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RESEARCH ARTICLE

Intraoperative Organ Deformation and 3D Visualization during MIS Using Spherical Harmonics

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Abstract— This paper is based on recent experiments on real time 3D visualization of intraoperative organ deformations. Restricted visualization is major challenge in minimal invasive surgery (MIS). For MIS procedures to be safe clear visualization of the surgical scene is required. This can be done based on limited field-of-view and a pre-operative image. Based on these patches we use spherical harmonics and obtain training sets. Such a structured dictionary is made and guides to the 3D visualization. This paper shows how the technique is implemented usefully. The experimental results provide significant improvements.

Key Terms: - Deformations; minimal invasive surgery (MIS); surface reconstruction

I. Introduction

Medical devices and personal computers, the recent two decades witnessed a rapid proliferation of Minimally Invasive Surgery (MIS) procedures and biopsies such as single-port laparoscopy. Single port procedures use a single small incision, and NOTES involves approaching the abdominal cavity (or other body cavities) through natural orifices such as the mouth or vagina using a flexible endoscope, without creating an incision on the abdominal wall. These MIS procedures show great promise for shorter hospitalization time, lower complication rates, and ultimately reduced morbidity and mortality from surgery. However, several challenges prevent these new approaches from reaching their full potentials. These challenges include limited visualization area, accurately tracking the instrument locations during the surgery, interpreting images from different modalities without ambiguity, high speed visualization of large amount image data, soft tissue deformation, among others. Current intraoperative visualization systems are promising. However, they can hardly meet the requirements of high resolution and real time 3D visualization of the surgical scene to support the recognition of anatomic structures for safe minimal invasive surgery procedures. Generally, most modelling approaches are intrusive and require continuous measurements of organ motions using tracking sensors implanted or attached to organs to track organ deformations and correct preoperative imagery or intraoperative imagery between successive scans. Particularly, these approaches proposed for organs with periodic motions are promising but suffer from limited applicability for organs with nonrecurring motions. 3D intraoperative visualization systems currently used do not meet the requirements of high resolution, real time and 3D visualization simultaneously to support the recognition of anatomic structures and accurate instrument localization for safe abdominal minimal invasive surgery procedures.

II. Existing Methods

General, most modelling approaches are intrusive and require continuous measurements of organ motions using tracking sensors implanted or attached to organs to track organ deformations and correct preoperative imagery or intraoperative imagery between successive scans. Current navigation and 3D intraoperative visualization systems do not meet the requirements of high resolution, real time and 3D visualization simultaneously to support the recognition of anatomic structures and accurate instrument localization for safe abdominal MIS procedures. Prior methods, such as established rigid navigation approaches, defining anatomical reference points or surfaces with a tracked pointer device, have so far failed to address challenges associated with tissue motion and deformation.

Sparse signal representation has been extensively used in various areas including signal compression, image de-noising, blind source separation, and compressed sensing. However, very limited applications can be found for 3D surface representation apart from rapid MRI. Generally the applicable algorithm which aims to provide surgeons with real time 3D visualization of complete organ deformations using 3D optical patch images with limited views and a single preoperative MRI or CT scan. Generally the applicable algorithm which aims to provide surgeons with real time 3D visualization of complete organ deformations using 3D optical patch images with limited views and a single preoperative MRI or CT scan.

III. PROPOSED SYSTEM

It refers to accentuation, or sharpening, of image features such as boundaries, or contrast to make a graphic display more useful for display & analysis. It includes gray level & contrast manipulation, noise reduction, edge crispening and sharpening, filtering, interpolation and magnification, pseudo coloring. In this project the filtering technique is applied for deformation of 3D organ images. In general most adaptive filters are based on adaptively adjusting the parameters of the supposedly optimum filter based on estimation of the unknown parameters. The approach for real time 3D visualization of organ deformations is based on optical imaging patches with limited field-of-view and a single preoperative scan of magnetic resonance imaging (MRI) or computed tomography (CT). The idea for reconstruction is motivated by our empirical observation that the spherical harmonic coefficients corresponding to distorted surfaces of a given organ lie in lower dimensional subspaces in a structured dictionary that can be learned from a set of representative training surface.

In the existing systems the computational complexity of the modeling methods is usually incompatible with the real time requirement for minimal invasive surgery. Also the problem of restricted visualization during minimal invasive surgery cannot be solved. In the new system a generally applicable algorithm is used. It aims to provide surgeons with real time 3D visualization of complete organ deformations using 3D optical patch images with limited views and a single preoperative MRI or CT scan. First step is to develop a novel algorithm for real time 3D reconstruction/ visualization of the deformable organ shapes from the limited field-of-view based on spherical harmonic representation (SHR) and structured dictionary. Then proposed algorithm is extended to reconstruct the interior structures of an organ by only sampling on the exterior surface. The idea for reconstruction is motivated by our empirical observation that the spherical harmonic coefficients corresponding to distorted surfaces of a given organ lie in lower dimensional subspaces in a structured dictionary that can be learned from a set of representative training surfaces. Now provide an implementation framework using MRI or CT scans and optical devices to achieve real time 3D visualization of organ deformations. In particular, we address the involved issues of multimodal surface registration and surface correspondence.

