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Design and Implementation Smart Respiratory Monitoring System Using Macrobend Fiber Sensor

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Abstract

In this research, the researcher decided to use the technique of macro-curvature of optical fibers in the respiratory system activity monitoring system. A micro-serrated cell was made of Teflon, through which the optical fiber suffers multiple micro-curvature depending on the number of times inhaled and exhaled. A sensor sensitivity was obtained that reached 0.815 nm/number of breaths. The microcell was fixed on the back of the seat to be pressed by the tested case.

Keywords: Macrobend, fiber sensor, Respiratory monitoring, Macrobend fiber sensor.

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تصميم وتنفيذ نظام مراقبة الجهاز التنفسي الذكي باستخدام متحسس الانحناءت الماكروي للالياف البصرية

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الخلاصة

في هذا البحث ارتى الباحث الى أستخدم تقنية الانحناء الماكروي للالياف البصرية في منظومة مراقبة نشاط الجهاز التنفسي. صنعت خلية مايكروية مسننة من مادة التفلون ومن خلالها يعاني الليف البصري انحناء مايكروي متعدد بالاعتماد على عدد مرات الشهيق والزفير .وتم الحصول على حساسية متحسس وصلت ٠٫815 نانومتر/عدد تكرار عملية التنفس حيث ثبتت الخلية المايكروية على ظهر المقعد الجلوس ليتم الضغط عليه من قبل الحالة المختبرة.

الكلمات المفتاحية: الانحناءات المايكروية، الليف البصري المتحسس، مراقبة النشاط التنفسي، متحسس الليف البصري للانحناءات المايكروية.

Introduction:

Healthy normal breathing is considered a vital sign for humans, the air containing oxygen is inhaled to the lungs, and this is what we call inhalation, as gaseous exchange occurs through the capillary membrane [1]. The resulting carbon dioxide gas is expelled from the process and released with the air through the nose or mouth and is called exhalation, and this process determines the percentage of oxygen in the blood. When a respiratory problem occurs, this manifests as a change in the respiratory rates of inhalation and exhalation, so the disease can be detected by monitoring the respiratory rate. Monitoring the respiratory rate is a vital sign used to determine the progression of the disease. An abnormal breathing rate is an important sign of a serious illness. Changes in respiratory rate are used to predict the risk of clinical events such as cardiac arrest or admission to an intensive care unit [2,3]. Research studies have been conducted on respiratory rate and demonstrated its importance in distinguishing between stable and dangerous patients compared to monitoring biometrics such as pulse and blood pressure [4]. Changes in respiratory rate were used to classify patients as high risk for up to 24 hours before the risk occurred [3]. Hence the importance of the respiratory monitoring system, as many researchers have conducted many researches to monitor the breathing process.

Respiratory rate monitors are classified as contact or non-contact. During the contact respiratory rate monitoring process, the device is in direct contact with the body. For the second category, the non-contact process is carried out remotely.

Contactless breathing monitoring methods have the advantage of improving patient comfort (particularly for long-term monitoring) and are not associated with an instrument that causes dyspnea that may alter respiratory rate.

In general, episodic respiratory rate monitoring systems rely on a measurement of one of the following variables: breathing sounds, respiratory airflow velocity, chest and abdominal movements caused by breathing, respiratory carbon dioxide emission and oxygen intake.

The normal respiratory rate for adults at rest is 12-20 breaths per minute. People with respiratory rates less than 12 and more than 20 per minute may have breathing problems, while a respiratory rate above 24 is very dangerous. The normal respiratory rate in children is more than in adults, and also varies by age, and these rates include by ages as follows [5]:

Table(1 The normal respiratory rate)

Age	normal respiratory rate
Newborns	30 to 60 breaths per minute
Infants	1 to 12 months 30 to 60 breaths per minute
Children from 1 to 2 years	24 to 40 breaths per minute
Children 3 to 5 years old	22 to 34 breaths per minute
Children 6 to 12 years old	18 to 30 breaths per minute
Adolescents aged 13 to 17 years	12 to 16 breaths per minute
rate for adults at rest	12-20 breaths per minute,24 danger

It is worth noting that the normal respiratory rate is higher in men and the elderly than in women.

