ON THE EQUIVALENCE OF THE 12-LEAD ECG AND THE VCG REPRESENTATIONS OF THE CARDIAC ELECTRICAL ACTIVITY

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Abstract

The electrocardiography (ECG) and vectocardiography (VCG) both describe the same phenomena: the temporal changes of the surface potentials resulting from cardiac electrical field. The ECG uses 12 leads positioned as it was found optimal from the medical point of view during a hundred years of practice. The VCG uses 3 channels connected to the psuedoorthogonal leads that placement is determined by the orthogonality of main Cartesian axes - in consequence a three-dimensional recording is performed. This paper is devoted to the experimental verification of the likeness of the data provided by both recording techniques. Two different transforms re-mapping the ECG to the VCG domain and vice-versa were studied with use of the set of 125 simultaneous ECG and VCG signals from the CSE Multilead Database. One of the possible technical interests of transforming the ECG signals to the VCG domain is reducing the data volume thanks to eliminating the information redundancy typical for ECG. Our results demonstrate that the forward and inverse transform has no perfect reconstruction property and some extent of distortion should be considered when applying this technique to the signal compression.

1. Introduction

The identity of expressed phenomena justifies the expectation of an informative equivalence of the representation of cardiac electrical activity in the ECG and in the VCG. Sophisticated techniques, like Karhunen-Loeve Transform-based decorrelation, has been proposed to eliminate the high redundancy of information in a typical 12-lead recording [Cetin 1993]. The aim of our research was to investigate the possibility of building an efficient compression method, dedicated to the ECG signals, on a base of the reversible ECG ↔ VCG transform. The existence of such transform, the various aspects of reversibility and distortions in processed signal is the main topic of this paper.

Several attempts have been made to establish a transformation of VCG to the ECG domain and vice-versa. Two of them: Dower Transform (DT) [Dower 1980] and Levkov Transform (LT) [Levkov 1987], although based on different theoretical background, are recently clinically accepted and commonly believed to be "lossless". This feature is highly important when applying spatial VCG methods, including the optimal loop superposition [Fayn 1990], to the data recorded with use of a conventional 12-lead system. On the other hand, the equivalence of information justifies the involvement of all the medical experience, gathered mainly for interpretation of 12-lead recordings, in analysis of vectocardiograms. Both transform were initially verified by their authors with use of limited custom-completed data sets, and high correlation of medical findings was interpreted as a sufficient condition for the data equivalence.

This approach is no longer valid when the VCG is considered as an alternative archive format for the storage of standard 12-lead recordings. In general, for this purpose full retrieval capability is expected in the meaning of the identity of original and de-archivized signals. The only reported complete research on the equivalence of the ECG and VCG representations was carried out at the Lyon INSERM-121 Laboratory. In that study the Dower Transform was considered and the VCG-based synthesized electrocardiogram was compared to the original 12-lead traces recorded simultaneously. Our work may be seen as extension of the Lyon research, and similarly we used the CSE-Multilead Database [Willems 1988] as a well-established worldwide standard of simultaneous VCG and ECG recordings. In our experiment the forward and inverse Dower Transform (DT, IDT) and the forward and inverse Levkov Transform (LT, ILT) were considered for testing. Moreover we tested superposition of these transforms that we found interesting aiming at the compression of electrocardiograms.

2. Materials and methods

In our research, the source of test signals was the CSE-Multilead Database (data set 3) providing a set of 125 recordings containing simultaneous 12-lead ECG + XYZ VCG accompanied with P-QRS-T segmentation points. The amplitude resolution is 12 bits and sampling frequency is 500 Hz. From each file the segment containing data for one heart evolution was extracted accordingly to the start- and endpoint from the database.
All parts of the numerical experiment including transformations and error assessment procedures were implemented in Matlab. Transformations are programmed following the published materials (figure 1). The only exception was the ILT not originally published. The implementation of the ILT was thus based on the pseudo-inverted Levkov matrix and uses the same computation rules as the IDT [Edelbrandt 1988].

