A real-time confocal microendoscope for in-vivo optical biopsies

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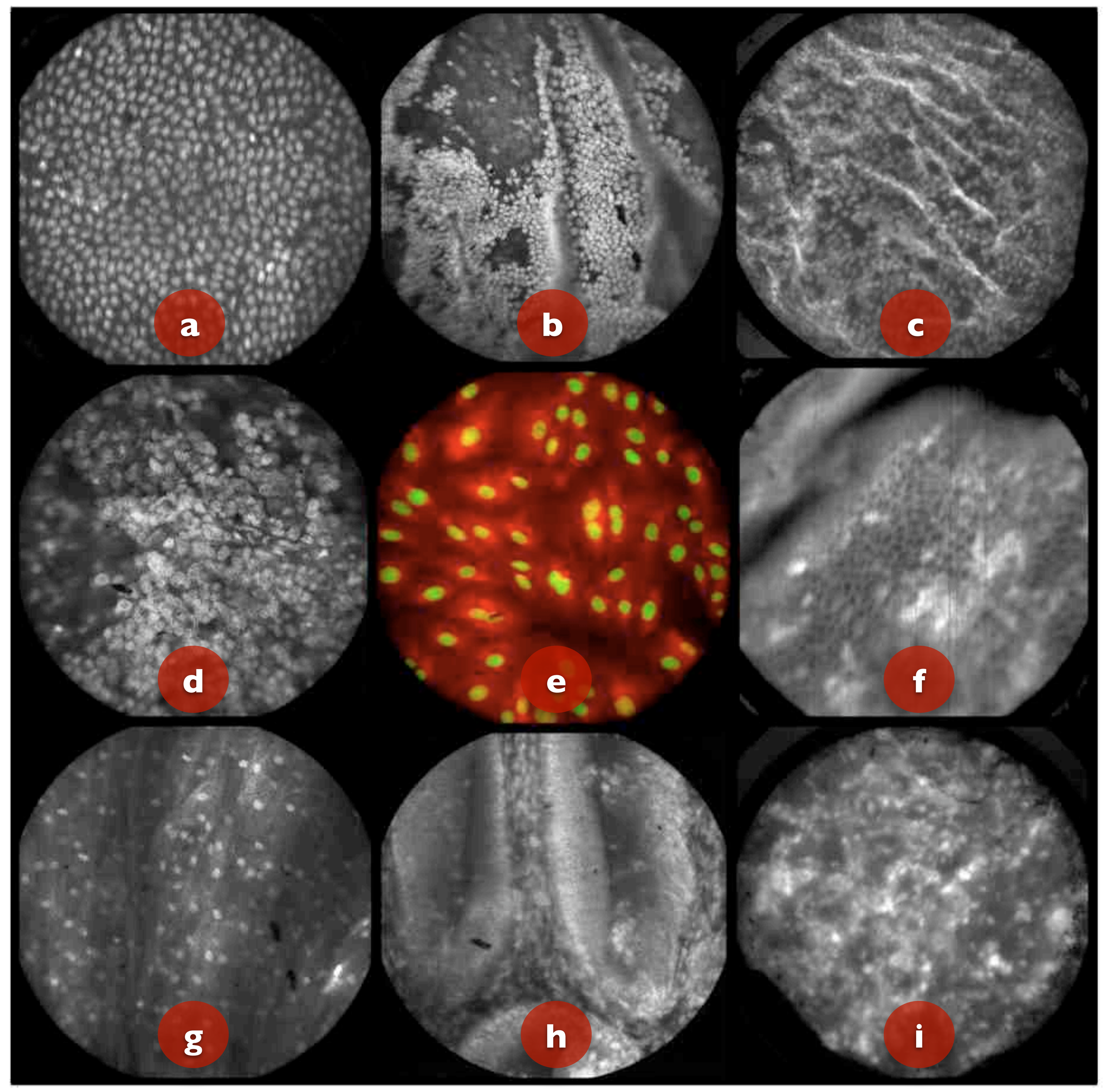
Live Optical Biopsies in Surgery

Live cellular imaging of ovaries during surgery. Dr. Kenneth Hatch directs a laparoscopic surgery in which a female patient's ovary with an abnormality is imaged during a clinical trial of our system. The surgeon locates the the ovaries using a wide field endoscope view (1) and then images the ovary with the confocal laparoscope entering through a 5 mm abdominal trocar. The integrated dye delivery system dispenses a tiny volume of fluorescent dye to stain the tissue. Real-time video of the epithelial cells are observed on a monitor (2). The instrument is housed on a standard endoscopy cart (3) that can be easily moved into the surgical suite when needed.