There are three types of breathing. (1) Diaphragmatic breathing: the main stretching in the abdomen and lateral parts. (2) Upper costal breathing: the chest expands more; and (3) a combination of diaphragmatic and upper rib breathing. Diaphragmatic breathing is the best, as the lungs expand in the largest form and result in the highest gas exchange [4; 5]. The three methods of breathing cause different parts of the human torso to stretch, which can be distinguished by measuring the change in pressure in different parts of the torso.

The optical fiber sensor is well suited B for optimal long-range monitoring to enhance convenience and versatility [6]. Other advantages of optical fiber sensors compared to electrical or chemical devices are that they are not affected by electromagnetic fields, light weight, small size, in addition to their resistance to water and corrosion [3; 7]. It is considered that they are not affected by electromagnetic fields of great importance, because most hospital devices emit electromagnetic rays [8].

An electronic sensor based on the principle of capacitance change [1], another sensor works on the principle of thermoelectric power generation and pressure [2], and other researchers used a Bragg grooving sensor [4; 5] and others worked on the principle of macro-bending optical fiber [3]. In hospitals really used to monitor the respiratory system is to count the number of times the chest rises or falls per minute [7]. Hence the idea of monitoring the respiratory system continuously and in real time with optical fibers, which is characterized by its flexibility and low cost. It is not affected by electromagnetic interference, such as magnetic resonance imaging (MRI) and computerized tomography (CT) and does not produce heat [8].

Other designs relied on losses resulting from bending, or vibrations caused by air flow during the breathing process, which affect the intensity of the optical signal [9], and another design relied on the stress obtained on a cantilever proportional to the amount of air flow on the FBG sensor [9; 10].

Working principle of optical fiber macro-bending cell in breathing sensor

The FOMBS system contains a 650nm semiconductor laser, a macro-bending cell and optical fiber spectrometer. The macro bending cell contains a series of teeth to corrugate the optical fibers that pass through it, and springs are installed at its corners to prevent abnormal loading and damage to the optical fibers. The bending cell is somewhat similar to a saw tooth in FOMBS.

The cell consists of two plates corrugated to become serrated with mechanical cycles. The sensitive fibers pass from the middle of the dentate plates and will bend due to the effect of dental pressure. When the dentate cell is exposed to external disturbance, it will change the degree of curvature of the sensitive optical fibers and thus cause the energy of the main mode i.e. the cladding to leak, and this will change the energy received from the other side of the fiber. The change in the degree of disturbance is recorded by recording the output power.

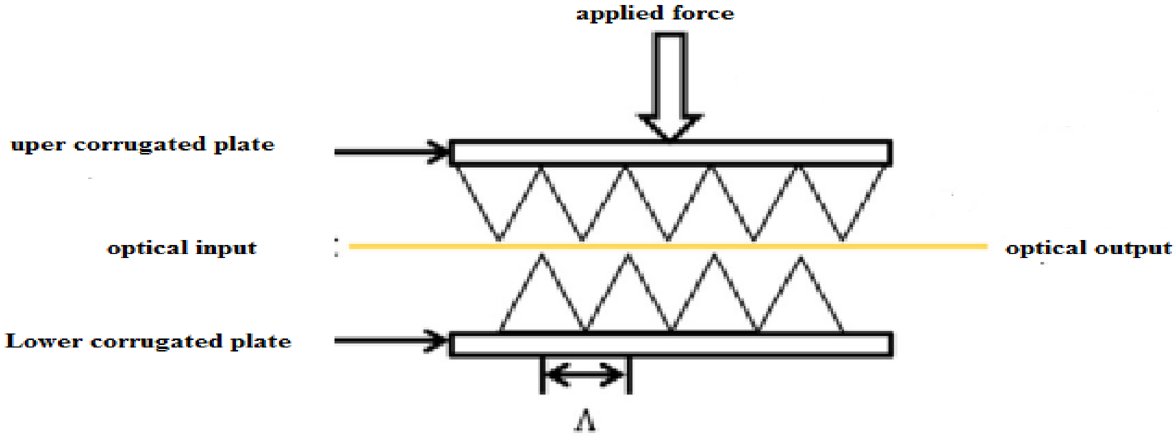

Fig (1): Represents the micro-curvature cell

The beta coefficient of the optical fiber constant, and under normal conditions, its value is confined to this formula n2k0 < □< n1k0 (n1, n2) is the refractive indecess of the core and clad, k0 = 2□ /□ is the coefficient of wave propagation in the vacuum state.

