New Computer Program for detecting 12 Lead ECG Misplacement using a 3D Kinect Camera

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Abstract

The accurate electrode positions are required by our cardiac isochrones positioning system. Therefore we developed a KINECT camera based system to localize the electrodes.

The KINECT camera was used to take 3D images of the torso of five male subjects with ECG electrodes attached. Our software transformed the 3D quantitative image into a subject specific electrode torso model. These torso models were scaled to obtain an objective standard for electrode misplacement.

New KINECT camera computer software automatically and rapidly detected misplacement of 12-lead ECGs electrodes. An increased database is needed to calculate the sensitivity and specificity of distances and angles to determine accurately misplaced leads.

1. Introduction

Our 12 lead ECG based Cardiac Isochrones Positioning System (CIPS) requires the exact electrode positions on the torso to localize accurately the origin of the PVC, VT and delta waves [1]. However, in the EP lab the electrodes are frequently not placed in the standard 12 lead ECG positions due to the other attached system's patches. Consequently, we developed 3D KINECT camera software that could automatically detect electrode misplacement and possibly we could create programs to correct for these misplacements.

The 3D quantitative image data was used to reconstruct subject specific torso geometry. To be able to compare electrode misplacement among the subjects, the torso models were scaled to a standard height, assuming the ribcage scales linearly with torso height. The triangulated torso geometry was additionally used to correct the ECG signals from the misplaced electrodes.

2. Methods

For this study software was developed using the Microsoft Kinect SDK version 1.7. This software retrieves the data from the Kinect camera [2] and processes the data to obtain subject specific torso models.

Measurement setup

To test the ability to detect electrode misplacement from 3D image derived torso models, five subjects were included in this study. On each subject the 12 lead electrodes were positioned accurately by an experienced technician. Additionally the precordial electrodes were positioned one intercostal space higher and one intercostal space lower (see figure 1). Extremity electrode positions were unaltered during the ECG recording. For each configuration the ECG was recorded while the subject maintained a supine position (figure 2).

Table 1 Calibration of the KINECT measurement: The chest circumference directly measured was compared with the KINECT measurements. The circumference was measured at the height of 4th intercostal space and from the reconstructed torso model at approximately the same height. Note their similarity.

subject	**age (years)**	**chest circumference (cm)** *measured*	***Kinect***	**height (cm)**
KP001	65	108	110	188
KP002	54	107	110	186
KP003	21	87	91	173
KP004	41	84	91	177
KP005	42	85	90	192

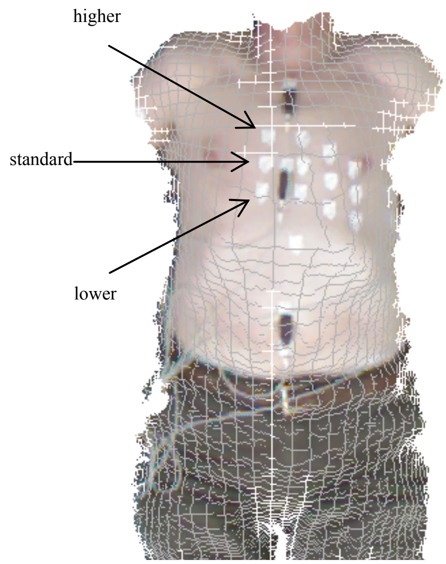

Figure 1. Left panel: the 3D image as taken with the Kinect camera. Clearly visible are the electrodes of V1-V4 at the standard positions and one intercostal space below and above.

In Figure 1 is the 3D image of a subject recorded in the Antero-posterior position with the attached electrodes. Therefore the accuracy of the V_5 and V_6 electrodes could not be determined.

Torso model construction to detect electrode misplacement

In order to make 3D computer models triangles are used to describe the surface of the human torso. To detect the misplacement of the electrodes a common reference point must be created. This requires the definition of a reference point. For the reference model the z-coordinate of the reference point was defined at ¼ of the height of the torso model (figure 3B). The height of the torso was taken as the distance between the shoulders and the crotch. The center of the horizontal plane at the middle of the torso resulted in the x-coordinate and y-coordinate of the reference point. All subsequent torso models were scaled to match the height of the common reference model. The distance in the z direction with respect to the reference point was used to detect the misplacement of leads.