It consists of three components:

1) Identifying deformation subspaces to construct a structured dictionary in which deformable surfaces can be represented sparsely with high accuracy;

2) Designing sampling strategies under different access constraints to determine appropriate sampling positions for reconstructing the deformations;

3) Reconstructing the surface of an organ in real time with samples from the limited field-of-view using the structured dictionary.

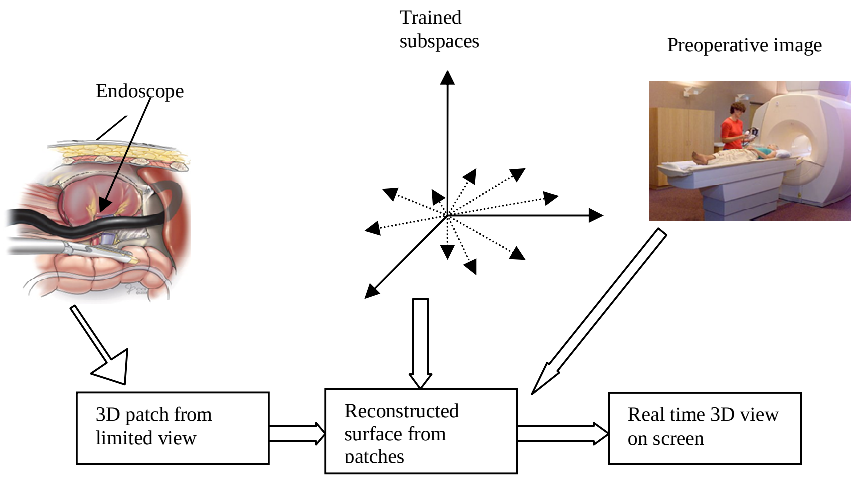

Fig 1. Framework of real time 3D visualization of deformable organs

A. 3D model construction

To identify subspaces that capture the potential deformation features of the organ under consideration, a representative training set is required. Images from a number of resources can be applied for the training purpose, such as realistic 3D computer models that account for organ mechanical and physical properties, ex vivo MRI or CT scans of organs under manual manipulation and in vivo scans. Except with computer models which export 3D surfaces directly, organ segmentation is required for all imaging modalities, such as MRI or CT, to obtain 3D surfaces of the desired organ. In our experiments, the surfaces were manually segmented from the 3D MR scans using Mimics (Materialise) by trained users. We do not have golden standard to evaluate the exact segmentation precision If the patterns of organ deformations to be reconstructed can be predicted according to the surgical plan, such patterns can be mimicked during the generation of the training data.

The resemblance between the training set and the testing set leads to higher reconstruction accuracy. If the deformation pattern cannot be estimated, random manipulation of the organ is statistically reasonable to obtain a representative training set. The training data is generally collected from different subjects. For the organ to be tracked and visualized, a single preoperative MRI/CT scan of that organ needs to be acquired, used as an initial model for both subspace identification and registration between the preoperative modality and the real time imaging device.

B. Processing manipulator and image spherical harmonics

Sparse surface representation is achieved via SHR and subspace identification. The training surfaces can be from various data sources, such as MRI/CT scans and realistic computer models. SHR is first Sparse surface representation is achieved via SHR and subspace performed to represent the deformable surfaces in the harmonic domain to decrease the length of surface descriptor and filter out the high frequency noise for achieving better homology among the training surfaces.

SHR is to represent a signal as a weighed sum of an orthogonal spherical harmonic (SH) basis. It has been widely used in different applications, including 3D model search and classification, rotation estimation and 3D organ modelling. In our approach, SHR is performed on each training surface using harmonics up to level.

C. Surface Extraction

The deformation subspaces are identified from the training vectors (columns) in F the transformed domain with OSP algorithm which runs iteratively until at least one of the predefined criteria is met. In this we define the following two stopping criteria: 1) an error threshold for subspace detection, 2) a maximum number of iterations for controlling the subspace dimensions and avoiding deadlock searching.

It first transforms the training surfaces into the harmonic domain to decrease the training vector size and remove the high frequency components. Then OSP subspace pursuit is conducted in the transformed harmonic domain to identify the subspaces that can generalize deformation variations in the potential population.

Surface registration is involved in both the training stage and the real time visualization stage. During training, deformations taken at different time instants or from different subjects need to be aligned to achieve pointwise correspondence after eliminating the linear transformation. In the reconstruction phase, registration is conducted to align the coordinate system of the sampling device with that of the visualization space.

Surface correspondence is to achieve vertex-wise matching over all training surfaces such that a common SH matrix can be applied during SHR. Different correspondence methods have been proposed, such as minimum description length and SH coefficient alignment. Each correspondence method must be evaluated as a function of the ultimate reconstruction accuracy that can be achieved with the proposed approach. Any correspondence method yields a reconstruction accuracy of less than the desired error is acceptable. In our work, we applied the SH based method for complicated surfaces and the proposed ray casting method for simpler surfaces to achieve surface correspondence.