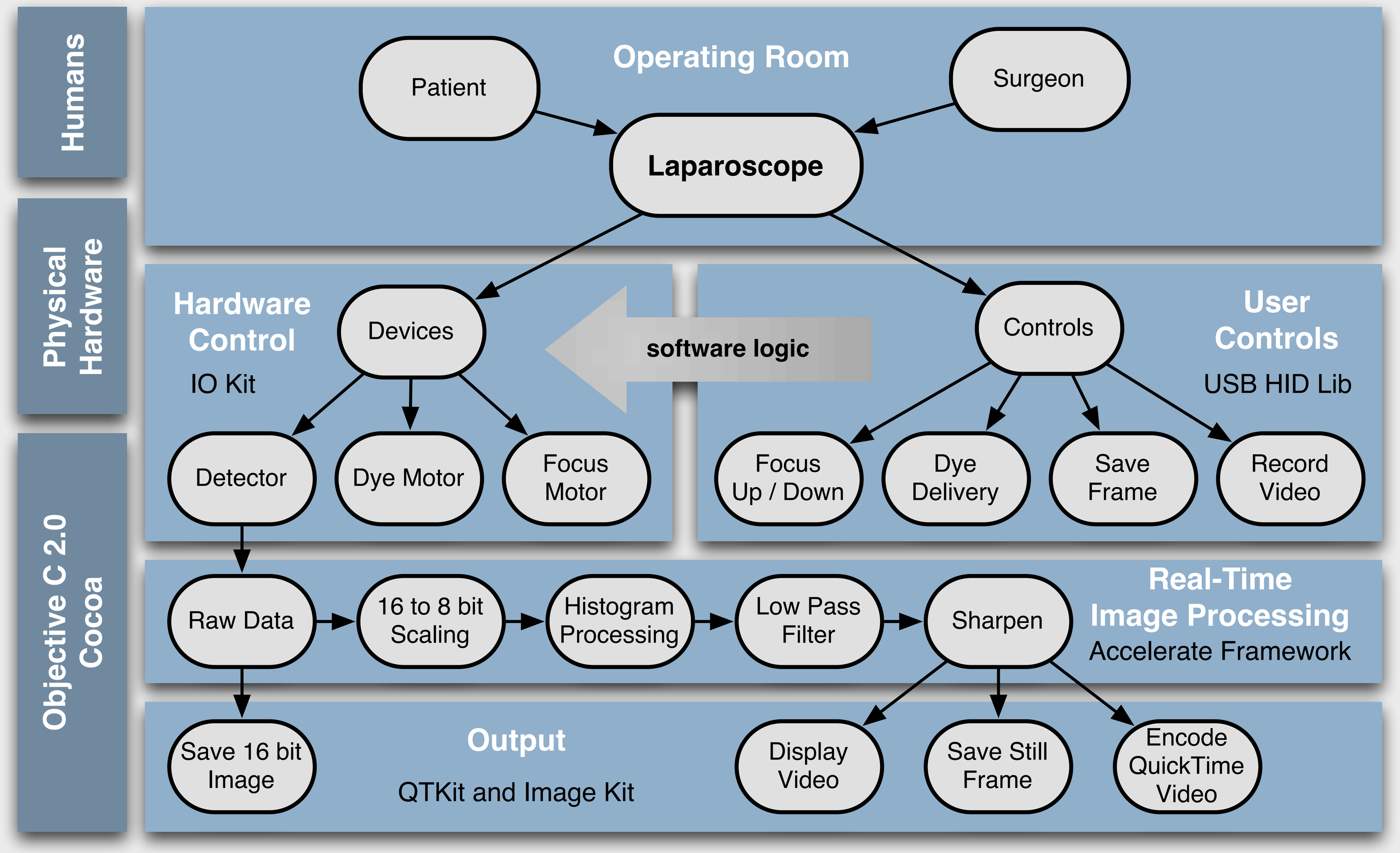
Results. Epithelial images demonstrating the system's ability to discriminate between normal and abnormal tissues. Human ovaries stained with acradine orange: normal (a), denuded epithelium (b), sclerotic (c), and tumor (d). Multi-spectral image of muscle cell culture (e). Human ovaries stained with fluorescein (f). Human esophagus stained with acradine orange: normal (g), Barrett's esophagus (h), and tumor (i).

