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Optical Communication System for Online Detection of Illicit Drug in Border Ports

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Abstract: In this study, we develop inspection technique for illicit drug detection based on optical communication system. This technique based on optical transmitter, chemical fiber Bragg grating sensor and optical receiver. The developed system detect and identified the concealed illicit drug. All samples are identified by their spectral shift extracted from refractive index (absorption) variation. Classification of the samples is achieved by using artificial neural network (LM) algorithm with rate of accuracy above 90%.

Key words: Optical transmitter, chmeical fiber sensor, optical reciver, artificial neural network, inspection, refractive index

INTRODUCTION

Illicit drugis the one of the most problems that difficult to control in Iraq. Many technique have been used for detection illicit drug in border ports such as manual handling, this method cause time consuming and considered not effective because it is easy to miss concealed items during searches and its operation. Use sniffer dogs but this method very expensive because we need specially trainer and also causing inconvenience to passengers at airports. There are other technologies that we will address here in our research such as optical fiber sensing technology which is a promising technology with a great future. The abundance of fiber optic technology has many advantages when compared to other technologies such as small size, light weight, low manufacturing cost, the same use of optical fiber for different measurements, remote sensing potential. All these advantages have made researchers in recent years rely on the use of fiber optic in various scientific applications (Filazi *et al*., 2012). Optical fiber sensors are sensors that are resistant to different environmental conditions such as working in the chemical or physical field. It also has immunity to electromagnetic interference (Saravanan and Sasithra, 2014).

Work principle of optical fiber sensor for illicit drug detection is based on use optical wave that applied on selected sample. The optical wave applied to the sample can be either coherent or non-coherent. In this research, we used a laser with different wavelengths that fall within the infrared band. This band is characterized by low photon energy not cause risk when exposed because of its inability to cause ionization in the human body. The main elements of the proposed system optical fiber sensor such as Fiber Bragg Gratings (FBGs) represent sensing elements.

The FBG optical fiber sensor consists of a piece of optical fiber with a periodic refractive index along fiber optic axis (Chu and Wang, 2013). FBG sensors made from optical fiber as we mentioned earlier are characterized by their small size, light weight, low cost and can be used as sensors for measuring pressure and temperature and measuring chemical concentrations with very high accuracy. The use of FBG a chemical sensor is successful due to its high ability to measure the refractive index changes resulting from differing absorption of the wavelengths falling on the sample to be tested. For best results end of the sensor coated with an interactive chemical material or stick to the end sensor (Mahdikhani and Bayati, 2008).

MATERIALS AND METHODS

Proposed system: The proposed system composed of four main parts: the optical (laser) source (s) an optical channel (fiber), transducer (FBG) chemical fiber sensor are used for chemical material detection and the detector (PIN) photodiode. The parts are then combined with a signal analyzing system (Artificial Neural Network (ANN)) to make final decision as shown in Fig. 1.

The laser beam used to examine samples can be transmitted through a wide range of materials such as leather bags, clothing, plastic bags, wood, cosmetics, human fabric, foodstuffs and other materials that can be used to hide narcotics. The unknown material to be detected will absorb various wavelengths in a variable manner depending on the wavelength used. The process of changing the absorbance of the optical intensity falling on the unknown material causes a change in the refractive index of the optical sensor in proportion to the absorption coefficient of the material. The change of the refractive index causes variable spectral displacements proportional to the change of sensor refractive index where it is used.

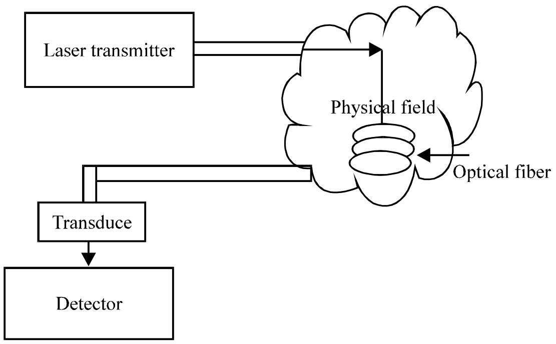

Fig. 1: Schematic illustration connection between laser transmitter, sensing area and optical receiver (Lucarini *et al*., 2005)

Optical transmitter: The design of the detection system requires three main parts as mentioned above. The first is a light source that is used to generate light signals with different wavelengths used to excite the optical sensor. Transmitter circuit of optical communication system consist of a light source and associated electronics circuitry. The source can be a light-emitting diode or laserdiode. Semiconductor laser or LED are used as optical source because of their compact nature and compatibility with optical fibers.

