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Thermographic Image Processing in Neurosurgery: Motion Estimation and Correction

durch

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Abstract

It is estimated that in each year thousands of people are diagnosed with dangerous abnormal cellular growth (tumor) in Germany. A brain tumor is one of the most dangerous ones in this category. Medical imaging plays an essential role in tumor diagnosis protocols and is able to detect functional information of the brain. Infrared Thermography (IRT) imaging is one of the imaging technologies among other technologies with different medical applications. IRT imaging is informative not only for disease inspection but also is fast and without radiation response. In neurosurgery, IRT imaging helps the surgeon to observe useful information for brain tumors while the tumor temperature changes over time. In neurosurgery, the patient creates multiple motion artifacts such as head and body movements along with breathing and pulse motion. Additionally, other IRT image artifacts e.g., outliers, occlusion, and noisy pixels can reduce the accuracy and robustness of motion estimation and correction method. These artifacts can disturb the image and make it difficult for the surgeon to diagnostics and analysis images. In this thesis, inspired by optical flow the Combined Local-Global (CLG) method, a new motion estimation and correction method for IRT images in neurosurgery is proposed. A Cellular Nonlinear/Neural Networks (CNNs) method is applied and implemented for image occlusion masking as a preprocessing step. The proposed method has proven a robust, accurate, and better quality performance of IRT images in neurosurgery. The result obtained in this thesis shows that the proposed method can lead to a robust and accurate motion estimation while retaining quality of the original image. The performance of the proposed method is comparable to the conventional method and shows promising results. The performance of the proposed method was evaluated from 12 data records gained during neurosurgery by using Average Angular Error (AAE), Average End-point Error (AEE), Structural Similarity Index Measure (SSIM), Root Mean Square Error (RMSE), Peak Signal-to-Noise Ratio (PSNR) and Normalized Cross-Correlation (NCC). Additionally, a phantom dataset (blood flow simulation) and a semi-synthetic dataset were generated and used to evaluate the performance, robustness, and accuracy of the proposed method in different situations. Results obtained demonstrate the favorable performance and confidence evaluated by the proposed method.

Contents

Chapter 1

Introduction

1.1 Motivation

Infrared Thermographic (IRT) imaging has been developed by United States military and Texas Instruments in 1947 for identifying and detecting enemies and their equipment [1]. Later, it is used in several applications such as firefighting, police work, perimeter surveillance, industrial and construction applications (e.g., energy conservation), and various medical applications. With increasing demands for IRT imaging in medical applications, motion artifacts during imaging act as a major degrading factor in diagnosis. The patient motion including body movements, breathing, and pulse in IRT imaging have a detrimental effect on the brain cortex, tumor position, tumor size, and so on. These artifacts create an error in tumor detectability and quantification, which leads to problems in diagnosis and treatment.

Nowadays, neurosurgery (or brain surgery) rely on digital image processing techniques which are providing a deeper understanding of functional brain areas. During neurosurgery (e.g., craniotomy and tumor resections), abnormalities of the patient's brain need to be monitored and detected. Intraoperative imaging helps neurosurgeons to gain more knowledge about the patient's postoperative result and quality of life to be increased. Intraoperative IRT imaging determines valuable information to analyses cortical perfusion and vascularization. IRT imaging enables the detection of abnormalities that are characterized by certain temporal temperature variations, invisible to surgeons through visual inspection. In neurosurgery, the patient's respiration gives rise to local (and often small) motion in imaging sequences while the body movements introduce global (and potentially large) image motion.

Additionally, during neurosurgery, recorded intraoperative datasets include inter-object occlusion caused by movements of surgery tools, surgery tools reflection, and sometimes the ice-cold saline solution over the brain surface can change the image content, texture, a certain color, and roughness. As elaborated next, some potential artifacts of IRT imaging during brain surgery can create serious problems for automated data processing. In this thesis, all intraoperative datasets have been recorded at the Department of Neurosurgery, University Hospital Carl Gustav Carus Dresden. Intrinsically, IRT imaging suffers from low signal-to-noise ratio (SNR), low image contrast, poor texture, non-uniformity of the detector array, and additive random noise. Consequently, it is very arduous for a surgeon, to extract relevant information from IRT image samples only. It is necessary to suppress artifacts, in IRT video imaging during neurosurgery by developing a robust motion estimation, and an image artifact rectification method is proposed that remains an open problem up to now.

