Design of a Digital Current Source with Temperature Feedback for fNIRS Devices

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Abstract

The most important problem encountered in Functional Near Infrared Spectroscopy is the loss of stability and reliability of the light emitting diode as a result of an on going heat transfer between the living tissue and the light emitting diode. This condition has an unwanted disruptive effect on the radiated light. Within this study, a current source circuit with temperature feedback is developed to reduce these effects to minimum and preliminary experiments are done with the developed circuit. The developed circuit is an op-amp based constant current source which consists of a digital potentiometer, a temperature sensor and a microcontroller. Regarding the temperature reading, microcontroller manipulates the value of the digital potentiometer, thereby manipulating the current supplied to the light emittng diode by the current source, instantly. Preliminary studies showed that, the circuit developed for operation between 20°C and 46°C temperature values is much more beneficial when compared to a simple current source. In future, manufacturing the circuit in a modular structure is planned for clinical applications.

1. Introduction

Functional Near Infrared Spectroscopy (fNIRS) is a low cost, non-invasive medical imaging technique which takes advantage of optical properties of the tissues to detect hemodynamic changes as a result of neural activities in brain [1, 2]. The optical structure of fNIRS devices generally consist of multiple wavelength (around 730nm and 850 nm) LEDs (light emitting diodes) and photodiodes with a high response at a large spectrum (between 600nm and 1050nm). Some of the light emitted by an LED at a specific wavelength is absorbed by oxygenated hemoglobin while others are reflected by deoxygenated hemoglobin, which are all found in the arterial red blood cells of living tissues. Reflected portion of the light is sensed by photodiodes, then transformed into electrical signals. Calculating the initial oxygenated hemoglobin percentage from these electrical signals indirectly is possible [3]. Although fNIRS technology is a promising one, some problems are encountered in practical applications.

One of the most important problems encountered in fNIRS applications is the overheating of LEDs at signal collection stage due to fitting the head probe to forehead too firmly. The temperature increase of LEDs result in decreased stability and reliability of them. Even though the applied current is fixed, short circuit takes place between junctions of the LEDs due to temperature increase, resulting in decreased radiation in the infrared light which causes an inconsistent SNR [4]. In this study, a temperature feedback constant current source is developed and preliminary studies are done to reduce the unwanted effect to the lowest point possible.

2. Circuit Design

The electronic circuit layer which is designed and developed consists of a current source, a digital potentiometer, a temperature sensor and a microcontroller.

2.1. Op-amp Based Constant Current Source

In this study, an op-amp based constant current source is used. The schematics of the current source is given in Figure 1. The op-amp used in this circuit serves as a voltage follower and is used to keep the total voltage drop across R-MIN and R-MAX resistors constant. The transistor reflects its base current with a gain regarding its alpha value to a load connected to the collector leg (In this case an LED). The R-MIN potentiometer is used to adjust the emitter current of the transistor, thereby setting the current across the LED. Increasing the resistance of R-MIN potentiometer results in a decreased current across the LED. On the other hand, R-MAX resistor limits the maximum amount of current across the LED. Setting LED current in this way is not the optimal one. Instead of manipulating the current across the load directly, the voltage applied to the base leg of the transistor can be set by adjusting the voltage applied to the non-inverting input of the op-amp.

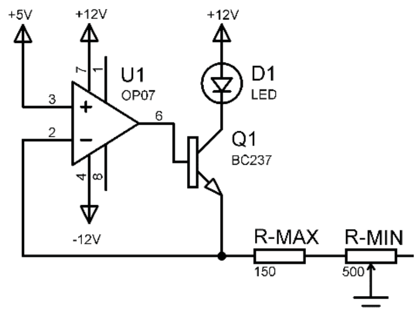

Figure 1: Simple adjustable constant current source

An improved version of the op-amp based constant current source can be achieved, by simply inserting a potentiometer (R-D) in a voltage divider setting to the non-inverting input of the op-amp and removing the R-MIN potentiometer (Figure 2). Increasing the resistance of R-D potentiometer in one direction, increases the current across the R-MAX resistor. As a result of this current increase, the collector current also increases regarding the formula down below.

$$I_{LED} = \frac{V_{RD}}{R_{MAX}}$$

This way, the current across LED is increased. After this, an automated control of the system is foreseen instead of continuing to manipulate the system manually as above. In this study, the automated control is done with a digital potentiometer.

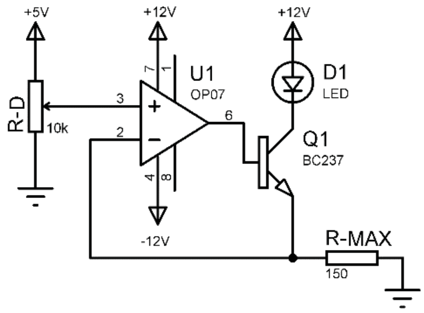

Figure 2: Improved adjustable constant current source

2.2. Digital Potentiometer

In this study, AD5241BRU10 (Analog Devices Inc., USA) digital potentiometer IC (integrated circuit) is used (schematics given in Figure 3). This fourteen pin digital potentiometer features one adjustable resistor with 10KΩ maximum resistance and 256 adjustable positions. The IC is capable of operating between +2.7V and +5.5V supply. The SDA and SCL pins, allow the IC to communicate with a microcontroller/microprocessor using the I2C communication protocol to set the resistance.

