Computing a New Central Terminal for ECG recording using combined Genetic Algorithm and linear regression from real patient data

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ABSTRACT

Modern electrocardiography (ECG)[1] uses the Wilson Central Terminal (WCT) as a reference point for the majority of leads. WCT is assumed to be near zero and steady during the cardiac cycle. However, due to the measurement encumbrances of the real amplitude of WCT, this assumption has never been verified in clinical practice. Using our own recently developed 15-lead ECG device that can measure WCT components in addition to 12-lead ECGs in a clinical setting, we propose a framework to derive a New Central Terminal (NCT) with demonstrated less variation and near zero amplitude during the cardiac cycle. Our method is based upon application of a Genetic Algorithm (first 1000 samples), and then a linear regression to calculate the NCT for the rest of the recording.

CCS CONCEPTS

Computing Methodology → Machine learning; Machine learning approaches • **Applied Computing →** Health informatics

KEYWORDS

Electrocardiography, Genetic Algorithm, Linear Regression, Wilson Central Terminal

1 INTRODUCTION

In 12-lead electrocardiogram (ECG) recordings, precordial leads are measured as the potential differences between each of the six exploring electrodes on the chest and a virtual reference point known as the Wilson Central Terminal (WCT) which was described in 1931[1]. It is defined as the voltage average of right arm ($\emptyset_R$), left arm ($\emptyset_L$), and left leg ($\emptyset_F$), and assumed to be near zero and steady during the cardiac cycle (Eq. 1) with condition c1.

$$WCT = \alpha\emptyset_L + \beta\emptyset_R + \delta\emptyset_F \quad (1)$$

$$\alpha, \beta, \gamma = 1/3 \quad (c1)$$

However, this assumption was proved wrong and has been recognized as a source of potential error in ECG [2]. In 1954, Frank was the first researcher who raised concern about WCT amplitude and variation. He warned clinicians that WCT is not null or steady during the cardiac cycle, and how it can bias ECG measurement [3]. Later, Bayley and Kinard were able to measure the raw amplitude by putting a human being inside a metal structure and immersing it into the water during the measurement of ECG [4, 5]. Due to the difficulties of the real WCT measurement, the WCT assumptions as they have been conceived by Wilson, have been widely accepted and considered as a systematic error in ECG recording.

We recently proposed a new ECG device that could record 12-lead ECG together with the raw voltages of the WCT components (right arm, left arm, and left leg) [6, 7]. Our results confirm the previous findings in 1954 by Bayley, and show that WCT amplitude is in average as large as 51.2% of lead II [6] Whereas lead II is the voltage difference between left arm ($\emptyset_L$), and left leg ($\emptyset_F$).

In this paper, we address the problem of the high variability of WCT in ECG recording, and propose a new reference point for human body.

2 PROPOSED METHOD

GECCO '17, Berlin, Germany

DOI: 10.1145/nnnnnnn.nnnnnnn

Availability of raw WCT components allows us to propose a new framework to compute a New Central Terminal (NCT) using a combination of the Genetic Algorithm (GA) and the Linear Regression model (LRM) that ultimately may lead to the use of NCT in real time data acquisition.

Recalling that WCT is the average of limb electrodes, NCT is defined as weighted mean of WCT components. We use a GA to compute the three weighted factors (α, β, γ) (neglectting c1 in Eq.1) with constraints of being non-zero, positive, and less than one in module. Our ideal reference point has a small variation, near zero amplitude during the cardiac cycle; in other words, NCT amplitude should be less than 0.1 mV to be considered clinically irrelevant. Off-note, WCT optimization using weighted resistors was also attempted in real time during the original experiment performed in 1954 with little success [4]. During this remarkable experiment, researchers attempted real-time changes of the summing resistors of WCT components whilst recording.

With our method, we compute (GA) the prototype of NCT for the first 1000 recorded samples (1.25 s) of WCT components. NCT is then refined and computed for the full signal using LRM (Fig.1). The population size contains 80 individuals, each of which is a vector of float in interval (0, 1). In every iteration, elite members are moved to the next generation, and if unchanged changed after five consecutive iterations, it was considered as the optimum answer. In this paper, we use data recorded from 29 volunteer patients (written consent), age range: 45-89 years (average 66; 38% females) (study protocol number HREC/15/LPOOL/302).

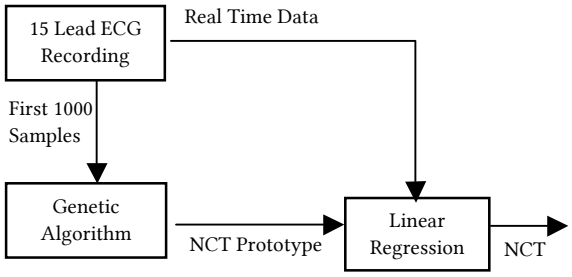

Figure 1 : The flowchart of NCT computation

3 Results

The average number of iterations necessary for the method to converge is quite small (16.36 in average). Since linear regression has linear time complexity, the overall performance of our proposed algorithm can be considered as time efficient.

Our assessment shows that while WCT exhibits proper ECG characteristics such as a P-wave and a T-wave, a large amplitude and variability (including random polarity), NCT is more close to the ideal reference point as it is almost steady with little variation during the cardiac cycle and has less medically relevant points. In comparison with WCT, NCT average relative percentage to lead II is 2.76% with standard deviation 3.68%, while WCT relative percentage to lead II has a mean value of 48.31% with a standard deviation 25.67%.

Table 1: Summary of measurement results. WCT and NCT relative amplitudes to lead II

Patient ID	Age	Gender	WCT amplitude as % of lead II	NCT amplitude as % of lead II	NCT medically irrelevant points decrease percentage
P001	63	F	27	1	-0.06
P002	51	F	40	2	-0.04
P003	65	F	35	5	-0.26
P005	88	F	90	12	-0.24
P006	52	F	90	3	-0.19
P007	70	F	59	3	-0.20
P010	71	F	23	0	-0.06
P012	89	F	25	1	-0.20
P013	63	F	23	1	0.00
P014	70	F	41	3	-0.08
P016	70	F	65	1	-0.15
P018	59	M	100	7	-0.05
P019	68	M	33	0	-0.11
P020	79	M	65	1	-0.18
P021	55	M	50	1	-0.30
P022	71	M	40	1	0.00
P023	52	M	60	0	-0.09
P024	45	M	20	0	-0.01
P025	79	M	50	5	-0.29
P026	85	M	22	0	-0.01
P027	52	M	30	1	-0.15
P028	62	M	41	5	-0.48
P033	78	M	57	1	-0.25
P034	73	M	100	13	-0.35
P037	72	M	25	0	-0.02
P038	56	M	48	0	0.00
P039	60	M	20	1	-0.34
P040	65	M	27	1	-0.01
P042	53	M	95	11	-0.09
Average	66.07		48.31	2.76	-0.14
			Polarity distribution		N: 6.9%; Negative: 24.1%
Total:	29		38% Females		

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