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Paper Session I-B - Medical Spin-Off Benefits of Hubble CCD's

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The science discoveries made by the Hubble Space Telescope (HST) and the recent success of the Second Servicing Mission have captured the imagination of the science community and the public as a whole. What is less generally known is that astronomers will not be the first to benefit from the new science instruments installed on orbit this year. For the last two years, technology developed for the Space Telescope Imaging Spectrograph (STIS) has enabled an advanced diagnostic breast biopsy procedure that has already benefited thousands of women.

Modern telescopic instruments rely on sophisticated detection devices that can convert observed photons into electrical signals, which can in turn be converted to images or spectrographic data. The stringent scientific performance requirements push the state of the art, and NASA scientists recognized early in the life of STIS that careful detector selection and development would be needed to achieve their science goals. The detector chosen for one of the three STIS observing channels was a charge-coupled device (CCD). CCD’s were originally developed by Bell Laboratories in 1970 and have enjoyed tremendous commercial growth over the past twenty-five years in high-speed imagers ranging from videocameras to industrial robots.

The operation of a CCD is simple in concept, and a familiar analogy\(^1\) for this “bucket brigade” type of device is shown in Figure 1.\(^2\) If one imagines rain (photons) falling over an area, the picture elements (pixels) of a silicon CCD are like an array of buckets, each of which reflects the amount of rainfall (by converting photons to electrons) at its location in the area. When the rain stops, the buckets in each column can be sequentially moved to the edge of the area on conveyer belts (registers), where each is emptied into a perpendicular bucket system that transports the contents (electrons) to a station where the amount of each can be measured (amplifier).
The problem confronting the STIS team was that their performance requirements demanded greater sensitivity, lower noise, finer resolution, wider dynamic range, and greater contrast over a larger area than was then available in industry. A four-year development program, in collaboration with Scientific Imaging Technologies (SIte) of Beaverton, OR resulted in devices (Figure 2) that meet or exceed all performance requirements on a million-pixel (1K x 1K) CCD chip. The best of these superb devices is now 350 miles up, installed with STIS (Figure 3) on HST, and ready to perform state-of-the-art science into the next century.

As was stated above, the CCD is not a new device, and it is in daily use in a variety of commercial applications. The path from STIS to breast biopsies requires an understanding of the dynamic interplay between driving requirements, manufacturing processes, and commercial viability. CCD’s are process-based, semiconductor devices. Well over one hundred chemical and mechanical process steps are needed to manufacture the wafers from which the CCD devices (“chips”) are obtained. Each process step has a characteristic statistical distribution curve associated with it that represents the outcome of the step. The ultimate performance of all the chips made has a final distribution that reflects a convolution of all the multiple process step distributions.
A performance requirement that envelopes all or most of the final distribution means that virtually all of the chips made can be used, and thus the cost per chip is low enough to make them commercially viable. Performance requirements that fall at the highest end of the distribution result in a very small number of usable devices; i.e., a large number must be made to yield the few that are acceptable, and the relative cost is thus very high. However, if the entire distribution can be moved in the higher performance direction, more devices are acceptable, the cost drops in tandem, and new commercial applications with more stringent requirements can become economically feasible.

Such has been the synergy between STIS and digital breast imaging. The common imaging requirements of high resolution, wide dynamic range to capture in a single image structures that span many levels of brightness, good contrast, low noise, and high sensitivity to shorten exposure time and see fainter objects enabled a new application. SIte knew how to make better CCD’s, but the challenge was learning to build more than one or two at a time with high reliability through development of new designs and processes. By pushing the state of the art, investing in design and process development, and working with SIte to achieve their common goals, STIS moved the distribution (Figure 4).
STe now makes CCD’s that are nearly identical to the STIS devices and sells them to LORAD of Danbury, CN where they are incorporated into an x-ray digital breast imaging device (Figure 5) called “Stereoguide.” This system is the heart of a new, non-surgical, much less traumatic breast biopsy technique called stereotactic, large-core needle biopsy. Performed with a needle instead of a scalpel, it leaves a small puncture rather than a large scar and is performed as an office procedure under a local rather than general anesthetic.

