Muscle Sensing Device Design Using a PANDA Ring Resonator System

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***Abstract*—We propose a micro-optical sensing system for muscle contraction and movement measurement, in which a PANDA ring resonator type is used as a basic optical device called Muscle Optical Sensor (MOS) system. The MOS system consists of an optical add/drop filter which is connected to two micro-ring resonators, of which the right ring is a sensing unit and the left ring is a reference ring. The key contribution of this paper is a novel approach for measuring contraction and transfiguration of muscles by using the small scale optical device. The contraction or transfiguration of muscle is directly perturbed into the sensing unit, which changes the optical path length. These resultant changes in wavelength (Δλ) are measured and obtained by the difference of the sensing and reference signals. The experiment was conducted by using the MATLAB and Opti-wave programs, which indicated that the changes in the sensing radius were associated with the change in wavelength. The results and techniques can be used beneficially for muscle sensing applications.**

***Index Terms*—muscle sensor, optical sensor, PANDA ring resonator, small scale optical device**

I. Introduction

Optical devices are rapidly developing and spreading. These have unique properties such as greater sensitivity, selectivity, are non-invasive, small size amongst others, which have become attractive options in various applications; for instance, communications, microbiology, automotive industry, surveillance and monitoring domains, and so on [1]-[4]. Furthermore, the current trend of numerous health care methodologies directly impacts the research and development of optical sensor devices which enable these new technologies to reduce patient trauma and recovery times and lower healthcare costs. These properties have demonstrated great potential for medical applications, such as use as a tool for diagnosis or part of treatment and patient monitoring procedure [5], [6]. An optical sensor is an optical device that has been developed and the production of which has grown, which can be seen from the increase in the number of researchers who have proposed various concepts and new techniques in order to obtain suitable devices for applications. Optical sensor properties which use photons as sensing elements have become an important tool in the field of non-invasive diagnostics and treatment. Recently, Yupapin *et al.* [7] have shown extremely interesting results when using the small scale optical device known as a PANDA ring resonator circuit for developing a powerful optical device. A PANDA ring resonator is a modified optical add/drop filter, in which the required optical sensor can be generated and obtained by changing the structure of the PANDA (i.e. parameters) ring resonator , input light signals, and different output signals. The last 2-3 years, a PANDA ring resonator system has been proposed as an optical sensing system which can be developed and applied to a variety of applications such as distributed sensors [8], molecular sensors [9], gas sensors [10] and force sensing device which is a new sensing device for a force sensing application [11].

In this paper, we propose the extended capabilities of a force sensing device for muscle contraction and movement measurement. An optical micro-ring resonator known as a PANDA ring circuit is proposed as the basic sensing device called Muscle Optical Sensor (MOS) system. The change in optical path length within the sensing system is coupled with muscle contraction and movements, which are the different forces of muscle contraction and movement which occur and can be measured. The experiment was conducted by using the MATLAB and Opti-wave programs which indicated that the change in the sensing radius is associated with the change in the optical path length. Finally, the simulated results showed that this device has the ability to be applied to measure the signal of muscle contraction and is much more beneficial for muscle sensing applications.

II. Basic Principle of Muscle Contraction Sensing Operation

Almost all movements of the organs in the body are the result of muscle contraction. The coordinated action results of joints, bones, and skeletal muscles produce obvious movements such as walking, running and other organ movements. In principle, the muscle contraction and force production is associated with the sliding

Manuscript received March 15, 2015; revised September 24, 2015.

doi: 10.18178/ijeee.4.3.273-276

filament theory, which is a sliding of the thin or actin filaments and the thick or myosin filaments [12], [13].

Forces are formed by the sliding to convergence of muscle fibers which will cause muscle contraction in order to respond to various stimuli from the environment. The changes (contraction) occur and can be measured through the reaction of direct perturbation during a contraction or transfiguration of muscle; which these changes will affect the optical path length changes in MOS system.

In principle, the MOS acts as an optical sensor to measure and detect changes of wavelength that lead to refractive index changes and optical path lengths, which can be used to produce the required measurement parameters. The change in the optical path L (ΔL) is affected by the distortion or change in the ring shape, which is introduced by the strain-optic effects due to the changes in the refractive index, n by Δn. Finally, the resonant wavelength, λ_m, is shifted by $\Delta\lambda_m$, given by:

$$\frac{\Delta\lambda_m}{\lambda_m} = \frac{\Delta n}{n} + \frac{\Delta L}{L} \tag{1}$$

here, m is an integer, n is the refractive index of the guiding material, and L is the circumference of the ring resonator. The schematic diagram of a muscle sensing transducer using a PANDA ring resonator is shown in Fig. 1, which consists of an optical add/drop filter connected to two micro-ring resonators. In our experiments, we assumed that the muscle sensing probe (thin film) or other sensing parameters can exert force on or directly perturb the sensing unit (R_R), in which the obtained signal is compared with a reference signal (R_L) measured as shown in Fig. 1, whereas the deformation or contraction of muscles introduced to the sensing device by means of the elastic modulus of materials, which caused the wavelength shift ($\Delta\lambda$) in the peak spectrum of signals and described [8] by (2), which is expressed by:

