The application of Quantum Tunneling Compound to sleep actigraphy

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ABSTRACT

The purpose of this paper is to describe the application of material constructed from Quantum Tunneling Compound (QTC) to the problem of detecting and recording movement during sleep. We describe the design and implementation of a pressure sensitive mat (PSM) incorporating QTC technology. Furthermore, we describe the neural fuzzy analysis of actigraphic data.

Keywords: Actigraphy, Polysomnography, QTC, Sleep

1 INTRODUCTION

This paper proposes the design of a Pressure Sensitive Mat (PSM) based on Quantum Tunneling Compound (QTC) for the collection of actigraphic data during a sleep study. The incorporation of QTC technology provides a higher level of precision and accuracy when compared with accelerometer or strain sensor technologies. QTC is a material which can be easily integrated into electronic circuits in order to provide pressure sensing capabilities. An increase in the precision and accuracy of detection and recording of movement during sleep is important since such measurements increase the value of sleep studies and thus cause a decrease in false negatives when testing for sleep disorders. The PSM system would support the diagnosis of three specific sleep disorders which include Obstructive Sleep Apnea Syndrome (OSAS), Periodic Limb Movement Syndrome (PLMS), and Restless Leg Syndrome (RLS).

The term 'sleep apnea' refers to a sleep disorder in which "oxygen desaturation and carbon dioxide retention" occur during sleep, activating the sympathetic nervous system and disturbing sleep[1]. The resulting sleep disturbance leads to many health problems such as daytime hypertension[1], anxiety, depression, structural alterations in the brain[2] as well as safety problems such as increased risk of vehicle accidents[3].

PLMS refers to a sleep disorder in which the patient is unable to resist limb movement when at rest. The uncontrolled limb movement makes it difficult to get a good nights sleep and increases the probability of developing insomnia, anxiety, and depression[4]. Similar to PLMS, RLS is a sleep disorder in which the patient is unable to resist random leg movements at all times.

Actigraphy is defined as the measurement of movement. Most actigraphs in use today are wrist actigraphs[5]. Additionally, bed actigraphy[6] has been validated as a non-constraining actigraphic method. Wrist actigraphy is performed using an accelerometer based, watch-like device[5] which is attached to the patients wrist or ankle. Wrist actigraphs are mildly constraining and patients, especially infants, may find it difficult to sleep with the device. Bed actigraphy involves placing the bed on strain pressure sensors and calculating changes in bed pressure over time. While non constraining, current bed actigraphy methods only identify the difference between wake and sleep[6] whereas the proposed PSM system will identify positioning on the bed in addition to detecting and recording movement.

2 PSM Description

This section describes QTC material and its implementation for PSM in sleep actigraphy.

2.1 QTC

QTC is a special type of electrically conductive material with pressure sensing capabilities. The electrically conductive material is composed of nano-sized metal particles with irregular spiked surfaces insulated by a silicone rubber[7]. This combination creates a special material that becomes more conductive when pressure is applied.

The term quantum tunneling originates from the fact that electrons can in some cases be described as waves and that there is a finite probability that an electron is able to tunnel through a normally forbidden barrier. In the case of QTC, electrons must tunnel through the isolating silicone rubber in order to reach a neighboring conductive particle. In practice, QTC is used as a variable resistor between two potential voltages. By measuring the impedance of the circuit it is possible to determine how much force is being applied to the material. Also, because there is no activating pressure required, the full voltage range is available to be utilized.

