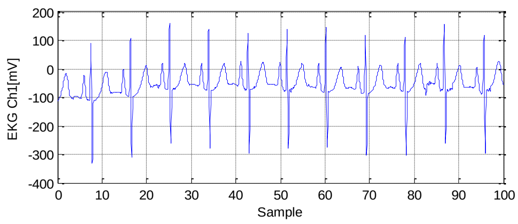

Fig 11: Results ILL patient.

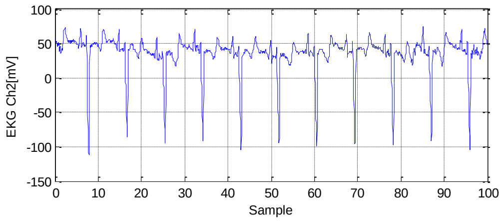

Fig 12: Results ILL patient.

In general, the derivations from the EKG are visually with no apparent change, but in contrast the attractor has significant visual changes.

IV. CONCLUSIONS

In this work, we demonstrate a system of cardiac monitoring in real time capable of showing a two-dimensional attractor reconstructed with two channels of an EKG. The system shows a graph of the patient's attractor, visually more useful to detect anomalies or critical conditions. This system can be widely used in hospitals since the components are affordable and they can be found easily. Yet another advantage is the low cost of the sensors and the microcontroller. In the future, we search to eliminate the computer and install the device as part of the patient monitoring equipment of the Critical Care Unit in *Hospital Regional "Lic. Adolfo López Mateos"*, in CDMX, México. We are working on a clinical protocol to validate the correlation with attractors shapes to specific disorders. Finally, the possible application of artificial intelligence on the automatic diagnostics or alarms for the medical team.

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