CT colonography: Accurate registration of prone and supine endoluminal surfaces of the colon

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Purpose

Colorectal cancer is a leading cause of cancer mortality with 1.23 million individuals developing the disease and 608,000 deaths annually. Population screening aims to prevent the development of advanced cancers by early detection and removal of both localised cancers and premalignant adenomas, from which more than 80% of cancers are thought to arise. Optical colonoscopy is the current gold standard method to inspect the whole-colon; however colonoscopy is time consuming and uncomfortable for the patient, and is occasionally associated with serious complications such as colonic perforation.

Computed tomographic colonography (CTC) is now widely considered the preferred radiological technique for detecting cancer and polyps, and has comparable sensitivity to optical colonoscopy while being more acceptable to patients and relatively safe. Patients undergo a full bowel preparation to cleanse the colon, which is then insufflated with gas immediately before helical CT imaging of the abdomen and pelvis (gas insufflation maximises attenuation contrast between endoluminal surface and intraluminal space). Graphics rendering software is used to generate high resolution `virtual colonoscopy' images of the three-dimensional colon surface, simulating those obtained using conventional colonoscopy.

Fig. 1: CT Colonography images with the patient in the prone (left) and supine (right) positions. Note the polyp indicated by the arrow.

References: Centre for Medical Image Computing, University College London - London/UK

CTC is performed routinely with the patient both prone and supine to redistribute gas and residue within the colon. This helps differentiate fixed colonic pathology from mobile faecal residue because abnormalities whose position remains fixed in relation to the colon luminal wall in both acquisitions are more likely to be true polyps. Also, using two
data acquisitions increases the chance of discovering pathology occluded by retained fluid or hidden by luminal collapse. Matching corresponding locations between prone and supine endoluminal colonic surfaces is therefore an essential aspect of interpretation by radiologists. However, interpretation can be difficult and time-consuming due to the considerable colonic deformations that often occur during repositioning of the patient. These deformations can induce diagnostic error and increase interpretation time. Hence, a method for automatic registration of prone and supine datasets has the potential to improve efficiency and diagnostic accuracy.
Images for this section:

![Figure 1: CT Colonography images with the patient in the prone (left) and supine (right) positions. Note the polyp indicated by the arrow.](image-url)

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Methods and Materials

We propose a novel method to establish correspondence between the two acquisitions automatically. The problem is first simplified by detecting and matching corresponding haustral folds, which are elongated, ridgelike endoluminal structures and can be identified by extracting curvature measurements from a triangular mesh representation of the colonic lumen (see Fig. 2). Image patches are generated at the fold positions using depth map renderings of the endoluminal surface and used to drive a virtual camera optimisation to provide a cost value for the matching of folds between the two views. An additional pair-wise cost function compares the geometric relationship between neighbouring pairs of haustral folds in the prone and supine CTC images. The problem is modelled as a Markov Random Field and solved to estimate the correct fold labelling. This process can establish an accurate correspondence between a set of positions in the two views even in cases where endoluminal collapses occur, which is very common in clinical practice.

Fig. 2: External (left) and internal (right) surface models of the endoluminal colon surface. The haustral folds have been automatically segmented and are shown in red.

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Most scenarios require obtaining a one-to-one surface correspondence between acquisitions, for example locating a possible polyp position in both the prone and supine views. Our surface-based registration algorithm recognises that the colon is topologically cylindrical and reduces the complexity of the registration by mapping each point on the endoluminal surface onto a cylindrical representation with the use of a conformal mapping technique. This allows the registration to account for the large 3D deformations between the prone and supine views as a more simple 2D cylindrical deformation (see Fig. 3). The registration is then represented as a transformation between the two cylinders and includes non-linear stretching along the cylinder, and local torsion and rotation. We use the set of haustral folds, for which we have found matching positions in both views, alongside a shape index metric, calculated at each point of the cylindrical image, to drive a
non-rigid registration in the cylindrical domain. This registration achieves correspondence between the two views over the entire colon surface.

**Fig. 3:** An overview of the registration process. The prone (top) and supine (bottom) CTC surface meshes are converted to a cylindrical representation before registration using a shape index metric (displayed with colour scheme) and the matched positions of detected haustral folds

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Results

Ethical approval and informed consent were obtained to use anonymised CT colonography data. Colonic cleansing and insufflations had been performed in accordance with current recommendations.

For the purpose of establishing a fold labelling between the prone and supine acquisitions, we selected 24 patient cases where the colon was optimally distended in both views, and where fluid tagging (allowing for digital cleaning of residual fluid) was used or little fluid remained. This allowed for a continuous segmentation over the full length of the colon. We also selected another 10 cases exhibiting local colonic collapse to further validate the method. The datasets were randomly allocated into tuning and validation sets using a random permutation resulting in a validation data set of 17 prone and supine validation cases of which 5 exhibited one or more areas of local colonic collapse, and 4 cases which had been excluded from the previous study due to marked differences in local distension and therefore different surface features.

Two radiologists (EH, AP) and a computer scientist (TH) with experience of reading CTC images, independently established a reference standard by matching haustral folds using virtual colonoscopic reconstructions, external renderings of the endoluminal surface, and unfolded images achieved by performing a conformal mapping of the endoluminal surface mesh onto a plane. The reference standards were compared for consistency, and any discrepancies were resolved by the three readers in consensus. This resulted in a total of 1743 corresponding fold pairs over the 17 validation datasets.

The fold matching algorithm achieved an accuracy of 96.1% in comparison to the reference standard of 1743 positions. Furthermore, when using the reference standard to access the accuracy of the surface registration algorithm, a mean error of 6.0mm was achieved.
Fig. 4: Synchronised "virtual colonoscopy" fly through videos using the resulting registration from our method. Surface renderings are created from prone (left) and supine (right) CT colonography acquisitions.

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Conclusion

We present a novel method for establishing correspondence between two CT colonography acquisitions with the patient in prone and supine positions. This process can establish an accurate correspondence between the a set of positions in the two views. The work flow presented is fully automated, taking as input a prone and supine colon lumen segmentation, and in disconnected cases, the ordering of those segments. The consistency of results across cases exhibiting varying characteristics indicates that the method is robust, even in more 'difficult' cases such as those showing marked differences in distension, or exhibiting areas of endoluminal collapse. This situation is very common in routine practice and algorithms must be able to cope in order to have clinical utility.
References

For more detailed technical information see:

