

Biomedical Device for Early Breast Cancer Detection: Device Performance Improving by Plasmonic-Photonic Mask

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Abstract: In this article, a new device to detect breast cancer at an early stage, is presented. The main advantages of the device are its easy operational procedure, portability, high accuracy due to usage of plasmonic-photonic mask and the low cost. In fact, the novelty of the device presented is to apply the new mask called plasmonic-photonic mask for precise analysis of the captured images. In the early stage of the work, a phantom model is employed and the operation of the system is realized. It is shown that the image processing toolbox is safely matched with the device. It should be noted that for the in-vivo imaging, the device should be completed and equipped with a high accuracy charge coupled device (CCD) and laser.

1 INTRODUCTION

The early and comparatively easier detection of cancer is a valuable task in medicine. Recently, detecting cancerous tumors at an earlier stage have been a major problem in medical imaging. There are some classical imaging devices such as magnetic resonance imaging (MRI) (Grover et al., 2015), computed tomography (CT) (Goldman, 2007), positron emission tomography/computed tomography (PET/CT) (Basu et al., 2014), X-Ray (Schueler, 1998), mammography (Moseley, 2016) etc. Such imaging devices have initiated a new area of image processing in the medical industry (Yasrib and Suhaimi, 2003). Using image processing techniques (Gonzalez, 1993) lead to analyze the captured images in more details based on the advanced algorithms (Joo et al., 2004). Also, there are some devices in biomedical imaging which utilizes the fluorescence to enhance the imaging performance (Moon et al., 2003).

Early breast cancer detection using plasmonic-photonic mask is an innovational imaging technique. The device presented aims to apply a mask called plasmonic-photonic mask for precise analysis of captured images. As it is a promising imaging system to be an alternative to mammography, trials are still executed on a phantom model. A superiority of the device presented is its portability. It is beneficial in

both lab environment and transportation purposes. Visuals of the device can be seen in Fig. 1.



Figure 1: Photograph of the investigated system.

A short introduction of the imaging system introduced in this work is as follows; since resolution in medical imaging is crucially important to detect the small tumors (DeSchepper et al., 1997), in this study, precise detection is aimed by the usage of plasmonic-photonic mask. This system operates at a specific near-infrared (NIR) wavelength, 808 nm. The system is operated at 808 nm wavelength which results in the penetration depth facilitated imaging soft tissues. The absorption ratio of the tissue at that wavelength is reported to be quite small i.e. about 4-5 mm (Cletus

et al., 2009). Thus, the penetration depth in soft tissues (Clement et al., 2005) – (Ash et al., 2017), at the NIR wavelengths, 808 nm, is preferred. Since the main purpose of this device is to detect the small tumors, this study is claimed to offer comparatively higher operational accuracy as compared to the classical mammography. This is because the system realized in this study includes additional NIR laser to scan the area of examination. Also using the plasmonic-photonic mask helps to improve the performance of the system (Salmanoglu and Salimi, 2017) – (Salmanoglu and Farhadnia, 2016). Interaction of the light with metal nanoparticle (NP) produces the mode called plasmonic mode (Salmanoglu and Gecim, 2018) – (Salmanoglu et al., 2018). Then the plasmonic mode is effectively coupled to the far-field by utilizing the photonic mode. In other words, using photonic structure leads to merging two presented modes (Salmanoglu and Salimi, 2017). The mentioned phenomenon is employed in image data acquisition.

It is claimed that performance of this device can enhance the mammography in some critical applications requiring high accuracy, together with mobility of the system, low risk, and low cost. Finally, it should be noted that as an important point the plasmonic-photonic mask used in this system can strongly improve the imaging system accuracy and resolution (Salmanoglu and Salimi, 2017).

2 SYSTEM DEFINITION

In this section, the system employed in this study is explained in detail. The correlation between the device's inner and outer elements is established according to the operational principles of the system. The layout of the system is illustrated in Fig. 2. It can be clearly seen that the mechanical parts are combined with optics and charge coupled device (CCD). The CCD is connected to the computer for further image processing. In this system a NIR laser is coupled to mechanical part through a single mode fiber. After the interaction between light and matter, photons are collected by the CCD camera. The image captured is transferred to the image processing unit in computer. The controller unit in the computer is used to control the position of the plates through RS232.

Drivers in the system are controlled by the position controller, to manage the rotation of the motors.