The source used in the proposed system emit signals at variable wavelengths within the infrared region (50-600 μm) with variable power from 1-100 mW. The source is connected to the transmission channel which is the optical fiber and then the wave is collect by the optical sensor FBG where the shiftwave is monitored as a result of the change of sensor refractive index.

The reflected signals from FBG chemical sensor are transmitted to PIN detector. The PIN detector convert optical signal to electrical signal all the collected data process with ANN to make the final decision for the unknown illicit materials.

Optical receiver: The detector is a fundamental segment of an optical fiber system and is one of the significant components which direct the general system performance. The photodiode (PIN) that detect the weakened optical signal emerging from the end of an optical FBG through optical fiber to change optical signal into an electrical signal which is then amplified before additionally processing (Dakin and Culshaw, 1988).

The producecurrent depend on the absorption coefficient α_0 of the light in the semiconductor material. Ipis the current result from incidentlight and the optical Power P_0 is given by Lecler and Meyrueis (2012):

$$I_P = \frac{P_0 e(1\text{-}r)}{hf}\left[1\text{-}\exp\left(\text{-}\alpha_0 d\right)\right] \tag{1}$$

Where:

e = The electron charge
r = Fresnel reflection coefficient at the interface of semiconductor air
d = The width of the absorption region

The absorption coefficients strongly dependent on wavelength of semiconductor materials.

Optical fiber sensor: Optical fibers are widely used in optical communications systems while in the recent years has been the use of this fiber in sensor field to measure the various physical and chemical quantities. In optical sensing technology one can measure the physical quantity and a very large number of chemical quantities (Shizhuo *et al*., 2008). Figure 1 shows the most important physical principles of the work of sensors which shows the interaction of light with the material. There are two main ways to design chemical sensors, direct and indirect methods. The sensors used in the field of drugs and biology use the near-infrared spectrum of their research (Pospisilova *et al*., 2015; Norris, 2000).

Exterior design: Scheme 1 explains the use of the external design of the optical sensors where the optical fiber acts as a guide to the sensor area that located outside the optic fiber (Lucarini *et al*., 2005). The fiber used as transfer medium to the light from the light source to the receiver but the modulation occurs outside the fiber transducer. The light leaves the fiber to be changed before it continues to the detector. By means of the return or receiving fiber and work as a transmission channel in this type of sensors. The core sensing mechanism of this type including guide the light from one side to another and launch it again after laser signal interact with detecting medium. Extrinsic sensors was used in real applications as shown in Fig. 2 (Fang *et al*., 2012).

Interior design: The intrinsic sensors, configuration has two functions: it's used to guide light in fiber channel (sensor), the second one used as transducer. The second kind of optical sensor is called the interior design. It depends mainly on modifying the characteristics of optical fibers such as the refractive index or absorbance when passing the material and labeling internally because the light stays inside the fiber and does not go out to the sensor area.

