

Development of a Multispectral Gastroendoscope to Improve the Detection of Precancerous Lesions in Digestive Gastroendoscopy

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1 STAGE OF THE RESEARCH

The actual stage of research is the beginning of the second year of the PhD thesis. The duration of the thesis is three years. The first year has begun with the state of the art involving two main parts. The first one focused on medical aspects related to the development and staging of stomach cancer. The second part was oriented to the actual technology and image processing techniques which are used to help in the diagnosis of malignancies in the stomach. The review of the state of the art mainly focused on the study of multispectral imaging. An overview of the state of the art is presented in section 4. Then, a multispectral endoscope prototype has been developed; this system is described in section 5. It is based on the use of a filter wheel to modify the regular white light of a gastroendoscopic system. Afterwards, a set of image pre-processing techniques has been developed to improve the usability of the multispectral images obtained by the prototype. These techniques are also described in section 5. Finally, in section 6 are presented the future work and the expected outcome.

2 OUTLINE OF OBJECTIVES

In order to improve the diagnosis during gastroendoscopy, practitioners need additional information from the tissue characteristics in a non-invasive, efficient and accurate way.

The actual technology used to perform gastroendoscopy is mainly based on the visual exploration under white light; an illustration is presented in figure 1a. Unfortunately, it is often difficult to visualize malignancies in the tissue with

this technology. Practitioners with all degrees of experience, including those with many years of practice mention this situation.

The diagnosis of gastric pathologies is performed based on biopsy acquisition and its histological analysis, which is the microscopic evaluation of tissue. This is considered to be the most reliable technique for diagnosis. Unfortunately, the collection is difficult because in many cases there are no macroscopic differences between healthy and wounded tissue. In consequence, practitioners usually collect biopsies randomly. This situation leads to the acquisition of tissue without any pathology, which produces undesirable false negative diagnosis.

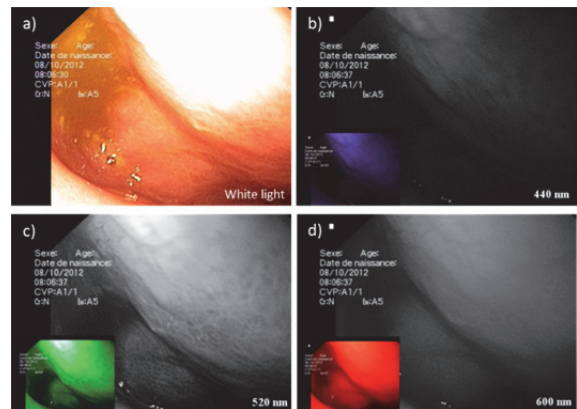


Figure 1: a) Colour image under white light. b), c), d) Monoband images which highlight different features.

Considering that the gastric pathologies are related to modifications in the properties of the tissue, there is an important need to measure these variations. Based on previously successful applications, we believe that multispectral imaging can help in the identification of early stages of

gastric cancer, even if these lesions present subtle colour and morphological differences in comparison with healthy tissues using conventional white light illumination.

In summary, there are two main objectives in this PhD thesis. The first one is the design and development of a prototype capable to acquire multispectral images of the stomach during gastroendoscopy. The system must be compatible with the actual systems used in gastroendoscopy. The second objective is to propose tools and methods to identify cancerous tissue at an early stage. This second part is not presented here. We present in the remainder of the document, the proposed acquisition system and the image pre-processing techniques implemented.

3 RESEARCH PROBLEM

The first challenge of the PhD is the acquisition of multispectral images during gastroendoscopy. Some recent works have focused on the analysis of the reflectance from gastric tissue using spectroscopy (Bashkatov et al., 2007). On the other hand, other recent works were focused on the analysis of multispectral images of gastric tissue from *ex-vivo* samples (Galeano et al., 2012); (Kiyotoki et al., 2013). To the best of our knowledge, there is no work on the analysis of pre-cancerous lesions using *in-vivo* multispectral images of the stomach tissue acquired during gastroendoscopy. Consequently, the first research problem to solve is the development of a system to acquire the data, which is not a trivial task due to the inherent constraints from the working environment.

