S22-43 ABS. ONLY

N94-35417

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SUBPIXEL RESOLUTION FROM MULTIPLE IMAGES

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Multiple images taken from similar locations and under similar lighting conditions contain similar — but not identical — information. Slight differences in instrument orientation and position produces mismatches between the projected pixel grids. These mismatches ensure that any point on the ground is sampled differently in each image. If all the images can be registered with respect to each other to a small fraction of a pixel accuracy, then the information from the multiple images can be combined to increase linear resolution by roughly the square root of the number of images. In addition, the gray-scale resolution of the composite image is also improved. We describe methods for multiple image registration and combination, and discuss some of the problems encountered in developing and extending them. We display test results with 8:1 resolution enhancement, and Viking Orbiter imagery with 2:1 to 4:1 enhancements.

Our problem is the inverse of computer graphics rendering. There, one is given a model of the relevant surfaces (shape and reflectivity), with associated viewing and lighting conditions. From this information, a graphics program projects an image of the scene. We have the inverse problem: given multiple images obtained under known lighting and viewing conditions, determine the most probable surface model subject to prior model constraints. Ideally, a planetary surface model would combine topographic information with multi-spectral reflectances at every point on the surface. Our current simplified approach is restricted to a single spectral band. We suppress topographic effects by requiring all images to be made from roughly the same direction under the same lighting conditions. Thus we combine the effects of varying ground slope and surface albedo into a 2-D model element ("mixel") grid. This mixel grid is made at some fraction of the projected pixel resolution, e.g., 20m instead of 80m.

Despite the above restrictions, we can achieve improved resolution in practical cases. For Viking Orbiter (VO), we can combine the overlapping margins and corners of high-resolution mosaics for a modest improvement. We can obtain dramatic improvement when dozens of images are available. Unfortunately, due to orbital mechanics, such sequences are always low-resolution.

Lacking geographic truth, our current work employs a relative registration. The mixel grid is initialized by interpolating values from one of the pixel images. Thus this image provides the geographic control. Successive pixel images are then registered by minimizing a mismatch function over the parameter space of the appropriate mapping transformation. For each pixel the mismatch function calculates the sum of mixel contributions over the projected pixel area, weighted by the instrument point spread function (PSF). The mismatch is then the sum of squared errors between the predicted and observed pixel values.

The choice of an appropriate geometric transform function is important. It must account for any inter-image distortions without introducing excessive degrees of freedom. For scanned images, rotation and translation are sufficient. With CCD detectors the addition of scale and shear will allow relative mapping, while projective transform is needed for geographic correction. The vidicon tubes on the Viking Orbiters and Voyagers introduce local and image wide readout distortions that we model with second order coefficients.

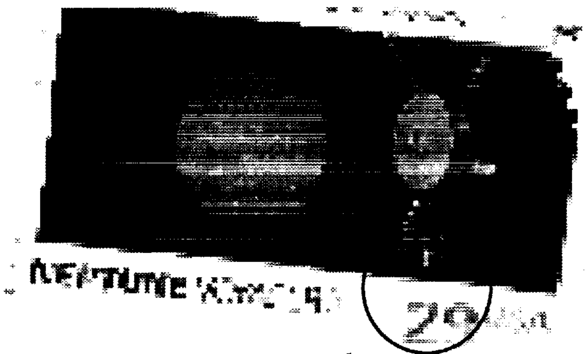
The final combined image is currently computed by setting each mixel to a weighted average of the pixel values influenced by that mixel via the PSF and registrations. This works surprisingly well, sufficiently to justify presenting the present technique. We are developing a full Bayesian solution to this inversion problem, to include PSF deconvolution and neighbor correlations.

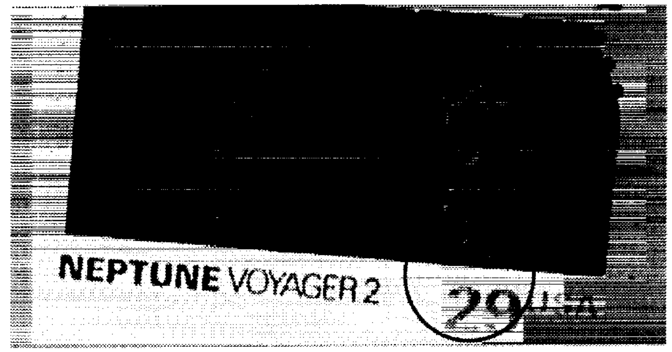
There are problems with the current system. The registration search can only find local minima in the mismatch error space, so it is necessary to manually pre-register images to within a few pixels. Practically, registration requires that there be several prominent features distributed over the image. Also, the mismatch function is very sensitive to edge interaction of the mixel and pixel grids. These can be avoided.

