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Space Station Allows Remote Sensing of Earth to within Six Meters

Budgetary challenges and research limitations of the International Space Station, which is currently being constructed, are routinely discussed in the media [e.g., *Lawler*, 2001]. In spite of these challenges, an Earth remote sensing experiment being conducted from the International Space Station, called Crew Earth Observations [*Robinson and Evans*, 2001], is already yielding significant data returns by using the successful photographic methods employed in earlier Earth imaging programs from the Space Shuttle and *Mir* Space Station [*Lulla and Dessinov*, 2000]. Early results show great improvement in our ability to compensate for the relative motion of the Earth and achieve high remote sensing spatial resolution in hand-held images. Images captured for Crew Earth Observations have spatial resolutions of less than 6 m, approaching the highest spatial resolution of color images now available from commercial remote sensing satellites.

Approximately 13,500 images of Earth were captured by the first three resident Space Station crews using digital still cameras, 35-mm film cameras, and 70-mm film cameras. Image acquisition by the fourth crew is ongoing. Similar cameras have been used successfully on the Space Shuttle and *Mir* to photograph Earth, with a >30-year data base of nearly 400,000 photographs collected to date [*Lulla et al.*, 1996]. The photographs are in the public domain, cataloged in a data base maintained by the Earth Sciences and Image Analysis Laboratory at the NASA Johnson Space Center, Houston, Texas. The data base is searchable on the World Wide Web (The Gateway to Astronaut Photography of Earth; see http://eol.jsc.nasa.gov/sseop). The photographs are routinely digitized for use in scientific analysis and can be used as three-band (red, green, blue) digital data [e.g., *Webb et al.*, 2000; *Robinson et al.*, 2002].

The spatial resolution of photographs of Earth from orbit is determined through geometric properties of the altitude of the spacecraft, magnification of the lens, size of the original image, and look angle [*Robinson et al.*, in press, 2002]. Further constraints on resolution include camera settings, film characteristics, and parameters of film digitization. If photographs on film are digitized at a spatial resolution appropriate to the grain size of the film [*Light*, 1996], their geometrically determined spatial resolution can be compared to the instantaneous fields-of-view that are used as indices of the spatial resolution of instruments on remote sensing satellites [*Robinson et al.*,

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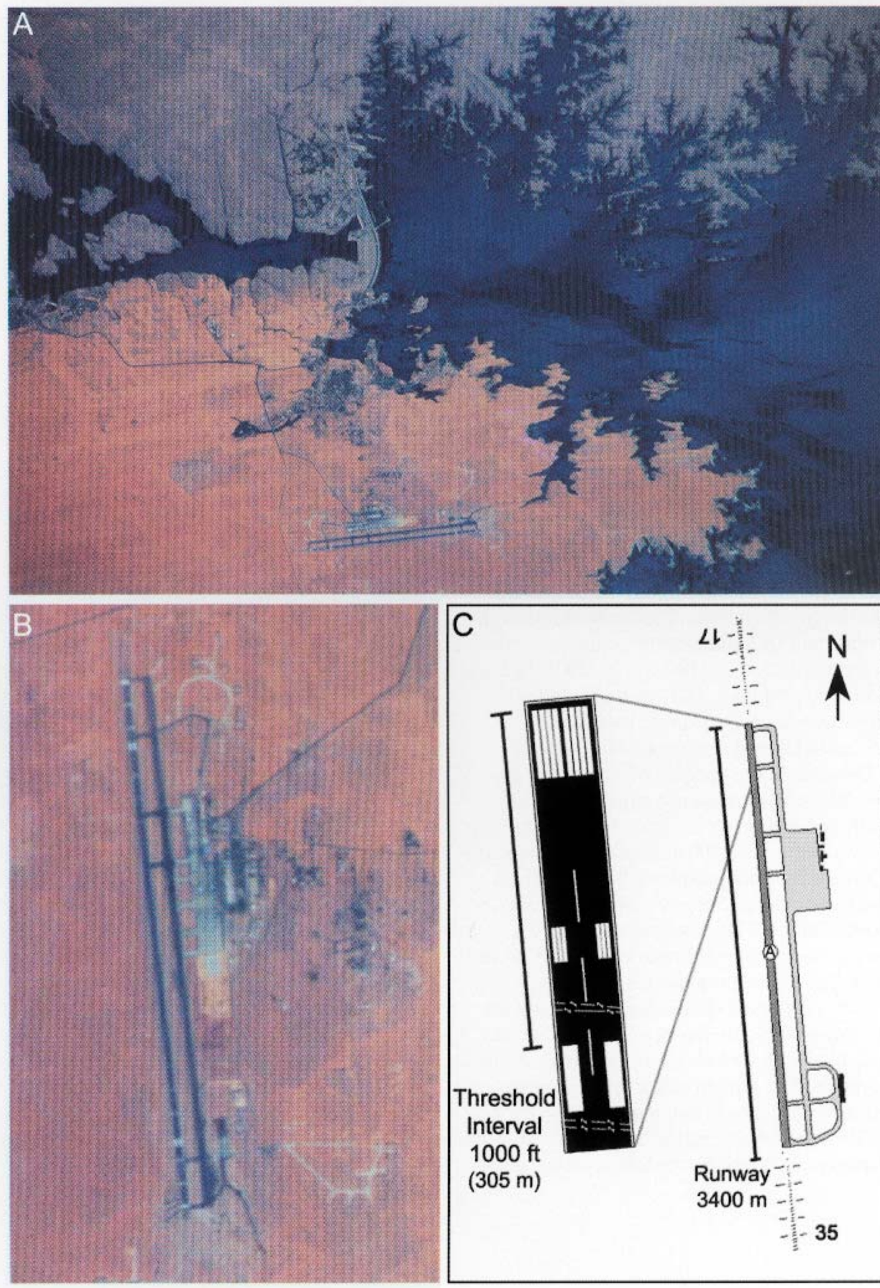

