MANIFOLD EMBEDDING AND SEMANTIC SEGMENTATION FOR BRAIN TUMOR DETECTION USING HYPERSPECTRAL IMAGING

Sachithra S.S [1], Shiji A.S [2]

PG Student (ME Applied Electronics) [1], Assistant Professor [2]

Department of Electronics and Communication Engineering, Narayanaguru College of Engineering, Manjalumoodu, Tamil Nadu

Abstract—Brain tumor is an abnormal growth of cells, reproducing themselves in an uncontrolled manner. Hyperspectral imaging is an emerging technology that can assist surgeons to classify tumors from healthy tissue in real time. Recent advances in hyperspectral imaging have made it a promising solution for intra operative tissue characterization, with the advantage of being non-contact, non-ionizing and non-invasive. Proposed framework mainly consist of two step namely manifold embedding and semantic segmentation. Manifold embedding is performed by using principal component analysis (PCA), which helps to reduce dimensionality of image. Then semantic segmentation is applied to embedded result by using discrete cosine transform based semantic texton forest (DCT-STF) algorithm. This algorithm has good accuracy for real time application than classical semantic texton forest algorithm.

Keywords— Hyperspectral imaging, Manifold embedding, Semantic segmentation, Brain tumor detection

INTRODUCTION

Brain tumor is generally diagnosed by a specialist called a neurologist. Imaging tests performed on magnetic resonance imaging (MRI) and/or computer tomography (CT) scan utilize computer technique to engender detailed picture of brain. But MRI is still not accessible for real time intra-operative use. Currently patients with brain cancer continue to have very poor survival rates. Surgery is one of the mainstays of treatment, together with radiotherapy and chemotherapy [7]. Since brain tumors diffusely infiltrate into surrounding normal brain tissue, it is extremely difficult for surgeon to accurately differentiate between tumor and normal brain tissue with the nacked eye. In some cases, unintentionally leaving behind tumor tissue after the resection is unavoidable, and in other cases, too much brain tissue is resected in an effort to ensure complete excision. Over segmentation can produce permanent neurological deficits that affect patient quality of life [15]. Therefore surgeons require a real-time method for the localization and assessment of tumor margin during surgery.

Hyperspectral imaging (HSI) is an emerging technology that can assist surgeons to classify tumor from healthy tissue in real time. Hyperspectral imaging is also called image spectroscopy. HSI is spectral imaging collects and process information from across electromagnetic spectrum. Hyperspectral imaging is a non-contact, non-ionizing and minimally invasive sensing technique [9]. Unlike standard red, green and blue (RGB) or spectral images (which have a few more bands than RGB image), hyperspectral images cover a wide range of electromagnetic spectrum and are able to capture a large number of contiguous and narrow spectral bands. This high amount of information conforms the spectral signature which offers the possibility of distinguishing between each type of material or substance presented in the captured scene. Hyperspectral imaging is an emerging modality and promising result have shown with respect to cancer detection. Hyperspectral imaging acquires a three-dimensional dataset called hypercube, with two spatial dimensions and one spectral dimension.

The HSI has a unique feature that it includes numerous bands associated with a single image, so that its resolution will be so high that in accumulate many unique features of the subject. It includes both the spatial and spectral information, since it is a two dimensional spatial images spread out in hundreds of bands of large spectral resolution. Its band not only include just the visible spectrum, but also it includes the ultra violet (UV) and near-infrared (IR) bands. Thus it can be a perfect imaging tool and can well examine all the internal properties of a tissue like emissivity, reflectivity, absorptivity etc which is not possible in conventional imaging techniques. The major advantage of the HSI is that it is fast, cost effective, no radiation effects and no requirement of the contrast agent or it is a completely non-invasive procedure. It is actually an optical spectroscopy technique. It can be applicable for the surgical assistance, especially image guided surgery. Fig 1 shows comparison between hypercube and RGB image.

