Peak Detection for Portable Multi-modal Nano-bio Sensor System

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Abstract

Sensitive and selective sensor systems are required to detect causes of disease. We outline the conceptual foundations of the novel approach to sensing based on multi-modal processing of signals of nano-bio sensors. Multi-modal sensing scheme can relax constraints of detecting conditions. It is able to detect the cause of the disease more effectively than single mode of sensor. Some peak detection algorithms which are suitable for portable system are compared to apply to multi-modal nano-bio sensors in this paper. It is shown that auto-threshold peak detection is useful for portable nano-bio sensor system with low cost processor.

Keywords: *Signal Processing, Peak detection, Nano-bio Sensors, Multi-modal approach, Auto-threshold*

1. Introduction

Infectious diseases spreading every day through food have become a life-threatening problem for millions of people around the world. Food or food products are the potent transmitting agent of more than 250 known diseases. So far only in the United States, 76 million cases of food-borne illness, 32,500 cases of hospitalization and 5,000 cases per annum of mortality are recognized [1]. Therefore, needs of high sensitive and selective detection system in the manufacturing and distribution stages is spreading. Sensors designed may be of mechanical sensors or actuators, chemical sensors, gas or bio-sensors for telecommunication, food, pharmaceutical, bio-medical areas [2]. Various sensors including nano-bio technologies are proposed to detect diseases.

Nanotechnology composes a trend towards a group of emerging technique form physics and biology for the creation of new-fangled nano-structures and manipulation of the matter at nano-scale [3]. This novel technology is now concentrating on in vivo sensors, so that on being injected it could acts as reporters of in vivo concentrations of chief analytes [4]. Biosensors are categorized into various groups according to the basic principles of signal transduction and bio-recognition elements. According to the transducing elements, biosensors can be classified as electrochemical, optical, piezoelectric, and thermal sensors. Applications of biosensors are developed majority for environmental and bioprocess monitoring, quality control of food, agriculture, bioterrorism and medical biosensor systems. Analytical techniques such as spectrophotometry and chromatography are time-consuming and expensive. They often require well trained operators for the sample pre-treatment steps, and cost-effective analysis [1].

Recently, most of the smart devices or structures include basically a sensor, signal conditioning circuitry, ADC, switch and a processor. The sensor designed and synthesized is expected to be of high conductivity and high integration compatibility with designed signal-conditioning circuits and processing which can be easily performed using a simple and cost-effective lower end processor. The performance of detection depends on signal processing with hardware and software. Therefore, Signal processing techniques are essentially required to classify diseases. As the usage of digital measurement instruments during the measurement process increases, acquiring large quantities of data becomes easier. However, the methods of processing and extracting useful information from the acquired data become a challenge.

In this paper, a novel scheme using multi-modal signals of nano-bio sensors is proposed to detect diseases with cost-effective and portable sensing system. As applying multi-modal sensing scheme, target material can be classified more exactly than single mode sensing and can be detected at the general environments.

At the multi-modal processing, it is required to classify signals which are combined. In order to extract useful information, peak detection algorithm is used. Peak detection is important in many applications, such as chemistry, biology and music. Works who use analysis techniques such as spectroscopy, chromatography and tone detection often use peak detection methods specific to those analysis techniques. Performances of peak detection algorithms are compared to get suitable for nano-bio sensors which are detecting causes of diseases. Peak detection algorithms are used to detect and classify signals for various applications including medical devices, such as EEG etc. Portal sensors are effective to detect diseases. It is shown that auto-threshold algorithm [5] is simple and useful for portable nano-bio sensor systems.

2. Nano-bio Sensor System and Peak Detection

It should be noted that the goal of this work was to implement a peak detection algorithm especially to detect peaks in multi-modal signals of sensors using a simple and cost-effective lower end processor. In this section, a basic scheme of multi-modal nano-bio sensor and a peak detection algorithm are discussed.

2.1 Multi-modal nano-bio Sensor System

It is not suitable for single featured sensor to classify and analysis proteins, amino acid and medicines which change the properties as size, electrical and structure of material. Most of single mode sensing is processed at the limited environment.

As sensing target materials with multi-channel and multi-modal scheme, its properties can be analyzed exactly. Concept of multi-modal sensing is illustrated in Figure 1. The property of Botulinum toxin is measured the same as other material with single mode sensing at the x-axis. As measuring with y and z-axis properties, Botulinum toxin can be separated from other materials. Multi-modal sensing scheme can relax constraints to detect target materials.