Overview

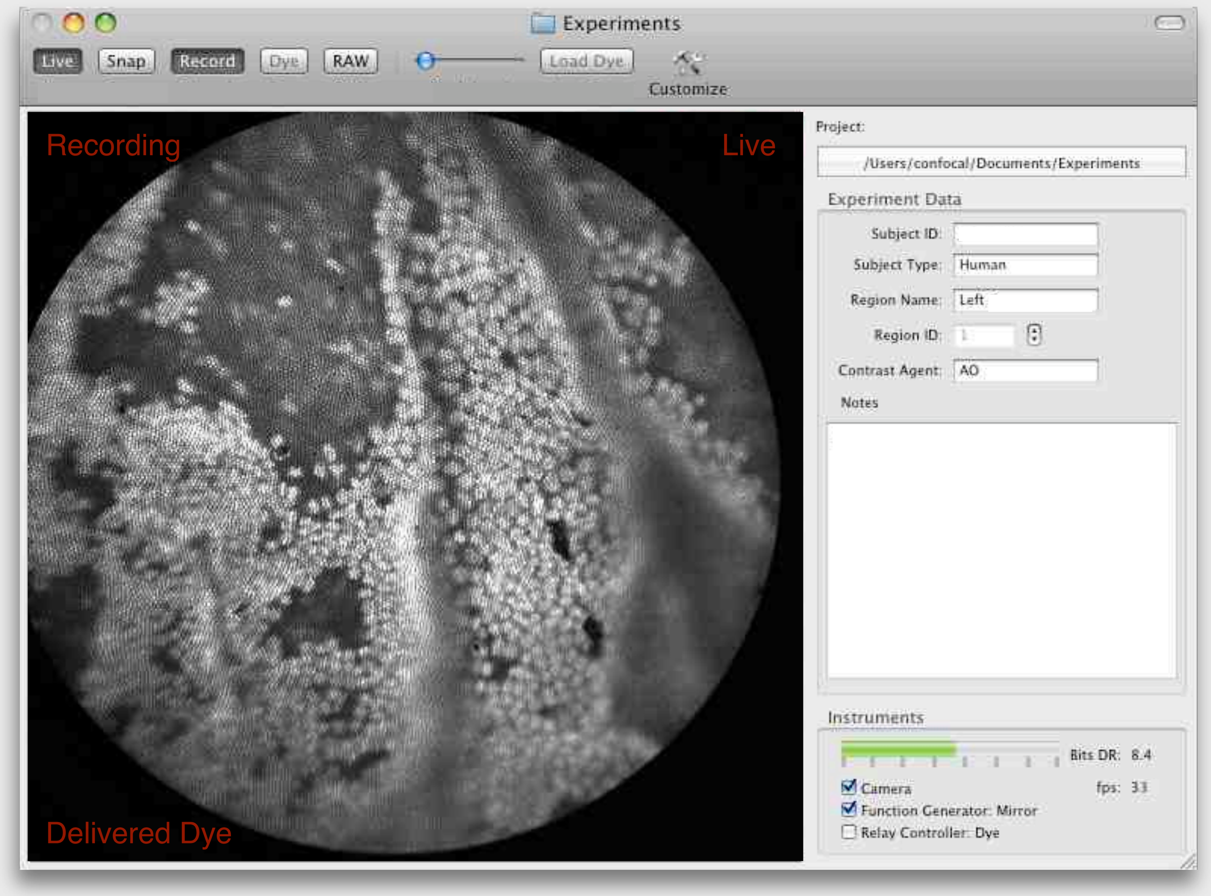
Successful treatment of cancer is highly dependent on the stage at which diagnosis occurs. Early diagnosis, when the disease is still localized at its origin, results in very high cure rates — even for cancers that typical have poor prognosis. Unfortunately, many cancers are not found until later stages due to inadequate diagnostic techniques. Approximately 90% of cancers arise from the epithelial cells. Development of surgical devices that can better interrogate epithelial surfaces for abnormalities would enable earlier detection of cancer and significant gains in overall patient survival.

We have developed a real-time multi-spectral fluorescence confocal microendoscope that provides surgical teams with instant optical biopsies at 30 frames per second via a 5 mm diameter rigid laparoscope or 3 mm diameter flexible daughter endoscope. The hardware control and real-time image processing have been implemented using Cocoa and Objective-C 2.0 with automatic garbage collection. The real-time image processing was accomplished using the Accelerate framework with a custom class that manages the memory for image processing operations. The surgeon's controls are interfaced through a USB connection via the IOKit framework. Using the QTKit framework, surgical videos are encoded in real-time. Finally, an unobtrusive interface was developed using Interface Builder to display the live video during surgeries.

To date, we have imaged 20 patients in-vivo and over 50 patients ex-vivo. Our initial in-vivo human results indicate that the device can successfully image the ovaries without complications. Our ex-vivo results demonstrate that the instrument can resolve sufficient cellular detail to visualize normal epithelium and detect the cellular changes that happen with the onset of cancer in ovaries and the esophagus.



Flow of information during surgery. Using Objective C 2.0 and Cocoa with automatic garbage collection we were able to quickly write a software package that interfaced with the data collection devices and the laparoscope controls. The software links the surgical controls on the laparoscope to the control systems that manage contrast agent delivery, focus, and data acquisition. Parallel processing allows the software to run smoothly while live images are acquired, processed, and encoded as videos at 30 frames per second. A custom image processing memory pool class enables efficient resource management under automatic garbage collection.



User interface. The control software provides an interface for viewing and collecting live images during the surgical procedure. Through on screen controls and the laparoscope's buttons, the surgeon can: start live acquisition, save the current frame, record video, deliver contrast agents, and change the imaging depth. In addition to the basic controls, the system also records procedure and patient information. Basic diagnostic information including dynamic range and device status are visible.

Surgical Laparoscope. In use, the laparoscope feels like a traditional wide field endoscope except that imaging is done by placing the 5 mm diameter tip in contact with the tissue. When the front optic is in contact with the tissue the surgeon presses a button and a tiny volume of contrast agent is delivered locally. Instantaneously, live cellular images are displayed at 30 frames per second for diagnosis. Once an unusual site is located, the surgeon can press a button to save a still image or elect to record a live video. Within the instrument a tiny 3 mm diameter micro-objective relays laser light into the tissue, which excites fluorescent signals generated by the locally delivered contrast agent. The collected signal is imaged onto a coherent fiber optic bundle and sent back to the optical scanning system for processing.

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