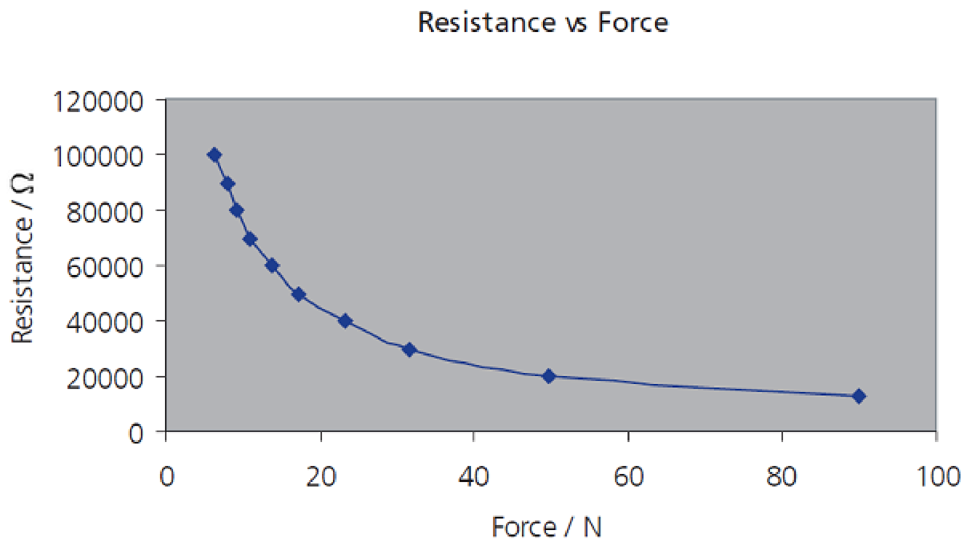

Figure 1. The impedance caused by applying force[8]

2.2 Implementation of QTC

The construction of the QTC sheet consists of three layers: a charged conductive layer, the QTC material and a wire grid. A voltage defined as V_{in} is applied to the charged conductive layer and HIGH-Z is applied to the wire grid. A weighted graph can then be created by analyzing the voltage at intersection points across the wire grid.

The wire grid allows the measure of the voltage level at a point defined by the intersection of vertical and horizontal wires. This is accomplished using switches on both the vertical and horizontal wires in order to allow only 1 circuit pathway at a time.This pathway passes through an op-amp circuit which produces an output voltage inversely proportional to the resistance[9] as represented by the following equation:

$$V_{out} = -V_T \times \frac{R_F}{R_S} \tag{1}$$

The advantage of using an op-amp circuit is that it produces a linear change in the output voltage. An analog to digital converter uses V_{ref} in order to output an 8bit value describing V_{out} in relation to V_{ref} at the intersection point. Figure 2 illustrates an example of an op-amp circuit where R_S represents the resistance from the QTC material.

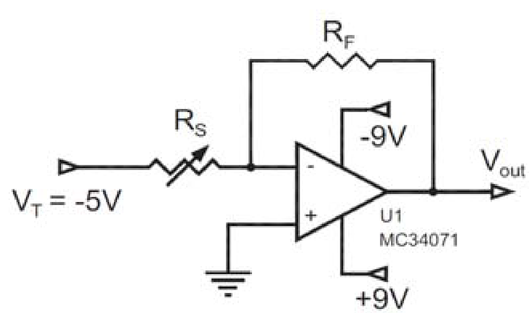

Figure 2. Example circuit illustrating how QTC is used as a variable resistor affecting the output signal[9]

The PSM circuit consists of gates to control which wire intersections are active, an analog to digital converter in order to digitize the measurement as well as a control unit and communication port to transmit the the data. Using a wire grid allows the system to iteratively take measurements for each row and column intersection. The data output is a contiguous block of bytes with a size of rows × columns × 1 byte. When interpreting the data, each row is represented by a stride of data. A stride of data is the equivalent byte size of columns $\times$ 1 byte. The total number of strides is equivalent to the total number of rows. The construction of the PSM consists of a QTC sheet over-top of a dense rubber layer. The purpose of the dense rubber layer is to impede the dissipation of the force being applied to the PSM. Impeding the dissipation of the force is important in order to produce accurate measurements of force. Figure 3 illustrates a cross-section of the PSM. Furthermore, the QTC material is calibrated by adjusting the density of the nano-particles. Selecting a nano-particle density from the lower end of the scale allows the overall thickness of the QTC material to be reduced without affecting the impedance property.