The detection of peaks in signals is an important step in many signal processing applications. Several real time systems are embedded in sensors and function as optimized digital controllers. Figure 2 shows general configuration of multi-modal nano-bio sensor. Multi-channel ADCs and signal conditioning circuits are included in controller. Signal conditioning means manipulating an analog signal in such a way that it satisfies the requirements of the next stage for further processing. Generally, signal conditioning includes amplification, filtering, converting, range matching, isolating and many other processes required to make sensor output suitable for further processing after acquisition study and analysis [6]. Figure 6 shows implemented sensor controller including 4 channels ADCs, signal conditioning circuits and Zigbee wireless communication module using MG2455 transceiver. 8051 micro-controller is embedded in MG2455 which is low power consumption and suitable for portable system.

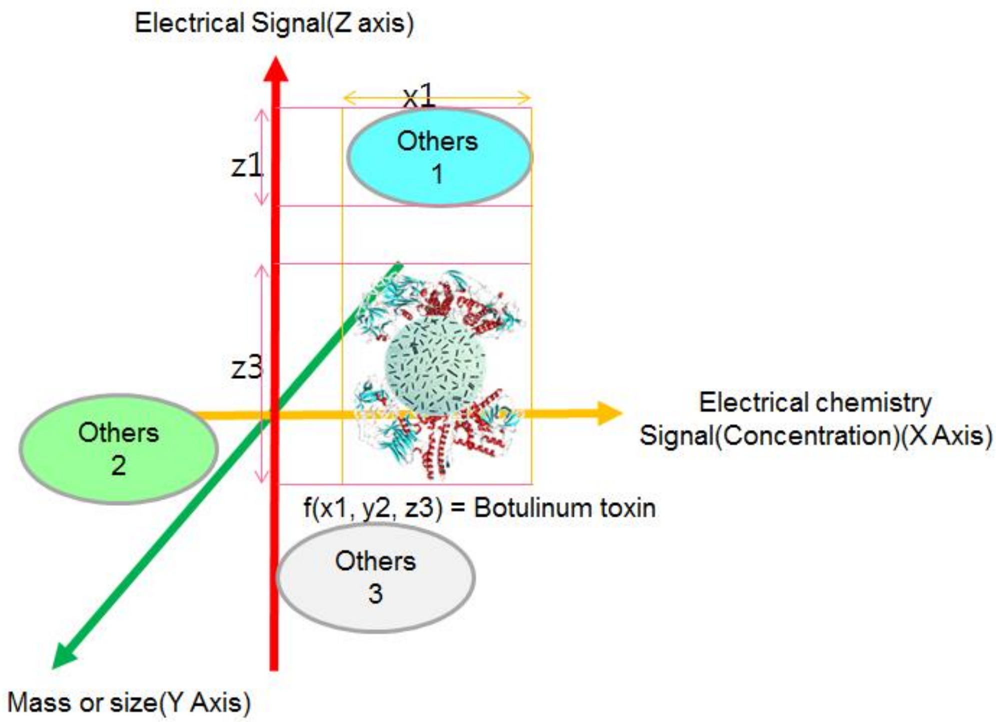

Figure 1. Concept of multi-modal nano-bio sensor

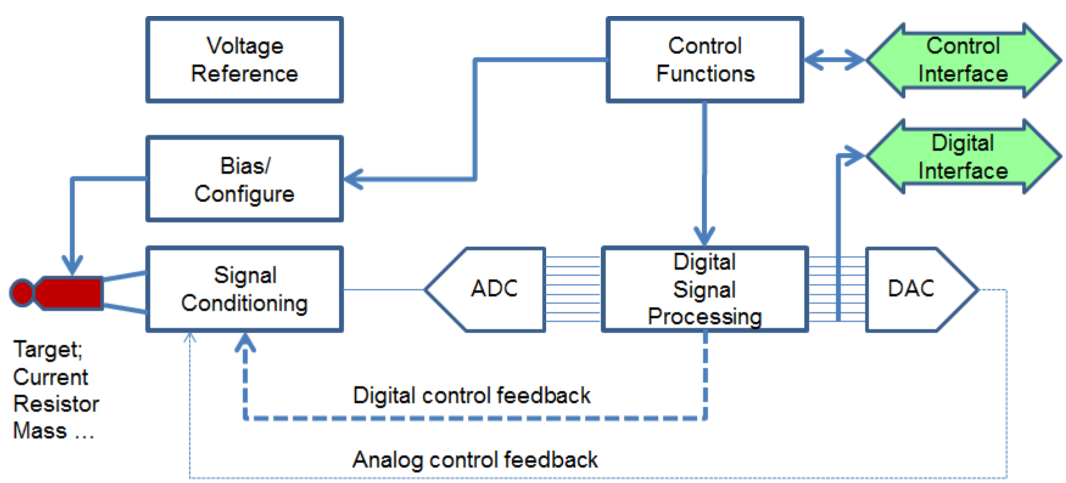

Figure 2. Configuration of nano-bio sensor controller

MG2455 is a full single-chip that is compliant to the specification of IEEE802.15.4 and Zigbee specifications and can be applied to Zigbee applications such as home control and sensor network [7]. It consists of RF transceiver with baseband modem, a hardwired MAC and an embedded 8051 microcontroller with internal