Haptics Modelling for Digital Rectal Examinations

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Abstract. Digital Rectal Examination (DRE) plays a crucial role for diagnosing anorectal and prostate abnormalities. Despite its importance, training and learning is limited due to their unsighted nature. Haptics and simulation offer a viable alternative for enhancing the learning experience by allowing the trainees to train in safety whilst trainers are able to assess competency. We present results of our geometrical, deformation and haptics modelling for two key anatomical structures obtained from patient specific MRI scans, namely the rectum and the prostate. Rectum mobility and hardness are modelled via a centreline consisting of control and structure points that are ruled by a mass-spring model based on elastic energy. Prostate mobility, hardness, deformability and friction are modelled via a surface model consisting of colliding spheres interconnected by springs with elongation, flexion and torsion properties. Clinical input and model fine-tuning was provided by three consultants from clinical disciplines that routinely perform DREs. Our approach is modular with scope to support additional palpable anatomical structures and the potential to be used as a teaching and learning tool for DRE.

Keywords: Digital Rectal Examination, Internal Examinations, Haptics Modelling, Prostate Cancer, Anorectal abnormalities, Deformation.

1 Introduction

Digital Rectal Examination (DRE) is recognised as a core skill to be taught as part of the medical curriculum. During DRE, the finger is inserted through the back passage to diagnose anorectal and prostate abnormalities. Among the structures that may be palpated are: the prostate (lobes and medium sulcus), seminal vesicles (only occasionally), anus (anal canal, inter-sphincter groove, anorectal junction), rectum (rectal ampulla), peritoneum (only occasionally), coccyx, and ischial spine (only possible in thin individuals). DRE plays a key role in the early diagnosis of anorectal [1,2] and prostate [3] abnormalities. However, teaching and learning of DRE, as well as competency assessment, are limited. Current benchtop models are unable to reproduce the wide range of normal and abnormal findings. Practicing on patients has its own limitations as they may be unwilling to be examined by an inexperienced trainee. The
unsighted nature of DRE renders both traditional approaches ineffective in terms of formative or summative assessment. Simulation offers obvious benefits by improving the learning experience through timely feedback and its ability to systematically expose trainees to a wide range of normal and abnormal anatomy.

Previous work on modelling organs for unsighted examinations includes a training tool for the diagnosis of prostate cancer [4], haptic feedback models for organ-to-organ interaction [5], bovine reproductive tract [6] and gynaecological examination [7]. The underlying models presented by these authors tend to be simplistic in terms of geometry, deformation and haptic interaction.

We propose a flexible and modular modelling approach based on patient-specific data, capable of supporting normal variability and common abnormalities of rectum and prostate, as well as the interaction of the examining finger with palpable objects through the constraining rectal walls. Models for the finger, rectum and prostate are presented. Firstly, the finger, placed in a thimble attached to a haptic device, is represented by a sphere that collides with the coccyx, rectum and prostate models. Rectum mobility and hardness are modelled via a centreline consisting of a set of control points supported by structure points. Control and structure points are interconnected with elastic links via a mass-spring model based on elastic energy. Mobility of the rectum is achieved by assigning stiffness values to these links. Haptics modelling of the rectum is based on the interpolation of neighbouring control points and the penetration depth inside the rectum walls. Hardness of the rectum is controlled by defining a stiffness constant in the reaction force. Prostate mobility, hardness, deformability and friction are modelled via a surface model consisting of colliding spheres that are interconnected by springs with elongation, flexion and torsion properties. Mobility of the prostate is controlled by setting a spring constant based on the resting position. Deformability of the prostate is defined by stiffness properties of the springs and the displacement of surface spheres towards the centre of gravity, with lumps modelled by stiff links and fixed spheres. Collision detection is determined based on penetration depth. Hardness of the prostate is obtained by computing reaction forces based on the surface normal, whereas friction of the prostate is modelled via friction planes / arcs. Geometrical modelling is described first, followed by deformation modelling and haptics modelling. Model fine-tuning and clinical validation are then discussed, with conclusions and future work presented at the end.

2 Geometrical Modelling

Ethics approval was obtained from the NHS National Patient Safety Agency Research Ethics Committee to recruit ten male volunteers (age range 18 to 65 years with informed consent and no known genito-urinary or colorectal disease) who were MRI scanned (GE Medical Systems Discovery MR 750 3.0T MRI scanner with resolution of 0.625x0.625x0.6mm scanning the pelvic region). ITK-SNAP (www.itksnap.org) was used to segment the anatomical structures of interest. Active contours semi-automatic segmentation was used for the bladder and coccyx. Manual segmentation was preferred for the rectum and prostate. Meshes were refined using MeshLab (meshlab.sourceforge.net) Two-Step Smooth and Laplacian Smoothing filters (Fig 1).