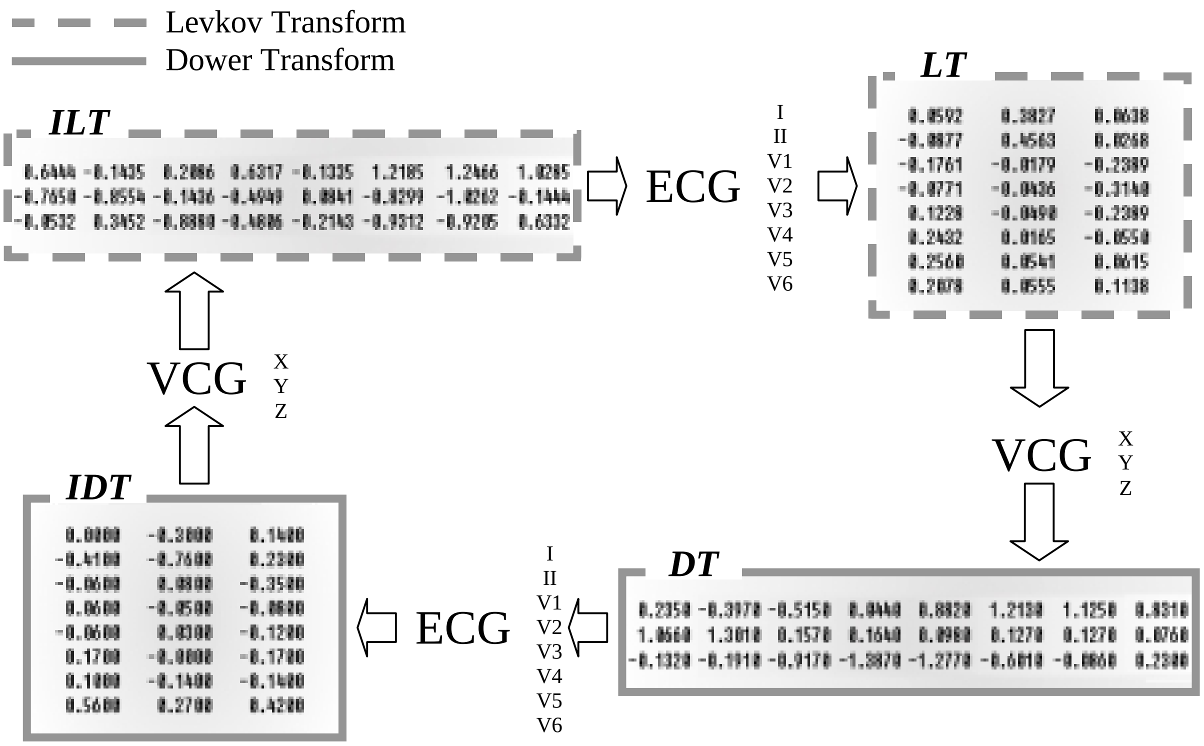

Figure 1. The circle of ECG ↔ VCG re-mapping methods

The content of the CSE-Multilead Database allows testing of the VCG → ECG transformation with the 12-lead reference and the ECG → VCG transformation with the XYZ reference. Within the confines of our research we tested the following procedures:

- DT (VCG → ECG) with the simultaneous ECG trace as a reference,
- IDT (ECG → VCG) with the simultaneous VCG trace as a reference,
- LT (ECG → VCG) with the simultaneous VCG trace as a reference,
- ILT (VCG → ECG) with the simultaneous ECG trace as a reference.

Since the idea of compression for ECG signals with use of the reversible ECG ↔ VCG transform involves the superposition of two transforms, additional tests were carried out for the following processing schemes:

- e' = DT [IDT (e)] (ECG → VCG → ECG) with autoreference to the original signal,
- e' = ILT [LT (e)] (ECG → VCG → ECG) with autoreference to the original signal,
- e' = DT [LT (e)] (ECG → VCG → ECG) with autoreference to the original signal.

The measure of dissimilarity between the transformed signal and its reference was computed as Percent Root-mean-square Difference (PRD) (1). Although this measure does not reflect the variability of importance of particular ECG sections and is contested as a reliable distortion estimate, it is widely used and applied here for the reason of compatibility.

$$PRD = \left\{ \frac{\sum_{i=1}^{n} \left[x_1(i) - x_2(i) \right]^2}{\sum_{i=1}^{n} \left[x_1(i) \right]^2} \right\}^{\frac{1}{2}} \cdot 100\% \qquad (1)$$

3. Results

All results of the numerical experiment are presented as statistically processed data gathered over a whole set of 125 test signals of various morphologies in all available channels. The obtained values (mean value and standard deviation) are summarized in the Table 1.