Depending on the variable value, the final change of the transmitted radiation will vary as it happens in evanescence sensors (Senior and Jamro, 2009). The

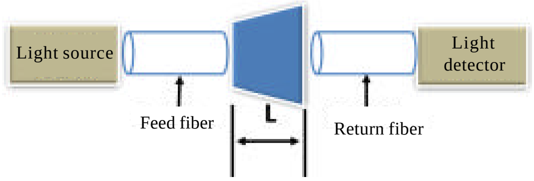

Fig. 2: Schematic illustration of the extrinsic fiber sensor

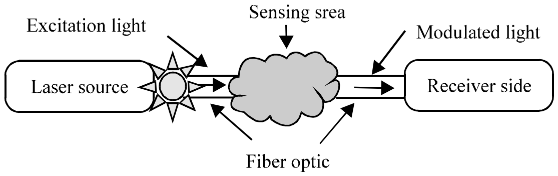

Fig. 3: Schematic illustration of intrinsic fiber sensor

transducer function is converts the physical value that be measure into an optical information. This will be occur in an intrinsic optical fiber sensor. In any intrinsic sensor the fiber itself is the sensing element. Where the fiber is directly affected by the measure area. This scheme shown in Fig. 3 where the light signal does not escape from the fiber but is always varied whilst exist contained within it (Poeggel *et al*., 2015).

The collected light signal contains all information about the materials to be detect such as refractive index, absorption spectrawhere. Laser signal has been modulate if interact with detect material. The modulation mechanism included change carrier parameters such as frequency (wavelength), power (intensity) and phase. The detection system depend on laser light source, photo PIN detector. The detect signal through opticalfiber sensoris depend on replacing a cladding segment by a material sensitive to the chemical compound. In this case, it suffer from change due to new cladding that is effect on the light passing through segment this is because the sensitivity of the sensor depends on the optical power rounded or coupled to the evanescent field causing penetration deeply into the modified cladding. The travel light through fiber depend on the ratio of refractive index between cores to cladding.

Chemical Fiber Sensor (CFS): The optical chemical fiber sensor like fiber sensor its waveguide structure that supports Electromagnetic (EM) waves. The electromagnetic waves are transmitted within the optical fiber with the Total Internal Reflection (TIR) and suffer from reflection and absorption during the transmission to the sensor area. There are a number of factors that determine the efficiency of the chemical fiber sensor design, including the type and efficiency of the sensitive material coated to the optical fiber tip as well as the type of light source, the efficiency of the receiving circuit and its ability to process the data as well as the programs used in the analysis of the data. The best method for manufacturing chemical fiber sensor is to remove a part of cladding, permit the evanescent field at the core boundary interact directly with the analyte (Culshaw, 2004). CFS used for measured the spectral shift and concentration of selected test sample. The operation explained by two steps. The step number one identifies targetand interacts with analytic, the second one is a transducer, the collected signal and then coupled to the first step (Lucarini *et al*., 2005). In identification mechanism the sensor detect area interacts with unknown material producing a changing in sensor parameters such as vibrational, chemical reactions, etc. this change in parameters used to material recognition. The optical response of sensors (chemical fiber sensors) based on sample concentration and used to classify the materials depend on reflectance, fluorescence, refraction index, etc. When we use optical fibers as sensors, fiber can be usedas an optrode.

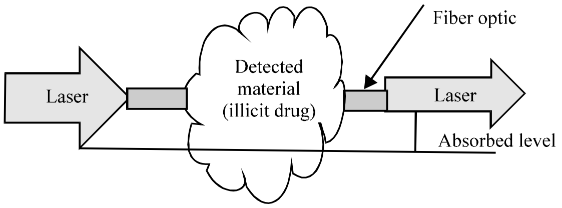

Fig. 4: Chemical sensoroptical fiber

Mathematical model of CFS: Optical sensors based upon spectral (wavelength) shift shown in Fig. 4 are manufactured for specific application. Hence, these sensors use a range of wavelengths and depend on light intensity fluctuation when incidenton test material through the sample (Lucarini *et al*., 2005).

The chemical sensor used in external configuration schemes, Fig. 5 including reactive substances inside the fiber that cause increase response time many fiber sensor used single fiber or bifurcated fiber. In any design case chemical sensor locate at the fiber end (Lucarini *et al*., 2005).

