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Method of Infrared Thermography for Earlier Diagnostics of Gastric Colorectal and Cervical Cancer

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Abstract In this work we present a novel non-invasive method and the corresponding devices to diagnose ansinternal anomality, that is, various kinds of intrinsic cancer, in a living subject by sending a passively occurring middle-infrared (MIR) radiation signal associated with the abnormality and inside an orifice of the Diagnostics includes detection and identification of the abnormality. A device or instrument is used either to bring a sensor into the orifice (in vivo diagnosis) or to transmit the MIR signal to the device or instrument located outside of the orifice (in vitro diagnosis). The example of instrument includes a prior art endoscope or gastroscope. The corresponding test results are presented as a proof of the proposed methodology of earlier diagnostics of internal cancerous structures.

Keywords Non-invasive method · Infrared thermography · Earlier diagnostics · Gastric colorectal · Cervical cancer

1 The Field and the Background of the Research

During the recent decades it was stated a few common intrinsic cancers associated with orifices and the current art methods of diagnosis. Various embodiments were configured for detection, imaging and identification of colon cancer, cervical cancer, lung cancer, cancer of the esophagus, and stomach cancer, as well as of

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different kinds of internal tumors, lesions and other inner cancers by combined analyses of visible and infrared (IR) optical signals based on integral and spectral regimes for detection and imaging leading to earlier diagnosis and treatment of potentially dangerous conditions.

Gastric cancer is the seventh most frequent cause of cancer mortality over the world. The main screening methods for gastric cancer are:

Upper endoscopy imaging—A small visible spectral-range camera and light source are attached to a flexible guide and inserted through the throat and into the stomach of the patient. The resulting images are examined by a doctor and, if abnormalities are noted, tissue samples can be taken. This technique undergoes new improvements, like the ability to enable a zoom of magnification helping to identify the detailed surface structure [1]. Yet, this technique is a subjective and depends on the experience of the operator.

Barium upper gastrointestinal radiographs—For this test, people drink a barium-containing solution that coats the lining of the esophagus, stomach, and first portion of the small intestine, then, the radiologist takes multiple *X*-ray pictures. The accuracy of this test is not high, accomplished with other test can improve reliability [2].

Endoscopic ultrasound—A transducer probe placed into the stomach through the mouth or nose uses sound waves to produce images of internal organs. The transducer emits sound waves and detects the echoes bounced off internal organs. It is used to estimate how far cancer has spread into the wall of the stomach, to nearby tissues, and to nearby lymph nodes. To date endoscopic ultrasound is the most accurate imaging technique for staging depth of tumor invasion, not for preliminary detection [3].

Computed tomography (*CT*)—The CT scan is an *X*-ray procedure that produces detailed cross-sectional images of the stomach. Good sensitivity and accuracy are achieved with this non invasive method [4]. Main drawback is the *X*-ray radiation.

Positron emission tomography (*PET*)—In this test, radioactive glucose (sugar) is injected into the patient's vein. Because cancers use sugar much faster than normal tissues, the cancerous tissue takes up the radioactive material. A scanner can spot the radioactive deposits. This test, which is still being studied, is useful for spotting cancer that has spread beyond the stomach and can't be removed by surgery. It may be a very useful test for staging the cancer [5].

Magnetic resonance imaging (*MRI*)—MRI scans use radio waves and strong magnets. The energy from the radio waves is absorbed and then released in a pattern formed by the type of tissue and by certain diseases. A computer translates the pattern of radio waves given off by the tissues into a very detailed image of parts of the body. At present MRI appears to perform well in evaluating the local and distant extents of cancer but less well at detecting unsuspected primary tumors [6].

Endoscopic autofluorescence spectroscopy—A new technique based on emitting UV light for the excitation of tissue autofluorescence via the endoscope. Endogenous fluorescence spectra emitted by the tissue is collected with a fiberoptic probe and analyzed with a spectrograph. Yet results are not satisfactory [7].

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Colorectal cancer is the third most common malignant neoplasm worldwide. The following current methods are used for colorectal screening [8–12].

Fecal occult blood test—The presence of hidden blood is detected in the stool. Blood in the stool that is not visible is often the first warning sign that a person has a colorectal disorder. The disadvantages of this method are that it detects blood in stool, but not its cause, and false-positive and false-negative results are common. Thus a more sensitive and precise test is needed.

Flexible sigmoidoscopy and endoscopy—These techniques are similar to upper endoscopy except that the endoscope is called a sigmoidoscope or colonoscope and inserted in the rectum rather than the throat. These techniques can discover from 50 to 65 % of polyps and are subject to all of the limitations of upper endoscopy.

Virtual colonoscopy (*CT Colonoscopy*)—Refers to examination of computer-generated images of the colon from data obtained by CT or MRI machines. The performance of this non-invasive method depends heavily on the size of the lesion. It can miss polyps smaller than 10 mm and generally suffers from the limitations of CT and MRI imaging mentioned above.

DNA mutation of the stool—This new non-invasive method is based on the detection of mutations in faucal DNA. At present the cost of this technique is high and sensitivity results are the same as colonoscopy.

Barium enerma—Flow of barium is monitored on a *X*-ray fluorescence screen. This method has a low rate of detection even of large adenomas, but the technique is valuable in cases in which the colonoscopy does not reach the lesion [13].

Cervical cancer is cancer of the uterine cervix, the portion of the uterus attached to the top of the vagina. Ninety percent of cervical cancers arise from flattened or "squamouse" cells converting the cervix. Most of the remaining 10 % arise from the glandular, mucus-secreting cells of the cervical canal leading into uterus, This cancer is the second most common cancer in the women worldwide. The following methods are usually used for cervical screening and detection [8–10].

Pap smear—This screening examination is obtained by collecting a sample of cells from the cervix with a wooden or plastic spatula and brush. Specimens are placed on glass slides and examined by a special pathologist or cytologist. If abnormalities are found, women are typically asked to return for colposcopy. The quality of the pap smear technique can be compromised by inflammatory exudatem or failure to sample the transformation zone. As a result, a relatively high false-negative rate of 20 % pap smears might cause failure to diagnose pre-invasive disease.

Colposcopy—This technique uses a magnifying lens to view the surface of the cervix under white and green light after a mild vinegar solution is applied. If pathologic areas are seen, a biopsy is taken. This method is not performed in real time and has the disadvantages of other forms of visible light endoscopy as was mentioned above. Particular, visible light endoscopy is subjective and depends on physician experience alertness.

It should be stated that none of above mentioned techniques of detection of all kinds of cancers are capable of positively identifying tumors. Therefore according to current art distinguishing tumors from other benign or pathotological conditions

requires biopsy. However, biopsies have many obvious disadvantages which we briefly reflect: firstly a biopsy requires intrusive removal if tissue that can be painful and expensive. Particularly, in internal cavities and more particularly, in the stomach and intestines, biopsies run a high risk of serious simplifications. These simplifications can lead to very painful conditions, including ulcers, they can force limiting diet or activity of a patient for significant periods of time and complications may even require treatment and drastic interventions (for instance surgery). Only a very limited number of sites can be biopsed in one session. Secondly, biopsy samples must be stored and transported to a laboratory for expert analysis. Storage and transportation increase the cost, increase the possibility that samples will be mishandled, destroyed or lost, and also cause a significant time delay in receiving results. This time delay means that examination follow up requires bringing the patient back to the doctor for a separate session. This increases the inconvenience to the patient, the cost and the risk that contact will be lost or the disease will precede to a point of being untreatable, Furthermore, the waiting period causes significant anxiety to the patient, Finally, interpretation of biopsies is usually by microscopic analysis, which results in qualitative subjective results that are not well suited to consistent interpretation.

Therefore, in medical diagnosis, there is great interest improved sensitivity, safe non-operative detection technologies capable of revealing internal cancers in their earlier stage and also in improved techniques for identification to differentiate between cancer, benign conditions and other pathotolies of internal tissue.

The present work relates to a novel method and the corresponding devices to detect and identify pathologies inside orifices of a living subject and more specifically to a method and devices to detect and identify gastric, colorectal and cervical cancer, based on near infrared (NIR) and middle infrared (MIR) devices and instruments.

2 The Proposed Methodology and the Device

The proposed method is based on the detection of malignant tissues related to the gastric, colorectal and cervical cancers based on two techniques [14]:

1. Infrared imaging method-NIR and MIR.
2. NIR and MIR spectral method

Optical methods of imaging were coming from detection and diagnosis of skin cancer. We do not enter into this subject because it is out of scope of our work, referring the reader to excellent papers [15–17].

