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Tomographic Micro-Diagnosis Using Multi-Functional OCT: Tissue Classification Imaging of Atherosclerotic Plaque Using ARV-OCT

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Abstract

Optical Coherence Tomography (OCT), based on a low coherence interferometry, has been being improved as a 3-dimensional and tomographic subsurface imaging of micro structural biological tissue with high resolution of 1 to 10μm. OCT can provide morphological tissue structure as scattering intensity profile generated from spatial variation of refractive index. Recently, "Multi-Functional OCT (MF-OCT)" has been proposed as a promising *in/ex vivo* and *in site* clinical diagnostic modality. This can employ multi-modal optical biopsy of functional information at the micrometer scale, bio-mechanical properties by OCSA; 3-dimenational strain, blood velocity by OCDV; Doppler frequency by flow, bio-chemical composition by OCM and OCD; water content and delivered drug infiltration, tissue characterization of fibrous/lipid tissue by ARV, respectively.

In this paper, we propose a new atherosclerosis diagnosing technique using "Attenuation, Reflection and Variance" (ARV-OCT). The tissue discrimination of fibrous and lipid is crucial to diagnose atherosclerotic plaque predisposed to rupture. "ARV" can offer tissue characterization of fibrous and lipid by harnessing optical information interacted with complicated biological tissue in OCT interference signals, i.e. attenuation, reflection, variance. Three optical parameters are extracted with almost the same high resolution as that defined by OCT system, by means of weighted moving least square method. The validation study was experimentally carried out using atherosclerotic plaque specimen of WHHL rabbits. The optical signals extracted from OCT image, which are correlated cross-sectionally with manually discriminated region of fibrous/lipid tissue in histological images by medical histologists, can make a calibrated 3-dimensional state map with respect to attenuation, reflection and variance. Comparing with this state map, the tissue-mixing ratio between fibrous and lipid is calculated locally using k-means clustering algorithm. Consequently, the atherosclerotic tissue distribution classified into fibrous/lipid tissue could be visualized as a tomographic color map of tissue mixing ratio. High efficacy of ARV was *in/ex vivo* demonstrated clinically in terms of atherosclerosis assessments, that is, vulnerable characteristics of unstable plaque predisposed to rupture.

Keywords: Optical Coherence Tomography, ARV-OCT, Tissue Characterization, Biomedical Imaging, Atherosclerotic Plaque

Segmentation of Surgical Instruments from RGB-D Endoscopic Images using Convolutional Neural Networks: Preliminary Experiments towards Quantitative Skill Assessment

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Abstract

Manipulation of the endoscopic instruments is a challenging task and its quantitative and objective assessment is difficult. Taking advantage of the recently released view-angle adjustable stereo endoscope that our hospital uses in clinical routine, we aim to assess the surgical skill by comparing quantitative metrics such as the time for each manipulation, length of the tool tip trajectory and the number of errors during a routine surgery (not with training phantoms nor surgical simulators). In order to achieve the goal, we attempted tracking of surgical instruments using the stereo endoscope images.

The algorithm of 3D tracking of forceps from a stereo endoscope video acquired by da Vinci system was published previously by Reiter et al. [1]. In general, tracking of the tool tip from a stereo video requires the following steps. (1) Stereo camera calibration, (2) segmentation of the tool, (3) tool tip tracking, (4) 3D reconstruction of the tip. Among these steps, segmentation is important that determines robustness of the algorithm, especially in a real surgical video containing more background noise such as surgical gauze and staples.

In this paper, we propose and evaluate a method for segmentation of surgical instruments using convolutional neural networks (CNN) [2]. The proposed network uses RGB and depth image that was calculated from the stereo endoscope images and the output of the networks is a likelihood image (Fig. 1). In Fig.1, the white pixels indicate high probability of instruments and the black pixels indicate high probability of background. The training dataset is generated as follows. A three dimensional instrument model is reconstructed from a manually segmented stereo image and then projected onto the background images with random perturbation in translation and rotation in 3D. We compared the proposed algorithm with the previously proposed one using GMM [1]. The result shows that the GMM method confused the gauze with the instrument (Fig. 1 third column) and contained more noise as opposed to the correct and cleaner segmentation by the proposed method.

