Shape Reconstruction from Endoscopic Images

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Abstract

Endoscopy is an important visualization tool in minimally invasive orthopedic surgery. During surgery an endoscope consisting of a camera and one or more light sources is inserted through a small incision into the body and the acquired images are analyzed. Due to the small field of view, only a small part of the bone and its occluding contour are visible in any single image, making a perception of bone shape from such images difficult. We present a novel technique to reconstruct the surface of the bone by applying shape-from-shading to a sequence of endoscopic images, with partial boundary in each image. We demonstrate the accuracy of our technique using simulations and experiments with artificial bones.

Introduction

Endoscopy is attracting increasing attention for its potential role in minimally invasive computer aided surgery. Since the field of view of the endoscope is small and the bone is usually a few millimeters away, only a small part of the bone can be observed at a time. As a result, it can be difficult even for a skilled surgeon to infer bone shape from a single endoscopic image. Better visualization can be achieved by overlaying endoscopic images with 3D surfaces obtained from CT scans [1]. However, this still requires us to solve a complex registration problem between CT and endoscopic images during surgery. Thus, there is an immediate need for explicit computer reconstruction of bone shapes from endoscopic images.

Since bone surfaces have few identifiable features, surface shading is the primary cue for shape. Shape-from shading has been used in computer vision and biological perception, [4, 2]. But all these works assume the light source and camera center are co-located. Due to the small field of view, only a small part of the shape of interest can be reconstructed from a single image. By capturing image sequences as the endoscope is moved, it is possible to cover a larger part of the shape that can be more easily perceived [6, 3, 5] However, that is difficult to achieve for relatively textureless bone or cartilage surfaces. Therefore, neither shape-from-shading nor shape-from-motion can individually solve the problem of bone reconstruction from endoscopic images. In this work we combine the strengths of both approaches to develop a global shape-from-shading approach using multiple partial views.

Methods

First, for a single image, we formulate shape-from-shading under a near-point light source and perspective projection, given only a partial object boundary, when the source and camera are not optically co-located. Because the endoscope is tracked during image acquisition we can then transform the sequence of reconstructed shapes from a local view to a global coordinate frame. Initially, due to the errors in tracking, calibration and reconstruction, the individual shapes are not fully aligned. We use iterative closest point (ICP) algorithm to match them further. The shape-from-shading is then restarted for all images simultaneously, using boundary constraints in world coordinates in each iteration. This process of growing shape locally and updating constraints globally is iterated until convergence.

Results

The orthopedic endoscope has a single camera and one or more point light sources equipped at the tip of the scope. For this work, we used the Stryker 344-71 arthroscope Vista (70 degree, 4mm), an oblique endoscope with two point light sources. The algorithm is first tested on a series of synthetic examples and then on the shape reconstruction of a synthetic spine model (147mm x

60mm x 60mm) from 18 images. Figure demonstrates the accuracy of our technique by comparing the reconstructed shape with the ground truth shape obtained using a laser range scanner. For comparison, we choose only the points that are on the surface of the spine. The maximum, minimum, mean and RMS errors are 3.1mm, 0.0mm, 1.16mm and 1.5mm respectively. With global constraints, our algorithm converges quickly, though not real-time (around 5 minutes for 18 images in Matlab, P4 2.4G CPU).

Discussions and Conclusion

Shape-from-shading and shape-from-motion are both successfully used in many vision applications, but both have difficulty when applied to orthopedic endoscopy due to relatively featureless surfaces and partial occluding boundaries in a small field of view. In this work, we combine the strengths of both approaches: we formulate a shape-from-shading for single image under near point lighting and perspective projection, and develop a global shape-from-shading algorithm using multiple partial views. A shape of a larger bone area can then be reconstructed, providing useful visualization for surgical navigation in a minimally invasive procedure. We believe that our techniques can significantly enhance the capabilities of endoscopy in minimally invasive orthopaedic surgery. There are several unsolved problems such as automatic boundary detection, obtaining good initial guesses, recovering high frequency details in shape, dealing with image noise due to blood and tissues.

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