Figure 4. An example of improved process distribution due to STIS CCD design and process development. Amplifier noise was reduced by 60% compared to the previous standard STe device.
Previous stereotactic methods used imprecise x-ray films, introducing uncertainty in position and the need for a larger exploratory incision. In the new version, the film is replaced by CCD's that are fiberoptic or lens coupled to a phosphor which absorbs the x-rays and re-emits in a wavelength region where the CCD is very sensitive. Dr. Hans Roehrig, Research Professor of Radiology and Optical Science at the University of Arizona has stated: “The image quality is much better because the signal-to-noise ratio is better with CCD's. You don’t get the granularity that you do with x-ray films, which causes the signal-to-noise ratio of the film to be poor.”
The radiologist locates the suspected abnormalities by taking two images, spatially separated by 30 degrees, a few seconds apart. A real-time, three-dimensional image is generated by triangulation, and a click of a button results in the precise, computer-calculated location of the targeted spot. If required, the machine can then guide a biopsy needle directly to that location where a small sample of tissue is removed.

Many benefits accrue from this greatly improved system. The procedure can be performed in one-half to one-third the time, due to its non-surgical nature and elimination of repeated delays while x-ray films are developed. A small Band-Aid and immediate return to normal activities replace a surgical incision, scar, and one-week recuperation. Exposure to x-rays is dramatically reduced, since only a small portion of the breast is exposed to radiation for a short time. Evaluation is near real time, and the digital images can be stored on disk or sent instantly to distant experts via computer network. Again quoting Dr. Roehrig: “Stereotactic biopsies were done before the advent of CCD’s, but they took a long time. First, two x-ray pictures of the abnormality had to be taken. The pictures had to be developed in the darkroom, which takes about three minutes. Then, measurements had to be taken on the film images and run through a computer in order to perform triangulation to determine the coordinates. The process of taking pictures, developing the film and locating the coordinates of the abnormal tissue mass typically takes about fifteen to twenty minutes, and during this whole time the patient - still at the machine - cannot move. Now, in near real time, the entire process of locating the mass can take as little as five minutes and is much more comfortable for the patient.”

Over 500,000 American women undergo breast biopsies annually. At a comparative cost of $850 versus $3,500, savings in medical costs could approach $1 billion a year.

Hubble continues to enable commercial CCD applications through the Advanced Camera for Surveys (ACS), currently in build for installation on HST in 1999 during the Third Servicing Mission. The ACS requirements, which call for a ten-fold improvement in instrument performance over the Wide Field/Planetary Camera currently returning remarkable images from HST, demand a larger (16 million pixels, 4K x 4K) CCD with performance beyond that of STIS. The larger area is obtained by butting together two smaller (2K x 4K) chips on special, lightweight packages (Figure 6). These packages, and the processes, techniques, and equipment needed to assemble them, have been jointly developed by SITe, the Johns Hopkins University, NASA, and the instrument contractor, Ball Aerospace and Technologies Corporation. The same techniques can be used to scale up beyond the 4K x 4K required by ACS by combining multiple chips, expanding the achievable imaging area to a level that will enable full breast digital mammography. The lightweight, space-ruggedized assembly will greatly increase the reliability and stability of the digital imaging equipment over the heavy, bulky mechanical assemblies previously attempted. The continued push on performance requirements is expected to enable applications in industrial and medical spectroscopy.
In conclusion, the rewards from STIS and ACS in the science realm are gratifying and straightforward. Equally gratifying to those teams is the reward that is best reflected by a quote from Dr. David Dershaw, Director of Breast Imaging at Memorial Sloan-Kettering Cancer Center in New York: “The woman who has gone through a needle localization procedure and formal surgical biopsy on a prior occasion and now comes in to have the same thing done, but has it done as a stereotactic biopsy, is about the most appreciative patient you can imagine because you have taken a long, drawn-out, anxiety-ridden, and expensive event and made it shorter, easier to schedule, and more comfortable. She has no surgical wound.”

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