The second problem to solve is the registration between successive monoband images. Due to the configuration of the acquisition system, the monoband images that compose the multispectral images are acquired sequentially and present a shifting. It is necessary to register the monoband images to form the multispectral image. This registration is highly complicated because many assumptions, upon which the majority of the state of the art techniques rely, are not respected for our data. These methods are usually based either on the use of anatomical references, texture features or the underlying assumptions to the use of optical flow, where there is a small displacement of a constant intensity between two images. In our particular case, the images obtained are not compliant with these fundamental assumptions, for instance the gastric tissue is highly homogeneous with subtle texture in

some cases, it is in constant movement (non-rigid deformations) and the environment is moist (large variations in photometric properties). Moreover, monoband images of the same area at two different wavelengths present strong differences. In figure 1 is shown an example of these difficulties with 3 monoband images from a gastric multispectral image.

The two above problems are detailed in this document. We can also mention the difficulty to extract information from these images. The first problem will be given by the quality of the images. The methods to detect pre-cancerous lesions should be sufficiently robust to operate on noisy images. Then, the methods should be fast enough to identify in real time tissue which is more likely to develop cancer, in order to help the practitioner during the gastroendoscopy. These issues will be a major part of the work during the second and third year of the PhD thesis.

Before introducing the acquisition system and the image processing techniques, we present in the following section the state of the art.

4 STATE OF THE ART

Nowadays, the majority of gastroendoscopy imaging devices provide colour images acquired under white light. Some systems have been developed that increase the visualization of the lesions from a macroscopically point of view. These systems can be classified in two main categories. The first one takes advantage of an external agent, for instance a dye is used to highlight specific features of the lesions. The main technique in this category is chromoendoscopy (Kida et al., 2003).

The second class of systems increases the spectral resolution of the images in order to enhance the visualization of the tissue. The Narrow band Imaging (NBI proposed by Olympus) or Multi Band Imaging (FICE proposed by Fuji) belongs to this category. For these systems, a false colour image is formed with 2 or 3 monoband images at a specific wavelength (Wong Kee Song et al., 2008). These techniques can be considered as a virtual version of chromoendoscopy.

Even if they are limited to a few bands, these techniques show the potential of multispectral imaging for gastroendoscopy. A multispectral image is formed by monoband images taken at different wavelength. This technique has an important advantage since it provides spatial and spectral information. This situation leads to use image and

signal processing algorithms for data treatment.

There are different examples of successful implementations of this technique oriented to medical applications. For instance, it has been used to increase the proportion of anomalies found in skin, but also to characterize and delimitate lesions (Tomatis et al., 2005). Recent approaches have showed that it is possible to retrieve biological parameters from the tissue under controlled acquisition conditions (Jolivot et al., 2011).

Multispectral imaging presents some disadvantages, for instance the amount of memory required for a single image (width x height x total of wavelengths). In consequence, the computational cost increases significantly. Furthermore, the images are acquired typically sequentially; this can be problematic in case of non-static scenarios.

After reviewing the actual technologies to detect pre-cancerous lesions, as well as the advantages and disadvantages of multispectral imaging, we introduce in the following section the acquisition prototype and the algorithms used.

5 METHODOLOGY

In this section we describe the development of the multispectral prototype, as well as the pre-processing image techniques implemented.

5.1 Prototype of the Acquisition System

Multispectral imaging acquires information in two spatial dimensions (width and height) and one spectral dimension (wavelength). The acquisition is performed in most of the cases through two dimensions at the time, creating two options (Simon et al., 2013); (Grahn and Geladi, 2007).

The first one acquires one spatial and the spectral dimension; this option demands some kind of motion to scan the other spatial dimension.

The second one acquires the spatial dimensions whereas the remaining spectral dimension is scanned. In practice, this option can take advantage of a CCD camera to acquire monoband images at different wavelengths. Therefore, this configuration is selected over the other due to its compatibility to use the camera from the current gastroendoscopes.

Physically, there are two main options to scan the spectral dimension as is presented in figure 2.