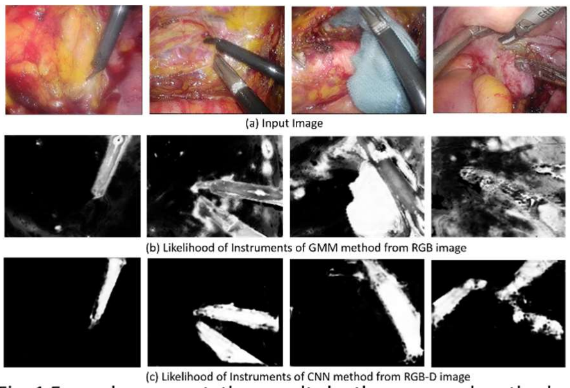

Fig. 1 Example segmentation results by the proposed method. Each column shows different time frame from a surgical video. (b) and (c) show the results of conventional and proposed method, respectively. (Note that the proposed method uses also the depth image as its input.)

Future works include an extensive evaluation of the segmentation accuracy and comparison with other state-of-the-art segmentation algorithms.

Keywords: Endoscopic skill assessment, Segmentation of surgical instruments, Convolutional Neural Networks.

Acknowledgements

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Biomechanical Structure and Haptic interaction

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Abstract

A kind of haptic displays, which render touch sensation, and biomechanical simulation have been studied especially for force feedback in tele-operation, and medical training and support. However, most existing devices are large and needs to be fixed on the environment, which reduce mobility and workspace. In this talk, the presenter focuses on haptic interaction studies using biomechanical structures of a human body to improve compactness and mobility of the device as well as applicability of augmented reality situation. The presenter also introduces a biomechanical simulation study based on finite element method to enable haptic interaction with reduced artifact in case of large deformation. Finally, the roles of medical and biological imaging in this field are discussed.

Keywords: haptic interaction, biomechanical structure, finite element method.

Application of hyperspectral imaging in medicine

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Abstract

Early detection and proper excision of the primary lesions of malignant melanoma are crucial for reducing melanoma-related deaths. In order to support the early detection of melanoma, melanoma screening systems have been extensively studied and developed. Recently we have proposed a melanoma discrimination index derived from hyperspectral data in the visible to near infrared wavelength region. The index represents variegation in spectra over a lesion and its peripheral normal skin. Performance of the system has been studied for 34 cases of melanoma, and 118 cases of non-melanoma. The index has achieved a sensitivity of 77 % and a specificity of 85 % for the population.

Keywords: hyperspectral imaging, spectral diagnosis, melanoma, cosmetics.

Figure 1. Hyperspectral imager for medical use

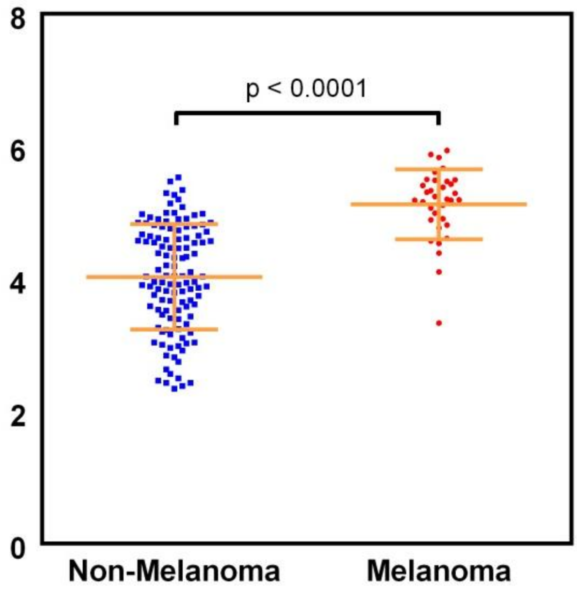

Figure 2. Melanoma discrimination index

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Medical and Biological Imaging for Bioscience

