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Guided ECG sensor placement using a RGB-D camera

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Abstract. One of the fields in which human-machine interaction is more and more relevant is medicine, especially because, in this area, a specialized digital system has better chances of detecting illnesses, injuries or other significant aspects, than human perception. This paper proposes an experimental solution, designed to help guide electrocardiography (ECG) sensor placement on a patient. At the core of the solution is a Microsoft Kinect camera, providing both color and depth information that is used for generating a cyber representation of the patient's skeleton. Electrode placement locations are calculated and then overlaid on an RGB image, so the user has real-time feedback for correctly placing the sensors. The purpose of this solution is to contribute to the process of assistive ECG measurements, enabling home treated patients, students and doctors to experiment guided measurements procedures without the need of specialized medical assistance or second opinion confirmation.

Keywords: eHealth, Kinect, heart activity, ECG, human-machine interaction.

1. Introduction

Health is the most important element in our lives and we ought to appreciate it greatly. Although medical technology has evolved at a staggering pace in recent decades, human error is still the leading factor in misdiagnosing health problems and injuries, resulting in further medical expenses and even death. The most common errors that occur in the area of medical ECG measurements are: reversing hand or foot sensors, positioning sensors on the patient in an incorrect position (caused by body proportions) or reversing their order.

The purpose of this paper is to propose a solution that helps patients and doctors to detect or monitor various cardiovascular problems.

Usually, home treated patients with special health problems need to monitor the heart activity before or after medication and report the values to their doctors. The pulse measurements are easy to monitor and there are many affordable electronic devices that are already offering precise measurements. In the case of ECG, such measurements are usually performed by doctors and very rarely by patients because of the sensor placement logic. A patient can learn to set the ECG sensors by himself or with the help of an assistant and send the results to the doctor for interpretation.

For learning students and early practitioners, a tool that can guide and correct them in the process of placing the sensors has the capacity to speed up the learning time and offer real-time reliable feedback.

For clinics and hospitals where the personnel is responsible for tens of measurements per day, the human error represents a common mistake that causes double or triple measurements for the same case. The non invasive system can be mounted on top the ECG measuring table and it will serve only as guidance without interfering with other medical procedures.

The presented contribution describes the ECG technique (Section 2), together with a brief review of the state of the art (Section 3); the system logic and operating conditions are provided in Section 4, while the experiments and results are delivered in Section 5; the paper ends with conclusions and future work (Section 6).

2 The ECG Technique

One of the best techniques for obtaining health-related patient data, without leading to a personal space intrusion, is the ECG, a technique used to record the electrical activity of the heart muscle fibers. Each contraction of the myocardium is the result of an electrical excitation, originating from the sinus node and transmitted to the muscles of the heart.

The ECG technique is more than one and a half centuries old, being discovered by Alexander Muirhead, an electronic engineer, in 1866-1870. Many people developed this technique further reaching the current state as result. The one that realized and published the results of an ECG is Willem Einthoven; he placed the patients in salt baths in order to have better electrical conduction (Barold et al., 2003). More important is that there are no risks associated with conducting the electrocardiogram (Mäntynen et al., 2014).

The ECG can help doctors to detect evidence of increased volume of the heart, signs of insufficient blood flow to the heart, of new or old heart injury (infarcts), heart rhythm problems (arrhythmias), changes in electrical activity caused by an electrolyte imbalance, or signs of inflammation of the sac around the heart (pericarditis). However, an ECG does not predict a myocardial infarction; it can only be used to prevent it and to determine whether there has been a history of myocardial infarction (LaPierre et al., 2012).

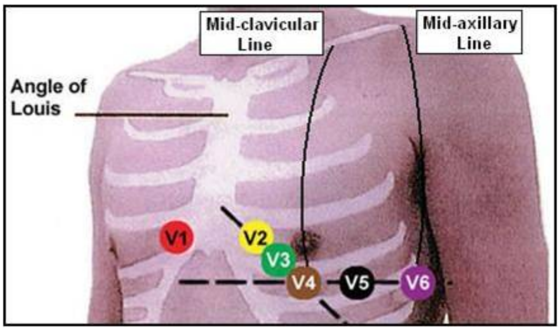

Figure 1: V1-V6 electrodes position on the body (MedSchoolJournal et al.,2010)

The heart activity can be detected at the skin level by placing metallic plates (electrodes) on the body. These electrodes are attached to the skin at the torso level (V1-V6), and also at the limbs level (RA, LA, RL and LL), as shown in Figure 1. The electrodes are connected to a device that converts electrical impulses into a graphical representation (see Figure 2), interpretable by a doctor.

