# A system for medical Photoacoustic image processing

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***Abstract***
Photoacoustic imaging is a valuable imaging modality that provides functional information about the biological tissue of interest; it is even more useful when complemented by ultrasound imaging for anatomical information.
In a photoacoustic imaging, the optical absorption properties of matter are imaged by detecting the ultrasound emitted when the material is illuminated by a laser. In this work, we employ pattern recognition systems to study a set of medical images for tumor identification and extraction, in order to detect the particular area where the tumor is present. The goal is to incorporate this information in real-time systems for image acquisition in order to improve medical diagnosis. Preliminary results obtained from the image dataset under study demonstrate the interchangeability of the proposed system. For the evaluation of the proposed method we conducted two tests with photoacoustic images: carcinogenic masses and brain functionality. Results allowed us to see the feasibility of the proposed system.

**Keywords:** Pattern Recognition, Medical Imaging, Photoacoustic

## 1. INTRODUCTION

Medical imaging is an exciting field where researchers develop new techniques for diagnostic imaging and guidance of therapeutic interventions. Photoacoustic imaging is a relatively new hybrid imaging modality that combines the physics of optical and ultrasound imaging. Photoacoustic imaging is a promising technique that relies on optical excitation and ultrasonic detection. In photoacoustic imaging, a laser pulse heats an optically absorbing medium causing a rapid thermal expansion. This creates a source of pressure that propagates through the medium as an acoustic wave. Ultrasonic transducers that are positioned at several locations on the boundary of the medium are able to detect the acoustic wave as a time-domain photoacoustic signal, known as a RF-line (radio-frequency line). Since the acoustic wave travels at the speed of sound ($\sim$=1500 m/s) through the medium, the RF-lines can be used to create a 3D spatial map proportional to the optical absorption strength of the medium. In their simplest form, Photoacoustic images can be constructed by displaying only the amplitude of the envelope of the underlying RF photoacoustic signals received by a broad bandwidth ultrasound transducer as image brightness.
The photoacoustic technique involves targeting nanosecond pulses of visible laser light to the surface of the skin: absorption of the laser energy results in rapid thermoelastic expansion and the emission of broadband pulses of ultrasound, typically on the order of tens of MHz. The latter propagates to the surface where they are detected at different spatial points using either an array of ultrasound receivers or a single mechanically scanned detector. By measuring the arrival time of the ultrasound pulses at the surface and knowing the speed of sound in the tissue, an image of the absorbed optical energy distribution can be reconstructed. Spatial resolution is defined by the physics of ultrasound propagation and is limited by the frequency-dependent attenuation characteristics of soft tissue. On the other hand, image contrast is strongly dependent on the optical absorption, which makes this technique particularly suitable for blood vessel imaging due to the strong optical absorption of hemoglobin.

Other studies have shown that changes in tissue perfusion, which is characteristic of skin tumors [2], as well as dermal vascular lesions and soft tissue damage, such as burns [3], can be observed using photoacoustic methods. Photoacoustic systems can produce high-resolution, high-contrast images of vascular structures, is a non-invasiveness techniques the capability of imaging without harmful side effects. Photoacoustic imaging is a nonionizing and noninvasive optical imaging modality that provides good soft tissue contrast, excellent spatial resolution, and deep penetration depth tomography is a natural complement to existing ultrasonography and should enlarge the scope of ultrasound in the diagnostic imaging and therapeutic monitoring of various types of cancer (for example, prostate cancer), by providing additional information. As a result, photoacoustic imaging has been extensively studied and notable results have been published for imaging in humans and small animals [4-6]. To perform quality photoacoustic imaging, the acoustic transducer should provide good axial and lateral resolution, high sensitivity, wide bandwidth, and should ideally acquire a complete three-dimensional image with a single shot at fast frame rates, without scanning [7].