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Abstract

Bioimaging is a technique used to analyze the protein dynamics and molecular distribution and localization by capturing images at the individual, tissue, or cellular level. With advances in optical techniques (e.g. high-resolution microscopy) and genetic engineering techniques (e.g. fluorescent protein and genome recombination), bioimaging has become important in the advancement of bioscience research. Cells and particles can be observed using methods such as phase-contrast or differential interference microscopy or using confocal laser scanning microscopy with fluorescently-labelled samples. Multiphoton excitation microscopy is also used for intravital cellular or protein live-imaging observations. These sophisticated forms of microscopy can concurrently capture images over fixed intervals from multiple fields to produce time-lapse images for the observation of long-term changes. Meanwhile, High-resolution and high-throughput bioimaging data capture has made the development of techniques for automatic cell tracking and statistical analysis an urgent issue. Here, I introduce a case study of analyzing multichannel imaging data in which the cell cycle was visualized using fluorescent proteins. In this case, automatic cell tracking was implemented based on particle filter, and quantitative analysis of drug efficacy was conducted.

Keywords: bioimaging, cell tracking, particle filter, quantitative analysis.

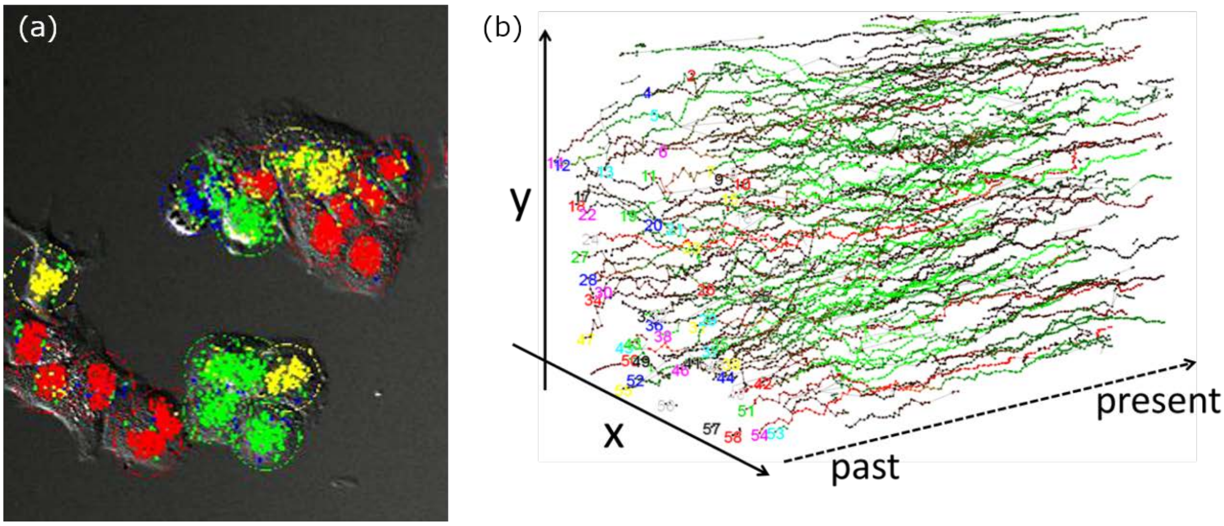

Figure 1. Visualization of the cell cycle using the Fucci system and tracking cells using particle filter (a). A tracking result of cell positions and cell cycle phases (b).

