Development of a Novel Breast Cancer Detector based on Improved Holography Concave Grating Imaging Spectrometer

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Abstract. Breast cancer can be detected by B-mode ultrasonic imaging, X-mammography, CT imaging, and MRI. But some drawbacks existed in these methods, their applications was limited in some certain. So, a novel high resolution breast cancer detector (BCD) is developed in this paper. Meanwhile, an improved holography concave grating imaging spectrometer (HCGIS) is designed. In this HCGIS, the holography concave grating is used as the diffraction grating. Additionally, CCD with combined image acquisition (IAQ) card and the 3D scan platform are used as the spectral image acquisition component. This BCD consists of the light source unit, light-path unit, check cavity, splitting-light unit, spectrum acquisition and imaging unit, signal processing unit, computer and data analysis software unit, etc. Experimental results show that the spectral range of the novel BCD can reach 300-1000 nm, its wavelength resolution can reach 1nm, and this system uses the back-split-light technology and the splitting-light structure of holography concave grating. Compared with the other instruments of breast cancer detection, this BCD has many advantages, such as, compacter volume, simpler algorithm, faster processing speed, higher accuracy, cheaper cost and higher resolution, etc. Therefore, this BCD will have the potential values in the detection of breast disease.

1. Introduction
Breast cancer is becoming the major diseases of threatening to the health of women. In some developed Europe countries and USA, the breast cancer has occupied the second place in women’s cancer diseases. In some cities of China, such as, Beijing, Tianjin, Wuhan, etc, the incidence of breast cancer is steadily arising. Except for the treatment of the breast cancer, the diagnosis of breast cancer in early stage is most important. In recent decades, some methods based on the ultrasonic, optical and magnetic technology have been used for the detecting of the breast cancer, such as, the conventional hand-touch method, B-mode ultrasonic imaging [1], the X mammography [2], CT imaging [3] and MRI [4], etc. Although these methods have gotten some achievements in some certain, the applications are limited by some drawbacks. For the conventional hand-touch method, this method is limited due to the inconvenience for the patients and the doctors, especially for the different gender. For the B-mode ultrasonic imaging, its spatial resolution is low. For the X mammography, its application is also limited due to the low contrast and spatial resolution, and the X-ray is harmful to the health of the patients. For the CT imaging, although it has the higher resolution and contrast, the algorithm of image reconstruction is very complicated. For the MRI, its cost is very expensive for the patients and hospitals. Since about 70-90% of the breast tissues and gland are composed of the fat, the breast tissue has the characteristic of the light-penetrability [5]. When a beam of the light irradiates...
into the breast, the hemoglobin of the blood and the cancer tissues will absorb the light, but the breast fat and the gland are nearly transmissive. Some researches have proved that the optical absorbance of the cancer tissues is 3-5 times more than that of the normal tissues [6]. For the image, the images of the blood vessel and the cancer tissues for the light are the shadow area, the normal tissues are the bright area. For the breast cancer in the early stage, the changes of the tumor cell and the hemoglobin are not obvious. It is difficult to diagnose the cancer tissues simply relies on the transmission image. But, the spectral changes are obvious. And these changes are the important information. Therefore, in order to overcome the drawbacks of these methods above mentioned, a novel breast cancer detector based on the imaging spectrometer is developed in this paper. This detector is the combination of the optics and the image. Not only the image information but the spectral information of the breast tissue can be gotten. So, this novel detector can offer more accurate and more information about the breast diseases. Meanwhile, an improved custom-built holography concave grating imaging spectrometer (HCGIS) also is designed to as the splitting-light unit of the detector. In additional, the virtual instrument (VI) technology based on LabVIEW is used to control the spectral image acquirement of CCD with combined the image acquisition (IAQ) card. Experimental results show that this detector can get not only the clear image of the breast cancer tissue, but also the spectrum of the tissue. It is proved that the method based on the image with combined the optical spectrum is feasible in the breast cancer diagnosis. Compared with others, this detector has many advantages, such as, non-invasive, more accurate, simpler algorithm, more convenient and cheaper cost, etc. And, experimental results show that the spectral range of the imaging spectrometer can reach 300-1200nm, the resolution can reach 1nm. Therefore, this detector has the potential values in the biochemical research and the diagnosis of the breast cancer.