transform	ECG-leads												VCG-leads		
	I	**II**	**III**	**aVR**	**aVL**	**aVF**	**V1**	**V2**	**V3**	**V4**	**V5**	**V6**	**X**	**Y**	**Z**
	mean value of PRD distortion [%]														
DT	8.10	6.02	9.82	5.54	30.8	8.21	7.37	7.52	7.32	5.59	5.06	5.58			
IDT													4.42	5.92	7.70
LT													3.29	5.88	5.64
ILT	15.9	7.25	12.2	10.2	16.8	8.52	12.9	10.2	12.0	6.69	12.5	9.19			
DT (IDT)	8.63	2.43	5.59	5.51	31.7	2.58	6.18	2.84	2.84	3.19	3.24	4.67			
ILT (LT)	13.9	5.73	8.76	9.40	13.7	5.04	10.4	10.1	11.7	6.10	11.9	5.21			
DT (LT)	7.62	4.10	6.87	5.31	31.9	4.79	5.66	5.89	5.24	4.28	3.65	3.25			
	standard deviation of PRD distortion														
DT	4.44	5.57	7.95	3.42	18.4	8.05	4.02	4.57	4.81	3.21	4.34	4.32			
IDT													3.71	4.73	5.46
LT													1.94	4.57	3.04
ILT	9.40	5.46	7.06	7.21	9.64	6.23	7.44	3.25	2.60	5.24	8.92	7.76			
DT (IDT)	4.78	1.74	3.25	3.41	19.4	2.17	3.84	1.56	1.66	1.89	2.26	2.70			
ILT (LT)	8.14	4.43	4.12	6.53	7.60	2.16	4.81	2.52	2.27	4.50	8.39	3.83			
DT (LT)	3.79	2.23	4.55	3.28	19.0	2.92	2.95	2.29	3.18	2.73	2.63	1.75			

Table 1. The results of numerical experiment

The examples of differences between the synthesized signals and their simultaneously recorded counterparts for the CSE file no. mo-001 are summarized in the Figure 2.