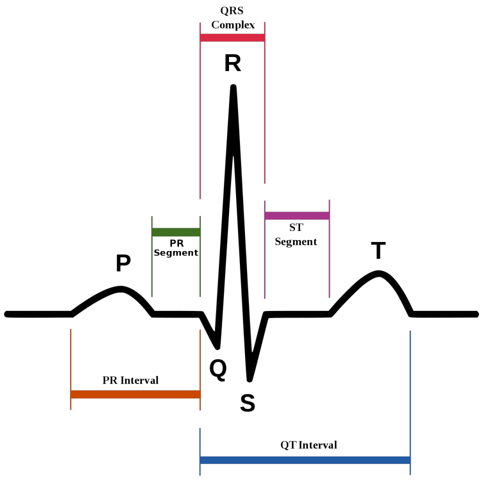

Figure 2: Graphical representation of the electrical impulses of the heart (*Electrocardiography* et al., n.d.)

The position of the ECG sensors on a patient's body is a very important factor, because it directly affects the test results. If not placed properly, it can lead to misdiagnosis or failure to detect heart disease. Thus, the electrodes should be placed as follows:

- two at the hand extremities, anywhere between wrist and shoulders;
- two at the feet extremities, anywhere between ankles and basin;
- the other six on the chest:
  - V1 is placed at the 4th intercostal space from the right side of the Angle of Louis
  - V2 is placed at the 4th intercostal space from the left side of the Angle of Louis
  - V3 is placed in the left side, half the distance between V2 and V4;
  - V4 is placed at the 5th intercostal space, on the midclavicular line;
  - V5 is placed on the same horizontal line as V4, on the left side of the midaxillary line;
  - V6 is placed on the same horizontal line as V4 and V5, on the left side, in the middle of midaxillary line;

During the ECG, the patient sits on a table or on a bed. The areas on the chest, hands and legs where the electrodes are placed will first be cleaned, so that the contact between the electrodes and the skin is optimal. In addition, a special gel or small tampons soaked in sanitary alcohol may be placed, to improve electrical impulse control.

Current research efforts are focused on developing wireless devices that have a wide range of applications in medical services, military rescue missions, cardiovascular monitoring at home, especially for elderly people, but also methods to improve the accuracy of the apparatus and to develop devices that are cheaper than the ones on the market (Mukala et al., 2010).

3. Related work

3.1 Real Time Extraction of Body Soft Biometric from 3D Videos

(Velardo et al., 2011) describes the usage of a Kinect camera to obtain anthropometric information of a person, such as height, weight and gender. The anthropometric information is obtained from a series of soft biometrics, measured by the RGB-D camera. Soft biometrics are traits used to classify people, grouping them on certain physical characteristics. Using such characteristics, human bodies can be classified according to three main phenotypes: Ectomorph, Endomorph and Mesomorph. The information can be used during the recognition process of missing people or crime investigation cases.

By taking advantage of 3D coordinate information, the Kinect sensor is able to calculate the distance between the head and the feet of the user, resulting in his height. Weight information is obtained by combining the capabilities of the Kinect sensor with a series of anthropometric measures, later applied to the system body mass estimator. As for the gender information of a person, the researchers trained a Neural Network using the same anthropometric measures exploited in the weight calculation. In the demo presentation, researchers mentioned a few fields in which this application could be used: medicine, gaming industry and in automatic demographic data collection, which has multiple applications.

Obtaining the most relevant anthropometric data is shown to be a challenge, as the person that is being measured, needs to be positioned in a specific way in front of the camera, to ensure that the extracted information is valid.