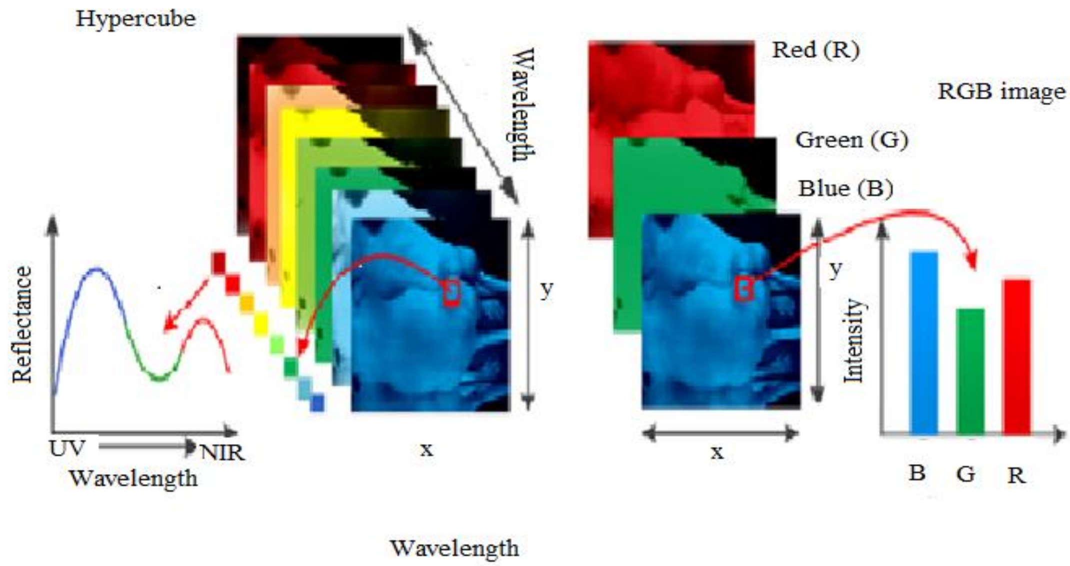

Fig1: Comparison between hypercube and RGB image

In order to obtain the hyperspectral images of in-vivo human brain surface during neurosurgical operations, Hyperspec VNIR A-series and Hyperspec NIR X-series cameras are using. The VNIR (visible and near infrared) camera ranges between 400nm to 1000nm. The near infrared (NIR) camera ranges between 900nm to 1700 nm. Table 1 shows Camera Specifications.

Table 1: Camera Specifications

Camera Specification	**Hyperspec VNIR**	**Hyperspec NIR**
Spectral range (nm)	400-1000	900-1700
Spectral resolution (nm)	2-3	5
Slit(µm)	25	25
Spatial bands	1004	320
Spectral bands	826	172
Frame Height (FOV) (nm)	129.21	153.6
Pixel Dimensions (IFOV)	0.1287	0.4800
Max Pixels per Frame	1004	320
Max Frames per pixel (nm)	1825	489
Dispersion per pixel (nm)	0.74	4.8
Detector array	Silicon CCD	InGaAs
Frame rate (fps)	90	100

RELATED WORKS

Existing approaches to brain tumor visualization are commonly based on CT or MRI. The main steps of medical image processing is segmentation, Feature Extraction and Classification. Usha B.L et al. [16] presents K means algorithm for segmentation and gray level statistical analysis (GLCM) for feature extraction. The linear discriminate analysis (LDA) based classification is used for classifying brain tumor of type benign with that of malignant. Anam Mustaqeem et al. [1] presents threshold and watershed segmentation algorithm for brain tumor detection. K.Sathiyasekar et al. [13] presents near infrared imaging technology (IIR) to detect brain tumor of size below 3mm. Fuzzy least mean squares algorithm is used for segmentation purpose. Dina Aboul Dahab et al. [4] presence Probabilistic Neural Network (PNN) classifier for brain tumor detection. Nilesh Bhakarrow Bahadure et al. [10] propose Berkeley Wavelet transform (BWT) and Support Vector machine based (SVM) based classifier for brain tumor detection. Asra Aslam et al. [2] proposes improved edge detection for brain tumor detection. Rajeshwar Nalbalwar et al. [11] proposes Artificial Neural Network (ANN) for finding brain tumor. Hamed Akbari et al. [6] proposes cancer detection using infrared hyperspectral imaging. B. Fei et al.