Since the training and preoperative scans are in a coordinate system different from that of the optical device, the optical images have to be registered to the same coordinate system. The problem of accurately localizing instrumentation tips is beyond the scope of this paper, so we assume that the 3D optical device is equipped with tracked motion sensors which can provide geometric information to compensate for the linear transformation of the device relative to its initial position. In this research we only consider a small scale transformation between the optical imagery and the training coordinate system during the real time reconstruction stage after the initial registration.

D. Deformation of the image

Identified deformation dictionary from the training procedure, the sampling strategy design is to determine sampling locations to reconstruct new deformations using sparse surface samples in real time. First consider a completely random sampling method assuming that the entire surface is accessible. Then introduce patch sampling and localized sampling by imposing different constraints on the sampling location. The latter two methods are designed to address the visualization challenges of restricted access to the organ and limited field-of-view, encountered during the MIS operation.

IV. EXPERIMENTAL RESULTS

The experimental result given here illustrates that the proposed method using region growing provides comparatively better visualization accuracy as that of the existing systems.

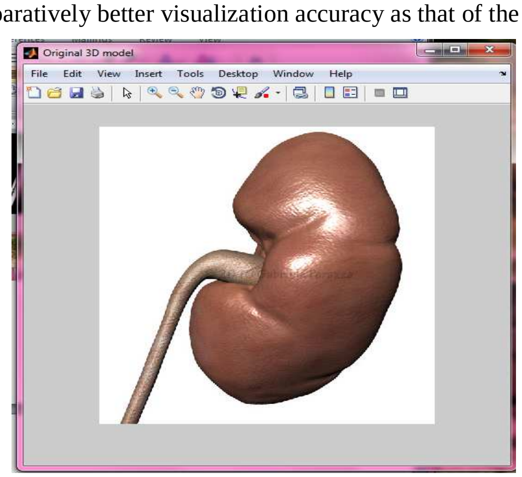

Fig 2 a) Original 3D image

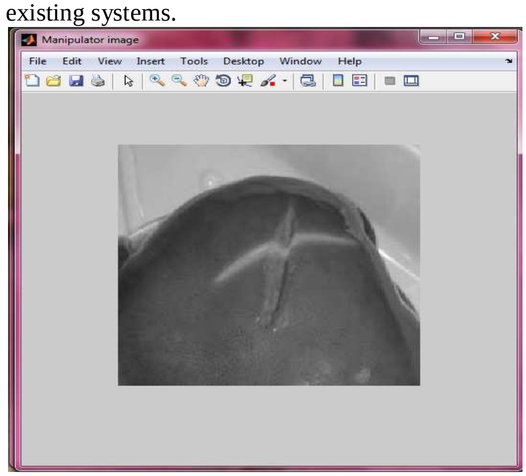

Fig 2 b) Manipulator image

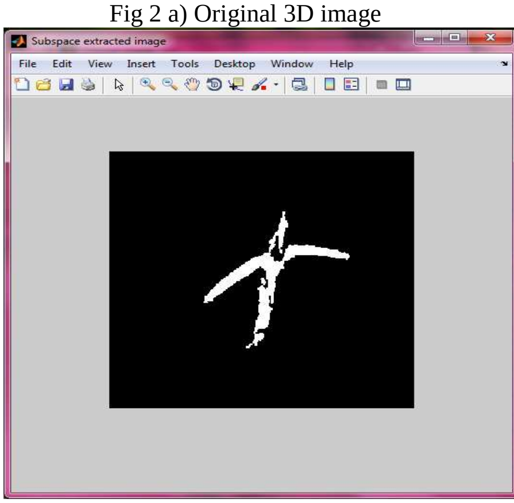

Fig 2 c) Subspace extracted image

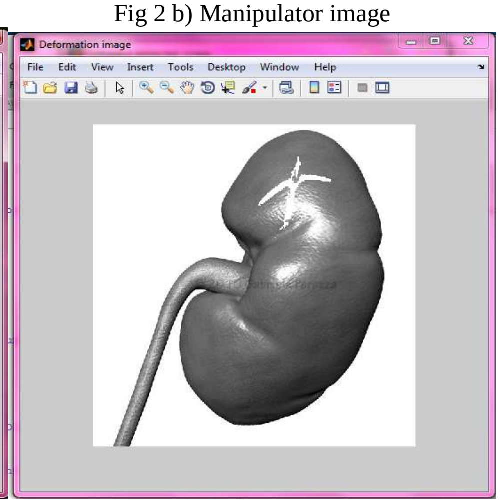

Fig 2 d) Deformation image

V. CONCLUSIONS

The paper presents a novel approach for real time 3D visualization of organ deformations using a single preoperative MRI scan and optical patch imaging from a limited field-of-view. Then reconstructs complete deformable shapes of an organ in real time using limited surface samples based on a structured dictionary. Reconstruction algorithms can be used. The proposed approach involves sparse surface representation and surface recovery from sparse samples. Thus the proposed approach aims at better 3D real time visualization of intraoperative organ deformations using structured dictionary.Sparse surface representation and surface recovery from sparse samples. The experimental results demonstrate that the proposed procedure can greatly improve the visibility of the vascular features in the MIP images.

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