3.2 Estimating human motion through multiple Kinect Sensors

Human motion estimation is an active field of research, where important contributions have been made during the last decade. In (Chatzitofis et al., 2013), three Kinect sensors were used to estimate the motion of an individual and replicate it in a virtual environment.

Using more than one Kinect sensor in an integrated setup is a difficult task, due to the difference in estimation generated by each sensor, as well as due to occlusion. To interconnect the three sensors, the solution employed a Fuzzy Logic System which resembled a genetic algorithm; this system estimated the body's joints and limbs position. Twenty to thirty generations were needed to converge to a good result. Noise interference posed a major challenge; this was addressed through the Fuzzy Logic System.

The purpose of the experiments were to replicate the occlusion caused by the objects, as well as self-occlusion. During the experiments, the subject was asked to move on a treadmill and make rotational movements of 45° to his right and to his left. Its motion was recorded with three Kinect devices: one placed in the front of the subject and the other two, on either side. The results were vague, but the sensor with a lower confidence sometimes was estimating better than the one that had a higher probability of being right. As a result, the algorithm converged to a correct position, even though it was needed for the system to restart the algorithm whenever a large body rotation occurred.

3.3 Self-assisted 12-lead ECG Sensor Placement using RGB-D Sensors in Microsoft Kinect

(Ay et al., 2016) proposed a "self-operable solution for placing wearable sensors", that requires little or no medical assistance. Their application use case followed the placing of the wet-gel electrodes of a 12-lead Electrocardiogram (ECG) system. Their solution consisted of a software which identifies a patient's skeletal points through a Microsoft Kinect camera and estimates the locations of the ECG electrodes, with the aim of helping the patient obtain correct ECG measurements, avoiding improper lead placement and reducing costs as specialized medical assistance is no longer required.

Three algorithms were used to calculate ECG sensor locations, based on different skeletal points provided by the Kinect camera. The first algorithm is based on the two shoulder joints and the neck joint. The second algorithm is using the torso and the shoulder joints, while the third algorithm is using an intersection of points of the two diagonal lines (right shoulder to left hip, left shoulder to right hip). The correctness of the proposed algorithms relies mostly on the accuracy of the skeletal point provided by the Kinect sensor.

The researchers tested the accuracy of their first prototype, on a benchmark of approximately 20 human subjects. Firstly, reference images were generated with the sensors placed by a healthcare professional; these were compared to the results obtained after each subject placed the ECG sensors on their own. Out of the 3 proposed algorithms, the last algorithm achieved the best performance, with a precision of ±1.5 cm.

The proposed system is mainly limited by the accuracy of the skeletal points provided by the Kinect camera. Consequently, many factors need to be taken into consideration, such as the height of the Kinect sensor from the floor, the distance of the subject from the Kinect sensor and the angle at which the sensor is oriented toward the patient.

4. Materials and methods

As learned from the related work section, skeletal points can be used in calculations aiming to find where to place the ECG electrodes on the human body. While their research does not detail the exact formulas used, Ay et al. mention that they used shoulder joints, the neck joint, hip joints as well as torso area information. The approach is challenging, as there are multiple factors that need to be taken into account, such as: the distance between the user and the Kinect camera, or from the Kinect camera to the ground, occlusions, the angle at which the Kinect camera is placed, relative to its user and also the relative size of the patient that is using the Kinect camera (obese vs skinny).

Our work differs from (Ay et al., 2016) in the sense that it firstly details the formulas used for calculating the ECG points (hence experiments can be repeated and validated) and also the algorithms developed use a partially different set of skeletal points.

The experimental setup we developed consists of a C# application that uses Microsoft Kinect's SDK for obtaining information defining the skeletal points, in addition to the RGB and depth data flow that can be used in estimating the ECG V1-V6 points. The system setup is simple, composed of a computer with a compatible Microsoft Windows operating system, that has a Microsoft Kinect camera attached and has our application installed.

In order to calculate the V1-V6 coordinates, we firstly conducted some calculus on the joint positions received from Kinect. The distance between 2 joints is represented as the Euclidean distance between the corresponding sets of coordinates:

$$\text{distance(A, B)} = \sqrt{(A.X - B.X)^2 + (A.Y - B.Y)^2}$$

where A and B are the points containing the X and Y coordinates of the joints we want to find the distance between.