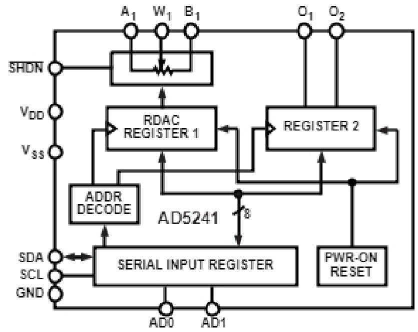

Figure 3: AD5241 schematics [5]

2.3. Temperature Sensor

In this study, LM35 temperature sensor IC is used. This three pin temperature sensor IC is capable of measuring temperatures between +2°C and +150°C, the IC outputs 10mV analogue signal for each 1°C increase. Usage of these analogue signals as a control variable is possible after the A/D conversion is handled by a microcontroller.

2.4. Microcontroller

As a µC (microcontroller), PIC18F4520 (Microchip Technology, Arizona, USA) is used. This low cost – high performance µC has a 32KB FLASH program memory, a 1536Byte random access memory, a 10bit resolution analogue – digital converter and an I2C communication protocol module. Eight pins of this fourty pin chip, can be programmed to serve as analogue inputs and two of them can be programmed to be used for I2C communication. The schematics of the whole circuit designed for this study is given in Figure 4.

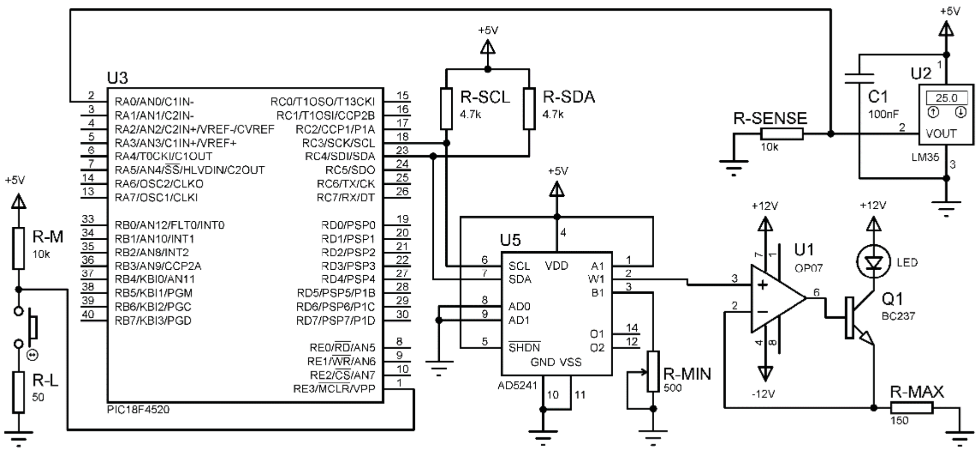

Figure 4: Developed electronic circuit

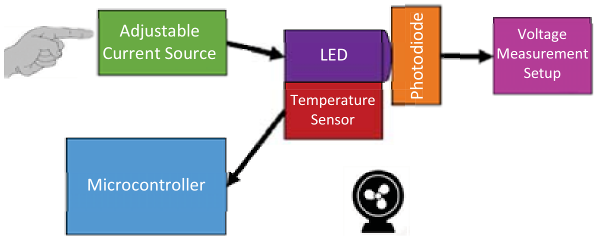

*Figure 5:*Analogue adjustable setup (Setup #1)

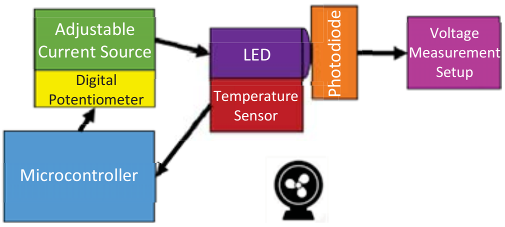

Figure 6: Temperature feedback full automatic adjustable setup (Setup #2)

3. Practical Experimental Setup

Within' this study, two different experimental setups are built. The first setup consists of a full analogue manually adjustable constant current source, which allows the user to adjust the current across the LED one time only, in advance but not after. While the second setup consists of a microcontroller – digital potentiometer controlled, ambient temperature feedback, automatic improved adjustable constant current source. In both of these setups, a temperature sensor is placed right next to the LED of the constant current source, in a facing and touching position to keep track of the temperature of the LED. Again in both of these setups, a photodiode is placed right in front of the same LED in a facing and touching position to keep track of the amount of light radiated by the LED. A heater – ventilator is placed to the setup to blow heated air towards the LED (Figure 5 and 6).

