GigaPixels for Science

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During the Mars Exploration Rover landings in January 2004, Randy Sargent, a member of the NASA/Ames Intelligent Robotics Group, saw particular power in the way Martian imagery was used for geologic exploration. Because the rovers were able to create tiled, panoramic images with extremely high resolution, the scientists became drivers and explorers of the imagery itself. By deciding how to pan and tilt a panorama, and which part of the panorama to zoom into, the scientists were, as a community, directing their attention as if walking on Mars with a magnifying glass in hand.

The inspiration taken by the scientific study of Mars suggested a consideration for technology empowerment on Earth: could such gigapixel image acquisition be done affordably by the masses? Could a robotic device enable any point-and-shoot camera to create billion-pixel images, and would the robot be sufficiently simple for anyone to use? If so, how would communities of practice be empowered by creating, examining and jointly annotating images with billions of pixels of information?

The system prototyping took nearly two years to complete, as three major challenges must be addressed to create a low-cost gigapixel system: image acquisition, image stitching and image interaction. The GigaPan robot is designed to minimize cost: rather than using expensive optics that obviate the ability to reach low-income communities, the robot holds any small format digital camera and pans and tilts accurately to acquire an entire panoramic scene with calibrated overlapping images. The robot pictured in Figure 1 attaches to a camera tripod, holds nearly any small camera on the market, and triggers the camera using a universal technique: a robotic finger presses on the camera's shutter release button. By using commercially available stepper motors and clever driver electronics, we achieve a cost of manufacture well below the retail cost of the digital cameras one places inside the device, removing the hardware cost as an impediment to educational dissemination.

Figure 1: The GigaPan robotic imager

The image stitching challenge is significant, especially if one assumes no *a priori* information about the relative placement of individual source images, as is the case with many available image stitching packages. But because we know the kinematics of the robot, our stitcher can begin with strong adjacency constraints between images, solving for image alignment, blending and finally re-projection for viewing on flat computer screens. With a complete stitched panorama, we face the third and final challenge: a single GigaPan image can easily exceed one billion pixels. With an image so large, students cannot share the results, print them or even view them with standard photo viewing software. Thus the GigaPan project needed to design, code and release a new website, *gigapan.org*, to serve as a storage and interaction space for very large, explorable images. By storing each panorama with layers of varying resolution, the site is able to stream the appropriate fidelity to a viewer's computer as done by Google Earth and map-viewing programs. Because each image can be explored to extreme depth, viewers can discover objects in a panorama that even the photographer had not noticed, and so annotation facilities enable both author and viewer to tag sub-regions of the panorama, as though they are physically exploring a new scene and engaging in location-specific discussions.

With the three-part GigaPan system complete, the CREATE Lab received a grant from the Fine Foundation to begin a new educational robotics experiment: empower leading scientists with this robotic technology and measure change in how they document and communicate their discoveries both to their peers and to the public. Image-making is already a compelling tool in the sciences, from geology to paleontology. But what about images that would capture the entire context of a place, and also capture sub-millimeter features on the objects of interest? What if those images could be shared, over the internet, with fellow scientists and with the public? Over the past two years we have begun to address these questions by deploying a curriculum for teaching top internationally recognized scientists how to use the GigaPan robot as a tool for inquiry, documentation and outreach to the public. Three *Fine Outreach for Science* workshops have been held in 2008 and 2009 with a total of 95 scientists, enrolled by tapping the MacArthur Fellow recipient pool and their peer network from amongst the fields of agriculture, anthropology, archaeology, botany, climate research, ecology, entomology, forestry, geology, linguistics, paleontology, sustainable design, urban planning and others.