$$Y_0 = \frac{\frac{F}{A}}{\frac{\Delta L}{L}} = \frac{stress}{strain} \tag{2}$$

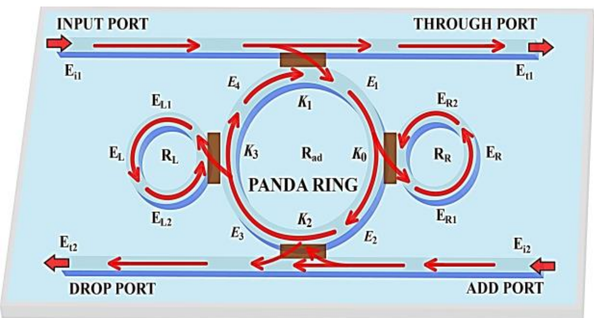


Figure 1. Schematic diagram of the MOS using PANDA ring resonator and deformation shape of sensing ring within the sensing unit with and without external force, where R_s is ring radii, κ_s is coupling constant, and E_s is optical fields.

The relationship between force and the change in sensing device length is described by:

$$F = \left(\frac{Y_0 A_0}{L_0}\right) \bullet \Delta L \tag{3}$$

where F is the applied force, Y_0 is the Young's modulus that is material parameters of *InGaAsP* as 6.27×10^{10} Pa [14], A_0 is the initial cross-section area, L_0 is the initial length and ΔL is the change in length. The simulation results were obtained by using the practical parameters, which are in the sensing range in terms of wavelength shift ($\Delta\lambda$) with the muscle optical sensing resolution is measured by comparing the sensing and reference signals. The wavelength shift between sensing and reference signals is compared by means of a mathematically rigorous approach for calibrating the high-precision phase using the phase to calibrate itself. The self-calibration and the wavelength shift between center peak wavelengths are given [10] by $\Delta\lambda = \lambda_2 - \lambda_1$ where λ_1 is the center peak wavelength of the reference signal and λ_2 is the center peak wavelength of the sensing signal.

III. Simulation

Fig. 2 shows the schematic of the simulation, which has set up to simulate the process of muscle contraction monitoring using the muscle optical sensor. Muscles of facial expression were selection as the area for mounting the probe, which was positioned above frontalis muscles. The mechanism of contraction and relaxation of the frontalis muscles cause facial gestures such as raised eyebrows, closing eyes etc. Force is a result of the contraction of the muscle to directly affect the sensing unit (right ring) stimulating and causing deformation of the shape of the sensing ring (optical path length change).

The muscle optical sensor is responsible for monitoring the change of the signal which occurs and compares it with the difference between the sensing and reference signals. In the simulation, the parameters of the PANDA ring resonator were fixed to be the Gaussian beams wavelength of 1.55 µm and power of 10*m*W introduced in the input port of the PANDA ring circuit. The waveguide material used is *InGaAsP/InP*, with core index is n_0 = 3.34 [15], [16], core area of the waveguides is A_{eff} = 0.3 µm^2 and waveguide loss coefficient is α = 0.1 dBmm-1. The coupling coefficient ratios were κ_0 = 0.018, κ_1 = 0.44, κ_2 = 0.92, κ_3 = 0.39. The right ring (R_R) is a sensing unit which was placed as the ring perturbed by the applied force, the ring radii varied from 3.249 µm to 3.254 µm, the left ring (R_L) is a reference ring, with radius R_L = 3.249 µm, and the center ring (R_{ad}) is used to form the interference signals between signals from the reference and sensing units, with the radius R_{ad} = 12 µm. In operation, the radius of the right ring (sensing unit) was changed by a shift of the circulated signals in the interferometer ring (center ring).