flash memory for application program. It also includes several general-purpose I/O pins and many peripheral devices such as timer and UART. Therefore, peak detection algorithm can be implemented on MG2455 and ADCs processing can be conducted.

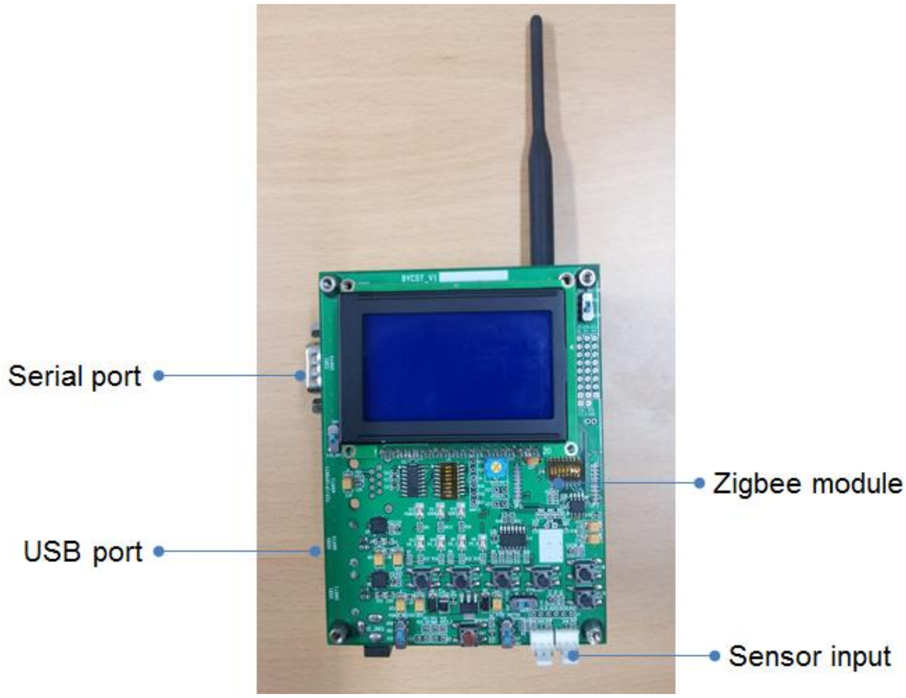

Figure 3. Implemented sensor controller with zigbee module

2.2 Peak Detection

The detection of peaks in signals is an important step in many signal processing applications. Up to now, many different methods have been developed [6], including those based on traditional window-threshold technique, wavelet transform, Hilbert transform, combining Hilbert and wavelet transform, artificial neural networks, techniques using templates, morphology filtering, nonlinear filtering, Kalman filtering, Gabor filtering, Gaussian second derivative filtering, linear prediction analysis, higher order statistics, K-Means clustering, fuzzy C-Means clustering, Empirical Mode Decomposition, hidden Markov models, and techniques using entropy, momentum, histogram/cumulative distribution function, intensity weighted variance, stochastic resonance, nonlinear energy operator. However, these algorithms are too complex to implement with low performance processor. As mentioned previously, various machine-learning systems can automatically detect the multiplicity of a peak and then determine the peak parameters without requiring user intervention. However, the system is too complex to implement as cost-effective and portable system.

