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論文題目	Towards Visuocomputational Endoscopy: Visual Computing for Multimodal and Multi-Articulated Endoscopy		

（論文内容の要旨）

Endoscopy in the medical context aims to provide a view inside the human body. The tool for providing this view is called the endoscope. The principal applications of endoscopy are three-fold: the examination of various parts of the body based on symptoms exhibited, the confirmation of diagnoses through biopsies, and the enabling of surgical operations for treatment of a disease. Various different types of endoscopes exist, and the style of endoscope used is dependent on the clinical target. For example, examining the ear is done with the short-nosed tapered otoscope, while for respiratory tract examination, a long, thin flexible bronchoscope is used. Recently, endoscopy has paved the way for minimally invasive surgery, an approach to surgery that aims to minimize the harm caused to the patient by the surgical procedure. Minimally invasive surgery chiefly differs from traditional open surgery in that surgical tools are inserted through small incisions, rather than the surgeon operating in an opened cavity, and in that vision is provided mainly by the endoscope. Thus, it can also be said that the rising popularity of minimally invasive surgical techniques also brings forth a need for better tools for visualization.

Research and development of endoscopes can roughly be divided into two categories: hardware, and computational innovations. The former mainly focuses on developing novel hardware designs related to the structure of the endoscope and the sensing capabilities. For example, the capsule endoscope used for imaging the digestive tract differs greatly from traditional endoscope shapes. For sensing capabilities, both ultrasound and optical coherence tomography probes that allow for tomographic imaging close to the clinical target have been integrated to endoscopes. Computational methods, on the other hand, can find applications in both the design of novel endoscopes, as well as in processing the data that is output by them. Computational methods successfully applied to endoscopes range from basic image processing that can help highlight particular features of images, to clinical decision support systems that can help the clinical professional make judgments in case of clinical examination.

Visual computing is an umbrella term covering all aspects of visual information handling, such as image processing, computer vision and computer graphics. Due to the recent advances in both available computing power and visual computing methods, it has found many applications in the field of endoscopy. Through various information processing techniques, visual computing can help provide navigational and clinical decision support to the user, potentially leading to increased accuracy of diagnoses, and reduction in the time taken for endoscopic operations. Visual computing methods can be also applied during the development of novel endoscopes through methods like computer-aided design. Finally, virtual training systems have recently entered the market, which employ computer graphics to provide an environment for endoscopic and surgical training.

In this thesis, we explore the possibilities for applying visual computation in the field of endoscopy. Due to the two fields having become increasingly intertwined, we propose to call this intersection of the two fields, “visuocomputational endoscopy”. We explore the possibilities of this new field through two approaches.

In the first one, we have developed methods for the support of a novel endoscope that combines traditional visible light imaging with optical coherence tomography imaging. We develop volumetric methods to synthesize images from these two imaging modalities, and to assist in clinical decision making in measuring the degree of endolymphatic hydrops, a disorder in which endolymphatic fluid accumulates and causes morphological changes in the inner ear.

In the second approach, we apply visuocomputational methods to aid in the development and usability evaluation of a novel endoscope that is composed of multiple joints allowing for more freedom in viewpoint selection and navigation. We focus on creating an accurate virtual model of the endoscope concept, and then evaluate it through a user experiment. We also propose a highly immersive augmented virtuality platform for evaluation of similar virtual prototypes.

Through the above-mentioned approaches, we validate the visuocomputational endoscopy concept, and show that coupled with hardware advancements it has the power to realize better and more efficient examination, diagnosis, and surgical methods for endoscopy.

（続紙 ２ ）

（論文審査の結果の要旨）

情報技術の医療現場への導入においては、慎重にその技術の適用可能性を見極め、その技術の適用が本来医療の高度化にどのように寄与し、その技術にはどのような限界があるのかを予め明らかにすることが重要である。

本論文は、画像情報処理（Visuo-computation）技術による内視鏡術（Endoscopy）の高度化について、二つの研究を通じてその可能性を明らかにしたものである。

本論文では、まず、内視鏡術の医学的適用範囲、歴史、現状、及び、導入されつつある新技術の分析を通じて、今後、光学的視認だけでなく、超音波や光コヒーレントトモグラフィー（OCT）などを組み込んだ「マルチモード内視鏡」と、硬性内視鏡の操作性と軟性内視鏡の到達性の双方を満たす「多関節内視鏡」とが、今後の内視鏡ハードウエアの高度化の方向性であることを確認した上で、画像情報処理技術がどの方に寄与しうるかについて、二つの研究を通じて明らかにしている。

第一は、耳鼻科領域においてOCTを組み込んだマルチモード内視鏡を適用することを想定し、メニエール病態のOCT画像認識処理による定量評価を試みた。本適用によって、内臓表層の浅い三次元透視像に現在適用可能な各種画像処理技術を組みあわせて利用することで、内視鏡による検査等が大幅に高度化する可能性が明らかにされた。

第二は、呼吸器外科領域への適用を想定した多関節内視鏡の設計支援・操作訓練環境を、仮想現実感(VR)・強調現実感(AR)を活用して構築を試みた。本構築によって、現在適用可能なVR・AR技術が、複雑な動きを伴う内視鏡の設計・評価・訓練・操作の高度化等に充分適用しうることが明らかにされた。

以上の研究を通じて、本論文で提案されたVisuocomputational Endoscopyと言う枠組みは、今後の内視鏡ハードウエアの高度化に伴って、外科医療の高度化に大きく寄与するものであることを、本論文は主張している。

以上、本論文は、画像情報処理技術を外科医療分野へ適用する道筋を示し、その適用可能性を論じている。この研究成果は、情報学による医療の高度化に資するもので、学術上寄与するところが少なくない。よって、本論文は博士（情報学）の学位論文として価値あるものと認める。

また、平成29年8月16日に実施した論文内容と口頭試問における、個別技術の詳細、他領域への展開の可能性、本研究の限界、残された課題、社会との関係性についてなどの広範な議論から、合格と認めた。

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