Research Statement: John M. Galeotti

I seek to improve patient outcomes by improving the tools of science and medicine. Applications include image-guided interventions and computer-aided diagnosis, computer-vision for tracking ultrasound probes in anatomical coordinates, and innovative scientific instruments to further fundamental biomedical knowledge. I apply novel computer vision algorithms and optics to the design and real-time analysis of biomedical imaging modalities such as OCT, ultrasound, and camera/microscope imaging. OCT and ultrasound are some of the safest and most affordable biomedical imaging modalities, but they suffer from substantial noise, imaging artifacts, and limited anatomical context. Improving the usefulness of these modalities directly improves biomedical science and patient care, and adapting either of these for use in a procedure instead of CT or MRI would simultaneously lower the associated costs. My approach is to analyze and develop entire novel systems for image analysis that are enabled by a deep understanding of (1) the underlying imaging modalities' optics/beam-forming, (2) the expected perturbations of real-time robotic manipulations, and (3) the human-machine environment through which the images are viewed. My end-to-end understanding, coupled with my close collaboration with associated clinicians and biomedical scientists, leads both to new applications of existing image analysis techniques and to original core algorithm development.

Real-Time Tomographic Holography: My graduate work collaboratively developed and demonstrated the novel diffractive-optics technique of real-time tomographic holography (RTTH). When combined with a real-time imaging modality such as ultrasound, RTTH places a virtual image of an object's cross-section into its actual location, with correct accommodation cues and without obscuring a direct view of the physical world, enabling natural hand-eye coordination to guide invasive medical procedures without requiring tracking or a head-mounted device. My co-authored three-year NIH R21 funded my follow-on post doc.

Full 3D Volumetric Visualization: I am further working to extend RTTH to full 3D using a novel approach to rapidly time-multiplex through each slice in an in-situ 3D volume. Each slice would display the correct data at its 3D location relative to the display, producing a system capable of comfortable autostereoscopic human viewing of real-time volumetric image data, for the first time enabling real-time in-situ volumetric image guidance for invasive procedures with correct accommodation cues, without tracking equipment or head-mounted displays.

In-situ Microscopic Visualization of Optical Coherence Tomography (OCT): Through my coauthored $2.9 million NIH R01 grant proposal for microsurgical in-situ image guidance with OCT, I am fully funded for another 2.5 years. OCT provides real-time, 3-6-micron resolution images at video rates within a few mm of soft tissue. Ophthalmologic anterior-segment medical and scientific applications include surgery of the cornea, limbus, and lens, such as our world-first applications allowing surgeons to see Schlemm's canal for treating Glaucoma and the Palisades of Vogt to enable harvesting and transplanting ocular stem cells. When this system is finished, it will combine (1) custom image processing and analysis algorithms for the OCT and camera data, (2) custom visualization software, hardware, and computer-controlled optics, (3) the first OCT system suitable for intraoperative use, and (4) a unique scientific analysis of how clinicians spatially perceive, understand, and interact with the system's results when displayed under the distortions of a surgical stereomicroscope. A planned competitive-renewal R01 would extend guidance deeper to retinal surgery.

3D OCT for Closed-Loop Control of 3D Biomechanical Manipulators: In collaboration with a group of biophysicists and others, we have submitted a 5-year, $2.4+ million NSF major research instrumentation device-development proposal to build a unique system for the measurement of tissue biomechanics. A novel scientific OCT scanner with corresponding unique computer-vision software capable of tracking our custom micromanipulator in 3D in real time would enable essential closed-loop control of the system and make primary measurements of the specimen's biomechanical responses to the in vivo manipulations. This work is expected to lead to *new fundamental knowledge and quantal leaps* in multiple major research areas, including skin and cardiac tissue engineering scaffold design, developmental morphogenesis and organogenesis, and tumor cell phenotype, dormancy, and reemergence.

ProbeSight: Our *ProbeSight* system consists of small stereo cameras mounted directly on an ultrasound probe for video-based simultaneous localization and mapping (SLAM) of the ultrasound probe relative to the skin surface, deriving a real-time patient surface model suitable for guidance to targets not directly visible in real-time imaging modalities. We are studying both the camera-based computer vision aspects of this system and the combination of multiple ultrasound slices into a single volume, ultimately taking into account ultrasound's considerable viewpoint dependence. My collaboration with a reconstructive transplantation MD/PhD is pursuing groundbreaking scientific and clinical in vivo monitoring of nerve regrowth and chronic rejection within injured or transplanted hands. We submitted an invited co-PI DoD $1.1+ million grant proposal, with similar DoD proposals planned as well as an NIH/NIBIB R01 for general-purpose ProbeSight guidance with specific applications to liver and thyroid. I also have commercial interest in pursuing a collaborative SBIR.

Medical Image Analysis: I have made numerous contributions to the Insight ToolKit (ITK), an open-source toolkit for segmentation, registration, and analysis funded by the National Library of Medicine (NLM) at NIH. I implemented two segmentation algorithms and adding extensive support for both parametric contours and non-rectilinear images to ITK's core architecture. I was PI on an NLM two-part contract for teaching and multi-center collaborative development adding real-time video capability to ITK and interfacing it with OpenCV. My visiting student developed segmentation and malignancy classification methods for whole-slide digital microscopy of prostate, and I have collaborated on algorithms that simultaneously segment an image while extracting its medial structure, thereby combining bottom-up and top-down approaches with promising results for both vascular shape analysis and pulmonary embolism detection.

New and Other Interests: Our *FingerSight* assistive technologies for the visually impaired combine machine vision with tiny finger-mounted cameras to interrogate the environment and optionally provide finger-tip vibrotactile feedback. A former medical resident and I are developing a novel interactive technique to rapidly search a history of mammographies to match lesions across time. Finally, I'm working to adapt existing CT analysis methods for use with 3D breast tomosynthesis, which is a new low-radiation imaging modality similar to CT. Tomosynthesis differs from CT in that tomosynthesis does not acquire the full set of projective X-ray images necessary to fully constrain slice reconstruction, leading to quantitative ambiguities, but tomosynthesis nevertheless provides substantially more detail than traditional mammography, which it may replace in 5-10 years. I plan to submit both NSF and NIH proposals on my tomosynthesis work.

In summary, my work has laid a practical and theoretical foundation for my current research in biomedical image analysis and visualization. I have demonstrated success in acquiring funding and am currently 100% funded for ~ 2.5 more years. By building on my unique end-to-end expertise with biomedical image analysis, including hardware, software, computer-controlled optics, and human-in-the-loop analysis of the total system, I will develop a new research program in which the tools and techniques of computational optical imaging are applied to the fields of robotic control and augmented reality, especially within the biomedical context. I plan to leverage the above NIH R01 and SBIR future grant proposals on in-situ OCT image-guided retinal surgery and computer-vision anatomic localization of ultrasound, coupled with the above NSF and military funding initiatives on first-ever in vivo measurements of nerve regrowth and 3D biomechanics, to progressively push the boundaries of 3D vision and visualization in unique and challenging optical environments where numerous scientific and clinical applications nevertheless require quantitatively precise imaging. Tightly integrated with my teaching, this research will form the basis of a competitive NSF career-award application. My long-term goal is to invent fundamentally new optical imaging modalities to see things that have never been seen before, with corresponding breakthroughs in the analysis and visualization of such images.