

Abstract of Ph.D. Thesis

“Virtual endoscopy to generate benchmark datasets to augment endoscopic video analysis”

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The current state of medical technology has demonstrated a convergence towards minimally invasive diagnosis and treatment. In an effort to mitigate the patient's distress during the screening of gastrointestinal tract using traditional wired endoscopy, researchers have introduced the wireless capsule endoscopes (WCEs). The capsule is a pill-shaped swallowable device equipped with a camera; the patient ingests. It travels through the gastrointestinal tract by virtue of the natural mechanism of peristalsis and captures images of the inner lining. An accurate localization method is required for the decision of drug administration and other therapeutic procedures as it depends on the location of the ailment. The image-based localization techniques estimate the movement of the wireless capsule endoscope by processing the image sequence captured by the capsule camera without utilizing any additional device. Deep learning-based techniques have an immense potential to improve endoscopic video analysis, specifically the pose estimation of endoscope camera and simultaneous localization and mapping. At present, the absence of large, varied, and accurately annotated datasets of the gastrointestinal tract limits the efficient learning of deep learning-based models and their effective performance evaluation.

To address the lack of accurately annotated datasets of the gastrointestinal tract, we have developed SimIntestine, the virtual models of two major sections of the gastrointestinal tract: small intestine and large intestine. The virtual models closely mimic the anatomical structure and motility of functioning intestines inside a living human being. The models incorporate the distinctive characteristics of these organs: the intricate shape with various degrees of bends, plicae circulares, villi, deformation of the walls due to peristalsis, brush border-like appearance of the small intestine, haustral folds in the large intestine, their unique surface textures, etc. We have also developed virtual capsule endoscopes for both small and large intestines. These endoscopes navigate through the virtual models of the intestines and provide color images and depth maps. The purpose of implementing various physiological properties of the organs in detail is to produce virtual capsule endoscope images that closely resemble and are almost indistinguishable from real endoscope images. This allows the synthetic dataset to be used for transfer learning in supervised as well as unsupervised learning-based depth and ego-motion detection algorithms for real endoscope image datasets.

Using SimIntestine, we trained the state-of-the-art unsupervised learning-based network architectures, Endo-SfMLearner and Monodepth2 for depth estimation using the synthetic image dataset; and assessed its performance on images from KID dataset and REAL-Colon dataset. The results show that the models trained on our synthetic datasets work remarkably well on real endoscope images. We also used the techniques Endo-SfMLearner and Monodepth2 for the evaluation of pose estimation using the synthetic images from the virtual small and large intestine models. At the end, we used Endo-Depth-and-Motion for the 3D reconstruction of the small intestine from the synthetic images. The results demonstrate the utilization of synthetic datasets for evaluating depth and pose estimation, and 3D reconstruction techniques. In addition, we modeled some of the health conditions, polyp, bleeding, and ulcerative colitis, for rendering images of affected regions of the intestines to aid disease detection and classification algorithms. The proposed framework provides a comprehensive and physically realistic annotated synthetic dataset benchmark of intestines which can be used to improve endoscopic video analysis, specifically in the domain of pose estimation and simultaneous localization and mapping which is challenging to obtain using real endoscope unannotated dataset.

This research is intended to help physicians locate the wireless capsule endoscope's location inside the gastrointestinal tract and find the location of the ailment detected in the endoscopic images. Our datasets with ground truth position in virtual small intestines are expected to promote the development of real-time feedback systems to locate the capsule endoscope's position inside the gastrointestinal tract and determine the location of the abnormalities detected. The comprehensive and physically realistic annotated synthetic dataset captures the deformation of the wall in the gastrointestinal tract due to peristalsis and provides a benchmark which can be used to improve the ego-motion estimation techniques for endoscopic videos.