2. Theory
From the 20th century up to now, the spectrum analysis technology has been researched by many people in bio-chemical and medical fields [7, 8]. The theory of the breast cancer diagnosis by means of the spectrum analysis is based on the Lambert-Beer theory [9]. That is, we use the absorbed or reflected spectrum to analysis the pathology characteristic of the breast tissues for the patient. The Lambert-Beer theory can be expressed as follows:

\[
A = \log \left( \frac{I_0}{I} \right) = \log (I_0) - \log (I) = \varepsilon c b
\]  

(1)

Where, \(A\) is represented to medium absorbance of the incident light; \(I_0\) is intensity of the incident light; \(I\) is intensity of the transmission light; \(\varepsilon\) is Moore absorbance parameter of the medium; \(c\) is concentration of the medium; \(b\) is thickness of the medium.

3. System design of BCD based on HCGIS
The BCD mainly consists of the lamp source unit, light-path unit, check cavity, splitting-light unit, spectrum acquisition and imaging unit, signal processing unit, control unit, display unit, etc. where, the lamp source unit consists of the lamp, reflecting cup, fan, lamp shade, the lamp switch and the power of the lamp. The light-path unit includes the first collimating lens, filter components and the first focusing lens. The check cavity is used to contain the breast. The splitting-light unit consists of the second collimating lens, the second focusing lens, fiber and HCGIS. The spectrum acquisition and imaging unit consists of the CCD, driver module and IAQ card. The signal processing unit consists of the signal amplifier, signal filter, data buffer and time-sequence synchronous circuit. The control unit includes computer, data analysis software and outside control keypad. The input button to as the outside control unit, the LCD screen to as the signal display unit. The display unit is the LCD screen. The basic principle of this system is shown as follows: Firstly, the composite light is emitted from the lamp and reflected by the reflecting cup to become the parallel light and passes through the lamp shade, then it is collimated by the first collimating lens, is filtered by the filter components, focused by the first focusing lens in turn. The focused light irradiates into the breast tissue. The absorbed and reflected light by the breast tissue penetrate the skin, then is collimated by the second collimating lens and focused by the second focusing lens onto the interface of the fiber, the focused light is coupled...
into the fiber, then the light transmitted by the fiber pass through the slit to enter into the HCGIS, and irradiate onto the surface of the HCG, the multi-chromatic light is diffracted by the HCG into the monochromatic light and cast onto the surface of the CCD. The light acquired by CCD is transformed into the electricity signals under the driver control of the time-sequence of the CCD, then the electricity signals are acquired by the IAQ card to form the digital image, then the digital image is amplified and filtered by the amplifier and filter in turn, the filtered image signal is stored and sent into the computer to be analyzed by the analysis software. Finally, the image and spectrum of the breast tissues are displayed by the LCD screen, and the diagnosis results are gotten. The integrated system structure of BCD is presented in Figure 1.

**Figure 1.** The integrated system structure of BCD

3.1. Design of the front part unit for BCD

In this paper, the front part of the BCD includes the light-source unit and the light-path unit. In the light-source unit, the halogen-tungsten lamp is chosen to be the light-source of the BCD because it has the advantages of small volume, high efficiency, stability, low cost, long operating life, etc. And its spectrum range can be from 200nm to 2500nm. Its working is controlled by the lamp switch and power. The reflecting cup is used to reflect the light emitted by the lamp to become parallel light. The material of the reflecting cup and the lamp shade are the glass with high temperature resistance, and inner wall of the reflecting cup is coated the aluminum coating to enhance the reflectivity of the light. The diameter of the exit of the reflecting cup and the lamp shade is about 55mm. The fan is used to eliminate the heat of the light-source and prolong the using-life of the lamp. In the light-path unit, the first collimating lens is used to collimate the light reflected from the reflecting cup of the light-source unit. The first focusing lens is used to focus the light and irradiate into the breast tissue, and the focal length of the first focusing lens can be adjustable by the focusing knob, which makes the incidence-depth of the focusing-light adjustable in the breast. To get the different spectral images of the visible and NIR light, the filter component studded 10 pieces of the different wavelength filter is used. The first collimating lens, the filter component and the first focusing lens are fixed in the cylinder of 55mm diameter. The light-path unit and the light-source unit can be connected. The schematic diagram of the front part unit is shown in Figure 2.
3.2. Design of splitting-light unit based on the HCGIS

In the system of BCD, the splitting-light unit is the key part. In this splitting-light unit, the improved imaging spectrometer based on the holography concave grating is designed. The splitting-light unit consists of the second collimating lens, second focusing lens, fiber and the HCGIS, where the HCGIS consists of the slit, the plane holographic concave grating and CCD. In this HCGIS, the opening-groove technology is used to eliminate the stray-light. This HCGIS has many advantages, such as, lower cost, compact structure, wider spectrum range, better imaging quality and higher precision. The light-path structure of HCGIS and the schematic diagram of the splitting-light unit are shown in Figure 3 (a) and (b). In the inner wall of the HCGIS, the depth and width of the groove is 1cm and 0.2cm respectively.

3.3. Spectral image acquisition and pre-processing unit of BCD

In this paper, the spectral image acquisition unit consists of CCD, CCD driver module, high speed IAQ card. The splitting-light unit and the spectrum acquisition imaging unit are merged and fixed on the 3D scan platform. The 3D scan platform is driven by the stepper motor to do movement from up to down, from forth to back and from left to light. The acquired spectral image is amplified by the two-order amplifier, i.e. the first off-current amplifier and the adjustable gain amplifier. Then the amplified spectral image is filtered by the low-pass digital filter. The filter spectrum is send by PCI bus to be stored into data register. The synchronous circuit controls the time-sequence of the CCD driver module, IAQ card, amplifier, filter and data register. Finally, data are read by the computer and are analyzed by the software to get the diagnosis results.

4. Experiment and results

4.1. Materials
Halogen-tungsten lamp with the reflecting cup (Philp14546, ±12v/20W) is chosen as the lamp source of the BCD, its spectrum range is from 340 nm to 2500 nm. The water bottle driven by stepper motor is used as the water-cooling device of the light-source unit. The material of the check cavity is the synthetic resin. The curvature of the first and second collimating lens are all 26.33mm, the curvature of the first and second focusing lens is 6.24mm. Three optic fibers (IBM 39M5696, 100µm) are coupled to transmit the light enter into the HCGIS. The material of the custom-built HCGIS is aluminum-alloy. The HCGIS consists of the slit (50µm), the HCG (600 lines/400 nm) and the camera CCD (ICX404AK, Sony). The length of the input-forearm of the HCGIS is about 104mm, and the output-forearm is about 102mm. The effective pixels of the camera CCD (ICX404AK, Sony) is $510 \times 492$, its package is plastic DIP, 16 pins. The IAQ card (NI PXI-1411, NI) is used to acquire the electricity signals and converted into the digital signal. The amplifier has 4 channels, its input impedance can reach 100MΩ, the range of the gain can reach 10-5000, the frequency wide can reach DC-30KHZ, and its KCMR $>100$db. The low-pass filter uses the Butterworth low-pass filter, its cut-off frequency is adjustable from 100Hz to 100KHz. In the analysis software, LabVIEW (Version. 8.0 student edition, NI)[7] is used as the software platform to control spectral image acquisition and data analysis.