Fig. 1. Six-meter resolution was achieved in this photograph of the Aswan High Dam and Airport, Egypt, taken from the International Space Station. A camera with a 400-mm lens and 2× extender was used to take the photograph from an orbital altitude of 379 km. (a) The complete frame is shown as photographed (NASA Photograph STS102-303-17). (b) Detail of the Aswan Airport is shown with north orientation to the top. (c) In this example of airport data, the runway length and standard distances between threshold markings painted on the airstrip [Aircraft Owners and Pilots Association, *1999] were used to verify the ~6-m spatial resolution of the digital image.*

2002]. The resolving power of films used for astronaut photography ranges from 32 to 100 line-pairs/mm at low contrast (object/background ratio of reflecting power = 1.6/1), and is typically 55 line-pairs/mm or better [*Robinson et al.*, in press, 2002]. Based on Light's [1996] method, the acceptable range of scan spot size to preserve spatial information would then be between 6 and 9 μm, inclusive. This scan spot size corresponds to digitizing resolutions ranging from 4233 to 2822 ppi (pixels/inch) [*Robinson et al.*, 2002].

To achieve the maximum potential spatial resolution determined by the geometries, the camera system must capture information at a sufficient speed to eliminate the effects of relative ground motion. The speed of the Space Station relative to the ground is approximately 7.3 km s^{-1}. At a normal shutter speed of 1/500 s, the expected blur due to motion relative to the ground would be 14.6 m. From previous experience, we knew that apparent ground motion was not limiting spatial resolution in hand-held photographs. Photographs taken by astronauts from lower orbits using 250–300-mm lenses with 6.2 million mega-pixel digital still cameras, or 70-mm film cameras with film digitized at 2400 pixels per inch, have had calculated spatial resolutions of approximately 10–15 m, without adding the 14.6-m smear due to ground motion. These resolutions were confirmed by validation of actual ground-resolved distances [*Webb et al.*, 2000; *Robinson et al.*, in press, 2002], and showed no evidence of ground smear, even when calculated spatial resolutions were < 15 m.

Because of the success of astronauts in tracking and eliminating ground motion in their hand-held photography of Earth, new 350-mm and 400-mm lenses were recommended for photographing the Earth from the International Space Station and Space Shuttle flights. These lenses would give a best-case spatial resolution of about 8–11 m from Space Station altitudes.

Although never envisioned to be used for photographing the Earth, a 2× extender was also available for the 35-mm and digital still cameras. With time to adapt to the microgravity environment, special training in motion tracking [*Glazovskiy and Dessinov*, 2000], and extensive experience on orbit, Space Station crew members decided to test the new 400-mm lens along with the 2× extender to photograph the Earth.

The sharpness of images acquired using doubled magnification has surprised both crew members and scientists on the ground, and has changed our view of the level of detail that can be recorded by humans from orbit. An example of the high spatial resolution achieved is shown in Figure 1. Digitized at 2075 ppi, this 35-mm film image of the Aswan High Dam, Egypt, was taken using the Nikon F5 camera from a 379-km altitude while the Space Shuttle and Space Station were docked together in orbit. If the shot were a perfect nadir view, the calculated spatial resolution without ground motion would be 5.75 m/pixel. By measuring the known distances between airport marking aids on the Aswan Airport runway, the observed spatial resolution of the image is 5.98 m/pixel. This image is typical of the detail obtained for areas around the world by the International Space Station crew members.

Engineers are currently developing electronic and mechanical motion compensation strategies for use on remote sensing instruments to be mounted in the U.S. Laboratory Window Observational Research Facility (WORF). Motion compensation technologies will be used for a variety of remote sensing instruments that will be mounted in the window to achieve spatial resolution of 10 m or less on the ground. These instruments are engineered differently than satellite-mounted instruments because there is less control over the movement of the platform—in this case, the International Space Station—but there are also few requirements for the instruments to be space hardened, as they can be operated and maintained inside the cabin. The ability of crew members to compensate for motion represents a challenge to engineers to match their performance, while also validating the potential high resolution that can be obtained from the Space Station.

The International Space Station provides great potential as a remote-sensing platform capable of providing high-resolution imagery of the Earth's surface. The optical-quality window in the U.S. Destiny Laboratory [*Eppler et al.*, 1996] became part of the orbiting station in February 2001, with the WORF support system scheduled for installation in 2002. With several remote sensing instruments at different stages in the planning process and advancing imaging technologies for hand-held use, high-resolution images of the Earth from the International Space Station should soon be commonplace.

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