Method for ECG Lead correction

Three common electrode misplacements configurations were used to reconstruct the ECG signals at the standard positions:

1) $V_{1,2}$ higher, V_3 standard, and $V_{4\text{-}6}$ lower
2) $V_{1,2}$ and V_6 standard, and $V_{3\text{-}5}$ higher
3) $V_{1\text{-}3}$ higher, and $V_{4\text{-}6}$ standard

The ECGs recorded at these misplaced electrode positions were used to reconstruct the ECGs at the standard positions with a surface laplacian based interpolation method [3].

The differences between reconstructed and recorded 12 lead ECG data were quantified using the relative difference (*rd)* measure: the root mean square value of all matrix elements involved relative to those of the recorded ECG data.

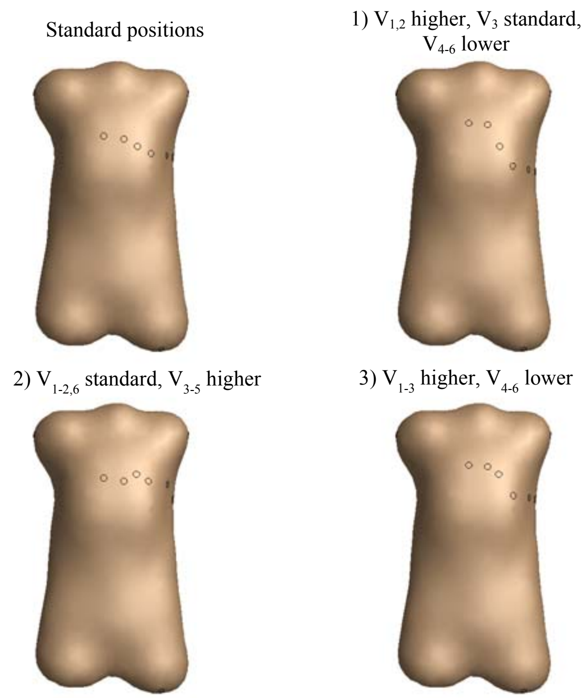

Figure 2. Torso models with electrodes: The standard 12 lead ECG positions and the three misplaced electrode configurations 1), 2), and 3).

3. Results

As seen in table 1, the KINECT torso models derived chest circumferences had a close calibration to the measured chest circumferences.

The distance between the standard electrodes and the electrodes placed one intercostal space above was 43 ± 3.5 mm and 42 ± 3.5 mm for the electrodes below.

Table 2. Correction of misplaced electrode ECGs: Relative difference (rd) before and after correction of the ECG signals. See Figure 2 for the used lead misplacement configurations. A rd of 0.2 corresponds to a correlation coefficient of more than 98%.

	1		**2**		**3**	
	before	*after*	*before*	*after*	*before*	*after*
KP001	0.37	0.44	0.22	0.20	0.28	0.47
KP002	0.24	0.27	0.34	0.34	0.21	0.26
KP003	0.23	0.26	0.20	0.09	0.24	0.19
KP004	0.23	0.27	0.20	0.13	0.24	0.22
KP005	0.41	0.26	0.39	0.24	0.36	0.15

