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Reliability analysis of a newly developed detector for monitoring spine health

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ABSTRACT

Following with tons of people studying and working in a sitting posture for long, spine disease became one of the most important occupational health problems. The patients with condition worsen have to suffer harmful CT scans or even painful serial lumbar puncture. We innovatively developed a biomedical optics based detector for spine health monitoring and particularly improved the circuit design for feeble signal detection. A series of experiments were performed to fully test its reliabilities, including scalability, noise and crosstalk, sensitivity, stability etc. The results showed that this device was very reliable, sensitive, and stabile, suggested the promising clinical use of our novel device in spine/spinal marrow health monitoring and diagnosis.

1. Introduction

For those people who suffering from spine diseases, there are two main clinical methods for monitoring and diagnosis. One of them is medical biopsy [1]. A special spine needle is used to insert into the spine, then tissue fluid is extracted from the spine and analyzed. Accordingly, spine disease is detected by the biopsy of the tissue fluid directly. Apparently this method is invasive and it is extremely brutal and of unbearable pain for poor patients. Moreover, most patients with serious spine diseases, such as multiple myeloma (MM), have to experience such painful test many times after treatments for therapeutic effect evaluation (etc., to test if there is any cancer cell left in the spine), until they are completely cured or died. The other method is imaging apparatus, such as X-ray [2], computation tomography (CT) [3], magnetic resonance imaging (MRI) [4]. They are noninvasive and patients can free from pain. However, these techniques are either ionizing or contrast agent intake, of big instrumentation, which are expensive and non-portable. Some of them are radioactive which are not really safe for multiple test, such as X-ray and MRI. Meanwhile, the non-portable design makes these techniques impossible in continuous monitoring or bed\home care.

In this study, we designed a novel detector for monitoring spine disease noninvasively and nonionizing. Its principle is based on near-infrared spectrum technology [5], which has been recently applied to medical diagnosis by detecting hemodynamic parameters, such as breast imager, functional activity imager, monitors for muscle function, shock, and thrombosis [6]. This technology is on the basis that the main substance water shows low absorption of near-infrared light and that hemoglobins are the main absorbers of near-infrared light and are of different absorption spectrum. With multiple well-selected wavelengths of near-infrared light, and the light propagation theory, we were able to quantify different hemoglobin concentrations in the measured spine site, which is key info for monitoring and diagnosing the health situation of the spine and spinal marrow.

However, the measured light intensity variation measured out of the spine tissue is quite weak compared to the background light noise and signal from other type of tissue without spine region. These signals are also easily interfered with crosstalk from other channels/measured site or other chromosphere [7], power-line interference [8], A/D conversion error [9] etc. We improved the circuit design to extract the weak signal and reduce the noise coming from photosensitive sensors in the whole detector design [10]. Finally, we implemented a sequence of performance tests to examine the reliabilities, such as scalability, sensitivity, specificity, signal-to-noise ratio (SNR) [11], stability, and consistency, the data of which verified the reliability of our detector.

2. Method and experimental design

2.1. Device design

Our detector contains 7 modules shown in the Fig. 1, which are power, probe, A/D converter, master control, probe driven, data transmission and storage. The power provides +5 V and +3.3 V DC voltage for other modules to work well. Probes have a three-wavelength LED [12] and eight light-sensitive detectors. The three-wavelength LED can respectively emit three near-infrared wavelength light (735 nm,

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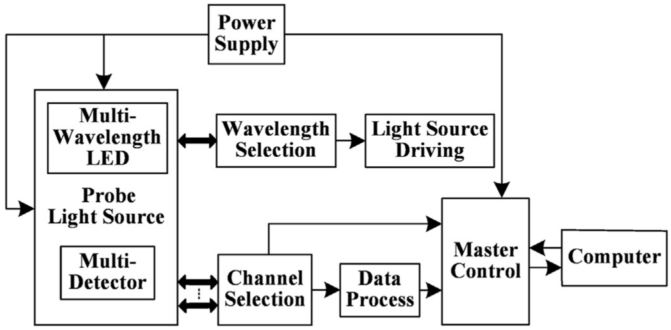

Fig. 1. Structure diagram of detector.

805 nm, 850 nm). The light-sensitive detector is OPT101 [13] which can change different light signals into electronic signals and it is with high responsibility 0.45A/W (650 nm) which make it possible for us to detect weak signals. A/D converter with the resolution of 16 bits and speed of 250 ksps changes the analog signals into digital signals precisely. Master control is an ARM chip which is used to control the light source, detectors, data collection etc. Computer is used to display the result by the upper computer.