[5] claimed that hyperspectral imaging is an emerging modality for medical application. David T. Dicker et al. [3] explained the differentiation of normal skin and melanoma using high resolution hyperspectral imaging. Here they experimented the use of high resolution hyperspectral imaging microscopy to detect abnormalities in skin tissue using hematoxylin eosin stained preparations of normal and abnormal skin, benign nevi and melanoma.

PROPOSED WORK

MRI or CT scan is performed on patient before surgical procedure. During each surgical procedure two sterilized fiducial markers are placed in brain. One in area that belongs to a tumor and other in healthy brain tissue. Evaluation of brain tissue is performed by surgeon based on visual appearance. Pointer defines position of fiducial marker with respect to pre-operative MRI or CT data. Afterward hyperspectral image is captured by using hyperspectral camera. After hyperspectal image have been captured, system is moved out of surgical zone and neurosurgeons continues with tumor resection until a new image can be captured depending on nature of surgical procedure

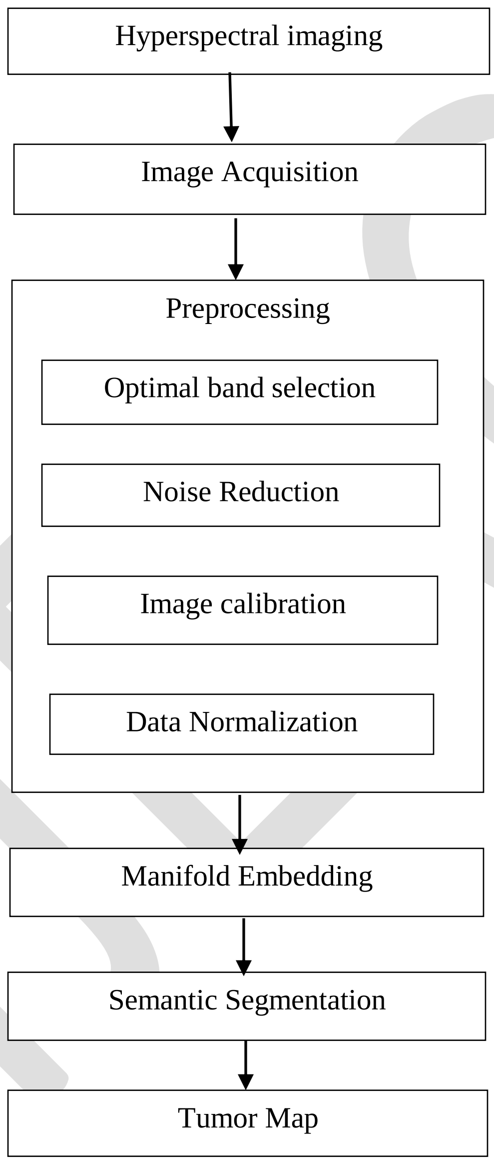

Fig 2: Flow Diagram of Proposed System

The pipeline of the proposed approach is summarized in fig 2. It consist of a hyperspectral image acquisition block followed by a pre-processing step, then manifold embedding and semantic segmentation classifier is performed to generate the tumor map.

IMAGE ACQUISITION

To capture the hyperspectral images, Headwall's VNIR A-Series and Headwall's Hyperspec NIR-X Series cameras have been used. The VNIR camera captures 826 spectral bands and NIR camera captures 172 spectral bands. The spectral range of VNIR camera is 400-1000 nm and for NIR camera is 900-1700 nm. Spectral resolution of VNIR camera is 2-3 nm and for NIR camera is 5 nm. The light source used in this system is a wide spectrum light that provides a uniform illumination on the subject. The distance between the lens and subject is kept constant at 40 cm and manual image focus is used.