The light propagation in optical fiber govern by Maxwell equations, the propagation of the electromagnetic field inside the single mode fiber is governed by the wave (Eq. 2):

$$\nabla^2 E = \frac{\in}{c^2}\frac{\partial^2 E}{\partial^2 t^2} = 0 \qquad (2)$$

Where:
C = Velocity of light
ϵ = Dielectric constant of the medium

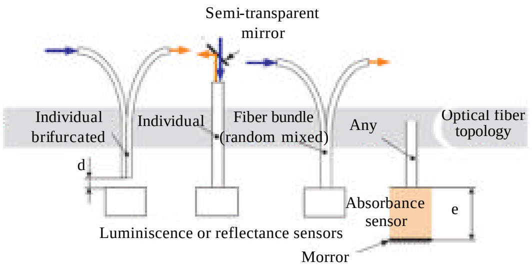

Fig. 5: Chemical sensorsoptical fiber topology (Lucarini *et al*., 2005)

Assuming the input light wave is linearly polarized and remain linearly during propagation inside fiber Bragg, the electric field inside the fiber can be written as:

$$E(x, y, z, t) = \frac{\hat{x}1}{2}\left\{F(x, y)A(z, t)\exp^{[j(k_0 z-\omega t)]+c.c}\right\} \quad (3)$$

Where:

$\hat{x}$ = Polarization unit vector

F(x, y) = Wave guide mode dispersion

A(z, t) = Slowly varying envelop associated with optical pulse

The complex amplitude relate to intensity of the signals as shown:

$$A(z, t) = S(z, t)\exp^{j\varnothing(z,t)} \quad (4)$$

Sub Eq. 3 into Eq. 4, neglecting the second derivative of A(z, t) with respect to z and t and integrating over the transverse dimensions and also take the internal losses into account yields:

$$\frac{\partial A}{\partial Z}+\frac{1}{v_g}\frac{\partial A}{\partial t} = \frac{j\omega_0}{2\tilde{n}c}x(N)A(z,t)-\frac{1}{2}\alpha_{in}A(z,t) \quad (5)$$

where, α_{in} = internal loss. Now, we study the behavior of optical pulse in FBG by modified Eq. 5 to include the forward and backward direction (Elosua *et al*., 2012):

$$i\frac{\partial A_f}{\partial z}+\frac{i}{v_g}\frac{\partial A_f}{\partial t}+\delta A_f+KA_b+\gamma\left(|A_f|^2+2|A_b|^2\right)A_f = 0 \quad (6)$$

$$i\frac{\partial A_b}{\partial z}+\frac{i}{v_g}\frac{\partial A_b}{\partial t}+\delta A_b+KA_f+\gamma\left(|A_f|^2+2|A_b|^2\right)A_b = 0 \quad (7)$$

Where:

γ = Nonlinear factor

δ = Detuning factor

K = The coupling coefficient

In general, the refractive index n is a complex number expressed as (Thakral and Manhas, 2011):

$$n = n_r+jn_i \quad (8)$$

Where:

n_r = Called real part and its known from Snell's law the second part is the imaginary part

n_i = Connected with α_a

(usually it is used in absorption spectroscopy) by the relation (Mauer *et al*., 2009):

$$n_i = \frac{\alpha_a(\lambda)*\lambda}{4\pi} \quad (9)$$

The concentration of the material to be tested and monitoring depends on the absorption factor $\alpha_a(\lambda)$ (refractive index n) and the wavelength λ and is calculated as follows (Gao *et al*., 2014):

$$\log\frac{I_0(\lambda)}{I(\lambda)} = \alpha_a(\lambda) = \varepsilon Cd \quad (10)$$

Where:

ε = The extinction coefficient (molarextinction coefficient) of the test sample

C = Theconcentration of the test sample

D = Optical path length in the sample

The absorption coefficient depends mainly on the wavelength used as shown previously which is a function of a physical or chemical parameter of the medium to be tested. The transmissivity of launched light source can be modeled Transmissivity T calculated as given (Federici *et al*., 2005):

$$T=\{[1-[\frac{(n-1)}{(n+1)}^2]\}^2 \quad (11)$$

The attenuation coefficient of the test sample (fingerprint of the test material) can be determine (Murdasp, 2012):

$$\alpha(\lambda) = -\ln\left(\frac{-T^2+\sqrt{T^4+4T_{total}^2R^2}}{2T_{total}R^2}\right) \quad (12)$$

Where:

T = Llight transmittance

R = Llight reflectance

CFS operating principle: Chemical Fiber Sensor (CFS) is a part from Fiber Bragg Grating (FBG) sensors can be used in different applications.