Medical Imaging in Sport Science: From Segmental-motion Analysis toward Anatomical Joint-motion Analysis in Biomechanics

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Abstract

Biomechanics in sports is the science concerned with the internal and external forces acting on a human body and effects produced by these forces, aiming to enhance performance outcome and to prevent injuries in sports [1]. In this presentation, I introduce an overview of biomechanics in sports in past, present, and future, using biomechanical analysis of baseball pitching as an example. Baseball pitching is a typical example of sports technique that rapidly accelerates the distal end of the limb to produce a high-velocity outcome (more than 150 km/h). Many baseball pitchers have experienced shoulder injury. However, the biomechanical cause of shoulder injury have been hypothesized by orthopaedic surgeons and physical therapists based on their clinical experiences without a biomechanical knowledge of anatomical joint-motion recorded in the actual baseball pitching.

A motion of scapula, a trigonal bone locating behind the shoulder, has been clinically hypothesized as an important factor associating with a risk of shoulder injury. In past, a motion of baseball pitching has been filled by a high-speed video camcorder, and then a rigid-body link-segment model has been adopted to analyze the human movement [2]. This model assumed that (1) body parts (torso and upper-limb) are rigid-segments, and (2) the rigid-segments are connected by a simplified mechanical connection (ball-and-socket joints), named "segmental-motion analysis". However, this model cannot test the clinical hypothesis about the scapular motion because the scapula is assumed to be in the simplified torso-cuboid. We recoded the 3D scapular motion during the actual baseball pitching using the small sensor attached to the skin overlying the scapula [3], named "skeletal motion analysis". The 3D skeletal-motion of the shoulder has been described, however, the shoulder injury are resulted from an interaction between the skeletal-motion and anatomical morphology of the bone and soft-tissues surrounding the joint. We have aimed to determine the cause of shoulder injury by a combination of the skeletal-motion analysis and the subject-specific morphology of the bone and soft-tissues acquired by the medical imaging analysis, named "anatomical joint-motion analysis". I'd like to discuss about an application of the medical imaging analysis to the biomechanics in sports.

Keywords: rigid-body link-segment model, skeletal model, anatomical morphology, shoulder, scapula,

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Interactive techniques for medical volume segmentation and their application to flower modeling

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Abstract

In this talk, we present our previous studies on interactive tools for volume segmentation [1] and a technique for modeling flowers by using X-ray computed tomography (CT) [2].

Interactive volume segmentation [1]. Volume segmentation is a time-consuming task, especially when a region of interest (ROI) contains ambiguous boundaries. We present a contour-based segmentation tool in which the user places multiple contours in the three-dimensional (3D) space. Given the multiple contours, our system constructs a boundary surface that passes through all the contours and fits to edges of the input volume. Since our contour-based interface allows the user to specify the boundary of a ROI directly, ROIs with ambiguous boundaries could be extracted accurately.

Flower modeling by using X-ray CT [2]. Reconstructing 3D models of flowers is an important topic in the field of computer graphics. It is however difficult to apply common 3D reconstruction methods (e.g., image-based reconstructions or range scanners) to flowers, since flowers often contain highly occluded structures. In this study, we adopt an X-ray CT; we first capture volumes of sample flowers and reconstruct their 3D shapes by using the volumes as guides. To reconstruct flower components, such as pistils, stamens, petals and sepals, we present a novel active contour and active surface model that semi-automatically fit to flower components in a CT volume. Our technique achieved to reconstruct highly realistic flower models.

Keywords: interactive segmentation, volume segmentation, shape modeling.

References

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Biomedical Images for Simulation and Analysis of Surgical Procedures

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Abstract

Virtual planning and preoperative simulation using computed tomography (CT) or magnetic resonance (MR) images enable quantitative, strategic planning of patient-specific surgical procedures. To perform evidence-based surgery and standardization of surgical procedures, the interest for an image-based estimator is increasing among surgeons and researchers. Statistical analysis of the surgical planning data and investigation of implicit factors affecting the decision-making are also important for designing next-generation planning/navigation system.

In this presentation, we will introduce our recent study on surgical process modeling and analysis using medical images. The concept of deformable resection process map [1] for tumor resection in abdominal/thoracic surgery is first introduced. (see Figure 1) Second, a user experiment to quantitatively analyze surgical process and decision-making in mandibular reconstructive surgery [2] is reported. Importance of simulation as a tool for coupling medical knowledge to machine learning will be discussed.

