Beads-on-String Model for Virtual Rectum Surgery Simulation

Jian Chang · Xiaosong Yang · Junjun Pan · Wenxi Li · Jian J Zhang

Abstract A beads-on-string model is proposed to handle the deformation and collision of the rectum in virtual surgery simulation. The idea is firstly inspired by the observation of the similarity in shape shared by a rectum with regular bulges and a string of beads. It is beneficial to introduce an additional layer of beads, which provides an interface to map the deformation of centreline to the associated mesh in an elegant manner and a bounding volume approximation in collision handling. Our approach is carefully crafted to achieve high computational efficiency and retain its physical basis. It can be implemented for real time surgery simulation application.

Keywords Virtual surgery · Collision detection · Simulation · Haptic device

1 Introduction

Colo-Rectal cancer is a life threatening disease. It is the third most common cancer after breast and lung with 37,514 new cases reported in the UK in 2006 alone. Surgery remains the most common treatment option with 80% of patients undergoing an invasive procedure. Due to the complexity of the anatomy and the delicate structure of the bowel, removing the cancerous tissue fully and cleanly is a very skilful job. Recent research into relapse rates highlights the importance of a specialist colorectal surgeon in effective treatment. However, such skills are born of experience and the reality is many new doctors gain these skills by operating directly on patients, which presents both a risk to the patient and inevitably prolongs the training period for capable surgeons.

A virtual reality based simulator allows trainee doctors to learn their techniques by operating on a virtual patient. There are a number of computer assisted surgery simulators available and their efficacy is well attested to However, these have primarily been for operations where there are only small movements and small deformations of soft tissue, such as knee surgery, and their graphical realism has been limited. Bowel cancer surgery is very different to be effective as a training tool the graphical representation, the sensation of force (haptic feedback) and the deformation response of the soft tissue needs to be realistic and accurate representation of these elements which is incredibly complex. And the most significant difference is, during the operation, there are lots of collisions between the intestine and other organs, even among themselves. This places a really high challenge for the efficiency of collision detection from soft tissue deformation. In order to get real time response, in this paper, we presented a beads-on-string method to solve the collision detection and soft tissue deformation in the same model.

There are many works published in the last few years to simulate the intestine deformation. One important idea is to represent the global deformation of a rectum by the shape of its medial axis (centreline) omitting the shape changing of the cross-section. Chang [1] used the Cosserat Rod to model a long thin biological structure and Li et al. [2] applied the Cosserat Rod to model elastic tubes. France et al. [3] represented the medial axis of intestine with a physical spline formulized by Lagrangian dynamics. It is beneficial in terms of efficiency to use 1D curve to capture the deformations, but an additional layer is required to map such deformations back to the 3D mesh which assembles the real shape/geometry in rendering. Smoothing skinning was used in [3] [4] to generate deformations of a 3D mesh of an intestine based on its centre line. However, the smooth skinning approach suffers from a number of anomalies, including the so called "collapsing joints" (significant volume loss around a joint when the joint bends) and "candy-wrapper artefacts" (an obvious shrinkage similar to a candy wrapper when a joint twists) [5]. Although [3][4] introduced an adaptive sampling technique to solve the problem by using more joints in area with high curvature, it also brought in additional computational loads associated with insertion of new sampling nodes(joints). In [2], Li et al. used Laplacian method to drive the mesh deform consistently with the centreline, however the surface deformation in this way can not be real time.

In this paper, we proposed a beads-on-string model to handle the deformation and collision of the rectum in our virtual surgery simulation. The idea is firstly inspired by the observation of the similarity in shape shared by a rectum with regular bulges and a string of beads. We find it is beneficial to introduce an additional layer of beads, which provides an interface to map the deformation of centreline to the associated mesh in an elegant manner and a bounding volume approximation in collision handling. Our approach is carefully crafted to achieve high computational efficiency and retain its physical

J. Chang, X. Yang, J. Pan, W. Li, J.J. Zhang
National Centre for Computer Animation
The Media School, Bournemouth University, UK
Tel: 01202 965055
Fax: 01202 965530
E-mail: {jchang;xyang;pjunjun; wli; jzhang }@bournemouth.ac.uk

basis. It can be implemented for real time surgery simulation application.

2 Outline of Beads-on-String Model

In our simulation system, as illustrated in Figure 1, the deformation of centreline is controlled by the mechanical model of Cosserat Rod [1], and a string of beads (spheres in the figure), which representing the approximated shape of the rectum, are rigidly attached to the centreline. Cosserat rod model represents a rod as a space curve with a local coordinate frame attached to each point of the curve. It can be bended and twisted.

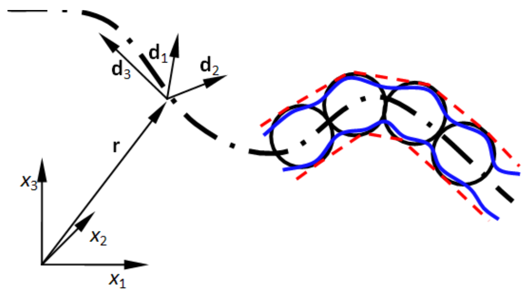

Figure 1. Illustration of beads-on-string model Without losing generality, a 2D diagram is given.