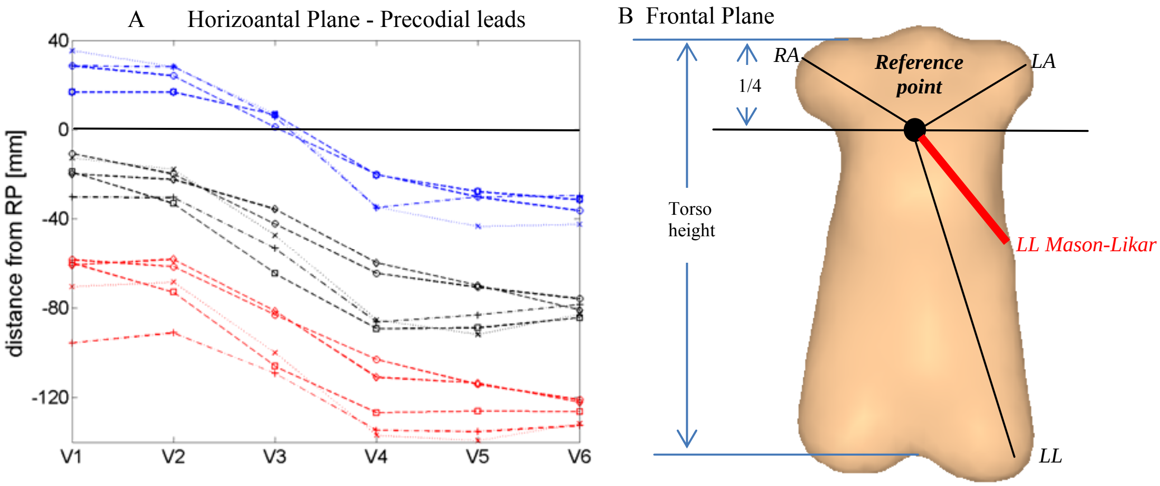

Figure 3. Left panel: the scaled height of the electrodes of the precordial leads with respect to the reference point of all 5 subjects. In **black** the electrodes at the standard positions, in **blue** electrodes were shifted one intercostal space up and in **red** one intercostal space lower. Right panel: extremity leads shown in the frontal plane (**black**). The **red** line indicates the location of the LL electrode in the Mason-Likar position, which can easily be detected as misplaced.

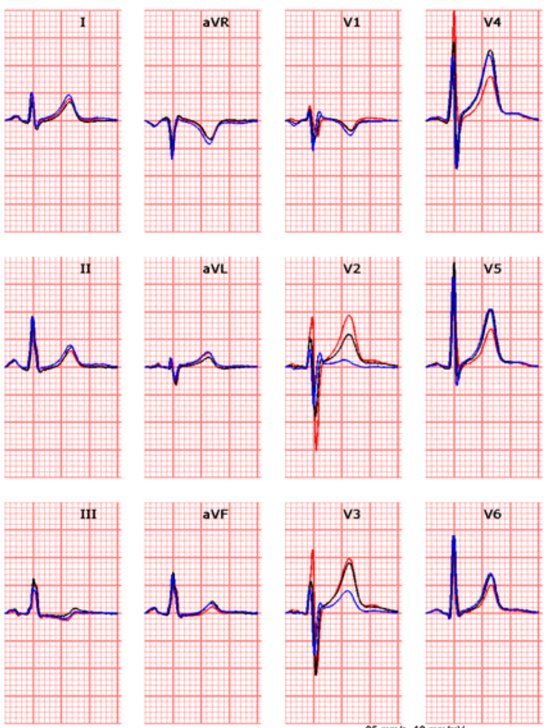

Figure 4. Precordial electrodes one intercostal space higher and lower: The standard 12 lead ECG of case 4 (**black**) one intercostal space higher (**blue**) and one intercostal space lower (**red**). Note: the major differences in $V_{1\text{-}4}$ that need to be corrected.

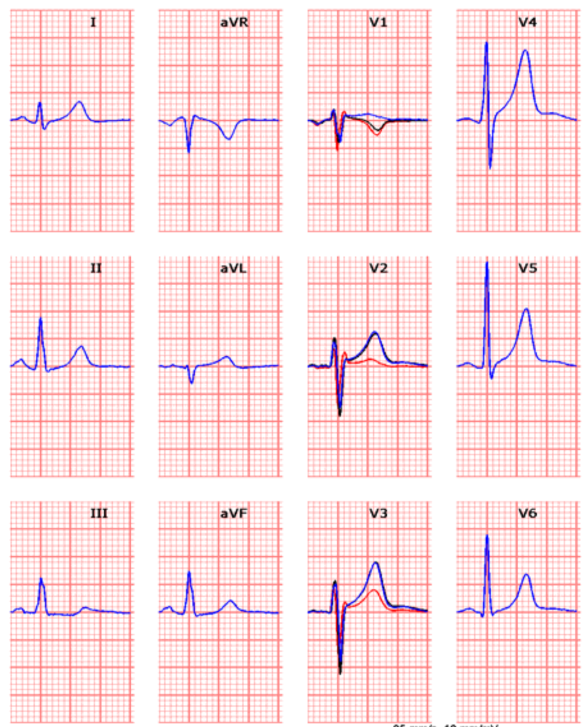

Figure 5. Misplaced Lead Reconstruction: standard 12 lead ECG of case 5 (black), misplaced electrode positions (red), and reconstructed ECG at the standard positions (blue). Note; V_2 and V_3 were completely reconstructed whereas V_1 was not.

As shown in Figure 3A, the electrodes placed one intercostal space above or below were calculated by the program to be significantly misplaced using the distance from leads V_1-V_6 to the reference point ($P \leq 0.01$).