For the classification of image motion estimation, there exist two common approaches for 2-dimensional (2D) and 3-dimensional (3D) image motion estimation, namely, sparse feature-based and dense intensity-/gradient approaches. On one hand, feature-based approaches are based on the calculation of geometrical structures that are extracted from the image, such as, points, edges, contours, blobs, and ridges. Due to low image contrast and low SNR in IRT images, it is problematic to extract geometrical structures. Hence, feature-based approaches do not provide an appropriate solution. On the other hand, gradient-based approaches rely on intensity variations. The so-called optical flow method is the gradient-based method, which estimating the motion of every pixel in a sequence of images. The classical optical flow method, developed in 1981 by B.K.P. Horn and B.G. Schunck [2] (Horn-Schunck), is based on a brightness constancy assumption (BCA) and smoothness almost everywhere in the image. The Horn-Schunck method uses a global smoothing by applying smooth function over the entire image domain. However, the Horn-Schunck method is sensitive to noise but is robust to large motion and produces dense optical flow. Later, B.D. Lucas and T. Kanade [3] (Lucas-Kanade) have proposed a method that only applies the BCA within a local neighborhood or window centered at each pixel, solving the optical flow constraint for all the pixels in that neighborhood. The Lucas-Kanade method uses a local smoothing and assumes constant pixel displacement within a small neighborhood. Although the Lucas-Kanade method is robust under noise, it is very fragile to large motion and produces sparse optical flow. In general, those classical methods often fail due to the type of data, lack of sensitivity, and low robustness towards outliers and occlusions. Bruhn et al. in [4] introduced a combination of the Horn-Schunck method with the Lucas-Kanade method, the so-called combined local-global (CLG) method to use local smoothing for improving dense optical flow. Even though this method is not well enough for IRT images due to outliers and occlusions shortcomings, the attempt to bring the local method inside the global method for solving the dense optical flow problem was successful. During IRT imaging in neurosurgery, several obstacles to IRT imaging have been observed namely, motion, noise, outliers, temperature drift, and occlusions.

These obstacles lead to violation of the early optical flow assumptions.

In this thesis, inspired by the CLG method, an optimized and adjusted optical flow method only for IRT images in neurosurgery should be derived. In the image preprocessing different steps should be considered namely a Region of Interest (RoI) segmentation, global movements correction, a detection and masking of the occluded image area, adjust the image intensity variation, and reduce noise (i.e., low SNR which implies as noise). The RoI segmentation is done by an iterative threshold selection [5] process. The idea of the Cellular Nonlinear Networks (CNNs) [6] invention was to develop a more practical network, architecture to replace fully connected classical nonlinear network, which can be hardly realized in hardware. The number of wires and circuitry used to connect each cell to every other cell in a fully connected non-linear network increase drastically with the number of cells. In opposition, in CNN the local connected structure, the calculation, and interconnection exist only within a prescribed sphere of influence [7]. Hence, a CNN is conceptually suitable for hardware implementation. Due to the parallel nature and locally connected structure, CNN are considered to be appropriate for image processing applications. A large variety of CNN templates have been developed for image processing applications. A CNN-based image occlusion masking algorithm exploits the dynamics of the parallel CNN computing structure. In this thesis, for the purpose of occlusion masking or removal, a CNN masking algorithm for IRT imaging in neurosurgery is proposed. In the processing phase, two steps need to be considered: the proposed optical flow method and an image $2D$ interpolation. The proposed optical flow method consists of a three-step process, in order to deal with movements and outliers in IRT brain images over time. The aim of this thesis is to implement a robust motion estimation and correction method for IRT imaging in neurosurgery. The proposed motion estimation and correction method should be able to suppress breathing and pulse motion artifacts in IRT intraoperative imaging in neurosurgery while preserving valuable image details.

1.2 Organization of the thesis

In this thesis, firstly, a brief history of IRT imaging in neurosurgery and related challenges will be presented in chapter 2. Subsequently, in chapter 3, motion in IRT imaging during neurosurgery will be described. In chapter 4, motion estimation approaches will be presented, and several differential-based techniques will be described in detail. The adjustment and optimization techniques for differential-based techniques will be explained in chapter 5. The proposed occlusion masking method for IRT images during neurosurgery will be given in chapter 6. In chapter 7, the complete derived method will be discussed. Experimental results and the evaluation of the performance of the proposed method against other methods will be given in chapter 8. Conclusion and future work will be outlined in the last chapter.