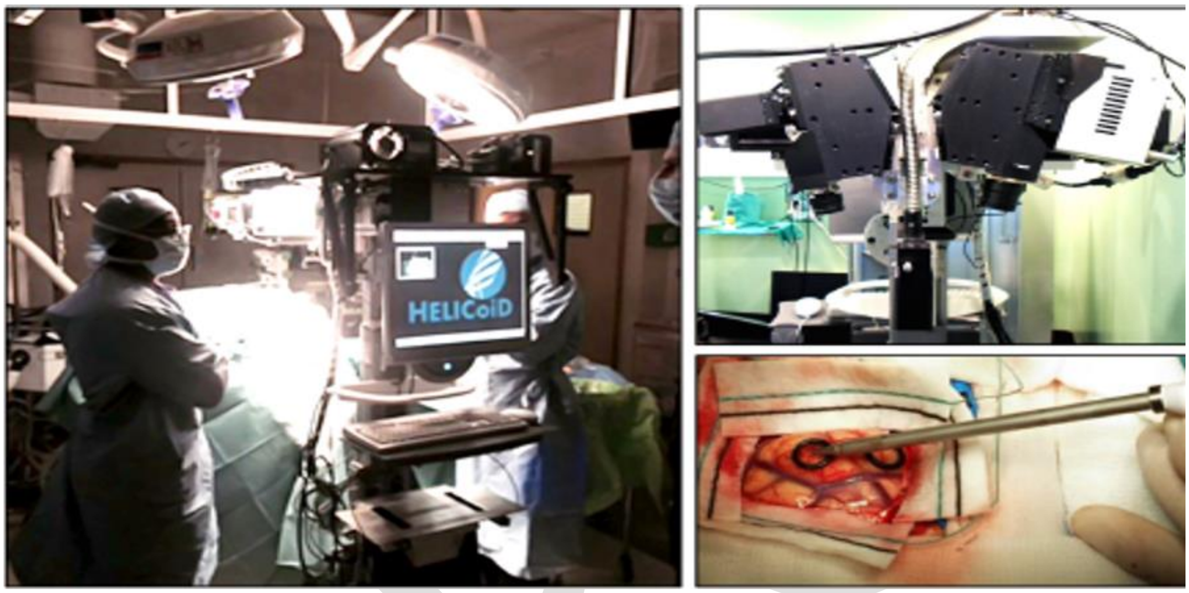

Fig 3: Image acquisition platform

PRE-PROCESSING

During the acquisition of a hyperspectral image the proposed method used a wide spectrum light that provides a uniform illumination. But the light uniformity along all areas of the brain can not always be guaranteed due to the three dimensional cortical folding of the brain that can introduce occlusions and shadows. Other external factors such as inconsistent environment light can lead to variation in spectral domain. These effects can be reduced by using a pre-processing pipeline that normalizes the reflectance of the hyperspectral image. The proposed pipeline is divided into four steps:

1. Optimal band selection
2. Noise Reduction
3. Image Calibration
4. Data Normalization

Optimal band selection

The optimal band selection is one of the important step in hyperspectral imaging processing. Here from the numerous bands available in hyperspectal image only those bands containing the necessary features alone may be considered. This step is used to discard all the distorted bands in the extreme sides. Before the 450 nm and after 950 nm for the visible and near infrared camera and before 950 nm and after 1650 nm for near infrared camera is discarded.

Noise Reduction

The main aim of this step is to remove the noise. Mainly the noise generated by common imperfections of the charge coupled devices (CCD) cells of the hyperspectral camera sensor is removed during this step. The noise removal is obtained by using the Hyperspectral Signal Identification by Minimum Error (HySIME) algorithm by assuming that the reflectance at a given band is well modelled by linear regression.

Image Calibration

During this step variation caused by non uniform illumination over surface of captured scene are adjusted. The hyperspectral image is calibrated using white and dark reference images. These reference images are acquired separately inside the operating theatre before the procedure. The white reference image is obtained from a standard white tile; the dark reference image is obtained by keeping camera shutter closed. The calibration is performed pixel wise.

Data Normalization

Due to scanning procedure of hyperspectral camera and non uniformity of brain surface, some areas of image can be captured with a different illumination. Inorder to avoid this issue, a unit magnitude normalization of brightness is performed for each pixel.