In addition to readout distortion, the VO and Voyager vidicon images are subject to camera shading and uncertainties in exposure duration. Many pixels are blocked by data dropout and reseau marks. Others are corrupted by multi-bit transmission errors, quantization noise, blemishes, etc. These are all part of the camera model and could be reconstructed along with the surface model, but currently their effects are removed by preprocessing.

We hope, in the future, to have a full geometric model that will allow us to take advantage of the multiple high-resolution coverage that can be found among the 50,000 VO images, as well as long-range Voyager flyby sequences of certain moons, such as Iapetus.

SUBPIXEL RESOLUTION FROM MULTIPLE IMAGES — Cheeseman et al.

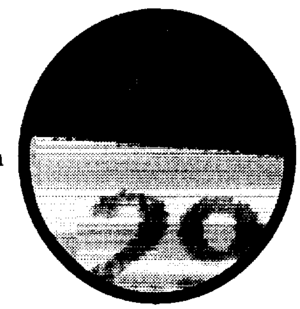


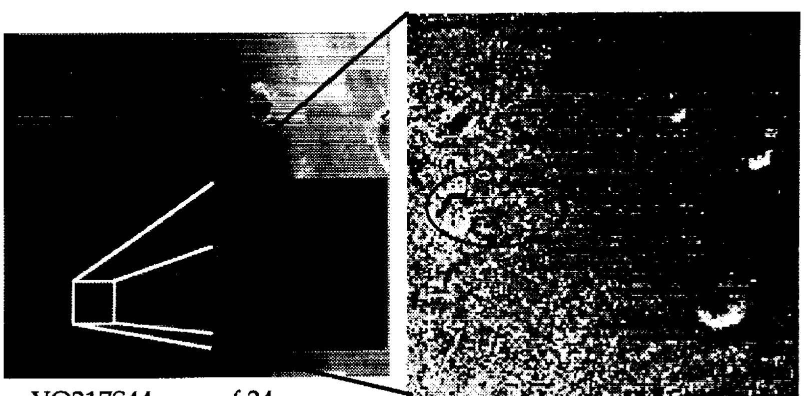


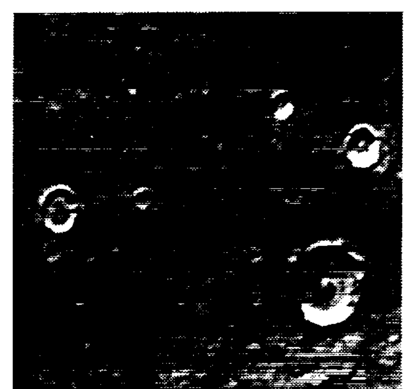
Postage stamp scanned on an Apple scanner as an 8-bit grayscale image.

scanned at 72 pixels / inch

reconstructed at 576 pixels / inch



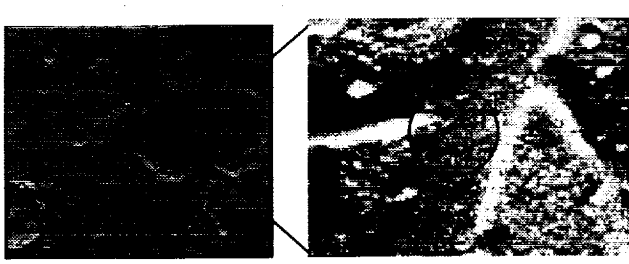




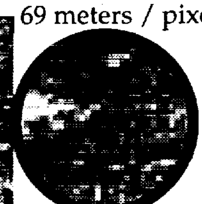
VO217S44, one of 24 wave-cloud frames

742 meters / pixel

186 meters / pixel



69 meters / pixel



VO434S10, one of 4 overlapping images from two mosaics of Gusev Crater.

35 meters / pixel