As for spectral regime, using optical radiated signal ranged at the wide frequency bands, it based on perceiving reflected light in the visible and near-infrared (NIR) bands. Identification by use of this regime of specific abnormalities is based on information about the corresponding “signature” of radiation associated with the

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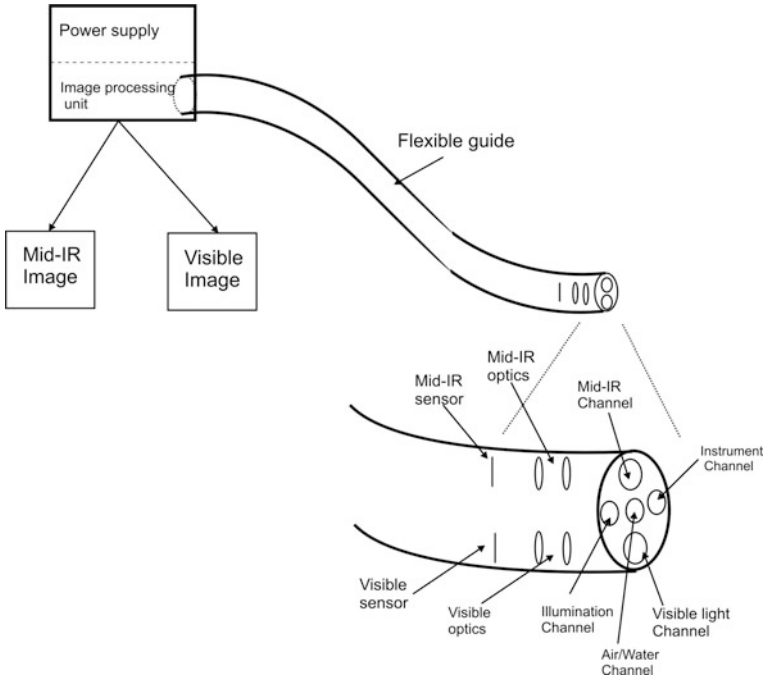

Fig. 1 Schematical presentation of the flexible guide

corresponding anomaly measured in the frequency domain. Recently, middle-infrared (MIR) spectral methods have also been used to improve an accuracy and reproducibility of biopsy evaluation for the gastric and stomach cancers [18–21].

In our case of interest, the image capturing is based on usage of an endoscope consisting of a NIR or MIR camera based on micro-bolometric or pyroelectric detector array mounted on the distal tip of the flexible tube (as shown in Fig. 1) and a conventional visible camera. In addition to capturing image frames in the visible and Mid-IR spectral regions, light source, air, water and small instruments can be used to take samples of suspicious tissues through the endoscope. This device is inserted through the mouth or anus the same method as it is done by the visible endoscopes at present. Schematic drawing of the endoscope is shown in Fig. 1.

The flexible guide consist of five channels:

(1) Mid-IR channel, which includes a window in the distal tip and a series of optical elements in a wide field configuration, all are transparent in the Mid-IR spectral range (like Zinc Selenide, Silver halide and others), and a microbolometric CCD.
(2) Visible channel the same as the Mid-IR channel except that the materials of the components are transparent in the visible spectral range.
(3) Air/water channel delivers air, water or to suction intraluminal contents.

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(4) Illumination channel provides illumination in the visible spectral range to the suspected tissue.
(5) Instrument channel provides the physician tools to take samples from suspected tissues.

The power supply unit is responsible to maintain the Mid-IR detector, the visible detector and the illumination unit in operational mode. The image processing unit delivers two video images captured by the two sensors, a Mid-IR thermal image and a visible image. This unit is carrying out image processing algorithms and performing the contrast algorithm to improve the probability of detection.

There are two methods of tissue surface and sub-surface anomalies detection and identification. The first method is called the *integral regime* of tissue detection using information about the corresponding gradient of temperature between the normal tissue and the cancerous tissue. The second method is called the *spectral regime* of tissue detection using information about the spectral lines of irradiated field from cancerous tissue, that is, about the corresponding "signature" of the anomaly in the frequency domain.

The broad spectrum from NIR- to MIR-band is used for diagnostics and identification of the tissue anomaly. This method is based on the integral and spectral thermograph analysis of infrared flows radiated by the living tissue surface, the cancerous and the regular tissue. It consists:

(1) Measure of the space distribution of the integral flow from the object at the range of wavelength from 3–5 μm (NIR-band) to 8–12 μm (MIR infrared), most often from the open surface of the body.
(2) Spectral regime based on the following parameter such as spectral density of emitting radiation ($dR/d\lambda$) from human body as a black body with temperature $T_0 \approx 36.6$ °C using visual spectrum from 200 to 900 nm and infrared spectral range of 3.0–20 μm. The normalized heat flow difference (or contrast) was measured in the anomalous zones in the chosen wavelengths with the known narrow waveband $\Delta\lambda_i$ of measurements. The counting of the mean spectral density of the measured heat flows in each band of measuring according the formula:

$$S_{\lambda i} = R_{\lambda i}/\Delta\lambda_i, \tag{1}$$

where
$S_{\lambda\ i}$ is the mean spectral density of the heat flow for the chosen;
λ_i is the bandwidth (ith wavelength);
$R_{\lambda i}$ is the measured value of the heat flow in the chosen λ_i band;
$\Delta\lambda_i$ is the spectral width of the chosen ith band.