During a step by step calibration phase (followed on the native Kinect calibration algorithm), we discovered that by including the Z coordinates represented by the depth dataflow, the estimated distances between joints were varying significantly, hence results were unreliable. Consequently, we decided to not use the depth information in our experiments and proceed only with the X and Y coordinates, obtained from the RGB image that was mapped on the depth matrix.

5. Experiments on ECG point estimations

This section details the experiments conducted in this research.

5.1 Estimation using shoulder and spine coordinate points

In the first experiment, the Kinect reference points used are the two shoulder points and the spine point provided. Using these coordinates, the distance from each of the shoulder joints to the spine point was calculated.

Based on the defined positions of the ECG V1-V6 points (Section 2), the coordinates for V1 and V2 were estimated as follows:

V1.X = Spine.X - distance(Spine, ShoulderRight) / 6

V1.Y = Spine.Y - distance(Spine, ShoulderRight) / 2

V2.X = Spine.X - distance(Spine, ShoulderLeft) / 6

V2.Y = Spine.Y - distance(Spine, ShoulderRight) / 2

As can be observed from the formulas, the Y coordinate is the same for V1 and V2, because they are on the same plane at the 4th intercostal space, the difference being that one of them is on the left side of the Angle of Louis and the other one is on the right side of it (see Figure 1).

The next 4 coordinates are calculated recursively, relative to the previous ECG estimated point (see Table 1).

V3-V6 points calculation - experiment 1	
V3.X = V2.X + 5 V3.Y = V2.Y + 8	V4.X = V3.X + 5 V4.Y = V3.Y + 8
V5.X = V4.X + 4 V5.Y = V4.Y - 4	V6.X =V5.X + 4 V6.Y = V5.Y - 4

Table 1: V3-V6 points calculation for experiment 1

These calculations were made based on the V1-V6 estimated locations (American Heart Association, 2014), while the small deviations were fixed via manual tuning. Figure 3 shows the result of the first experiment, after running the software with the formulas mentioned. The image shows the positioning of the ECG electrodes, as calculated through our algorithm.

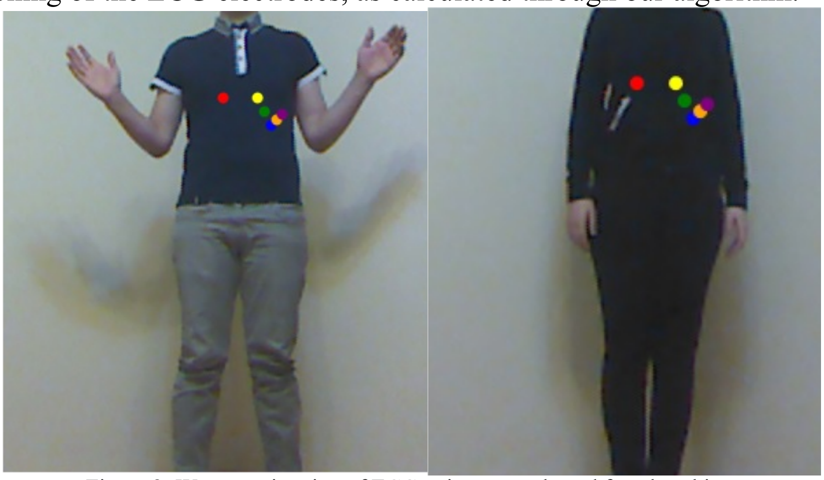

Figure 3: Wrong estimation of ECG points on male and female subject

An unexpected outcome of this experiment is that, in some of the cases (influenced by the user position and distance from the device), the Kinect sensor displays the user in mirror like format (default logic usually used for interactive games), meaning that also the estimated ECG coordinates are displayed reversed (see Figures 3 and 4).

