A Wireless Wearable ECG Sensor for Long-Term Applications

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Abstract
Electrocardiography (ECG) is an ubiquitous vital sign health monitoring method used in the modern healthcare systems. Different designs of ECG system have been developed as alternatives to the common twelve-lead ECG systems. The recent approaches of the ECG system are focusing on the signal quality, portability and power consumption. In this work, an ECG sensing system is developed with capacitive electrodes that can be implemented on the clothes for long-term monitoring. The two-leads electrodes, contactless to the skin with a interface clothing material between the skin and electrodes, are connected to an ECG system that is responsible for signal processing and transmitting wirelessly to a computer for data acquisition and processing. Experiments are conducted on different types of clothing materials with various body movements introduced for observations. The results of the detected ECG signals are comparable to other ECG sensing system alternatives.

Keywords: Capacitive coupling electrodes, ECG sensors, wearable ECG sensing system

Electrocardiography (ECG) has proven to be among the most useful diagnostic tests in clinical medicine. The ECG is now routine in the evaluation of patients with implanted defibrillators and pacemakers, as well as to detect myocardial injury, ischemia, and the presence of prior infarction. In addition to its usefulness in ischemic coronary disease, the electrocardiogram, in conjunction with ambulatory ECG monitoring, is of particular use in the diagnosis of disorders of the cardiac rhythm and the evaluation of syncope. Other common uses of the ECG include evaluation of metabolic disorders, direct and side effects of pharmacotherapy, and the evaluation of primary and secondary cardiomyopathic processes

In the early days of the ECG, Making the electrodes sensitive enough was a challenge. Then, in the late 1800's, early attempts to measure the electric activity in frog's hearts were successful only when the hearts were exposed directly to the measuring equipment. The measuring conditions were quite difficult. The scientists wanted to be able to measure the electric signals without having to enter inside the body. The problem was that the electric wave got weaker since it had to travel through bone and body tissue before reaching an electrode applied on the skin. This problem was solved a couple of decades later by Willem Einthoven [2]. He managed to improve the sensitivity of the ECG by using a string galvanometer, which represented a great leap forward in electrocardiography.
Einthoven’s improvements were very significant because the now familiar P, Q, R, S, and T waves were apparent. This was in contrast to the work of previous scientists such as Waller who demonstrated only ventricular depolarization and repolarisation. Many different types of ECG systems have been introduced to improve the signal quality and to provide convenience to the patients. The conventional ECG method is often known as wet method because it uses a gel between the skin and the electrodes to increase the conductivity of the signal path. However, the existing wet method uses gels that contain certain metallic material and can irritate the skin of the patients [4]. Some patients may even be allergic to this material, which in turn may affect the diagnosis from the ECG signals.

In order to prevent problem associated with using gel, an alternative has been developed in this work to provide a dry method without relying on the conductive gel that may irritate the patients with allergy. The dry electrode method does not require direct contact with the skin and is suitable for long-term monitoring. Despite the layer of interfacing material between the skin and electrodes, a capacitive coupling is still capable to detect significant signals from the skin potentials.

The interface material can be a thin layer of cloth material such as cotton that is tightly bonded to the skin for an optimal ECG acquisition. Cotton is a common fabric for clothes. In comparison with other materials, such as wool, silk or nylon, cotton has higher dielectric constant, which means better electrical conductivity when the materials are dried. Also, smart textiles are conductive fabrics with embedded electronics and they are becoming a big part of the ECG integration. The development of the smart textiles allows the electrodes to be wearable with appropriate interface conductivity.

The present gel method has several limitations:

- Need gel between the skin and electrodes - makes it uncomfortable for patient - especially in long-term monitoring
- Transfer resistance may change during time due to gel drying
- Needs direct contact with skin - makes it impossible for continuous ECG monitoring because of wires and electrodes
- Causes skin irritation, excoriation and at times impossible in a group of individuals
Restrictive, irritating, bulky

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Problems of present gel(wet) electrodes:

- Need gel between the skin and electrodes - makes it uncomfortable for patient - especially in long-term monitoring
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- Needs direct contact with skin - makes it impossible for continuous ECG monitoring because of wires and electrodes
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Our first Sensor System:

Electrode-body interface.

Comparison of Conventional ECG (top), CC-ECG after signal processing (middle), CC-ECG prior to signal processing (bottom).
Photograph of our designed sensor system

**Our second sensor system:**

Diagram of the ECG sensing system with a photograph of a designed capacitive electrode on the top.
Photograph of a capacitive electrode attached to RA on top of cotton material with portable ECG device (Biometrics DataLog) on the right.

ECG acquisitions in time domain with body movements. Electrodes on moisturized cotton towel by (a) slow abduction of left shoulder, (b) slow walking, (c) body rotation, and (d) fast abduction of left shoulder.
Future work – Smart Material

- Solution: Using Textrodes
  - Flexibility
  - Non-irritating
  - Higher sensitivity (larger effective area)
- Problems
  - High Skin-Electrode Impedance - needs Buffer in first step
  - Impossible to print circuit on top of it - Buffers must be moved to main board or on a clip on the electrode
Words of caution!

- The ethical, legal, and social limitations on medical data mining relate to privacy and security considerations
- Risk of lawsuits
- Balance the expected benefits of research against any inconvenience or possible injury to the patient
- Physician's interpretations are an essential component and indispensable
- Heterogeneity of data sources, data structures, and the pervasiveness of missing values for both technical and social reasons
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References


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**Dr. Tapas Mondal Bio**

Dr. Mondal is primarily a clinician educator devoting the majority of his time to patient care and teaching, working in a very busy tertiary care center in Pediatric Cardiology, McMaster University. Dr. Mondal has been recognized for his outstanding patient care by patients and colleagues. He was awarded the “Best Teacher Award” in 2006 and 2009 by the McMaster Residents. He enjoys teaching students from all learning levels, mentoring students from Health Science students to Fellows.

Dr. Mondal also has a keen interest in research, publishing several journal articles. For the last 2 years he is actively collaborating with others on a wearable wireless ECG monitoring system. He is also acting as a reviewer on a number of journals. Currently Dr. Mondal is working on the concept of easy access training and teaching CPR to lay people in developing countries. He is working on transportation for patients on remote islands in India, the boat ambulance is the first of its kind in the area. In collaboration with the Engineer group at McMaster Dr Mondal is very active developing an inexpensive small wearable and wireless electrode for ECG.