In order to implement with low-cost processor, simple threshold peak detection is suggested. Peak detection is the process of finding the locations and amplitudes of local maxima and minima in a signal that satisfies certain properties. Properties of signals of nano-bio sensors can be simple or complex. As shown Figure 1, peak detection with fixed threshold gets false peaks for a noisy signal.

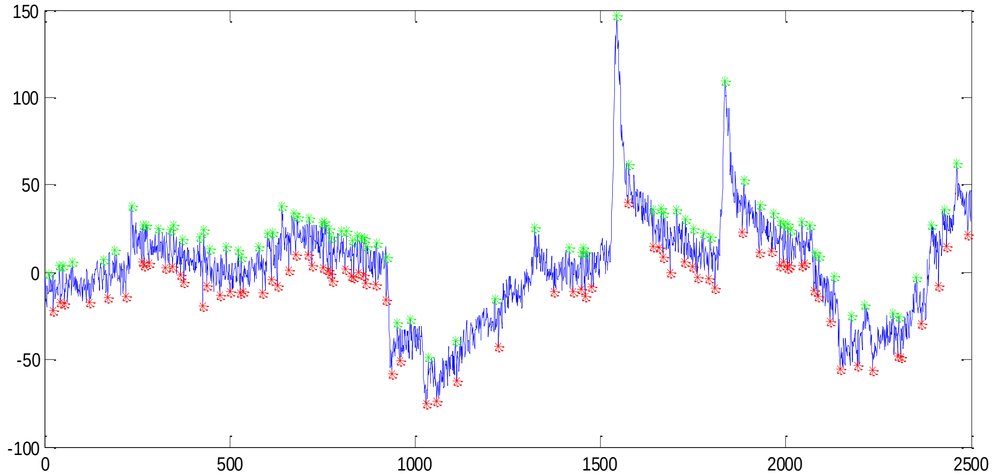

Figure 4. Results of peak detection with fixed threshold 20 for a noisy signal.

Jacoboson proposed an auto-threshold peak detection [5] which is very useful to implement with micro-controller because its computation is simple. Peaks are defined as local maxima. Specially, a peak is maximum value between two consecutive local minima [8]. Similarly, a tough is a minimum value between two consecutive local maxima. To be considered a peak, a sample value must be at least δ greater than a trough.
This threshold value, δ , is also used to define a trough as the minimum value less than δ between consecutive local maxima, equation (1).

$$X_{P_j} \equiv X_{T_i} + \delta \le X_{P_j} \cap X_{T_{i+1}} + \delta \le X_{P_j}$$
$$X_{T_j} \equiv X_{P_i} - \delta \ge X_{T_j} \cap X_{P_{i+1}} - \delta \ge X_{T_j} \qquad (1)$$

The performance of the algorithm depends on the value chosen for the threshold. Visual inspection of the data allows for easy threshold selection. However, this requires training of user acquiring the data and additional time. Automated threshold estimation greatly improves peak detection.

Considering the a priori information, it is known that the peak is positive since the slop of the leading edge is being detected. Therefore, the derivative of the samples greater than zero can be considered as two clusters: one consisting of the peak slopes and the other consisting of the remaining samples. To separate the slope data into two clusters, unsupervised learning, nearest neighbor criteria clustering is suggested. Unsupervised learning may be used since it is known that two clusters are desired. The nearest neighbor criteria is chosen since it requires far less calculation than sum-of-square-error or Bayesian maximum likelihood criteria [9].

The nearest neighbor criteria is implemented as the absolute difference between a sample and cluster means. The sample is assigned to the cluster mean with smallest difference. Once all the samples have been assigned, new cluster means are determined and samples are again classified to the nearest cluster mean. Algorithm termination occurs when the change in the cluster means is less than ε . Once the cluster means are determined, the larger cluster mean is the center of the peak data and used as the threshold for the peak detection algorithm.

3. Simulation Results and Considerations

In order to compare the performance of peak detection, it is used a noisy signal as Figure 5.