FOMBS is a typical Intensity modulation fiber optic sensor. The effect of loss of intensity due to partial bending of optical fibers is used to detect changes in external physical quantities. The diagram shown in the Figure (1) represents the macro-curvature cell. The optical fiber passes through the middle of the winding plate. By having an outside effect on the cell. The optical fiber bends periodically. The bending degree of optical fiber changes depending on external influence. The value of the external influence is revealed through the change in the loss of light energy. The following steps must be followed when using a macro-bending cell. The fibers are penetrated from both sides. Initially, the toothed plates are free without pressure on the fibers. A helical spring with a shaft is placed at each corner of the cell in order to make the sawtooth away from the optical fibers at an appropriate distance. Insert the optical source into the optical fiber after completing the initialization of the bending cell. The principle of operation of the micro-bent fiber sensor is to produce a corresponding displacement by the teeth of the upper plate as a result of the effect of the breathing force on the upper part of the toothed plate. A power loss will result from partial bending of the optical fiber. By removing the external influence, the upper serrated plate will return to its original position as a result of the elastic force of the spring. So breathing force can be detected by observing the frequency of breathing.

The rate of small bending losses for multimode optical fibers is noted. that with decreasing diameter

The bending loss increases sharply when the force applied to the locally manufactured models is increased, the resulting beam strength decreases and it slips into the direction of low energy with long lengths. The multi-mode optical fiber was placed in the micro-bending cell of the optical fiber.

The curvature cell has been developed to facilitate the process of being affected by inhalation and exhalation to achieve breathing monitoring.

The basic scheme for the design of the cell was based on the given equilateral triangle. The pointed ends were treated and made into arcs to prevent damage to the fibers. The design is shown in Figure (1).

The height of the triangle is inferred as follows. The hypothetical change of the height of the small curvature modulator and the triangle ABC respectively H and h. Λ is tooth bitch. The triangular tooth on either side of the tangent to the radius of curvature of the arc is R.

AO- /(Λ/2) = h/ H (1)

36 ΔABO' so =AOO'36

AO/ h = R/ AB = R/ (AO'2 + h2)1/2 (2)

B=(AO'2 + h2)1/2 (3)

/2 / H = R/(AO'2 + h2)1/2 =(R/ (Λ ·h/ 2H) 2 + h2)1/2 = R /h(1 + Λ 2/ 4H2)1/2 (4) h = 2HR/ Λ (1 + Λ 2/ 4H2)1/2 (5)

H = √ 3/ 2 , so

h = (3/ 2) R (6)

From the equation of the cosine asymptote, the displacement is set to X, that is, the small curvature modulator moves down the distance X. According to the actual curvature of the fiber, the equation of the curved part f(x).

f(x) = X /2 cos((2π/Λ) t)t ∈ [0, N]

R = (1 + f 2(x))3/2 /|f' (x)|

From the equation, the N, R represents the number of small bending turns and the bending radius, respectively.

The number of partial bending N has a significant effect on the bending loss. If the small bending cycle times are more, when T (T = 6) is constant, the slope of the curve is greater.

To increase the sensitivity of the sensor the number of teeth should be increased as much as possible while the size of the sensor is available.

The total curvature losses of the macro-curvature are represented by:

$$\text{Loss} = -10 \int_{t=o}^{t=NA} -2\alpha\,(1 + f\,2(X))\,dt$$

Practical Side

In this research, a macro-curvature cell with a mechanical frequency equal to 8 was manufactured from Teflon, which was placed at the corners of the cell by a rod inside a spring to prevent fiber damage and the return of the corrugated panels to their original position after removing the influent. The cell is fixed on the backrest of the test chair so that when the patient sits on the chair, was relied on the macro-cell to include information about the change in respiratory states for different situations such as the source position without influence, breathing in a sitting position, breathing in a walking position and breathing in a running state.

The schematic of the practical part shown in Figure (2), which consists of a laser source with a wavelength of 650 nm and a multi-mode optical fiber that is fed by the laser and passes through the cell with macro-curvatures, which translates the state of the respiratory system by changing the pressure force on the cell by changing the breathing state.