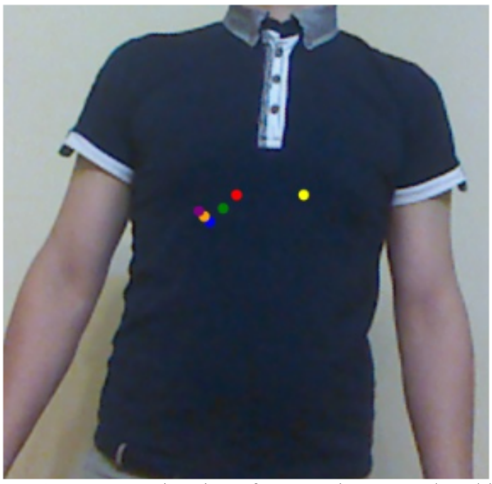
Figure 4: Correct estimation of ECG points on male subject

From this experiment it became apparent that, because of certain factors regarding the positioning of the Kinect device (such as the camera angle and the distance from the ground) and the positioning of the user (his distance to the device), the results are not consistent.

5.2 Estimation using shoulder, spine and hip coordinate points

The second experiment added the hip coordinates to our ECG point calculations, the new formulas being shown in Table 2.

V1-V6 points calculation - experiment 2	
V1.X = Spine.X - distance(HipLeft, ShoulderRight) / 8 V1.Y = Spine.Y - distance(HipLeft, ShoulderRight) / 3	V2.X = Spine.X + distance(HipRight, ShoulderLeft) / 8 V2.Y = Spine.Y - distance(HipLeft, ShoulderRight) / 3
V3.X = V1.X - 8 V3.Y = V1.Y + 10	V4.X = V3.X - 8 V4.Y = V3.Y + 10
V5.X = V4.X - 6 V5.Y = V4.Y + 6	V6.X = V5.X - 8 V6.Y = V5.Y + 8

Table 2: V1-V6 points calculations for experiment 2

The outcome of this experiment (Figure 5) was better than the previous one, because the mirroring problem was solved and after gaining feedback from the doctors, we made more fine tuning for points according to the feedback received from the doctor (author). The current state might need refinements for various body proportions, but it is considered a good starting point for expanding the solution towards including hands and feet sensors.

Figure 5: Estimation of ECG points - experiment 2

6. Conclusions and future work

The objectives for the first version of the solution was to test two or more different reference points that Kinect can provide, in order to develop algorithms and mathematical models that can be used for identifying the proper ECG points to use for sensor placement.

During the development of this early version, the solution was tested on 12 different users and 2 different light conditions. Because both, results and errors, were similar for all conditions, a preliminary conclusion was that before extending the tests to other users the algorithm needs to be in a more stable form.

One of the main outputs from the presented experiments is the multitude of parameters that are influencing the ECG calculation points. The most important factors are represented by the distance between the subject and the sensor and the distance from the sensor to the ground. Elements of setup, such as the inclination angle of the Kinect, also had an impact on the calculations, even though the experiments were conducted using the cartesian coordinates and not the 3D coordinates of the placement points. Since the experiments are using only one camera, occlusion represent the biggest factor that contributes to the real-time feedback and directly influences the skeleton data calculation, of which the system design is highly dependent.

For improving the solution, we aim to implement a visual comparison between multiple algorithms. The comparison will help us assess and understand the adaptability for various body sizes. Also, it is important to add an option for the user to select which one of the points provided by Kinect can serve as a reference point for calculation of the other ECG points, therefore reducing the need for calibration.

In order to bring the current approach closer to the medical environment, an advanced configuration feature will be added. The system will expose the coordinates and calculations to the user, so he can evaluate the information and have the possibility to calibrate it, ensuring that the coordinates provided by Kinect are accurate.

Furthermore, to cover the clinical trial period, a storage module will be integrated, allowing local and cloud storage. This module will provide data history, analytics and statistics capabilities, to the user.

Finally, the current solution covers only the upper torso region, ignoring the hands and feet area. In order to provide the correct guidelines for full body sensor placement, the next step is to build a physical frame attached to a standard size hospital bed. The Kinect sensor will be placed at an optimal distance and then the software will be updated to track other body parts.

Although the Kinect camera is very accessible (price and stock), it has multiple shortcomings (precision, light conditions, low distance problems), that is why, for the next version of the experiment the RGBD camera will be replaced with a Zed 2k camera.

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