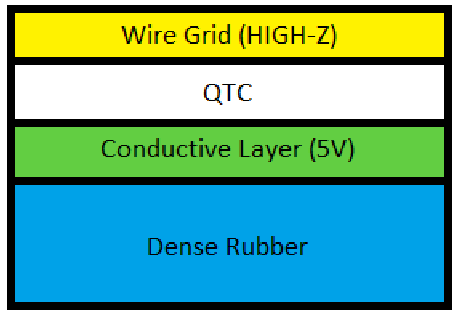

Figure 3. Cross-section of PSM construction

3 Data Analysis

There are two questions which we wish to answer using the actigraphic data output from the PSM; The first question is 'What is the current position of the patient laying on the PSM?', the second question is 'What change has been made in the position of the patient over time?'. The approach we take in answering these questions incorporates the use of artificial neural networks (ANN) and fuzzy sets (FS). In order to more easily analyze the data, the stored output from the PSM is first decoded into a set of 3 dimensional tuples $\overrightarrow{p_i} = < x,y,z >$ where $i \in (1,n)$ where $n \in \mathbb{N}$ is the number of sensor points embedded in the PSM. The first two coordinates x,y identify the location on the planar sheet while the third coordinate z, identifies a measure of the pressure being applied at that location. These coordinates partition the PSM into a set of rectangles bordered by 4 sensor points. Our data analysis begins with associating one input node of an ANN with each sensor point. We will be using a three layer ANN with n nodes in the input layer, $n-2$ nodes in the hidden layer and n nodes in the output layer. So, $in_i(t) = \overrightarrow{p_i} = < x,y,z >$ for the i^{th} input node. The input value for each hidden layer node coming from the input layer is calculated as:

$$net_j(t) = \sum_{i=1}^{n} w_{ij}(t) o_i(t) \tag{2}$$

Where $net_j(t)$ is the weighted sum of all inputs to hidden node j, $j \in [1, n-1]$. w_{ij} represents the weight associated with the edge joining input node i to hidden node j and $o_i(t)$ is the value output from input node i.
The activation function we're using for the hidden layer is the sigmoid[10]:

$$f_j(net_j(t)) = \frac{1}{1+e^{-net_j(t)}} \tag{3}$$

Since we wish to identify numerous positions and types of movement, a different ANN will be used for each with the same construction. As we do not currently have a sample of the QTC material, these training sets are generated using simulation. The training of each network is accomplished using the standard backpropagation technique using an error threshold of 0.001.

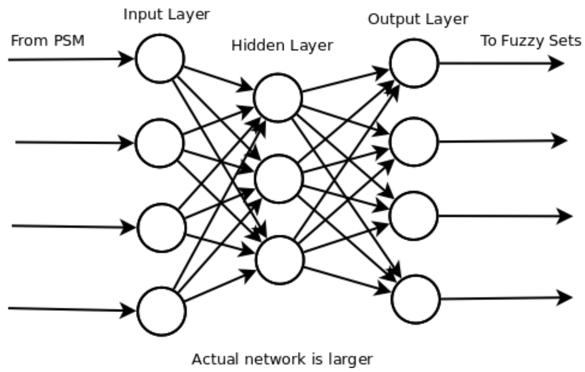

Figure 4. Triple Layer ANN

In order to identify the presence of movement and its type, data samples are tested from time t to time $t+q$ and their identification as per the neural networks they match is counted. The relative frequency of the matching for each network is calculated in order to identify movement. If no movement is identified, both questions have been answered, if movement is identified we continue. Each type of movement we are interested in is associated with a fuzzy set, the difference between samples is calculated for each node in order to create a set of output values which is then scored as before. Using the maximum type frequency as the membership function, we identify the type of motion. With this method we have answered both of the questions above.

4 CONCLUSION

In this paper we have described the design of an actigraphic method. This method has the potential to increase the usefulness of actigraphy in sleep studies for the diagnosis of OSAS, RLS, and PLMS. PSM is most useful in situations where standard methods of actigraphy are not sufficient. Situational usefulness of this method includes when a patient has skin hypersensitivity, or when precise measuring of body positioning is important. Additional medical applications of QTC PSM include gait analysis, physiotherapy, and posture analysis. The validation of the QTC method should be a subject of future study.

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