A cage (red dash line) is created to wrap the bead spheres. As the beads moving and rotating with the centreline, the shape of the cage changes accordingly. The change of the cage is then mapped to the deformation of the rectum mesh (blue solid line in Figure 1). A mean value coordinate interpolation scheme [6] is chosen to produce a smooth deformation of the rectum mesh.

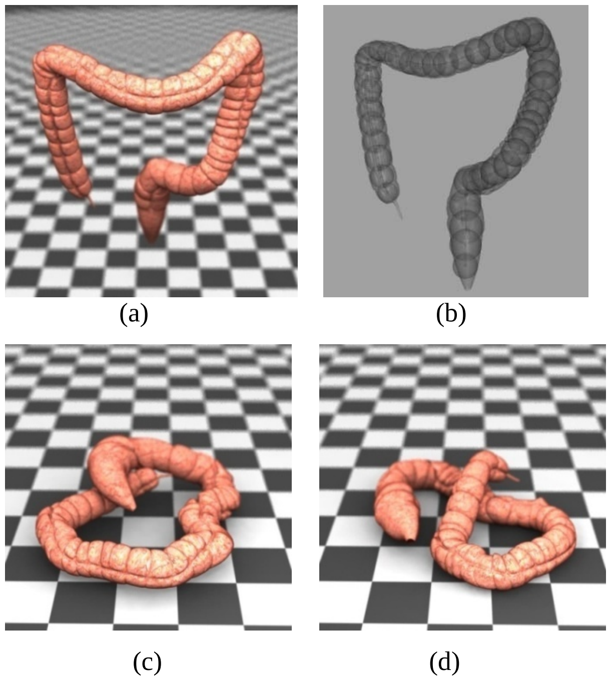

Figure 2. Experiements of the beads-on-string model. The intestine was released from the hanging position as in (a), fell on the ground to test both the deformation and collision detection. (b) shows the beads-on-string model. Because the release starts from one ending, and then spread out to other parts, (c) and (d) give two different results as they started from different endings.

Collision handling model is consistence with our deformation model, while the beads are used to detect the collision as bounding spheres. The use of bounding volume in collision detection is not new and a similar approach was implemented in [3]. The collision was handled with a penalty method in [3]. In our system, we propose to use a geometric projection method to handle the collision, which directly corrects the positions of beads after a contact is detected. In our method, there is no need to compute the penalty forces and hence it speed up the solving process.

Our virtual rectum surgery simulation system was developed on PC window system. The haptic interface with a Phantom Omni device was implemented using OpenHaptics Toolkit version 3.0. Figure 2 shows the experiments of our beads-on-string model. Figure 3 give a snapshot from our simulated laparoscopic camera.

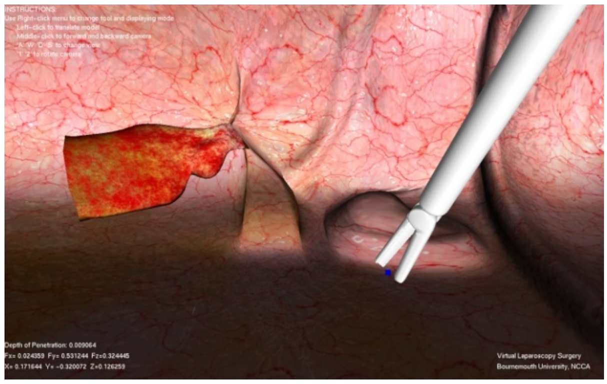

Figure 3. A snapshot from our laparoscopic camera.

References

1. Chang, J., Pan, J. and Zhang, J. J., Modelling Rod-like Flexible Biological Tissues for Medical Training, In: Workshop on 3D Physiological Human (2009), 29 Nov-2 Dec, Zermatt, Switzerland.
2. Li, H., Leow, W.K., Chiu I., Elastic Tubes: Modeling Elastic Deformation of Hollow Tubes, Computer Graphics Forum. 3(15), 141-153, (2010)
3. France, L., Lenoir, J., Angelidis, A., Meseure, P., Cani, M., Faure, F., and Chaillou, C.: A layered model of a virtual human intestine for surgery simulation, Med. Image Anal., 9(2), 123-132. (2005)
4. Raghupathi, L., Grisoni, L., Faure, F., Marchal, D., Cani, M., and Chaillou, C. An Intestinal Surgery Simulator: Real-Time Collision Processing and Visualization. IEEE Transactions on Visualization and Computer Graphics. 10(6), 708-718. (2004)
5. Chang, J., Yang, X. and Zhang, J. J. Continuous Skeleton-driven Skinning - A General Approach for Modelling Skin Deformation, International Journal of Image and Graphics, 9(4). 591-608. (2009)
6. Ju, T., Schaefer, S., and Warren, J. Mean value coordinates for closed triangular meshes. *ACM Trans. Graph.* 24(3), 561-566, (2005)