MANIFOLD EMBEDDING

Hyperspectral images have high dimensionality. It make real time processing difficult. High dimensionality is due to large number of wavelength bands that create the hypercube. For example an image that has 400×400 pixels captured at 200 wavelengths will be represented by 160000 vectors lying in the space. In order to handle a hyperspectral image adequately for real-time applications, its dimensionality needs to be reduced through the projection of the hyperspectral cube to a space with only a few dimensions. Dimensionality reduction transforms high dimensional data into a reduced dimensional representation that is still capable of describing the initial data. Principal component analysis (PCA) method [8] is used in this proposed method to reduce dimensionality. The fig 4(a) represents the hyperspectral brain image captured by using VNIR camera. The rings in the image are sterilized fiducial markers placed by doctors during surgical procedure. The fig 4(b) represents manifold embedded hyperspectral brain image. It represents one band representation of fig 4(a).

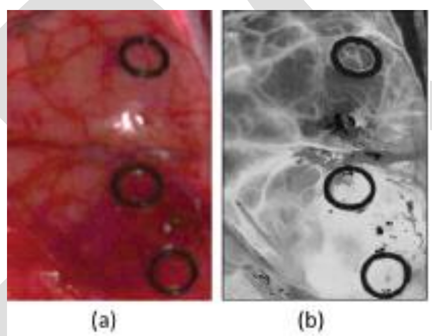

Fig 4: (a) Hyperspectral brain image (b) Embedded image

SEMANTIC SEGMENTATION

To obtain tumor classification map, a semantic segmentation approach is performed on the obtained embedded result. Color based segmentation is known as semantic segmentation. Semantic segmentation describes the task of partitioning an image into regions that delineate meaningful objects and labeling those regions with an object category label. One of the popular approach for this task is based on random forest and is called semantic texton forest (STF) [14] .This algorithm tries to exploit spatial arrangement of low level features to increase object discrimination. The proposed frame work uses discreate cosine transform based semantic texton forest algorithm (DCT-STF). This algorithm combine color and texture information for semantic segmentation purpose. DCT-STF [12] has better performance and less complexity than classical STF.

EXPERIMENTS AND RESULTS

The proposed system was implemented by using Matrix Laboratory (MATLAB) software. MATLAB is high level technical computing language. MATLAB is the interactive environment for algorithm development, data visualization, data analysis and numerical computation.
Hyperspectral brain image captured during surgery of brain tumor is used as input image. The image captured by using VNIR camera is shown in fig 5.

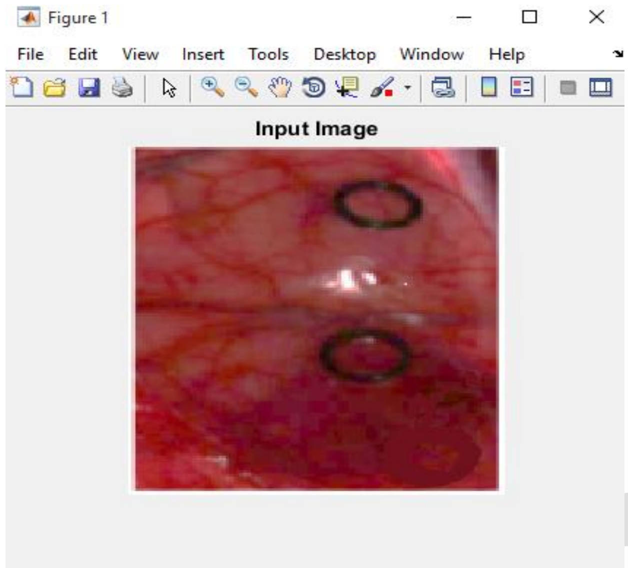

Fig 5: Input Image

After image acquisition and pre-processing, the dimensionality of image is reduced by using manifold embedding. Principal component analysis technique is used to reduce dimensionality of image. Fig 6 shows the embedded output