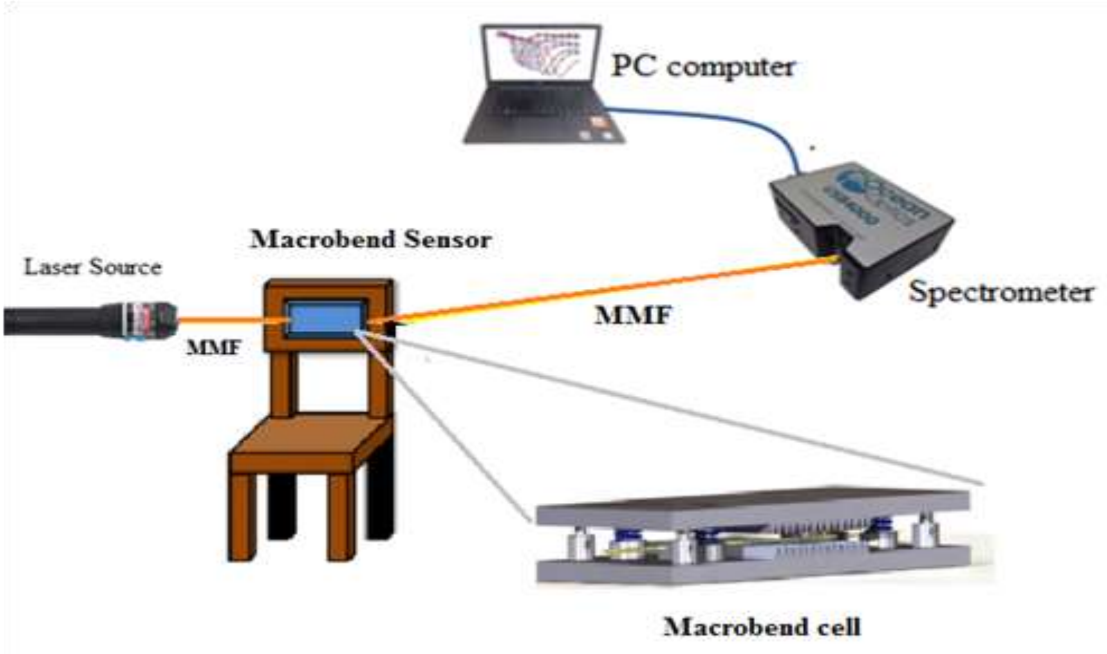

Fig (2): Experimental setup

Results:

The normal breathing rate in the case of resting without effort was 12 breaths / min, while in the case of sitting it amounted to 14 breaths/min and when walking it was 17 breaths/min and when walking fast it was 19 breaths/min in the case of jogging it amounted to 22 breaths/min.

Each case was tested by applying it to the system and recording the intensity of the transmission spectrum in each case, where it was 3222.27 at the wavelength of 662.2 nm for the case without any effort, followed by the sitting state, and it reached 3142.43 at the wavelength of 663.88 nm and in the case of walking the intensity was 3043.55 at the wavelength of 664.78 nm and in the case of fast walking 2893.28 At the peak of a wavelength of 667.46 nm and the last in the running state

2821.54 at a wavelength of 669.7 nm.

Figure (3) illustrated the relationship resulting from the change in the person's activity status when resting, sitting, walking, fast walking and jogging. It is clear from the figure that in the case of sitting, the visual intensity is higher than in the case of walking and jogging. This is due to the fact that in the case of walking and jogging, the number of times of inhalation and exhalation increases and therefore the force applied to the macro-cell increases. The losses increase with the shift towards long wavelengths as the breathing speed increases. The linear relationship between breathing states and the wavelength shift is shown in Figure (4). Where the sensitivity was calculated as 0.815nm/no.bearth and the R2 =0.980.