Numerous previous studies have demonstrated that the growth of new blood vessels, known as angiogenesis, is an inherent element of metastasis in most solid tumors, including prostate and breast cancer. Photoacoustic tomography, due to the high sensitivity of blood, may evaluate physiological characteristics of the tissue, such as tumor-related vascular distortion, including both angiogenesis and dilation of blood vessels in cancerous tissues, in a conclusive way to provide reliable support medical diagnosis [8]. The increase of blood volume in tumor regions, a typical functional hallmark of prostate cancer, might be reliably detected and localized by photoacoustic tomography with high optical contrast and high spatial resolution. The Photoacoustic effect explains how electromagnetic energy can be absorbed and converted into acoustic waves. PA imaging benets from the advantages of pure optical or ultrasound imaging, without the major disadvantages of each technique [3].

In this paper we analyze a set of medical images, using pattern recognition techniques in order to detect the area where the tumor is localized. The goal is to incorporate this information into real-time systems for image acquisition in order to improve medical diagnosis. Results will allow us to see the feasibility of the proposed method.

## 2. METHOD

Photoacoustic imaging has been demonstrated to be a useful tool for identifying blood flow in vivo, and may be valuable for better detecting the presence of the angiogenesis typically associated with tumor formation. Being able to find abnormalities (i.e. tumors, abnormal blood flow, and temperature changes) in photoacoustic/photothermal images is certainly an activity that requires an expert, and considering that it is necessary to efficiently complement the medical diagnostic using machines learning techniques, the development of new tools is indispensable. This is precisely the idea of this work: offering an alternative technique for the identification and discrimination of suspicious areas based on the feature extraction through texture analysis. Since texture-based analysis methods characterize texture in terms of the extracted features, segmentation depends not only on the images under study but also on the aim for which the image texture analysis is used.

As stated before, the proposed technique is based on texture segmentation which in turn is performed by using entropy analysis. In this particular case, the local entropy for a small region $\boldsymbol{\Omega_k}$ by a window size ($\boldsymbol{M_k}$ ***x*** $\boldsymbol{N_k}$) within the input image, which has been drawn as the first stage of the proposed algorithm, is defined as follows [10,11]:

$$E\left(\Omega_k\right) = -\sum_{i=0}^{L-1} P_i \log\left(P_i\right) \tag{1}$$

Where,

$$P_i = \frac{n_i}{M_k \times N_k} \qquad (2)$$

is the probability of grayscale ***i*** appears in the neighborhood $\boldsymbol{\Omega_k}$, $\boldsymbol{n_i}$ is the number of pixels with grayscale ***i*** in the neighborhood. ***L*** is the maximal grayscale and $\boldsymbol{E(\Omega_k)}$ is the local entropy of the neighborhood $\boldsymbol{\Omega_k}$. A texture image is then generated using the entropy filtering and then a rough mask of the bottom texture (i.e. background) is created. The background mask, which is used as a contrast mask along with the original image, allows identifying and then extracting the regions of interest (i.e. top textures). In other words, the implemented system takes a photoacoustic/photothermal image as input, which we first use to create a texture image; and is then used to create a rough mask for the bottom texture. Next, we use the rough mask to segment the top texture and finally we display the segmentation result. The information displayed is potentially very useful to strengthen medical diagnostics. In the next section we present the test and results of the described method.

## 3. TEST AND RESULTS

To demonstrate the utility of the proposed system for visualizing potential abnormalities, we have performed tests on several images. All images are obtained non-invasively, without signal averaging, and using an incident beam with power below the maximum permissible for safe exposure of the skin.

### 3.1. Test 1: Non-cancerous Mass

Figure 1 shows the photoacoustic image of a human palm showing its vasculature. The image dataset is available online for viewing and downloading as animated volume-rendered images and movie files at stacks.iop.org/PMB/54/1035 [12] or the University College London website [13]. These animations provide the most compelling demonstrations of the 3D imaging capability of the system.

