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Acceleration of brain cancer detection algorithms during surgery procedures using GPUs

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ABSTRACT

The HypErspectraL Imaging Cancer Detection (HELICoiD) European project aims at developing a methodology for tumor tissue classification through hyperspectral imaging (HSI) techniques. This paper describes the development of a parallel implementation of the Support Vector Machines (SVMs) algorithm employed for the classification of hyperspectral (HS) images of in vivo human brain tissue. SVM has demonstrated high accuracy in the supervised classification of biological tissues, and especially in the classification of human brain tumor. In this work, both the training and the classification stages of the SVMs were accelerated using Graphics Processing Units (GPUs). The acceleration of the training stage allows incorporating new samples during the surgical procedures to create new mathematical models of the classifier. Results show that the developed system is capable to perform efficient training and real-time compliant classification.

1. Introduction

Brain tumors have an estimated incidence of approximately 3.4 per 100,000 subjects and are among the commonest tumors [1]. The most common form is high-grade malignant *glioma* (a tumor that affects glial cells of the brain), which accounts for approximately 30–50% of primary brain cancers, with multiform *glioblastoma* (a malignant tumor affecting the central nervous system, usually occurring in the cerebrum of adults) making up 85% of these cases. These types of gliomas are characterized by fast-growing invasiveness, which is locally very aggressive, in most cases unicentric and rarely metastasizing [2].

Traditional diagnoses of internal tumors are based on *excisional biopsy* (removal of tissue from the living body by surgical cutting) followed by histology or cytology [3]. The main weakness of this standard methodology is twofold: firstly, it is an aggressive and invasive diagnosis with potential side effects and complications due to the surgical resection of both, malign and healthy tissues; and secondly, diagnostic information is not available in real-time and needs the tissues to be processed in a laboratory. The importance of complete resection for low grade tumors has been discussed and it has proven to be beneficial, especially in pediatric cases [4]. Currently, there are several alternatives to traditional optical imaging technology, being the most common ones the Magnetic Resonance Imaging (MRI), the Computed Tomography (CT), the Ultrasonography, the Doppler scanning and the Nuclear Imaging. Each one of these techniques has several disadvantages, being the most important ones that they do not offer real-time results, and/or they are highly invasive or ionizing.

Typically, tumor removal can cure low-grade tumors and prolong life in the more aggressive cases. The human eye is not always able to recognize tumor tissues from healthy ones and, in any case, it is not accurate enough. This situation is particularly critical when considering brain cancers, since they infiltrate and diffuse into the surrounding normal brain tissue [4,5]. Therefore, surgeons may unintentionally leave behind tumor tissue during surgery. The consequences are critical because the tumor can recur later [6]. If instead, the surgeon removes too much tissue to improve the security margins, this can lead to permanent disability [7].

The HELICoiD project [8–10] is integrated in this scenario. It was funded by the Research Executive Agency, through the Future and Emerging Technologies (FET-Open) programme, under the 7th Framework Programme of the European Union. It involved four universities, three industrial partners and two hospitals. It is focused on developing a system capable of distinguish brain tumor tissues from healthy ones in real-time, during a neurosurgery intervention. It is important to notice that traditional imaging techniques do not guarantee sufficient classification precision. To tackle this problem, hyperspectral imaging (HSI) has been exploited. This kind of images are acquired across the electromagnetic spectrum through a high number of narrow bands. This particular characteristic is very important because it allows extracting

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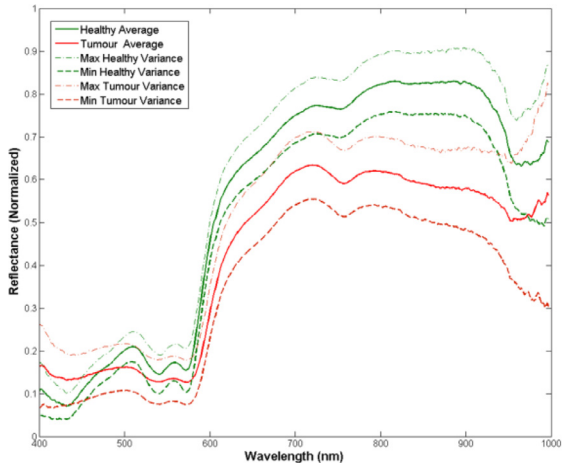

Fig. 1. Spectral signature of healthy and tumor tissue.

more information compared to classical RGB techniques, where the spectral information is limited. It is also important to notice that HSI is suitable for medicine, since it is a minimally invasive, non-ionizing and non-contact technique [11,12].