The first option is to illuminate the scene with a series of specific wavelengths. This can be achieved for instance by using a tunable light source or filtering the light from a single light source. This last

option is commonly used in practice through a filter wheel.

The second option is to filter the incoming light from the scene to the sensor, which can also be achieved by placing a filter wheel in front of the camera or by using a multispectral camera.

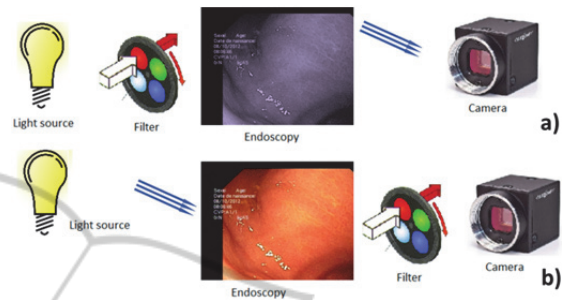


Figure 2: Techniques to acquire multispectral images. a) Single wavelength illuminates the scene. b) Filtering the light arriving to the camera.

For reasons of simplicity and compatibility with the actual gastroendoscopic systems, we decided to modify the source of light of the regular gastroendoscopes. The final configuration is presented in figure 3, where the source of light is a Xenon lamp, filtered by a filter wheel. This light is transmitted through the gastroendoscope (Olympus Exera II) to illuminate the stomach. Then, the camera from the gastroendoscope is used to capture the image which is finally transmitted to a computer connected to the gastroendoscopic station.

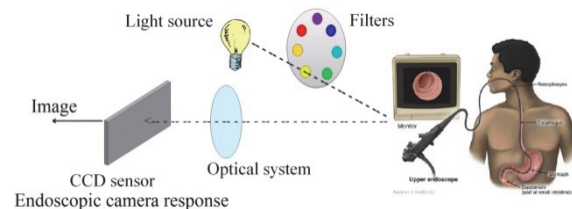


Figure 3: Multispectral acquisition prototype.

The filter wheel includes six filters in the visible range from 440 to 640 nm with an equidistant spectral separation. This option was selected over the others due to the wide range of available filters that facilitates the customization. Moreover the cost is reasonable and the light power allows strong input ranges in comparison with the wavelength generator light source. The output of this system is a video sequence at 25fps with a resolution of 640x480 pixels, from which we can extract the multispectral images.

The video is first deinterlaced using the widely known algorithm of Yadif (Hegenbart et al., 2013).

Then, the sequences of monoband images that formed the multispectral images are extracted from the video. The speed of the filter wheel is configured in order to obtain 4 monoband images from each wavelength. The first and fourth are the transition between two filters and are discarded. The second and third images can be used to generate the multispectral image; in our application, we use the third image.

The moist environment of the stomach produces areas of specular reflection in the images, these regions are easily removed using a threshold.

The acquisition time of a multispectral image is approximately one second. Because the stomach is in constant movement, the monoband images acquired sequentially present a shifting. This shifting can be reduced increasing the acquisition speed, but it is limited to the speed of the filter wheel and the frame rate of the gastroendoscopic camera. In the following section is addressed this shifting issue.

5.2 Image Registration

This stage is crucial for the image analysis, since it allows the superposition of the monoband images.

The first step is a pre-processing step in order to enhance the contrast information. The algorithm of contrast limited adaptive histogram equalization is used in each monoband image.

Then, an affine model is used to model the transformation between consecutive monoband images. The parameters of the transformation are computed using the hierarchical motion-based estimation (Bergen et al., 1992). The transformation matrix has six degrees of freedom, which covers the relative small variations caused in the image by the movement of the endoscope and the tissue during the acquisition.

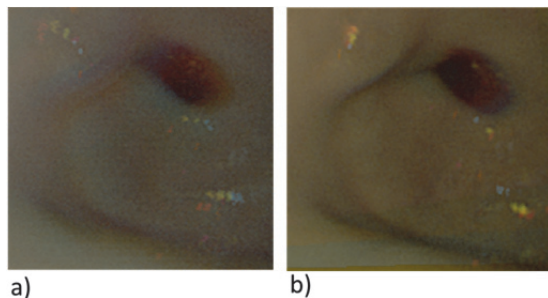


Figure 4: Virtual white light image computed from a) original monoband images and b) registered monoband images.