4.2. The experiment of the HCGIS for the BCD

To ensure the precision and feasibility of the BCD based on HCGIS and CCD, the improved custom-built HCGIS for BCD based on the optical platform is firstly established. The photo of this HCGIS is presented in Figure.4.

![Figure 4. The photo of the improved HCGIS for BCD](image)

4.3. The experimental results of the improved HCGIS for BCD

The custom-built HCGIS is used in the experiment, the spectrum information are gotten, where the information includes the diffraction, imaging distance and the dispersion of the different wavelength. The results are shown in the Table 1. From table1, we can see that the dispersion of this HCGIS for BCD is improved.

| Wavelength(nm) | Diffraction (angle deg) | Image distance(mm) | Dispersion (nm/mm) |
|----------------|-------------------------|--------------------|--------------------|
| 300            | 10.3700                 | 99.3841            | 35.8218            |
| 340            | 11.7709                 | 99.8202            | 35.1537            |
| 467            | 16.2899                 | 99.4926            | 34.9067            |
| 595            | 20.9159                 | 99.8000            | 34.4286            |
| 600            | 21.1000                 | 100.2419           | 34.0824            |
| 722            | 26.6897                 | 100.8099           | 33.6428            |
| 800            | 28.6851                 | 101.8179           | 33.0153            |
| 850            | 30.6635                 | 102.6497           | 32.4512            |
| 900            | 32.6830                 | 103.1826           | 32.1348            |
| 950            | 34.6625                 | 104.0658           | 31.6247            |
| 1000           | 36.6851                 | 104.8217           | 31.1563            |
4.4. **The resolution estimation of the HCGIS for BCD**

Spectral resolution is an important standard which is used to estimate the performance of HCGIS for BCD. For the estimation of different wavelength and resolution, Eq.(2) can be used to illustrate their relation. The Eq.(2) is shown as follows:

\[
\frac{1}{\text{line dispersion rate}(\delta l/\delta \lambda)} = \frac{1}{\text{integrated width of spectrum}(\Delta l)} = \frac{1}{\Delta l_1 (\text{diffraction width}) + \Delta l_2 (\text{the width of slot}) + \Delta l_3 (\text{aberration width})}
\]

Where, \( \Delta l \) (integrated width of spectrum) \( \approx \Delta l_1 \) (diffraction width)+ \( \Delta l_2 \) (the width of slot) + \( \Delta l_3 \) (aberration width).

The resolution estimations of the wavelength is 300, 550, 800, 1000 nm are shown in the Table 2.

| \( \lambda \) (nm) | \( \Delta l_1 \) (\( \mu \)m) | \( \Delta l_2 \) (\( \mu \)m) | \( \Delta l_3 \) (\( \mu \)m) | (\( \delta l/\delta \lambda \)) (\( \mu \)m/nm) | Resolution (nm) |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 300             | 10.3700          | 50              | 6.1             | 35.8218         | 0.93            |
| 550             | 18.9050          | 50              | 3.0             | 34.4286         | 1.04            |
| 800             | 28.6851          | 50              | 2.4             | 33.0153         | 1.23            |
| 1000            | 33.6851          | 50              | 2.0             | 31.1563         | 1.38            |

From Table 1 and 2, we can know that the resolution of the splitting-light of HCGIS for BCD can reach 1.0 nm and the spectrum range can reach 300-1000 nm.

**Acknowledgements**

This work has been supported by the Chinese National Foundation for Natural Scientific Research grant (60767001, F051206). The Science and Technology Pillar Program of Jiangxi Province (2009BSA12700), the Natural Science Foundation of Jiangxi Province (2008GQW0013), and the Scientific Research Foundation of Jiangxi Provincial Education Bureau (GJJ09307, GJJ10243). And, the Natural Science Fundation of Jiangxi Science and Technology Normal University (No.KY2009ZY10).

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