When the laser pulse striking the material reflected wave generated and impinging the FBG and Bragg wavelength shifted because refractive index change according to Eq. 16 and 17. The laser intensity pulse from semiconductor laser can be describe as (Saracoglu and Hayber, 2016):

$$I_{Laser}\left(r, t\right) = \frac{2p_0}{\pi^{\frac{3}{2}} w_0^2} \exp\exp\left(-k\frac{2r^2}{w_0^2} - \frac{t^2}{\tau_p^2}\right) \tag{13}$$

Where:

I_{FBG} = The light intensity with distance
r = From ray axis
τ = The time width

When this laser pulse injected into optical fiber, the laser energy will absorbed by test sample, the absorption occur at different spectrum and causing refractive index change the impinging area as (Wren *et al*., 2014):

$$S_{FBG}\left(r, t\right) = \frac{\partial I_A}{\partial t} = k(1+c)\frac{\partial I_{Laser}}{\partial t} \tag{14}$$

Where:

$I_{FBG} = k(1+c)I_{laser}$ = Absorption light intensity by sample
$k = a_o{*}d$ = A constant
a_o = Absorption
d = The medium thickness

The reflected wave created, this wave striking the FBG. Where the Bragg conditions descried as (Shizhuo *et al*., 2008; Guifeng *et al*., 2010):

$$\lambda_B = 2n_{eff}\Lambda \tag{15}$$

This equation represent core equation of FBG, any refractive index variation or grating period can detected by FBG. The change in refractive index due to test of illicit drug sample (Eq. 16 and 17). Produce change in grating period:

$$\Delta\Lambda = \varepsilon\Lambda \tag{16}$$

The spectral change in FBG $\Delta\lambda_B$ results from any change in grating period $\Delta\Lambda$ or refractive index Δn:

$$\Delta\lambda_B = 2n\Delta\Lambda + 2\Lambda\Delta n \tag{17}$$

In order to get the accurate recognition of illicit drug (cocaine) species, we measure the spectral shift of illicit drug (cocaine) sample where the spectral shiftresult from refractive index variation represent the finger print of the materials and it use to identification the material in important application.

The absorption process is the energy transfer (coupled) from the light to certain modes of the sample. A light beam illuminating a cocaine samples range (50-600 μm) which gives optical absorption spectroscopy, as shown in Fig. 6-11. The light spectral shift of FBG result from absorption spectrum can be considered an optical signature (finger print) of the cocaine detection in border ports. All the results showed the increasing of refractive index with increasing the cocaine concentration and as result increasing the absorbance of the sample producing large refractive index variation as shown in Fig. 8. The spectral shift (wavelength shift) of FBG, refractive index data was used to train the neural network to identify the cocaine samples according to two sets one the training set contain cocaine concentrations and the other control set pure cocaine concentrations.