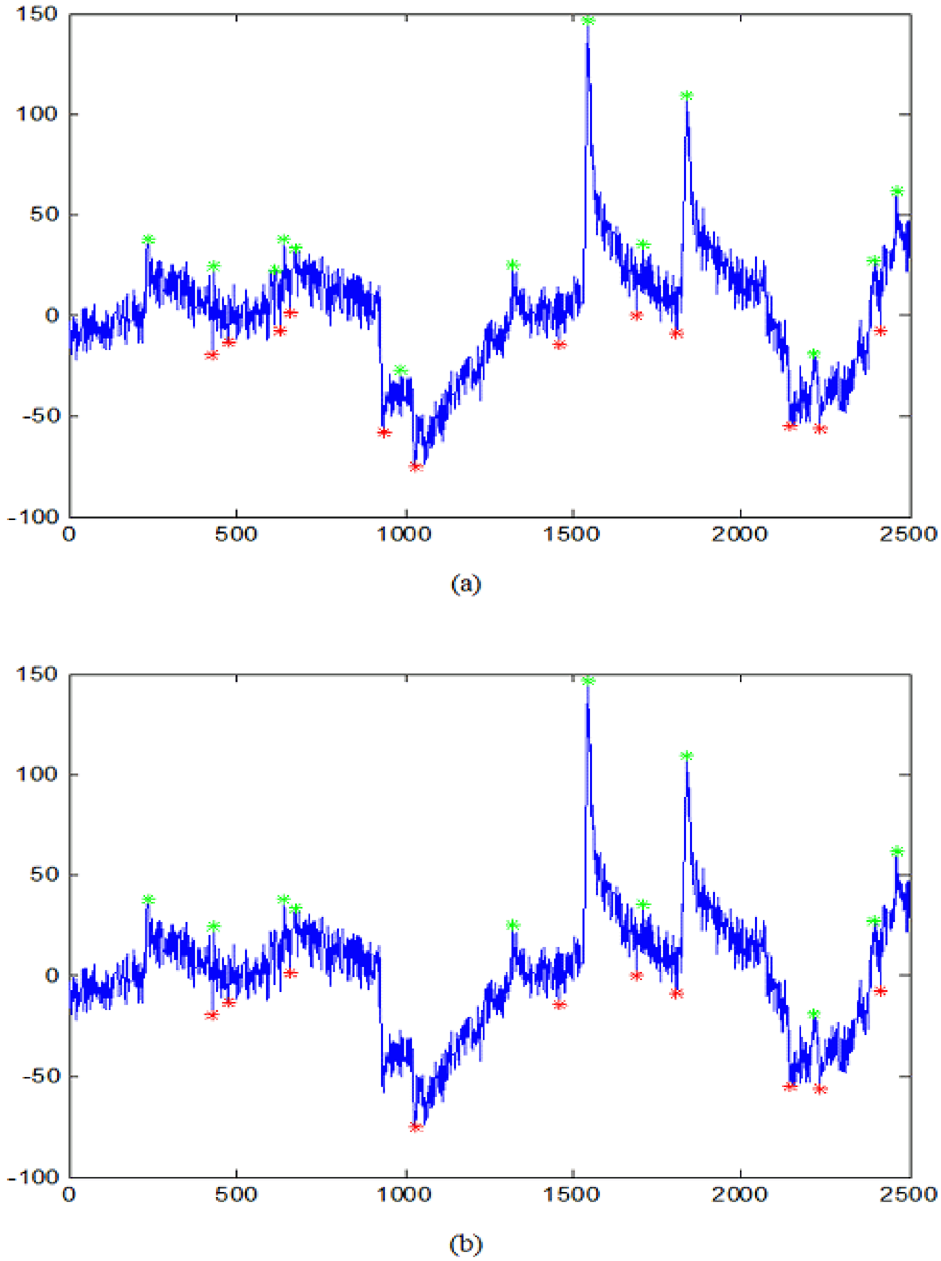

Figure 5. Peak detection results of auto-threshold algorithm. (a) result of simple threshold peak detection(threshold 30) (b) result of auto-threshold peak detection

Simulation is conducted by simple threshold and the auto-threshold peak detection algorithm implemented with Matlab. The following figures display the results of peak detection algorithms. (a) is result of simple threshold peak detection and (b) is auto-threshold peak detection algorithm. The results seem to be similar, but many times tried to select the fixed threshold.

There are false detections which can be eliminated by low pass filtering at the stage of signal conditioning. In this work, low pass filtering is not conducted at the pre-processing stage because filtering can cause problem with the measurements.

4. Conclusions

In this paper, for more effective detect and analysis of multi-modal signals of nano-bio sensors, the performances of peak detection algorithms are compared. Although there are some false detections, auto-threshold peak detection algorithm is simple and suitable for portable nano-bio sensor system. We would like to improve the performance of the peak detection algorithm and implement with 8-bit micro-controller in the near feature.

Acknowledgements

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