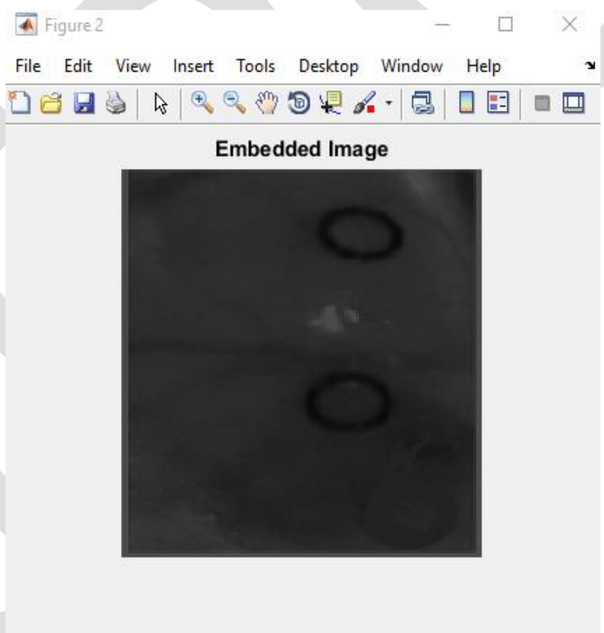

Fig 6: Embedded Output

Semantic segmentation is performed on the embedded result to obtain the tumor map. Color based segmentation is known as semantic segmentation. The discrete cosine transform based semantic texton forest algorithm is used for segmentation.

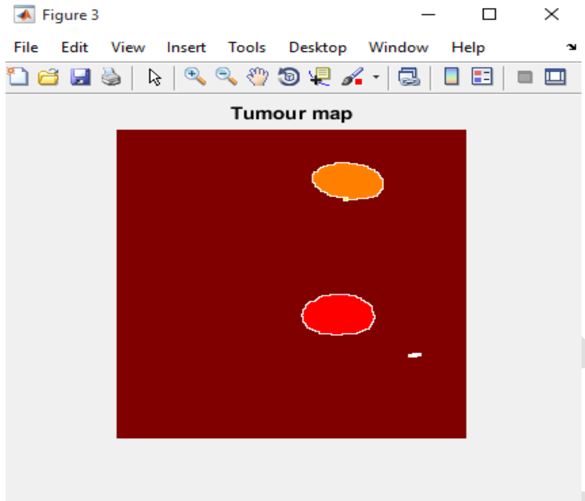

Fig 7: Tumor Map

The fig 7 shows tumor map. In this fig tumor cells are appeared in red color, normal cells are appeared in orange color and brown color indicate background.

Table 2: Computational time of proposed system for VNIR and NIR camera images

Camera Type	VNIR	NIR
Processing time	22 s	5 s
Manifold embedding time	2 s	2 s
Semantic segmentation time	16 s	5 s
Total processing time	40 s	12 s

The table2 shows time needed to process VNIR and NIR camera images. The brain image captured by NIR camera needs less processing time than VNIR camera image.

Mean class accuracy is obtained by averaging the accuracies achieved in each of the classes. Mean class accuracy is more reliable measure than overall accuracy. The mean class accuracy of discrete cosine transform based semantic texton forest algorithm is 80%.

CONCLUSION

The proposed frame work helps for real time cancer detection. The high dimensionality of hyperspectral image is reduced by using Principal component analysis (PCA) method. Then semantic segmentation is performed by using discrete cosine transform based semantic texton forest (DCT-STF) algorithm. The proposed method helps to determine the boundaries of tumors. The proposed method helps to allowing a complete resection of malignant cells at the time of brain tumor operation. The main weakness of the traditional approach are two fold. Firstly it is invasive with many potential side effects and complications and secondly diagnostic information is not available in real time and requires off-line histopathology sample analysis. The proposed system can overcome these problems and tumor resection can be greatly improved during surgical procedures, thus reducing the risk of disease recurrence. The real time nature of techniques improves surgical accuracy. Moreover proposed system helps in understanding cancer progression. Strength of proposed framework is in terms of processing speed and accuracy.

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