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3 Applications of NIR and MIR Techniques and Devices

For identification of gynecologic cancer cells during a surgical procedure, an in vitro system based on MIR-ATR spectroscopy was designed for the purpose of examination of the adequacy of MID-IR spectroscopy, in conjugation with ATR (see Fig. 2) for the detection of gynecological malignancies in real time during surgery. The second device with the corresponding ATR-MIR spectroscopy instruments for identification of the colonoscopic and gastric cancer cells during surgical procedure was developed recently (see Fig. 3). Its purpose was to examine

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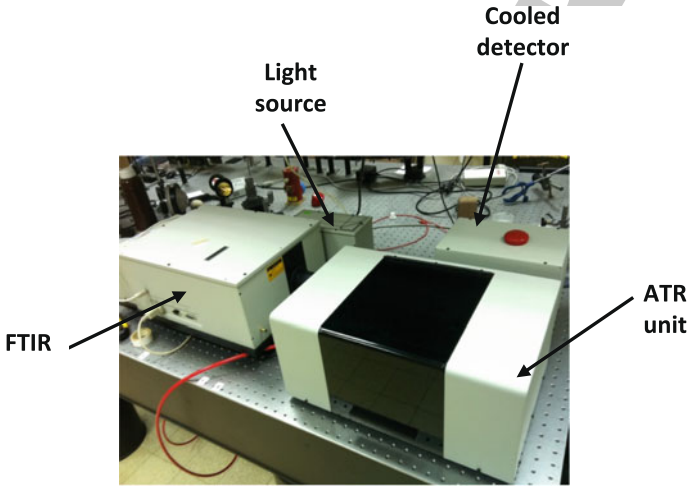

Fig. 2 An in vitro MIR-ATR spectroscopy system

Fig. 3 An in vitro MIR-ATR spectroscopy system

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Fig. 4 The view of MIR-ATR probe

the adequacy of middle infrared spectroscopy in conjugation with ATR, for the detection of colonoscopic and gastroscopic malignancies in real time during surgery. Recently, this device in a series of clinical tests at the medical center in Jerusalem. During this stage the system and histopathology data were taken in parallel and the correlation was computed between the two measurements. About 70 samples were taken up to date. In the next stage our system will classify the biopsies.

Then, the possibility to check in vivo all cancerous cells during surgical procedure was investigating and the corresponding hollow fiber and a MIR-ATR probe were performed based on the technology presented and described in Fig. 1. The corresponding product is shown in Fig. 4.

Such a probe allows us to identify in real time whether tissue is malignant. The technique involves inserting a hollow optical fiber in the working channel of the endoscope and detecting the signal from the ATR probe.

Moreover, the developed probe based on hollow fiber technology allows to construct an in vivo system for enhancing Colposcopy procedure, using the spectral properties of cervical cancer in the NIR spectral range. The main goal of usage of such a MIR-ATR probe was to improve the detection precision in the Colposcopy procedure by using the unique properties of the malignant tissues in the combined visual optic system (VIS) and NIR spectral ranges that now exists separately.

4 Summary

Using Near- and Mid-IR techniques for detecting and identification of gastric, colorectal and cervical cancers is different with respect to other methods in that the conventional methods are based on the subjective inspection in the visible spectral range of the physician, where in our method we are based on the overheated characteristic of cancerous tissues and detecting these anomalies with a NIR or MIR camera.

In our work, based on different kinds of instruments and devices, the detection and identification of cancers using the combination of the visible, NIR and spectral

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regimes in combination with the contrast, is different with respect to other methods in that the preliminary classification of anomaly is done, using IR optical band in the range of 3–12 μm.

We developed a new endoscope based on an array of infrared and visual optic micro detectors operating in the waveband range of 3–12 μm working both in integral and spectral regimes based on the sign and amplitude of the contrast of cancerous anomalies with respect to those for normal living tissues.

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