In both of these setups, ambient temperature is measured and visualized by the temperature sensor – microcontroller setup, instantly. In the first setup, the current across the LED is adjusted to a desired value manually in the beginning, independently from the ambient temperature. In the second setup, regarding the ambient temperature the microcontroller updates the value of the digital potentiometer, thereby updating the current supplied by the current source to the LED. Different microcontroller softwares are developed for each setup using the Proton Basic programming language and written to the microcontroller with the help of PICkit2 programmer.

In both setups, L6*730/6*850-40Q96-I (USHIO Epitex Inc., Japan) multi – wavelength LEDs are used (which is used in many fNIRS studies). This LED consists of six 730nm and another six 850nm wavelength LEDs, seperate from each other but in series in itself. Within' this study, only the 850nm wavelength LEDs are used.

In both setups, BPW34 (Vishay Semiconductors, USA) a high speed, highly sensitive, capable of detecting light waves between 600nm and 1050nm, less temperature affected photodiode is used. One end of the photodiode is connected directly to the ground while the other end is connected to the ground via a 10kΩ resistor. The voltage across the resistor is measured with a voltmeter for different ambient temperatures and noted down.

4. Findings

After the experimental setups are set at a 20^{o}C fixed ambient temperature; for setup #1 by adjusting the analogue potentiometer manually, for setup #2 by adjusting the digital potentiometer via microcontroller, the voltage measured across the photodiode is set to 507mV. Afterwards, the voltage across the photodiode is continuously measured while the ambient temperature is increased gradually until it reached 46^{o}C. Recorded temperature versus photodiode voltage measurements are listed in Table 1. Graphical lines regarding these measurements are shown in Figure 7.

For both setups, measured starting voltages across the photodiode was 507mV at an ambient temperature of 20^{o}C while measured starting voltages across the photodiode were 444mV and 503mV respectively at an ambient temperature of 46^{o}C. With an increasing ambient temperature; an unwanted important decrease in measured voltage is present in setup #1 while an acceptable tiny oscillation is present in setup #2. The average measured voltage for setup #1 was 475±20mV while it was 501±3mV for setup #2. The percent deviation of voltage was seen to be %13 at most for setup #1 while it was around %2 for setup #2. These findings point to the fact that change in ambient temperature may have an influence at voltage across the photodiode. On the other hand, these affects could be decreased to a minimum with the use of a temperature feedback microcontroller controlled improved circuit.

Table 1: Experimental measurement results

Ambient Temperature (°C)	Photodiode Voltage (mV)	
	Setup#1	Setup#2
20	507	507
22	502	506
24	498	504
26	493	499
28	490	498
30	485	499
32	478	498
34	472	499
36	468	501
38	464	502
40	458	497
42	453	501
44	449	504
46	444	503

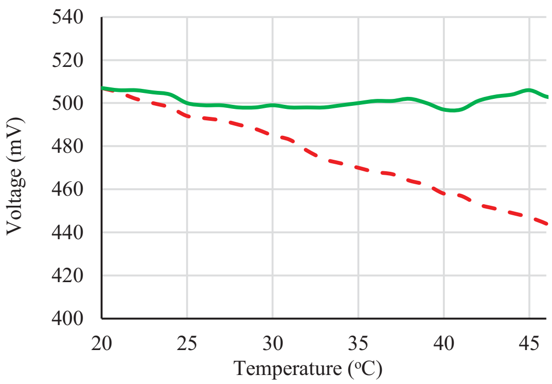

Figure 7: Temperature – Voltage deviation lines (Red dashed line: Setup #1 and green continuous line: Setup #2)

5. Results and Discussion

In this study, the source of a highly encountered problem in fNIRS measurements is investigated. Fundementally, a digitally based circuit is designed to compansate the emitted light change in LEDs due to temperature changes which is a probable problem in all the continuously emitting LED based setups. The design intends to coordinate the LED current source in a voltage controlled way to fixate the LED light intensity with the help of a temperature data feedback from a strategically positioned temperature sensor. Once the change in produced light intensity of an LED at a heating condition is calculated, it can be used for permenant calibration purposes in real measurements. With both of these temperature feedback and non-feedback measurements, it is shown that change in LED light intensity can be highly taken under control. This may be an explanation for the shift in base value of fNIRS measurements, which was a never understood problem.

In this study, some restrictions are present. Even though the temperature sensor provided functionality throughout the measurement process, it is probable that a high precision and accuracy digital temperature sensor may be needed in clinical applications. Even though usage of a heater ventilator to increase the ambient temperature made it easy, it may cause some unwanted air flows. The lack of living tissues in our constructed setups, forced us to position both LED and photodiode facing each other. In clinical applications, positioning the LED and photodiode next to each other while facing and touching living tissues may result in a decreased voltage measurements.

The designed digital constant current source is not fit to be used in fNIRS devices only, it can be applied to any medical device facing temperature based hardware problems, if the proper settings and modifications are done. In future studies, some changes can be made in the designed circuit to decrease the response time for increased accuracy.

References

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