These Fine Fellowship recipients have together captured, stitched, uploaded and annotated more than 1,800 publicly viewable gigapixel images on gigapan.org, and work is now underway to create a collected print edition that will describe each scientist's use of gigapixel imaging as a new robotic tool in service of their particular discipline. Peer-reviewed scientific journal articles utilizing gigapixel imagery are now emerging from the first class of Fine Fellows. In the journal *Rangeland Ecological Management* Dr. Nichols demonstrates the use of periodic GigaPan imagery of western ranges as a tool for macroscopic analysis of specific plant species changes as well as cattle use patterns, enabling scientists to better model change over time and therefore steer more ecologically conservative use of public lands. In *Critical Inquiry in Language Studies*

Dr. Hanauer describes the ethnographic analysis of a microbiological laboratory by capturing a full panorama of the lab, then explicitly analyzing the lab contents and distribution. This landscape analysis has deep potential to change the face of linguistic and ethnographic analysis in fields as disparate as educational analysis, rhetoric of science and the study of near-extinct spoken languages.

As part of the *Barcode of Life* project, the University of Guelph's *P*rofessor Alex Smith endeavours to DNA barcode animal species and quantitatively capture biodiversity and phylogenetic diversity within the context of population ecology and ecological monitoring. The GigaPan unit is used by field biologists as they make specimen collections. In Figure 2, the context of an entomology-focused collection is captured. Insects were barcoded around the perimeter of the sink hole, and the habitat information in the panorama preserves the ecological context for those finds, including a distant beaver dam in the sink hole.

Figure 2. Sink hole taken by Jason Straka; near the Georgian Bay in Canada (left) and a beaver dam within the gigapixel panorama (right)

Brown University archaeologists focused on Petra, the capital of the Nabataean kingdom in present day Jordan, sought to capture the spatial relationships in the city center that stem from the Great Temple, currently under excavation by Brown's Joukousky Institute. This archival GigaPan panorama (Fig. 3) captures the scale and position of elements in the natural and built environment and shows how the Great Temple relates to the Royal Tombs.

Figure 3. 260 degree view of Petra city center and surroundings (above); Royal Tomb (below)

We are encouraged to see great diversity in how a gigapixel acquisition robot can empower scientists to rethink documentation and sharing both within their communities and beyond their scientific boundaries. At the University of Hawai'i students are exposed to a full-sized, two meter by four meter GigaPan print of a lush forest to prepare for an actual ecological assessment in that forest on a field trip. In San Jose researchers have connected the stepper motors of the GigaPan to the X and Y stages of a scanning electron microscope, yielding astonishingly detailed microscopic images of entire ants at a level of resolution normally reserved for just one small part of such creatures.

In order to further stimulate cross-fertilization in this new area of inquiry between scientists of many disciplines and roboticists, we have recently announced a conference on Gigapixel Imaging for Science in November 2010 (www.cs.cmu.edu/~fofs). This conference, cosponsored by both AAAS and IEEE, brings scientists and technologists together to understand how massive gigapixel imaging and image annotation can help to revolutionize data capture, understanding and public outreach.

GigaPan is one example of robotic outreach positively impacting communities of practice that are normally far from robotics. As robotics further connects the physical world with information ecology its potential to provide technological fluency to new communities sees no boundaries. Thus educational robotics, as applied to students, publics, academics and even legislatures, has entered an era of significant growth.

References

Crozier R. H., Agapow P-M, Smith M. Alex (in press) Conservation genetics: from species to habitats. Biology International. In print, 2010.

Hanauer, D. Laboratory Identity: A Linguistic Landscape Analysis of Personalized Space within a Microbiology Laboratory. Critical Inquiry in Language Studies. In print, 2010.

Nichols, M., Ruyle, G. and Nourbakhsh, I. Very High-Resolution Panoramic Photography to Improve Conventional Rangeland Monitoring. Rangeland Ecological Management 62:579-582, November 2009.

Nourbakhsh, I., Acedo, C., Sargent, R., Strebel, C., Tomokiyo, L., Belalcazar, C. "GigaPan Conversations: Diversity and Inclusion in the Community," In *Proceedings of International Scientific Conference on Technology for Development*, United Nations, Lausanne, Switzerland 2010.