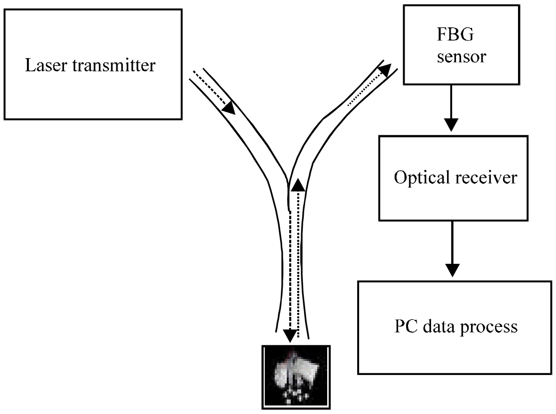

Fig. 6: Structure of the proposed system

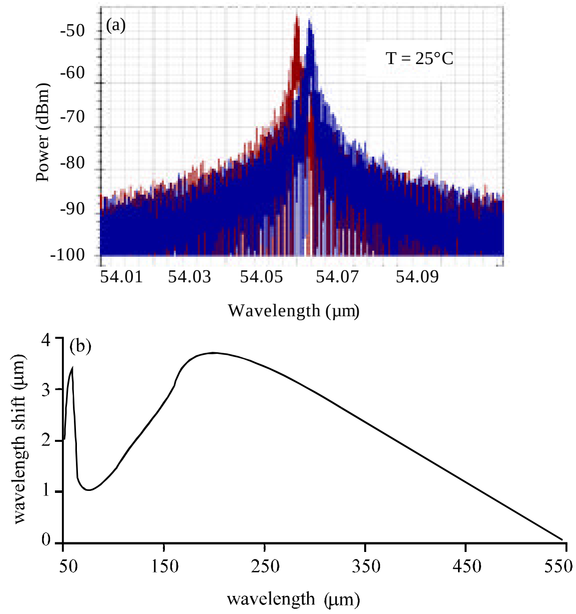

Fig. 7: a, b) Wavelength shift of FBG of the proposed work; Dual part optical spectrum analyzer (FBG sensor)

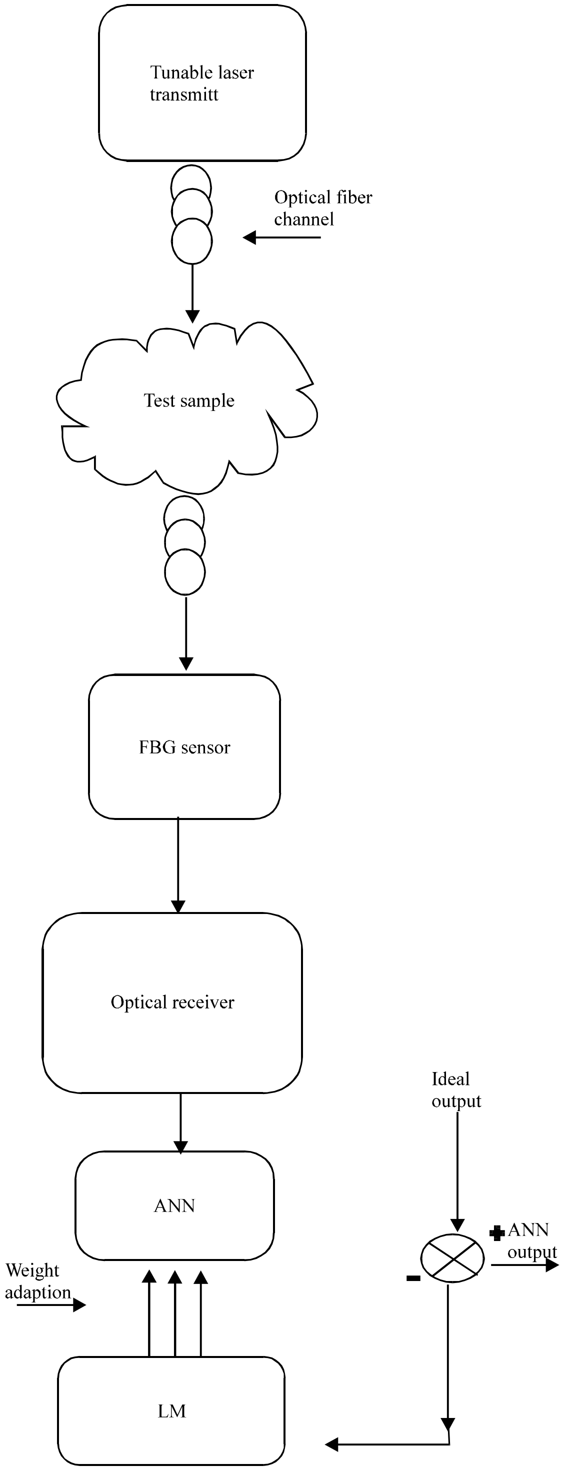

Fig. 8: Flowchart of the proposed work

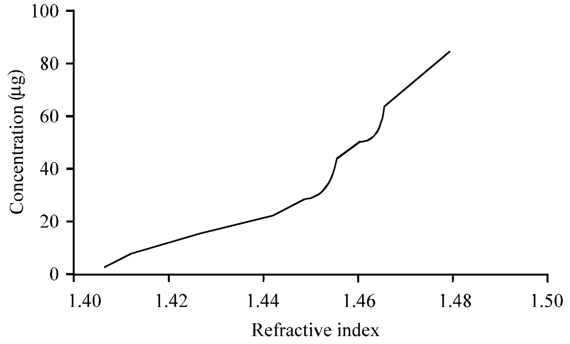

Fig. 9: Variation of refractive index with cocaine concentration; Calculation at wavelength 5633 nm

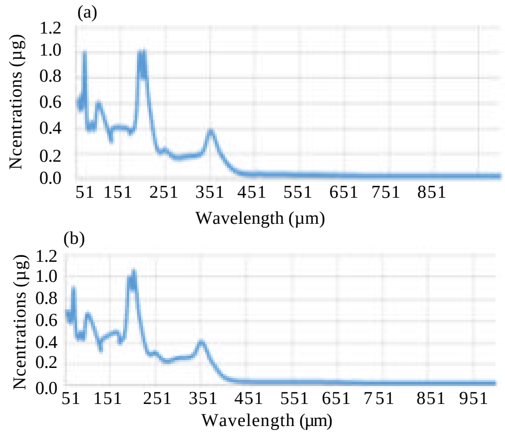

Fig. 10: a, b) Respectively, typical absorption spectra of illicit sample with cocaine at various concentrations: a) Cocaine 5 µg and b) Cocaine 10 µg

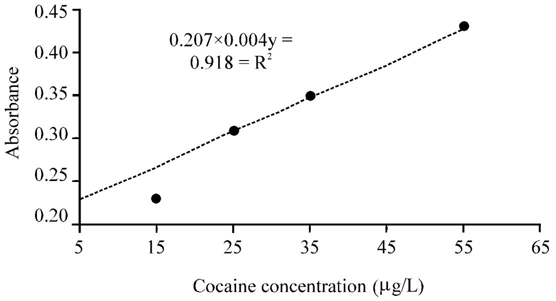

Fig. 11: Typical graph for thevariation of melamine concentration with absorbance of the milk sample; Absorption spectrum of cocaine sample at 5532 nm

Spectral shift from refractive indexesvariation represent the main physical property of a substance where it's used for its identification. Cocaine have refractive indices that depend on concentration and absorption wavelength of the sample. The accurate detection and identification was based on the combination of spectral shift result, refractive index of cocaine at specific concentration and wavelength.

RESULTS AND DISCUSSION

Figure 7a,b illustrate the relationship between the wavelength shift of the fiber Bragg grating chemical sensor (Δλ) and wavelength (λ) ofthelaser source. Can note from this figure the variation of wavelength shift depend strongly on the selected laser wavelength source at constant sample (cocaine) concentration, thickness Eq. 10 because refractive index of the fiber chemical sensor change according to selected wavelength of laser source (Eq. 13 and 15). The main cause of refractive index variation result from variation of attenuation coefficient at selected wavelength (Eq. 9). All the collected data from Fig. 7b can be used for adapted weight of ANN to identify the test sample.

All the results for refractive index were reported as shown in Table 1 and plotted as shown in Fig. 7b for different cocaine concentration. The receiver reading reported for optical fiber sensor. We can note from the receiver reading of CFS the wavelength shift variationaccording refractive index variation and related with absorption coefficient at specific wavelength with constant cocaine concentration.

The recorded data by Chemical Fiber Sensor (CFS) for wavelength shift based on refractive index, absorption coefficient used as pattern recognition, arrange as input vectors in a matrix form of the artificial neural networks. And another vector called target vector was indicate the classes at which the input vectors are assigned to detect the illicit drug (cocaine) material in the border port as shown in Fig. 8.

