Signal Processing 93 (2013) 1673–1683

Contents lists available at SciVerse ScienceDirect

Signal Processing

journal homepage: www.elsevier.com/locate/sigpro

3D CBIR with sparse coding for image-guided neurosurgery

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ARTICLE INFO

Article history:
Received 1 March 2012
Received in revised form
11 October 2012
Accepted 29 October 2012
Available online 17 November 2012

Keywords:
CBIR
Computer aided path planning
Neurosurgery
3D SIFT
Sparse coding

ABSTRACT

This research takes an application-specific approach to investigate, extend and implement the state of the art in the fields of both visual information retrieval and machine learning, bridging the gap between theoretical models and real world applications. During an image-guided neurosurgery, path planning remains the foremost and hence the most important step to perform an operation and ensures the maximum resection of an intended target and minimum sacrifice of health tissues. In this investigation, the technique of content-based image retrieval (CBIR) coupled with machine learning algorithms are exploited in designing a computer aided path planning system (CAP) to assist junior doctors in planning surgical paths while sustaining the highest precision. Specifically, after evaluation of approaches of sparse coding and *K*-means in constructing a codebook, the model of sparse codes of 3D SIFT has been furthered and thereafter employed for retrieving, The novelty of this work lies in the fact that not only the existing algorithms for 2D images have been successfully extended into 3D space, leading to promising results, but also the application of CBIR that is mainly in a research realm, to a clinical sector can be achieved by the integration with machine learning techniques. Comparison with the other four popular existing methods is also conducted, which demonstrates that with the implementation of sparse coding, all methods give better retrieval results than without while constituting the codebook, implying the significant contribution of machine learning techniques.

1. Introduction

At present, many research fields have developed plethora well-developed theoretical models that are waiting to be applied, whereas each application domain lacks tailor-made specific algorithms that fit for purpose. To fill this gap, this paper focuses on the development of path planning system for image-guided neurosurgery via the application of techniques resulted from both visual information retrieval and machine learning domains.

Thanks to the advanced imaging techniques, image-guided key-hole brain surgery has made a significant impact on patients not only by improving clinical outcomes, but also by reducing their recovering time, cost, and psychological issues with little scars. In this regard, the procedures involve path planning based on the acquired patients' MR or CT images, physical drilling of a burr hole, and inserting a probe through the hole [1] to extract the tumour matter. Since the last two steps, i.e., drilling a hole and inserting a probe, follow the path that is planned in the first step, the planning stage plays a crucial part in ensuring a successful clinical outcome of a surgery. As such, the current planning stage has been conducted mainly by experts manually due to its delicate nature of the brain. To alleviate expert's pressure and to train junior doctors, computer aided path planning (CAP) system is being developed.

Although still in a research field, a number of automatic CAP systems have been proposed. For example, it has been reported by a number of researchers that the analogous path can be worked out automatically not only in industrial robotic remit [2] but also in medical treatment. On the other hand, by the application of Java

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http://dx.doi.org/10.1016/j.sigpro.2012.10.020