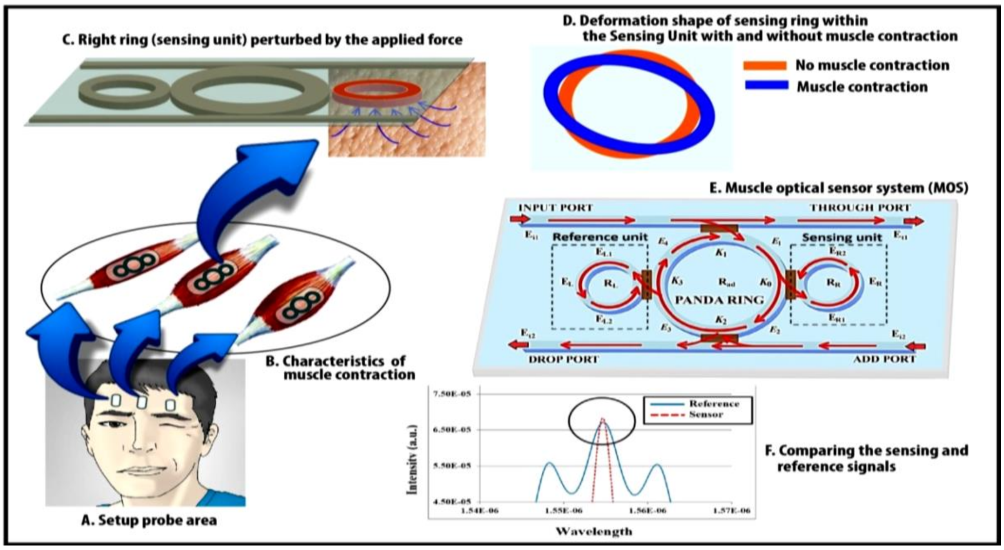
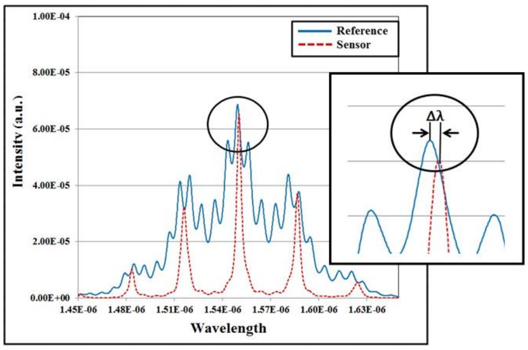
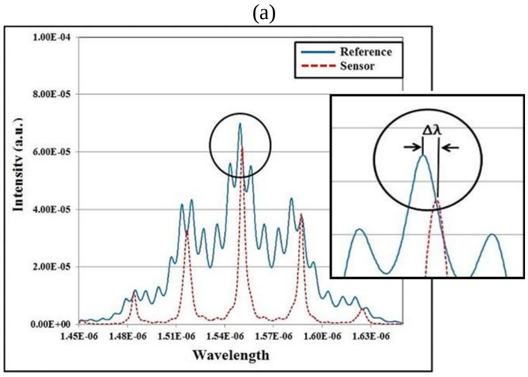


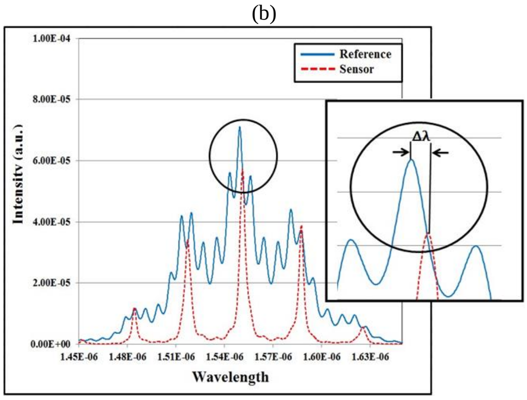
Figure 2. Schematic diagram of principles and the experimental concepts.



(a)



(b)



(c)

Figure 3. Shows the relationship between intensity and wavelength of sensing (E_R) and reference signals (E_L), with the radius R_L (blue line) and R_R (red line) is varying form 3.249-3.254 µm, (a) R_R = 3.251 µm, (b) R_R = 3.252 µm and (c) R_R = 3.253 µm

IV. RESULTS

The simulation results in Fig. 3 show the relationship between intensity and wavelength shift (Δλ) of sensing (E_R) and reference signals (E_L), which the self-calibration sensing transducer is formed. Finally from Fig. 4 the relationships between forces and the wavelength shift of the sensing signal are plotted. The linearity relationship between the applied force (contraction of muscle) and wavelength shift with is formed, which are shown in suitable linearity for muscle sensing application.

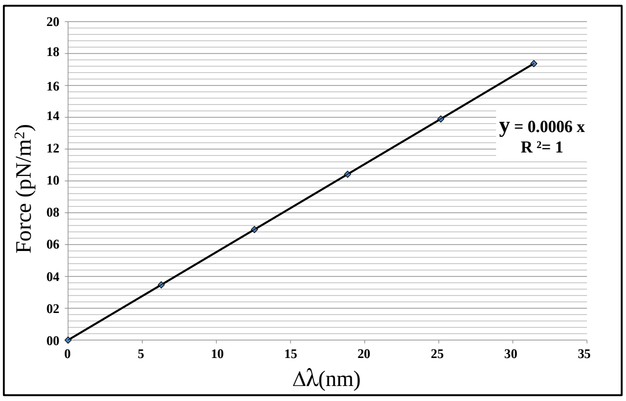


Figure 4. Graph of the linear relationship between force and the wavelength shift (Δλ)

V. CONCLUSION

We have proposed the extended application of a force sensing device to be used in the measurement of muscle contraction and movement. In principle, the MOS acts as an optical sensor to measure and detect changes of wavelength that lead to its refractive index change and optical path length, where the contraction or deformation of the muscle is directly perturbed into the sensing unit, which affects a the optical path length changes. The simulation results show that a change in the sensing radius is associated with a change in wavelength, which is measured and obtained by the difference between the sensing and reference signals. These signals can be used to generate pattern recognition and development for new human computer interface applications.

ACKNOWLEDGMENT

This work is partially supported by the Faculty of Science, Naresuan University, Thailand. Lastly, the authors also gratefully acknowledge the Faculty of Science, King Mongkut's Institute of Technology Ladkrabang, Thailand, for the laboratory and research facilities.

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