The number of neurons in hidden layer depend mainly on the classified problem. For the number of the neurons in input layer based on number of attributes while for the output layer depends on class attributes. In this research, the neural network was simulated according the flowchart in Fig. 8, Table 2 and Fig. 8 (wave shift) the performance parameter of forward feed type with 25 neurons at input layer, 3 hidden layers containing 8, 10 and 4, neurons, respectively and 1 neuron atoutput layer. The sigmoid function were used in the hidden layers. While the response to the output neuron is linear. The LM BP algorithms are used to train the network. Where the training data was used from the read out of the CFS sensor. The output of the recognized materials by using ANNs trained by LM-BP algorithms were a make decision on classification shown in Table 3.

Figure 9 shows the variation of refractive index versus cocaine concentration. It is clearly seen from the observed result that with enhancing the cocaine concentration, the refractive index was also increased which revealed that the refractive index of the sample has linearly relationship with cocaine concentration, the concentration sample is increased with the cocaineadded reducing the speed of light in the medium at Specific temperature creating (denser medium) high refractive index of the sample.

Table 1: Refractive index versus melamine concentrations

Cocaine concentration (μg)	Refractive index at (λ = 55 μm)
5	1.4120
10	1.4185
15	1.4276
20	1.4384
25	1.4492
35	1.4587
45	1.4610
55	1.4690
65	1.4713
75	1.4785
85	1.4846

Table 2: Performance parameters of designed system

Specification	LM
Number of iteration	90/1000 iterations
MSE	5.22*10-13
Time (sec)	30
Accuracy	90 (%)

Table 3: Detection based wavelength shift variation

Materials	1	2	3	4	5
Cocaine free base	Y	N	N	N	N
Cocaine hydrochloride	N	Y	N	N	N
Morphine (Guifeng *et al*., 2010)	N	N	Y	N	N
Pethidine hydrochloride (Guifeng *et al*., 2010)	N	N	N	Y	N
Papavenine (Guifeng *et al*., 2010)	N	N	N	N	Y

Y = Decision of detection yes; N = Decision of detection no

Figure 10 shows the absorption spectra of cocaine sample with cocaine at various cocaine concentrations, i.e., 5, 10 μg. It is clear from the observed absorption spectra that the increment of cocaine concentration leads to the increasing absorbance of the sample according to Beer's law where the absorbance and concentration are linearly correlated. Figure 10 a, b shows the measurements of optical spectra for cocaine sample.

The peak absorption occur at wavelength 203 μm. The measured absorption spectra of cocaine change is reversible and may be repeated several times. The measured optical absorption spectra of samplegenerally indicate that the refractive index increases with the cocaine concentration in the cocaine sample and as the result will effect on the wavelength shift. All the reported spectral data was used as a finger print to detect and identify the cocainein the border ports by using artificial neural network.

Figure 11 shows the variation of cocaine concentration with the absorbance of the cocaine sample at wavelength 150 μm which revealed that the good linear curve is obtained with an R^2 of 0.9185 between cocaine concentration and absorbance of purecocainesample. The fitting equation for the linear curve is $Y = 0.004x+0.9185$ indicating good fitting of the system response.

CONCLUSION

The study presented a developed system to illicit drug detection. This technique based on wavelength shift of FBG sensor. The wavelength shift of FBG extracted from the refractive index variation at 25°C by absorption spectrum to form a fingerprint data base. The obtained results show that these materials have characteristic spectral shift that can be used to identify cocaine material. The Chemical Fiber Sensor (CFS) read out for cocaine supported by Artificial Neural Networks (ANN) to give fast and accurate response for detection and recognition. The LM-BP algorithms were used in this research to optimize the Wight's of ANN that will use to identification and classification of cocaine materials in the border ports. The system exhibits good performance for all system specifications such as mean square error, iteration time, accuracy rate and recognition value.

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