Keywords: Surgical process analysis, semi-automatic planning

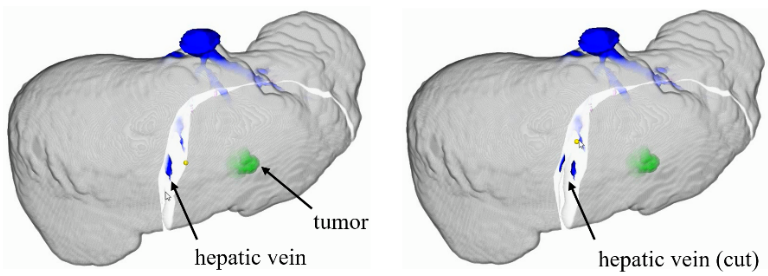

Fig. 1 Deformable resection process map as an intraoperative guide.

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A Study on Sparse Shape Modeling for Fibular Transfer Planning in Mandibular Reconstruction

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Abstract

Preoperative planning using computer-aided design with 3D CT data is an active area of research. For mandibular reconstruction with fibular segments, it is necessary to determine osteotomy lines for fibular shapes and the precise placement of fibular segments in the mandible, but recent interactive planning software [1] cannot secure objectivity of the planning and time-consuming trial-and-error processes are required.

In this study, we propose an automated preoperative planning method that estimates a plan fitted to the data of a new patient using a planned dataset of previous patients. The proposed method introduces sparse shape modeling using sparse shape composition [2]. In this modeling, we select a subset of the data from a prepared preoperative planning dataset to make an example or instance of reconstruction via a linear combination of the data. We conduct experiments using the dataset planned by medical doctors and compare the instance estimated by the proposed method to the manual placement by these doctors.

Keywords: machine learning, mandibular reconstruction, computer assisted surgery.

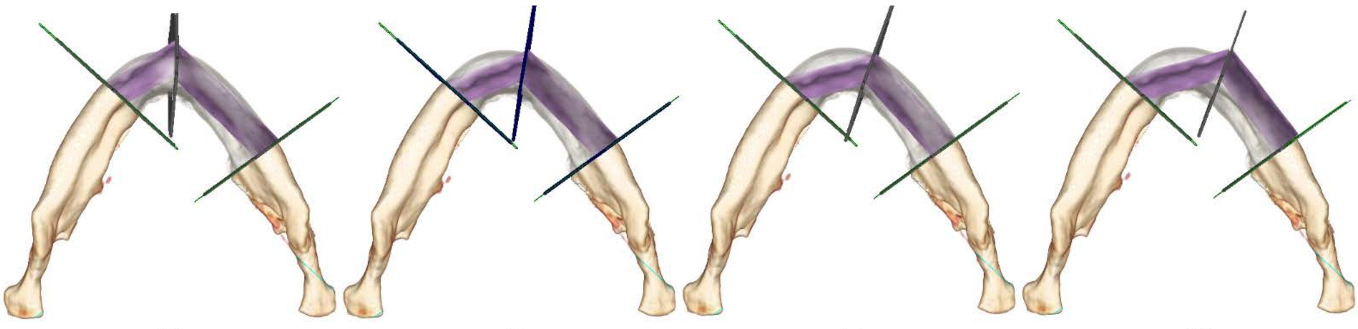

Figure 1. Comparison of fibular transfer planning results for (a) the manual placement given by surgeons, (b) the proposed sparse modeling, (c) the non-sparse modeling, and (d) the best-fit training data.