The standard 12 lead ECGs were reconstructed from the 3 different misplaced lead configurations (figure 2). In table 2 the relative differences (*rd*) are listed for all subjects and the 3 different lead configurations. In five cases the *rd* increases, in all other cases the *rd* did improve. Only in 4 cases the *rd* was below 0.2, a value that corresponds to a correlation coefficient of more than 98%. Especially for lead configuration 1 the interpolation failed to reconstruct the standard 12 lead ECG accurately. An example of the reconstruction of the ECG at the standard positions from the third misplaced lead configuration is shown in figure 4. The correction by interpolation works well for misplaced lead V2 and V3, but fails to correct V1.

4. Discussion

The KINECT camera is an appropriate tool to obtain the torso geometry including the electrode positions on the chest wall. Thus this tool enables the patient specific torso reconstruction in the EP laboratory, a requirement for the accurate localization of PVCs by the Cardiac Isochrones Positioning System [1].

The results of this limited feasibility study also show the ability to detect electrode misplacement by using the visual information recorded by a 3D camera. The precordial electrodes located approximately 4 cm from the standard positions could be significantly classified as misplaced (figure 3). An increased database is needed to calculate the sensitivity and specificity of distances and angles to determine accurately misplaced leads.

The major underlying assumption in the Torso Model is that the height of the ribcage, and consequently the standard precordial electrode positions scales linearly with the torso length. This assumption is adequate to detect the electrode misplacement. Furthermore, other landmarks of the torso, such as the angle of Louis or the xyphoid, might be mathematically derived from these models as well.

Correct electrode placement of the 12 lead ECG is critical for correct computerized ECG diagnoses systems. The likelihood of misplacement could be incorporated in computerized ECG analysis algorithms, thus increasing the sensitivity and specificity of the applied ECG diagnosis algorithms. As shown in Figure 3B, the detection of the LL electrode in the Mason-Likar position between the mid-left lower ribcage and the iliac crest. This position could be converted by a program to the standard position on the left leg.

This lead misplacement algorithm could also be applied in ambulances with equipment that transmit the acquired ECG's digitally to a hospital for on-line consulting and diagnosis. In a significant percentage of the patients suffering from acute coronary syndrome the diagnosis based on the transmitted ECG's is incorrect [4]. This might result in the transportation of these patients to a hospital where a percutaneous coronary intervention (PCI) procedure cannot be performed. Using the KINECT camera to detect electrode misplacement and the creation of a program to correct the diagnosis could reduce the number of patients transported to the wrong facility.

As a first experiment, the geometrical information of the torso was used to correct the standard 12 lead ECG from the recorded misplaced ECG signals. In figure 4 is demonstrated the leads that need to be corrected are $V_{1\text{-}4}$. In figure 5 is shown that the correction method proposed by Oostendorp et al. [3] corrected $V_{2\text{-}3}$, but not V_1. As shown in Table 2 the electrode configuration with $V_{1,2}$ too high, V_3 standard, and $V_{4\text{-}6}$ too low produced a reduced match for 4 out of the five subjects. Further research must be performed to create new computer models to detect these misplaced electrodes. This new technique presented in this study has created a new tool to improve the diagnostic accuracy of the standard 12 lead ECG.

5. Conclusion

New KINECT camera computer software could automatically and rapidly detect misplacement of 12-lead ECGs recording in the EP lab and other locations and thereby increase the accuracy of the 12 lead ECG. A greater database is needed to calculate the sensitivity and specificity of the required measures to determine accurately misplaced leads.

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References

[1] van Dam PM, Tung R, Shivkumar K, Laks M. Quantitative localization of premature ventricular contractions using myocardial activation ECGI from the standard 12-lead electrocardiogram. Journal of Electrocardiography 2013, in press.

[2] Han J, Shao L, Xu D, Shotton J. Enhanced computer vision, microsoft kinect sensor: a review. IEEE Transactions on Systems, Man and Cybernetics, Part B, in press, 2013

[3] Oostendorp TF, van Oosterom A, Huiskamp G. Interpolation on a triangulated 3D surface. J Comput Phys 1989;80(2):331-43.

[4] Mahmoud KD, Gu YL, Nijsten MW, de Vos R, Nieuwland W, Zijlstra F, et al. Interhospital transfer due to failed prehospital diagnosis for primary percutaneous coronary intervention: an observational study on incidence, predictors, and clinical impact. European Heart Journal: Acute Cardiovascular Care 2013;2(2):166-75.

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