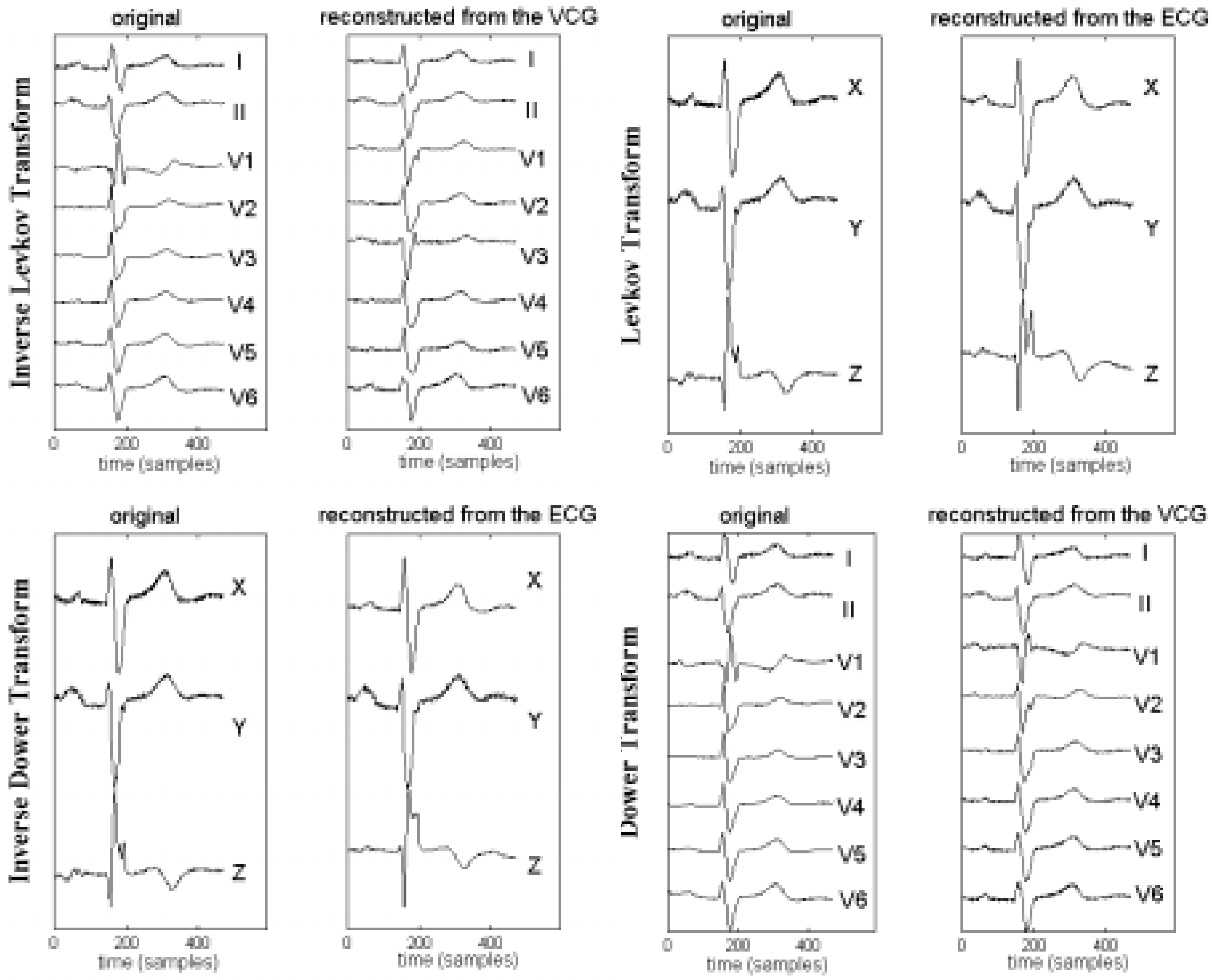

Figure 2. Differences between the reconstructed signals and their simultaneously recorded counterparts for the CSE file no. mo-001

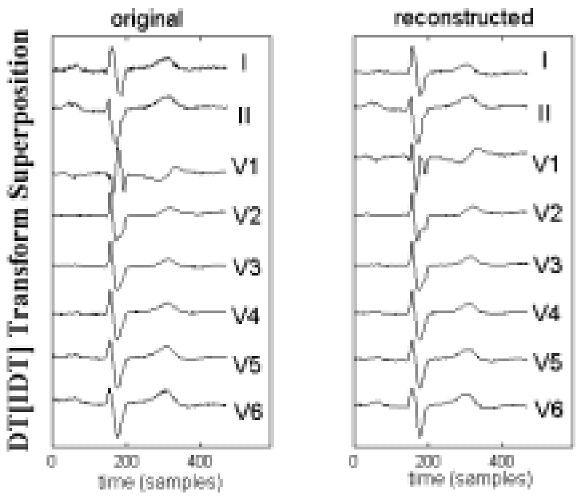

Figure 3. Differences between the signals issued by the DT[IDT] transform superposition and their original versions for the CSE file no. mo-001

Figure 3 gives an example of the ECG signals issued by the superposition of the DT and IDT. This version has been selected for its relatively low distortion level. Significant signal changes, however, may be easy noticed in particular in the first two chest traces V1 and V2.

4. Discussion

Both transforms (i. e. Dower Transform and Levkov Transform) are reported by their authors as “lossless” in the meaning of close similarity of medical results only. However from the signal analyst aspect, synthesized electrocardiograms are expected to be in 10.08 % distorted, while synthesized vectocardiograms in 6.347 % respectively.
Although the origin of electrocardiograms and vectocardiograms is the same as long as recorded simultaneously, effectively recorded signals contain many interference of extra-cardiac origin. These additional signals are to some extend dependant on electrodes positioning, so the reciprocal equivalence of electrocardiograms and vectocardiograms may be affected. The statistical study of distribution performed on the differential components may be an interesting issue for the future work and may result in the unambiguous identification of the source of differences. Another interesting issue may be a comparative study of diagnostic parameters such as P-Q interval, Q-T interval and so forth, performed for the original reference signals and their processed counterparts.
The results obtained for reversibility of ECG ↔ VCG transforms are not promising for the lossless compression, a lossy compression however, allowing some extend of distortions probably not very important from the medical point of view, is still possible. The expected compression ratio of 4 is competitive among of other lossy compression methods, and the simplicity of ECG ↔ VCG transform added to its medical advantages may be an important virtue for a real world microcontroller-based recorder implementation.

5. Acknowledgement

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