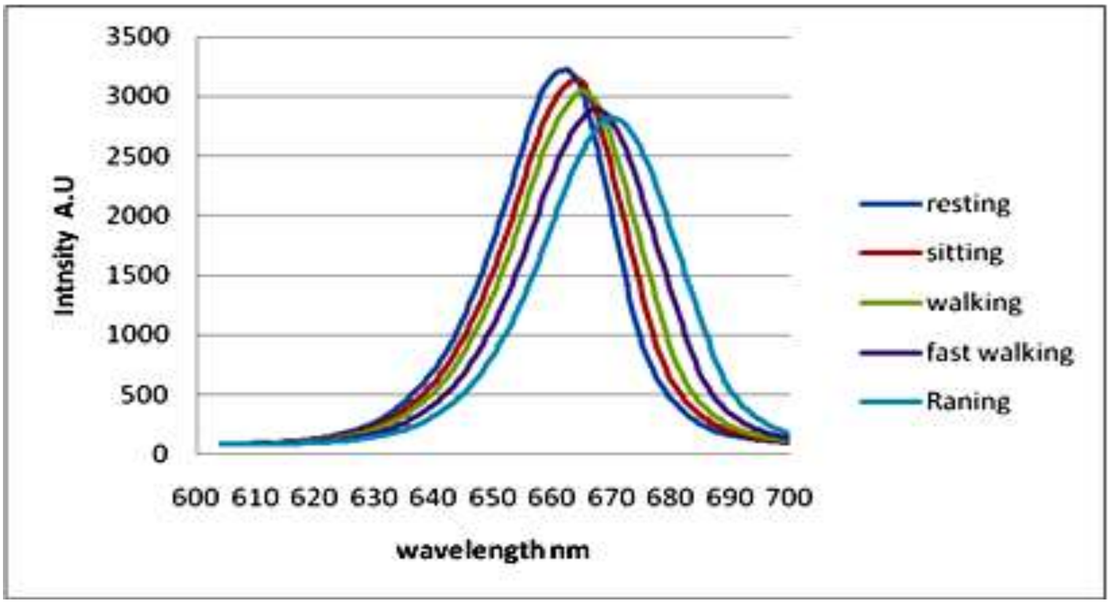

Fig. (3): Transmission Spectrum for different case.

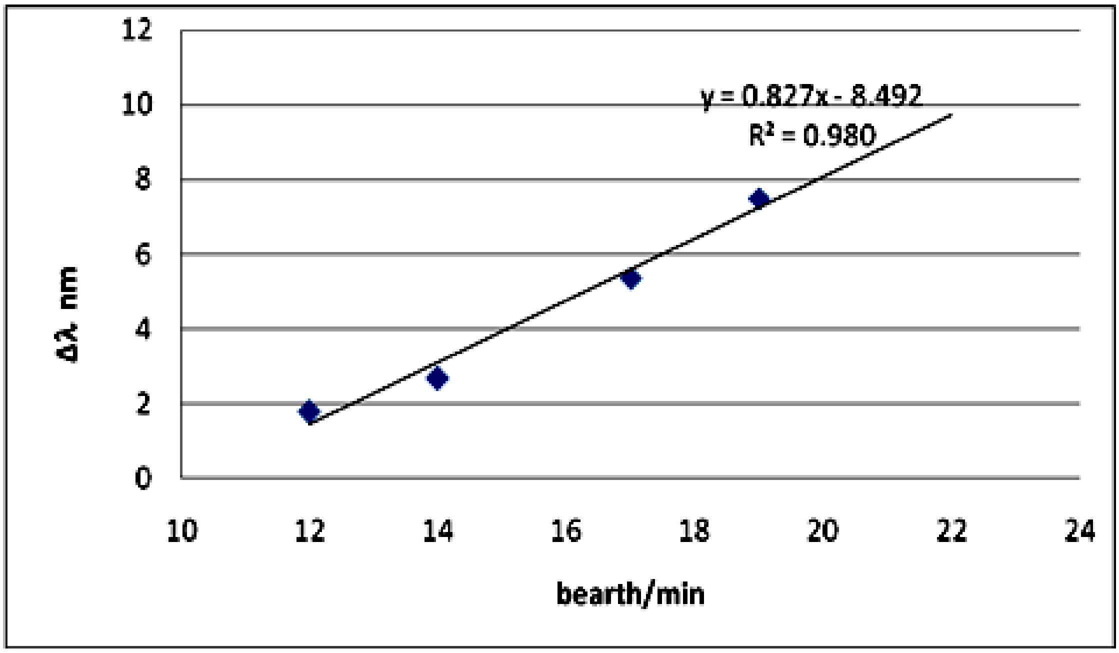

Fig. (4): The relationship between No. breath and wavelength shifting at different case.

Conclusions:

The design and implementation of a macro sensor using optical fibers passing through a macro cell that is affected by the effectiveness of the respiratory system. The sensor has been proven to be unaffected by electromagnetic fields, the accuracy and stability of the work, and its impact on the inhalation and exhalation process resulting from the activity such as a jolt or exercise. This effect was exploited to manufacture a sensor to determine the effectiveness of the optical system using a macrocell using optical fibers.

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