innovations

A candid camera for the gut

Arkady Glukhovsky is not yet sick of hearing references to *Fantastic Voyage*. In the 1966 science fiction movie, members of a medical team are shrunk and sent into a man's bloodstream on a miniature submarine to perform brain surgery.

Something similar, but for real, is going on at Israel's Given Imaging Ltd., where Glukhovsky is vice president of R&D. The company has developed a capsule that is swallowed and journeys down the gastrointestinal tract, transmitting images along the way [see illustration].

The capsule, at 11 mm in diameter by 30 mm long about the size of a large vitamin pill, provides the sort of inside view doctors try to get with an endoscope, a flexible optical-fiber device inserted through the mouth or anus—an inconvenience, to say the least. About 8.2 million gastrological endoscopies are performed in the United States every year. Glukhovsky said the disposable capsules will be competitive pricewise with endoscopy.

Dubbed the M2A (for mouth to anus), the capsule is being initially targeted at visualizing the small intestine. Situated before the colon and after the stomach, the small intestine is difficult to see using an endoscope. Especially well concealed is the portion nearest the entrance to the colon.

The operation of the M2A is straightforward. Once turned on and swallowed, the device activates a CMOS imaging chip, and with the help of four white-light-emitting diodes (LEDs), begins taking color images several times per second through a lens with a short focal length. The images are transmitted at a UHF frequency to an array of antennas attached to a recorder in a belt the patient wears. The recorder captures the image, and later, software on a workstation turns hours of data into a 20-minute movie clip. The capsule exits the body in 10–48 hours.

Getting an inside look at the small intestine required Given Imaging, based in Yoqneam, Israel, to solve several engineering puzzles. Two of the most pressing were how to fit all the components into such a small space and how to operate them at the lowest possible power. Micro-ball grid-array chip-scale packaging helped keep the size of the application-specific IC (ASIC) transmitter and CMOS imager down, but power was a more delicate problem.

While it may take only a few minutes for a physician to push an endoscope into and through a patient, the capsule must rely on the body's own internal motion, called peristalsis. That requires a 2- to 4-hour trip from the mouth to the start of the colon. Any device used, therefore, has to carry enough power to transmit signals through centimeters of highly absorbent flesh for at least that long. And such a device would have little room for more than the equivalent of a watch battery or two.

Using a CMOS sensor instead of a charge-coupled device (CCD) reduced the power requirements. The CMOS device required the invention of buffer amplifiers collocated with a photodetector in each sensor pixel. This so-called active-pixel architecture reduces the noise in the sensor and gives it CCD-like resolution.

The technique was developed in the mid-1990s at NASA for imagers on space craft such as the Mars Rover. Photobit Corp., of Pasadena, Calif., commercialized the active-pixel scheme and was asked to develop a miniature imager using less than 3 mW for the low light level at which the capsule would operate.

Limiting the number of images taken also helped reduce power "The capsule does not move very fast; so we don't need to acquire real-time video images," Glukhovsky said. Seamless video requires transmission of 30 images per second. "Using up to two images per second, we still won't miss an area of the intestine."

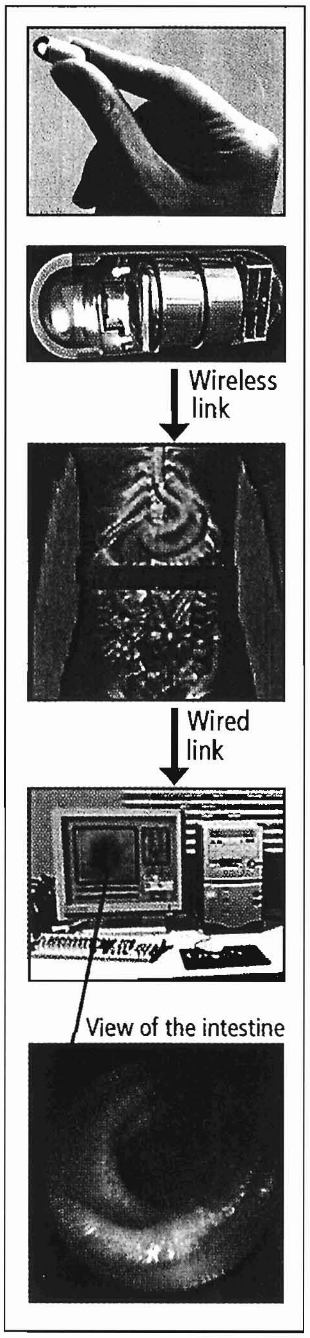
To lower the device's peak power requirements, its components are operated in sequence rather than simultaneously. The LEDs, the CMOS camera, and the transmitter are turned on and off in a particular order controlled by an on-board timer.

Given Imaging also had to produce images as close to what physicians are accustomed to seeing as possible. "We needed white light because physicians distinguish pathologies by slight differences in color," he said Generally, physicians use incandescent or xenon white light shone down the endoscope's light pipe. Color LEDs were out of the question. Instead, off-the-shelf white LEDs are used—in fact, blue LEDs containing red and green phosphors, whose emissions mix with the blue to make white.

Care was also taken with the geometry of the clear end of the capsule through which the camera peers. Light could not reflect back into the capsule and wash out the image.

To know where in the intestine an abnormality is seen, eight antennas are placed along the patient's belly. A special algorithm pinpoints the capsule's location by analyzing the differences in the strength of the signal at each of the eight. Millimeter accuracy would have been overkill, as the intestines themselves squirm about in the abdomen, noted Glukhovsky. It is sufficient to know which part of the intestine is involved.

Given Imaging is setting up manufacturing for the capsules while seeking approval from the U.S. Food and Drug Administration (FDA) for their use. So far, 20 healthy volunteers, including Glukhovsky, have given the capsule a test drive. "Swallowing it was actually much easier than swallowing an aspirin," he said. "The capsule just slips down the throat with a sip of water." And, he added, it slips through the rest of the body just as easily.



SAMUEL K. MOORE, *Editor*