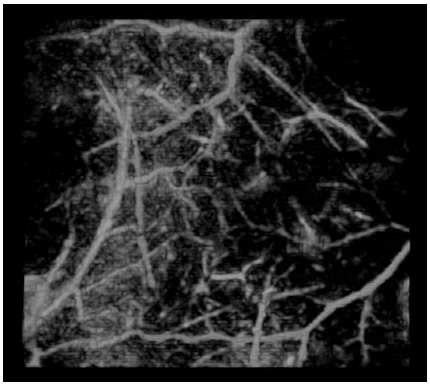

Figure 1. In vivo photoacoustic image of the vasculature in the palm using an excitation wavelength of 670 nm.

Figure 2 is a snapshot of a graphical user interface showing the same image being tested. In this case, no cancerous mass is present in the image. As it can be noticed, several processes are performed on the studied image simultaneously: primitive enhancement by normalizing the image (i.e. histogram stretching), segmentation and extraction of the identified structures, and pseudocoloring with three different color-maps (i.e. thermal, spectral and parametric dynamic pseudocoloring [14]).

We should highlight that this work focuses on the segmentation and extraction processes while enhancement and pseudocoloring are used only to support the results obtained.

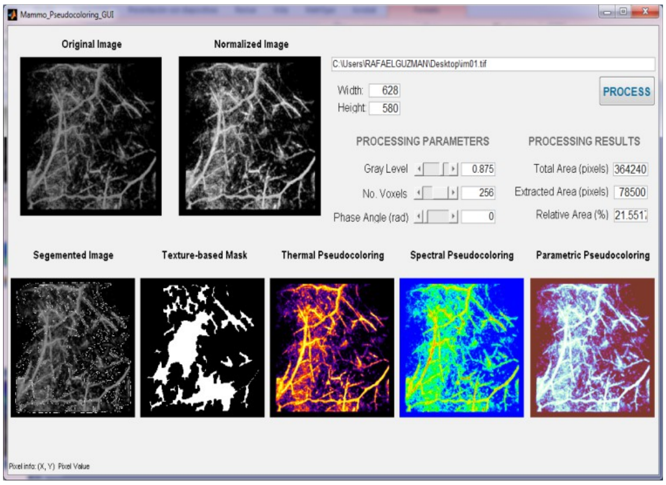


Figure 2. Graphical interface of the implemented system to find abnormalities in photoacoustic images.

Segmentation and extraction techniques are based on the feature extraction through texture analysis for the identification and discrimination of suspicious areas mainly related to cancer and benign tumors. Texture and morphological differences in the abnormality region allow identifying it and then analyzing, discriminating, and extracting it, so the first stage in the proposed algorithm consists in recovering the structural information of the original image through the local entropy with a standard 9x9 window. Once the structural information is represented in the image resulting from the entropy filtering, a threshold is performed on this first texture image to get a binary texture image. An additional cleaning of the overly segmented binary image is performed to remove all the "small" regions that are not significant in the segmentation process. The segmented regions from the binary texture are then filled and their edges smoothed, and then by using the generated rough masks, it is possible to extract the texture of interest.

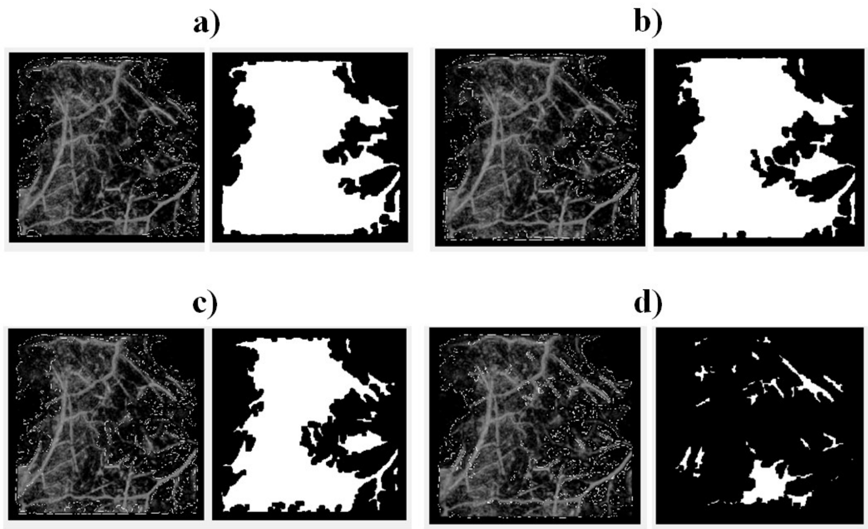


Figure 3. Segmentation (left of each sub-image) and Extraction (right of each sub-image) for reference gray-levels, a) 0.75, b) 0.80, c) 0.85, and d) 0.90.