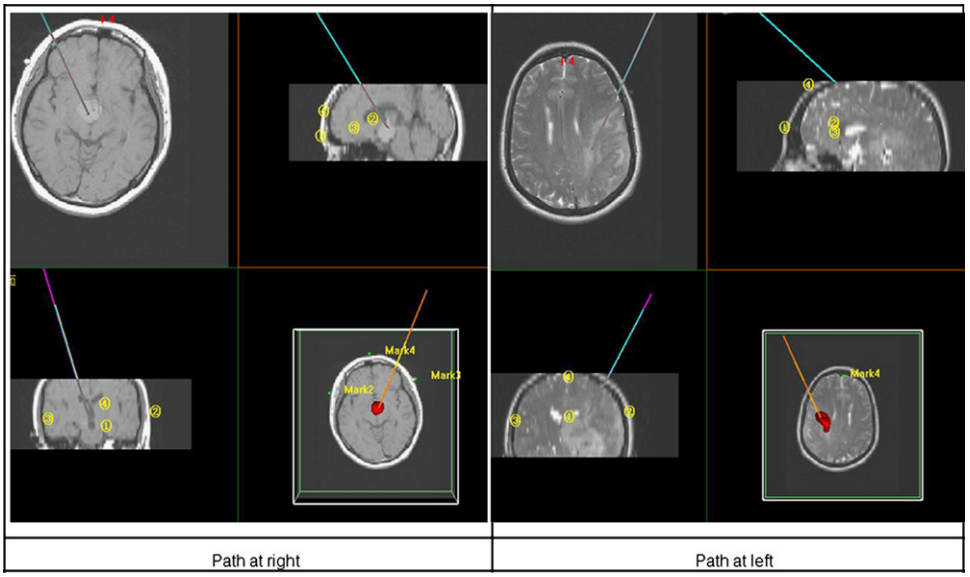

Fig. 1. Two examples of surgical paths that are indicated using lines.

programming, a group of reserchers [3] have developed an autonomous robot motion planning system that can visualize each phase of the planning process graphically. Similarly, another graphical technique to view multimodal images interactively is presented in [4], facilitating complementary tools to allow neurosurgeons to manupulate segments of images, leading to the application of path planning for surgical therapy in epilepsy. In this case, the data that can be visualized simultaneously include modalites of MRI, CT, fMRI and PET. In reality, however, it is very expensive to have more than two modality data acquired for each patient. In addition, a method of automatic neurosurgical path searching is described at [5], which integrates the structure of blood vesssels obtained from MRA and brain tissues. Their path searching machanism consists of a voting scheme by assiging each region assigned with a number between 1 and 4 according to the importance of the region; i.e., a smaller number can be given to a region that is further from blood vessels, by which the regions with minimum values are classified as the safest paths. Although this approach has a potential to provide a comprehensive system to help neurosurgeons to design a perfect path, the classification of the importance values is not so specific and MRA is too extravagant for ordinary hospitals and average patients. Therefore, the search for neurosurgical path planning in this investigation focuses on the reasoning of those successful cases that have already been collected by the application of technique of content-based images retrieval (CBIR).

In general, a CBIR system extracts features of images in terms of their global visual information, such as colour, texture, and shape, and then represents these features using mathematical vectors that in turn are employed to index each image. When a query image is submitted, the system only needs to extract these features from the query and performs the comparison with the feature database that has been stored in advance. In this way, the retrieval process of an image can be as fast as that in a text-based system since the similarity calculation is based upon numerical data only. In the past two decades or so, CBIR has been researched mainly on two dimensional images [6]. Only recently, CBIR for 3D images have been attempted with very promising results [7]. Because of the subjectivity nature of visual information and the differences between users' search intention, CBIR remains within a research domain.

Within CBIR, machine learning techniques have been introduced in two ways in an attempt to further improve its effectiveness. One way is to adopt unsupervised learning technique of Bag of Words (BoW) paradigm to train a codebook of the visual features of a training dataset which was first introduced in [8]. As a result, an image is represented by using the statistic summaries of the appearance of each word in the codebook as feature vectors that are then in turn utilized in image retrieval and classification. Another approach is to apply supervised learning technique by the employment of the technique of relevance feedback [9,10], leading to the study of both positive and negative examples selected by users from retrieved results, to discover and capture users' real intention, and to the modification of the retrieval process, thus obtaining retrieval results entailing the user's actual request as precise as possible.

In this paper, 3D CBIR is to be applied in assisting path planning procedures for image-guided neurosurgey, which is coupled with a machine learning technique of sparce coding, incorporating both experts' experience and knowledge by way of learning from the past through the reasoning of the existing data.

Fig. 1 demonstrates two examples of planned paths employed during two operations, which are initiated by an expert, where the lines can be viewed from different directions indicating the paths that a probe (i.e., a catheter) has been inserted through.