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Multi-scaled bioimaging with near-infrared luminescence and cathodoluminescence

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Abstract

Correlative light and electron microscopy (CLEM) is an emerging technique which combines the advantages of these two microscopies to observe the same region of interest. Light microscopy (LM) visualizes cellular components and protein distributions using fluorescent probes of different colors. Since the spatial resolution of LM is restricted by the diffraction limit of light, the positions of proteins cannot be resolved precisely. Electron microscopy (EM) plays an important role in identifying the protein distributions and visualizing ultra-structures of cellular components. Due to its use of an electron beam, EM has higher spatial resolution compared with conventional LM. CLEM overcomes the limitations of the individual microscopies and combines colored imaging and high spatial resolution imaging of a sample.

Although CLEM technique keeps advantages of LM and EM, there are still some drawbacks of both microscopies. LM observation is suffered its imaging depth due to the scattering and adsorption of incident light by water and intrinsic tissue molecules. Multiphoton fluorescence microscopy is known as its high penetration depth of incident light; however, the imaging depth is limited around a few hundred micrometers to one millimeter. Meanwhile, EM observation has difficulties to observe multiple kinds of proteins because EM images are monochrome.

Near-infrared (NIR) microscopy and CL microscopy have possibility to enhance the conventional CLEM technique including deep observation and recognition of kinds of molecules. Using NIR wavelength region for both excitation light and emission light enables deep observation in biological samples. In addition, higher spatial resolution compared with LM is expected by CL microscopy due to the excitation with electron beam. CL microscopy remains the advantage of colored imaging and kinds of targets can be recognized by emission wavelength of CL. To realize correlative NIRL and CL imaging, rare-earth oxide Y_2O_3: Tm, Yb and Y_2O_3: Er, Yb nanophosphors (NPs) were developed. Luminescent properties of the NPs under excitation with 980 nm NIR light and electron beam were reported. Multiscale NIR luminescence/CL bioimaging with the NPs was demonstrated through *in vivo* and *in vitro* NIR deep-tissue observations, cellular NIR luminescence imaging, and high-spatial resolution/multi-colored cellular CL imaging.

Keywords: up-conversion, near-infrared imaging, cathodoluminescence, rare-earth doped materials.

A Proposal on Biomechanically-combined Deformable Image Registration for Cervical Cancer Radiotherapy

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Abstract

Image registration is one of image processing techniques that are fundamental to medical image interpretation and analysis. Various methods in deformable (non-rigid) image registration have been employed to find an optimum solution for clinical cases, however previous methods are not intended to solve organ deformation caused by physical intervention, such as the case happened during cervical cancer radiotherapy. During brachytherapy, target organ (uterus) is deformed by insertion of applicator. This results in difficulties when performing dose calculation together with images from external beam radiotherapy images, in which uterus does not receive intervention by tool.

Taking the physical intervention characteristic into account, this study proposes a method to solve image matching for images taken during radiotherapy for cervical cancer. The proposed deformable image registration method combines image registration based on intensity and physical modeling of target organ. The location of applicator and internal wall of uterus in images are used as corresponding points to match uterus structures with finite element method (FEM). Displacement field obtained from this process is then compared to the transformation field from parametric intensity registration, and this process is used as a penalty term when combined with the cost function in intensity image registration. The new term provides correction in the viewpoint of biomechanical simulation that is expected to minimize error in image matching just based on intensity.

In the experiment, CT images of woman's pelvis phantom are used. Material properties that are used in physical simulation are typical values of urethane, which is the material uterus phantom is made of. The resultant image based on combined method is evaluated by comparing position of markers in it with the result of image registration based on only intensity to see the contribution of biomechanical part in improving registration accuracy.

Keywords: deformable image registration, finite element method, uterus, radiotherapy

Computational Cardiac Modeling Project using Human Specimens

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5) SCIEMENT, Inc.

Abstract

Vast macroscopic and histological specimens on cardiovascular diseases have been saved since its founding in National Cerebral and Cardiovascular Center. We conduct the project for contributing medical research and education by digitizing those specimens and developing novel computational cardiac models. We consider that the digitalization of histological specimens improves the accessibility and raise the value of them. In this presentation, we introduce the progress of our project.

Keywords: computational cardiac model, human specimens.

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