When the image is processed with the implemented algorithm it can be observed that different layers are separated depending on the reference gray-level. In this particular case, the threshold value to get the binary texture is the relative gray-level of the pixels in the abnormality region and, since the gray-level represents the intensity detected by the sensor, this reference value is directly related to the depth of the layer thus allowing direct correlation between the identified texture with its depth in the tissue.

### 3.1. Test 2: Brain Functionality

Functional brain imaging allows, for instance, sensing changes in oxy- and deoxy-hemoglobin as well as abnormal blood flow to provide reliable information on hemodynamic and behavioral characteristics. Fig. 4 shows a typical image of hemodynamic analysis. The image was taken from the website of the Biophotonics and Biomedical Imaging research group of the University of Otago [15].

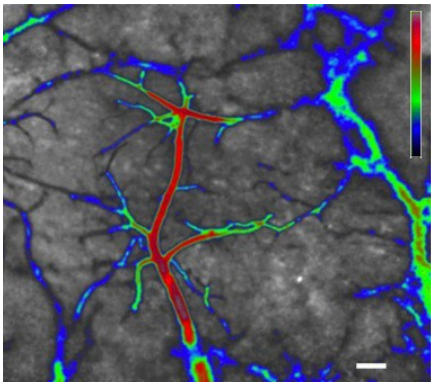

Figure 4.Functional brain imaging: hemodynamic measure.

In a similar way to the previous example, segmentation and extraction are performed on the image. As shown in Fig. 5, the result is the successful extraction of regions where a higher blood flow is registered.

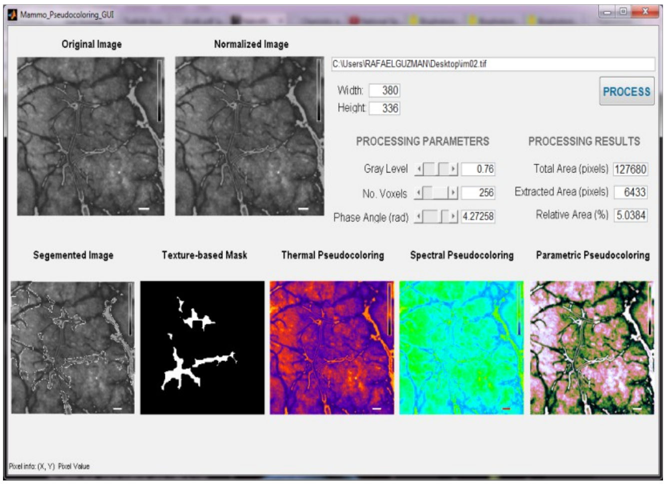


Figure 5. Graphic interface of the implemented system to disclose brain hemodynamic.

In terms of the reference gray level, it was observed from the obtained results that this value strongly determines the area that is identified and then extracted. It can be clearly noticed that as the reference gray value increases the amount of extracted area decreases, but also a cleaner extraction of the hand-marked area is achieved.

Our results show that for lower values of the reference gray level most of the abnormality is identified and extracted but some other regions with similar textures also appear. On the other hand, for larger values of the reference gray level, these regions with similar textures gradually disappear from the image but the abnormality region is still identified and discriminated with a smaller area.