In order to minimize the cumulative error, we visualize the six monoband images as a sequence,

where the center image is used as a common image for two subsequences.

The fourth monoband image is assumed to be the center image and functions as reference for the registration of the other images. Then, to explain the procedure, we use the smaller subsequence as an example (images fourth, fifth and sixth); the fifth monoband image is registered to the reference image. Then, the sixth image is registered to the fifth image producing a temporal image; later on, we apply to this image the transformation before estimated to register the fifth image with the reference image. If there were further images, this procedure can be iteratively repeated until all the images from the subsequence are registered. Then, the same procedure is applied to the other subsequence.

Finally, when all the transformations are known, they are applied to the original data to produce a new set of six monoband images. In order to highlight the advantages of the registration, figure 4 shows two images whose simulate an endoscopic image acquired under white light. It is clear that the figure 4b generated from the registered images is sharper in comparison with 4a.

5.3 Normalization

The fact that the distance and the orientation between the tissue and the camera are not constant, has an important impact in the amplitude of the estimated spectrum as is shown in figure 5a.

We believe that the shape of the spectrum is more significant than the amplitude to differentiate precancerous lesions; therefore, a normalization step is clearly necessary in order to accurately identify malignancies in gastric tissue. In this sense, the Area Under the Curve (AUC) is selected as a spectral normalizer function. Figure 5b presents the spectra after normalization, where the spectral shape remains, facilitating its comparison. This characteristic is highly desired in the input data for classification algorithms.

The multispectral images acquired with the prototype and the described treatment produce promising spectra. These findings lead the path to the second and third year of PhD in order to propose methods to identify pre-cancerous lesions at an early stage.

6 EXPECTED OUTCOME

The three years of PhD thesis are expected to

produce two main results.

The first one is a multispectral acquisition system for gastroendoscopy. This system is being designed to be compatible with the actual acquisition systems used in gastroendoscopy.

The acquired multispectral image during gastroendoscopy leads to the second outcome, which is the identification of cancerous lesions at an early stage. The research is oriented to the proposal and development of tools and methods oriented to identify pre-cancerous lesions. These methods are expected to be robust to noise due to the acquisition conditions and fast enough, in order to recognize in real time the tissue, which is more likely to develop cancer. These algorithms will be a major part of the work during the second and third year of the PhD thesis.

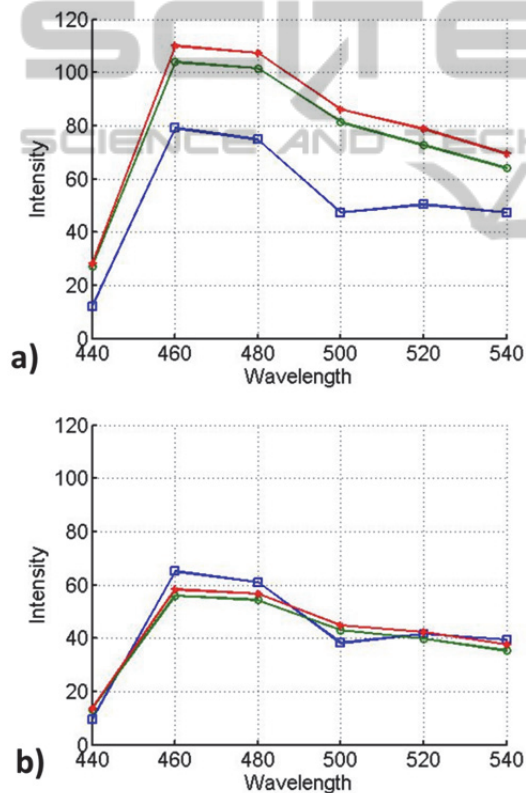


Figure 5: Spectrum from healthy tissue, a) original spectrum, b) normalized spectrum.

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