Towards Multiple 3D Bone Surface Identification and Reconstruction Using Few 2D X-Ray Images for Intraoperative Applications

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ABSTRACT

This article discusses a possible method to use a small number, e.g. 5, of conventional 2D X-ray images to reconstruct multiple 3D bone surfaces intraoperatively. Each bone’s edge contours in X-ray images are automatically identified. Sparse 3D landmark points of each bone are automatically reconstructed by pairing the 2D X-ray images. The reconstructed landmark point distribution on a surface is approximately optimal covering main characteristics of the surface. A statistical shape model, dense point distribution model (DPDM), is then used to fit the reconstructed optimal landmarks vertices to reconstruct a full surface of each bone separately. The reconstructed surfaces can then be visualised and manipulated by surgeons or used by surgical robotic systems.

Keywords: 2D, 3D, Dense Point Distribution Model (DPDM), Images, X-ray

1. INTRODUCTION

The ability to be able to access and update 3D patient-specific surface models of the bones and other structures during an operation is a nontrivial task. Most of existing technologies are not feasible to be implemented in an intraoperative environment. Normally, a 3D reconstruction has to be done by a CT or an MRI pre operation or post operation. Due to some physical constraints, it is not feasible to utilise such machine intraoperatively. The models have to be reconstructed before or after an operation. If the model is required to be updated during an operation, the patient has to be moved from the operating table to a CT or MRI machine before returning to the operating table again. A special DOI: 10.4018/ijacdt.2014010102
type of MRI has been developed to overcome the problem. However, all normal surgical tools and instruments cannot be employed. This seriously limits the use in orthopaedic applications. Also any metal surgical robots cannot be utilised. In addition, they are expensive and/or induce high radiation doses (Rajamani, Styner et al., 2007). The costs associated with CT are high. CT imaging can also produce radiation hazards.

The main aim of this article is to propose a new design and possible method towards rapidly identifying, reconstructing and updating patient-specific 3D surface models of multiple bones using a small number of 2D conventional X-ray images feasible for intraoperative applications. The technique should be capable of reconstructing 3D bone surface models without having to move patient from the operating table. This article is based on our preliminary work (Prakoonwit, 2011) which can only deal with a single object. New effective methods on edge contour detection and multiple object identification are presented in this work.

2. BACKGROUND

In an intraoperative environment where the scanning geometry of a CT or MRI is not suitable, a C-arm conventional X-ray system can be used to acquire a number of 2D images to reconstruct a full 3D volumetric description, in terms of voxels, of an object of interest, e.g. (Atesok, Finkelstein et al., 2007; Ritter, Orman et al., 2007; Zbijewski & Stayman 2007). However, to reconstruct at a reasonable resolution, the number of 2D images required is very high, e.g. 40 to 180 images, and to extract the surface of an object from the reconstructed voxels is very computationally expensive. Moreover, due to the large number of 2D X-ray images required, the patient is inevitably subjected to high dose of radiation.

Another approach is to use statistical shape analysis and modelling, e.g. Cootes, Taylor et al. (1995), Dryden and Mardia (1998) Rajamani, Styner et al. (2007), Zheng, Dong et al. (2007), Prakoonwit (2011) and Zhu and Li (2011), which has been an important tool in 3D model reconstruction from incomplete data. In this approach, only a small number of sparse landmark vertices on the surface of an object, e.g. a bone, are needed to be determined. Those sparse landmark vertices alone contain inadequate information for the complete 3D surface reconstruction of an object. Hence, a priori knowledge is required. A statistical model can be reconstructed from a set of training surfaces representing reasonable variations of the surfaces of an object of interest. In intraoperative applications, the statistical model is then used as prior knowledge in the reconstruction process to fit to the patient anatomy using intraoperatively acquired sparse landmark vertices. Thus, in conclusion, the aim of statistical shape model fitting is to extrapolate from an extremely sparse and incomplete set of 3D landmark vertices to a complete and reasonably accurate 3D anatomical surface. The fitting process aligns and deforms the statistical shape model to fit the sparse landmark vertices. Therefore the model-based approach is widely accepted due to their ability to effectively represent objects Morooka, Nakamoto et al. (2013).

Many researchers have presented methods for fitting statistical models to sparse vertices to create full patient-specific surfaces. The input data can be acquired from a small number of 2D X-ray images (Fleute & Lavallee, 1999; benameur, Mignotte et al., 2003; Benameur, Mignotte et al., 2005; Lamecker, Wenckeback et al., 2006) or digitised sparse vertices (Fleute and Lavallee 1998; Fleute, Lavallee et al. 1999; Rajamani, Styner et al. 2004; Rajamani, Ballester et al. 2005). Principle Component Analysis (PCA) based statistical shape models have been widely used in surface extrapolation. In Fleute, Lavallee et al. (1999), a joint optimisation technique is applied to fit the statistical model to intraoperatively digitised landmark vertices. In this method both pose and deformation are concurrently optimized. Later, Chan, Edwards et al. (2003), used a different approach by optimising deformation and pose separately and implementing the iterative
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