When master control illumines one wavelength of the LED, the detectors are chosen sequentially to work and receive the light intensity out of the tissue. Then repeat it with other wavelength. At the same time, the A/D converter is changing the analog signals achieved by detectors into digital signals. The master control sends the data to computer.

2.2. Reliability analysis

In the above-mentioned data collection process, because the signals collected out of the tissue are very weak and many of the channel signals need to be obtained orderly, it is inevitable to involve many noise into the signals. There are three main noises, crosstalk, power-line interference, interference of A/D scanning module. To make our detector of good sensitivity, specificity, high SNR and stability, some important measurements were taken to weaken those interference.

2.2.1. Crosstalk

Crosstalk is a signal in the transmission channel on the transmission and is caused by the wires which are parallel and close to each other. One of these wires will introduce electromagnetic interference [14] to the others. Excessive crosstalk may cause false triggering of the circuit, causing the system to fail to function properly. It mostly occurs in multi-core cable, bundled connector, PCB parallel wires. The intensity of crosstalk [15] is decided by the circuit capacitance, mutual inductance and circuit impedance. So crosstalk is usually classified into two kinds of noise: capacitive coupling and inductive coupling [16]. The voltage change of aggressor will produce induced current in victim in spite of electromagnetic interaction. The intensity of crosstalk depends on a series of factors such as the distance between single lines, the length of wire, the structure of signal lines etc. According to the previous research, the shorter of the distance between signal wires, and the longer of the wire length, the greater noise will be introduced into the other signals. So in this study, the class twisted-pair line [17] is used to reduce the noise caused by crosstalk. One of the twist-pair is connected to ground and the other is the acquisition signal wire. In this way, we can greatly reduce the coupling capacitance and the coupling inductance by isolating the signal wires.

2.2.2. Power-line interference

The other main noise is power-line interference [18]. The signals we collect are weak, it is easy to be interfered by the power-line interference which is around in the air and interfere the electronic device. Power-line interference is caused by the mains voltage which is AC voltage of the frequency of 50 Hz. Therefore, the noise caused by power-line interference has the same frequency of 50 Hz. To avoid this interference of our signals, a 50 Hz trap filter is used into our circuit before the A/D converter.

2.2.3. Interference of A/D scanning module

It has been introduced before that our detector receives many channel signals each period. Each channel signal is collected by scanning mode which let each channel work orderly. In this mode, with the scanning frequency getting much higher, the sampling capacitor Cs of A/D converter, which is connected to ground in the A/D scanning module, will not have enough time to charge and discharge. Therefore, the successive channel signals will interfere with each other. Therefore only to increase the sampling time or reduce the channels' resistances can it reduce the sampling error voltage ΔU. So there are two methods to reduce this noise. One is to decrease the value of input resistance. For this purpose, a voltage follower is designed between signals and A/D converter. In this way, the equivalent resistance of signal source significantly decreases. The other way is to increase the sampling time. However, the sample frequency will be reduced which is not good. Therefore, in our device, voltage follower is introduced before A/D converter.

2.3. Reliability experiment design

To evaluate the reliability of our instrument, we conducted sensitivity experiment and interference assessment test. In these experiments, we analyzed our instrument's sensitivity, channel consistency, stability in detail.

2.3.1. Sensitivity test

In this experiment, we selected a polyethylene container as the experiment container. 500 ml water was added into the container first. Then 0.5 ml of ink (diluted 1000 times) was injected into the container each time, so the concentration of the solution changed over time. At the same time, our instrument was detecting this high scattering solution. Because the different concentration of the solution had different scattering and absorption coefficients [19,20], the detected intensity of our detector changed together with the concentration of the solution. Therefore, this experiment result can respect the sensitivity of our instrument. Meanwhile, our instrument has 8 channels. When comparing all the channels' data of different wavelengths, we found that the channel's consistency can be verified.

2.3.2. Interference assessment test

Interference assessment test was designed to test the anti-interference performance. In this experiment our detector was used to detect a uniform material which had stable scattering and absorption coefficients. While a stable light source illuminated into this material, and the background intensity was kept unchanged and the detector and material were left untouched, the photons out of the material should be stable. So by detecting the result of the out photons, the reliability and anti-interference of our detector can be certified.

2.3.3. Scalability test

An in-vivo physiological test was designed by this work to evaluate and test the clinical performance of our detector. To achieve a reality effect, we choose an arm as the detecting part. The probe was tied tightly on the subjects' forearm muscles with no sunlight detected by our detector and a bandage was tied on the upper arm. The bandage was used to block blood flow to let the forearm be lack of oxygen. Therefore, the oxygenated hemoglobin concentration and deoxy-hemoglobin concentration of forearm changed in this process. Whether our instrument can detected those change or not can easily be used to evaluate the performance.

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