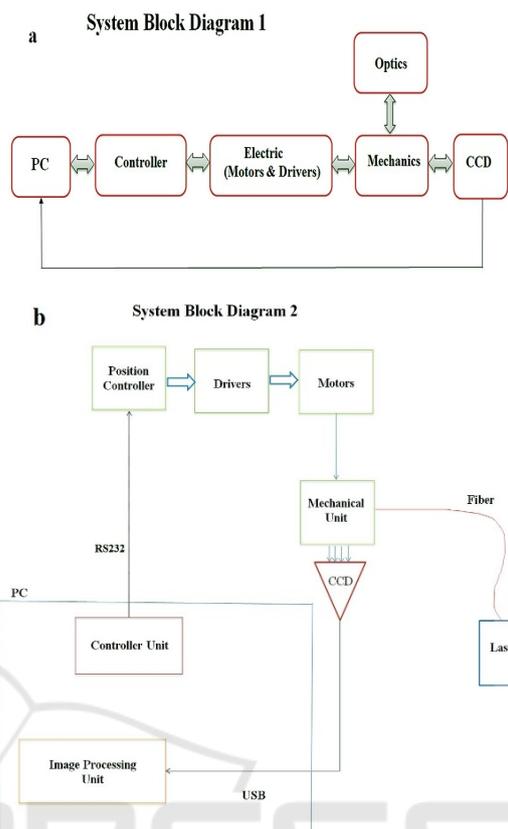


Figure 2: Operational principle of the system (a) Layout of the system, (b) Inner structure of the system.

The motors are directly linked to the plates. The electro-mechanical pieces of the system are connected to the computer. Mechanical unit of the system is shown in Fig. 3. The camera is positioned on Plate 1, whereas the optical fiber comes through Plate 2. Thus, optics and CCD are directly connected to the mechanical unit. For a better understanding, the top view of the system is shown in Fig. 3. The mechanical unit is composed of two moving plates with different radius values. Radiuses of the plates 1 and 2, are marked as r_1 and r_2 . Plate 1 has a bigger radius as r_1 . Also side view of the system is illustrated in Fig. 3.

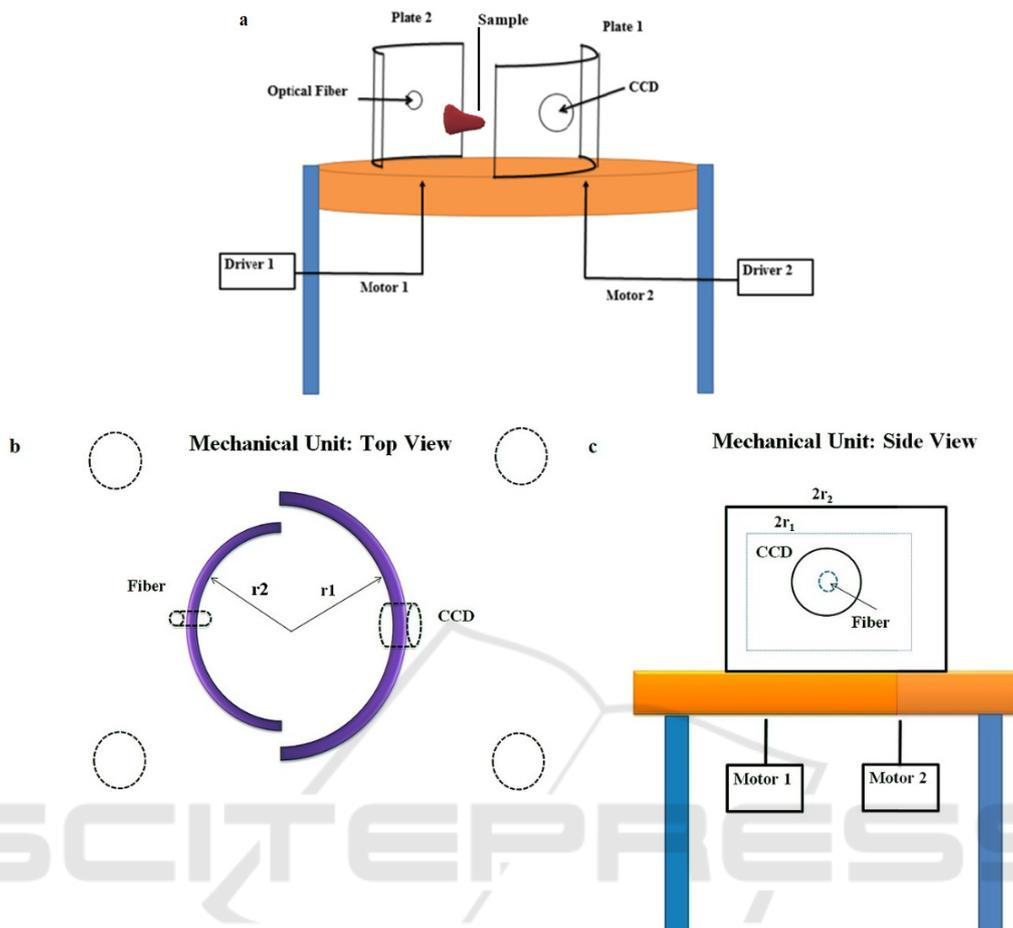


Figure 3: (a) Mechanical unit of the system, (b) Top view of the system, (c) Side view of the system.