HSI classification involves the analysis of the so-called *spectral signature*, which describes the variation of reflected light with respect to wavelengths. Since brain tumor changes the cellular physiology within its evolution, the reflectance of the tissue is also altered [13]. Therefore, by analyzing the spectral signature of a tissue, it is possible to perform an accurate classification [8,14]. Fig. 1 compares the spectral signature of healthy tissue with respect to the signature of tumor tissue in the visual-and-near-infrared (VNIR) range, i.e. from 400 nm to 1000 nm. These average signatures have been obtained using the HELICoiD imaging system.

The main objective of this project is to develop a prototype capable of classifying tissues in real-time and to show to the surgeon a false color map overlapped with a traditional RGB image on a display [9]. The false color map substitutes the natural colors in order to ease the detection of certain features. In this context, the false color map highlights which class each pixel belongs to.

This paper addresses parallel SVMs training and classification for hyperspectral images on GPUs, which will be included in the final system. In particular, SVMs classification involves linear algebra operations, which are intrinsically parallel and can be efficiently exploited by GPU computing. GPUs have been widely used for exploiting data parallelism in several applications from different scientific fields [15–19]. Moreover, GPUs have been successfully employed in SVM training [20,21] and classification in different contexts [22,23]. In this work, the target device has been an NVIDIA Tesla K40c GPU, which is equipped with an architecture optimized for scientific floating-point computations.

Experimental results show that SVMs training can benefit from GPU computing. Moreover, the classification is real-time compliant and shows an excellent quality of the results.

In this paper, we describe the activity performed by the University of Las Palmas de Gran Canaria, in collaboration with the University of Pavia, concerning SVMs implementation on GPUs. Section II describes the HELICoiD system, while Section III is about the adopted classification framework. Section IV gives details about the parallel implementation of training and classification. Section V describes the experimental results. Finally, Section VI contains the conclusions, together with some possible future research lines.

2. HELICoiD system overview

The HELICoiD system has been designed to give the surgeon confidence that the goal of removing all the tumor tissue has been reached without removing excessive normal tissue. A schema of the HELICoiD system is depicted in Fig. 2. The system is composed by four main parts:

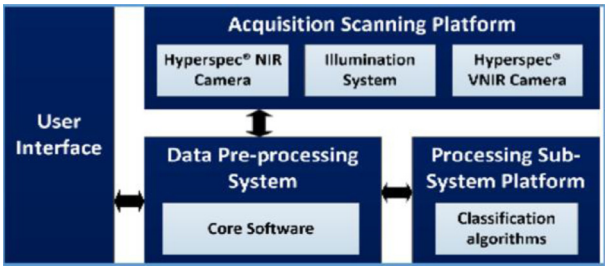

Fig. 2. Overview of the HELICoiD system [8].

1. the acquisition scanning platform;
2. the data pre-processing system;
3. the processing sub-system platform;
4. the user interface.

The acquisition scanning platform is responsible of the adequate data collection. It consists of an illumination system and two hyperspectral cameras. The former is a Hyperspec® VNIR A-Series that covers the spectral range from 400 to 1000 nm (VNIR) with 826 different spectral bands. Each image line is made up of 1004 pixels. The latter is a Hyperspec® NIR 100/U, which acquires 172 spectral bands over the range from 900 to 1700 nm (NIR, near-infrared). Each image line includes 320 pixels.

Both cameras are *push-broom* capturing systems. This well-known acquisition technique is schematized in Fig. 3. The linear detector array acquires the spectral information across all the bands, together with a single spatial dimension of the scene. The acquisition of the other spatial dimension requires shifting the camera's field of view (FOV) over the scene. The scanning platform is the system component responsible of performing this movement by controlling a stepper motor. The HELICoiD platform has a maximum path of 230 mm with a step resolution of 6.17 μm.

As far as the illumination system is concerned, it includes a light source and a cold light emitter. The light source emits within the spectral range between 400 and 2200 nm. The main drawback of this illumination system is that it generates high temperatures near the bulb. In this kind of applications, high temperatures are dangerous since they can cause breakage and premature death of cells [24]. Thus, it is necessary to reduce the temperature. This is the task performed by the cold light emitter, which lowers the incident temperature over the brain surface by transmitting the light trough optical fibers.

The data pre-processing system is in charge of controlling the

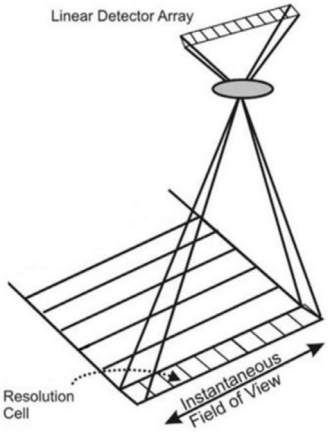

Fig 3. Push-broom acquisition schema.