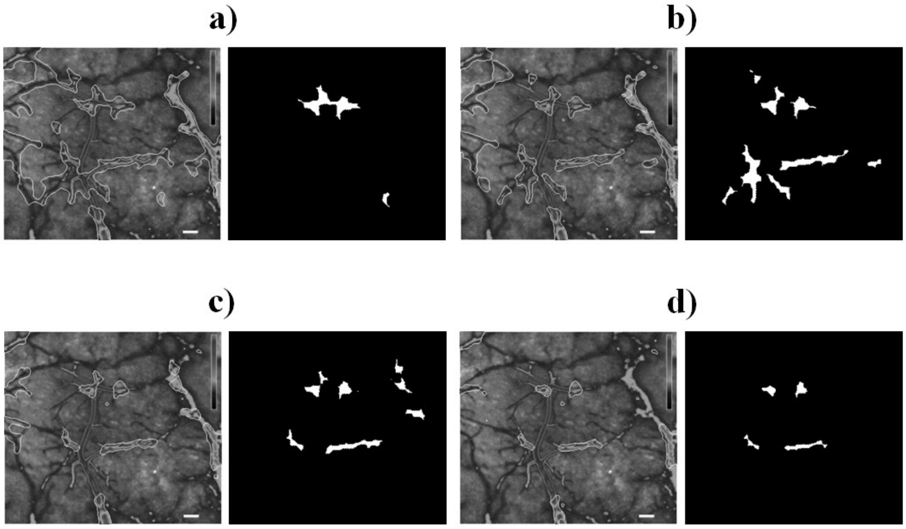


Figure 6. Segmentation (left of each sub-image) and Extraction (right of each sub-image) of neural hemodynamic for reference gray-levels, a) 0.75, b) 0.78, c) 0.81, and d) 0.84.

According to our results, an adequate value of the reference gray level allows us to achieve a successful segmentation and extraction of the suspicious regions while they are discriminated in a clear and effective way, avoiding the extraction of non-relevant regions with similar textures as much as possible. On the other hand, it has been found that by selecting different values of the reference gray level it is possible to use the extracted binary image (i.e. extracted abnormality) as a mask to discriminate regions of interest within the original image.

Furthermore, since the overall process is based on texture analysis, by using the extracted binary image as discriminating mask, raw data belonging to layers at different depth of the tissue can be independently analyzed since the binary mask allows separating the information to locally study the regions of interest based on texture characteristics.

In terms of medical diagnostic support, being able to discriminate suspicious from non-relevant regions could be a difficult task because we can omit important information related to possible abnormal regions. Therefore, our method provides a very simple way to realize such task without compromising crucial information that could avoid the detection of potential tumors.

## 4. CONCLUSIONS

A method for pattern recognition is proposed for abnormalities identification and extraction from several thermoacoustic images. The proposed algorithm has the potential of being incorporated into real-time systems for image acquisition in order to improve medical diagnosis. While the photoacoustic phenomenon has been known for a long time, photoacoustic medical imaging is a recent domain and we have yet to see all of the possible applications.

The present work leaves open the possibility to perform well-localized study of regions of interest within the original image based on the intrinsic texture properties: raw data belonging to layers at different depth of the tissue can be extracted to be independently analyzed since the resulting binary mask allows separating the regions of interest based on texture characteristics.

The performance of the proposed algorithm is evaluated by processing different medical thermoacoustic images. In this particular case, two cases are explored: processed images illustrating non-cancerous tumor detection and brain functionality for hemodynamic analysis, respectively. The main parameter to control the performance of the proposed algorithm is the reference gray-level around which the abnormality will be searched. The obtained results suggest that, by selecting an adequate value of the reference gray level, the proposed method provides the capability to achieve a successful segmentation and extraction of the suspicious regions while they are discriminated in a clear and effective way, avoiding the extraction of non-relevant regions with similar textures as much as possible.

Since the reference gray-level of our method can be easily adjusted, it provides a simple and versatile way to discriminate suspicious from non-relevant regions without compromising crucial information that could avoid the detection of potential tumors. The tests results of the extraction of carcinogenic masses in photoacoustic/photothermal images allow validating the effectiveness and suitability of the proposed method since the obtained information after processing can complement the medical diagnostic in a very important way.

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