The operational principle of the optics and CCD is introduced in Fig. 4. Laser beam interact with the sample mounted. Then scattered beam is multiplied and collected by the camera. Intensified scattered beam can clearly be observed. Fig. 4. By interaction of the scattered photons with the small NPs such as Au NPs, the surface plasmonic modes are created. This is due to the incident wave sent, being aligned in phase with the electrons on the near-field of nanoparticles. Then the produced near-field plasmonic modes are coupled to the photonic mode. The consequent mode is transferred to the far-field called focal point in this study. While the bandwidth of the scattered photons decrease, their intensity increases. Thus low intensity photon beam sent, transforms into high intensity photon beam. Consequently the final image is re-constructed using the plasmonic-photonic effect. In fact, using plasmonic-photonic effect, leads to improvement of the imaging system accuracy. It is claimed that in the study, the presented system can be used to detect the

small breast cancer tumors. Also, it has been reported (Salmanoglu et al., 2017) that using low power laser to scan the breast, results in the detection of a very small amount of the scattered photons. Therefore the plasmonic-photonic mask is offered.

The plasmonic-photonic mask used in the system is an array of gold nanoparticles. The inter-distance of nanoparticles are the same as the operation wavelength, which 808 nm. This wavelength is chosen for maximum amplification (Salmanoglu et al., 2017). Top view and side view of the plasmonic-photonic mask is shown in Fig. 5. So from that point of view, the contribution of the study is to be able to produce high intensity photon beam for imaging without using high power laser beam which may harm human body. That can also be explained as the captured image is always constructed by low intensity photon beam. The major advantage offered by the study is utilizing a plasmonic-photonic mask producing high intensity photon beam needed. Finally, the constructed image quality is improved.

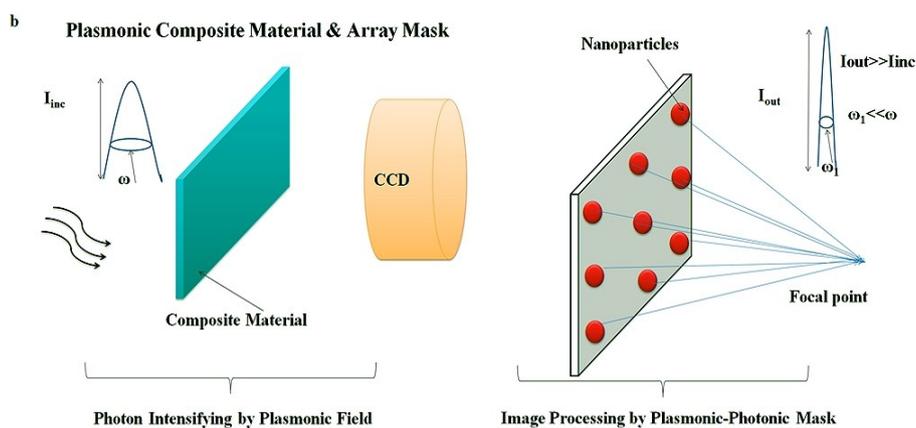


Figure 4: (a) Optics and CCD working principle, (b) Plasmonic-photonic mask.

Plasmonic Array for Image Processing Section



Figure 5: Plasmonic array mask, regular arranging of plasmonic NPs; top view and side view.

3 RESULT AND DISCUSSION

In this study operational results are shortly discussed. To obtain preliminary results, a phantom model (Salmanogli et al., 2017) is employed in the system and data related to imaging are collected. After number of operational runs, some images were selected from the collected data in order to investigate the effect of plasmonic photonic mask. In Fig. 6 it can be clearly seen that the plasmonic mask can effectively help to clarify the blurred image. One has to realize that the blurred images occur as a result of low intensity scattered photons from the breast. As additional information some results obtained with the plasmonic mask on the captured images is shown in Fig. 6.

As a matter of fact, the comparison between the states are done and illustrated in Fig. 6b and d. In Fig. 6, we considered two original figures (Fig. 6a and Fig. 6c). Fig. 6a is recorded with high intensity input, while the picture illustrated in Fig. 6c is recorded with low

intensity laser. The main objective is to compare the plasmonic-photonic mask effect on the images considered. In other words, it is shown that using plasmonic-photonic mask improve the images that has been recorded with low intensity incoming photons. These cases are performed due to scattered photons from the area like the breast being dramatically attenuated. Therefore, the original images obtained without the plasmonic-photonic mask is unclear to the observant.

Before studying the processed image by the plasmonic-photonic mask, a short description of the mask is explained. The Au NPs radius is 50 nm, and the inter-distance between the Au NPs is around 808 nm. The experimental setup revealed that due to the photonic effect, the structure's plasmonic peak has a large red-shift and is about 808 nm whereas the Au NPs plasmonic peak is 532 nm. In this work, a plasmonic resonance at 808 nm which is the same with the incidence wavelength is needed. By applying this

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