Technology for imaging is evolv impossible for many non-technica

Eyes in

The GI News 'Guide to the Current State-

In the first of two articles, Professor Gordon Petrie describes the main types of imagers and gives the lowdown on airborne imagery.

Over a long period, terrain imagers had evolved into a few easily distinguished groups. On the optical side, film cameras were mainly used on aircraft, while line scanners were mainly used on spacecraft. Microwave radar imagers, whether operated from aircraft or spacecraft, played a very minor role in terms of provision of terrain imagery. However, over the last few years, the situation has changed entirely, especially with the introduction of numerous types of all-digital optical imagers, often of a novel design. Radar imaging is still quite a small activity in comparison with optical imaging, but the whole area has been re-energised through the development of InSAR – interferometric synthetic aperture radar. The purpose of this article is to provide readers with an overview of the situation today in the terrain imaging field.

MAIN CATEGORIES OF IMAGERS

Since there now exist an almost bewildering array of imagers, it would seem best to try first to put them into some sort of order by highlighting their main features and outlining the basic differences between them. This would help to define the various distinct categories of imager. We can attempt to do this by first distinguishing between the main imaging technologies, then discussing the main spectral characteristics of different imagers, and finally looking at the various platforms on which they can be mounted.

Imaging technologies

With regard to the actual imaging technologies, the basic distinction is between optical and microwave imagers. In turn, the optical imagers can clearly and simply be divided into two categories (see figure 1).

The first are the frame cameras producing individual frame images of the terrain (figure 1a). Each individual image is acquired from a single exposure station in the air or from space to cover a substantial area of ground. A series of these discrete frame images are then taken at appropriate intervals to cover the area of the terrain over which imagery is required.

The second group are the line scanners producing continuous strip images of the ground (figure 1b) with each individual line being imaged from a different exposure station, either in the air or from space.

Frame cameras

In the case of the frame cameras, the dominant technology is still the photographic film camera – either the metric frame camera used for mapping purposes or the special framing or panoramic film cameras used with

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-of-the-Art in Terrain Imagers & Imagery'

military reconnaissance aircraft. However, digital frame cameras are now being introduced into both of these fields – although with restrictions in the format size that has been available until now. Besides which, the production of colour or false-colour images is a special problem with these digital cameras. It is not just a matter of changing to a film with a different emulsion, as is the case with film cameras. Either an interpolation technique has to be used to generate the required colours or, most often, multiple digital cameras need to be used – with each camera recording a specific spectral band to make up the final composite colour or false-colour image produced by image processing.

Line scanners

With regard to line scanners, until recently these have mostly been operated in the near vacuum of space. This provides a non-turbulent medium for the orbiting platform on which the line scanner is mounted and operated. By contrast, the unpredictable platform motions that are caused by the turbulence of the Earth's atmosphere resulted in unacceptably large image distortions in the linescan imagery that could be acquired from airborne platforms. Now, however, with the introduction of fast-acting gyro-stabilised mounts and the development of modern DGPS/INS systems to provide positional and attitude information on a line-by-line basis for georeferencing purposes, line scanners are starting to be introduced on airborne platforms.

While formerly, line scanners often used rotating optical-mechanical elements to scan the terrain to produce continuous strip images of the ground, nowadays the use of linear array sensors employing the pushbroom method of operation is almost universal – irrespective of the platform on which it is deployed. Previously, linescan images were almost always monoscopic; now overlapping 3D stereo imagery of the ground is being acquired using along-track scanner imaging techniques. This transforms the use of linescan imaging technology in terms of its potential for topographic mapping applications, using highly automated methods for DEM (digital elevation model) and ortho-image production.

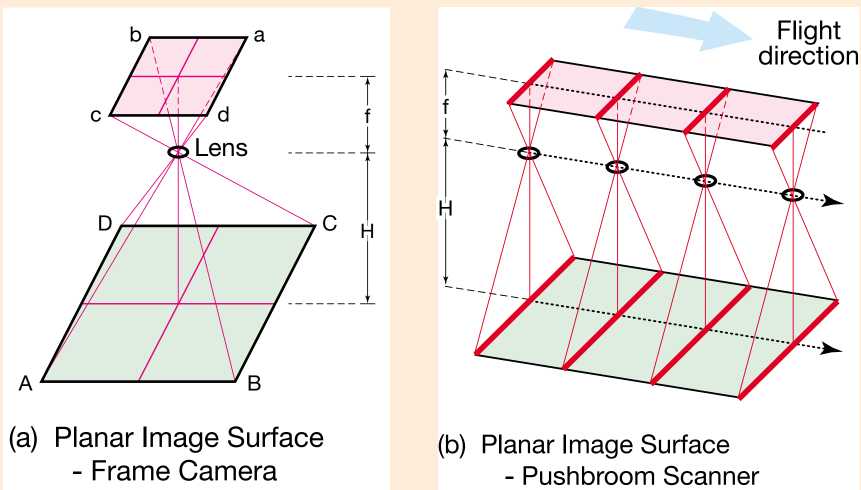


Figure 1: Optical Imagers – left (a): Frame camera providing discrete frame images of the terrain and right (b): Line scanner providing a continuous strip image of the terrain. (Drawn by M. Shand)

Microwave imagers

Nowadays, microwave imagers are almost all of the active (SAR) type: there has been comparatively little development of passive microwave imagers. SAR imaging technology is both complex and expensive, as is the subsequent processing of the imagery it acquires. However, its continuous development is fuelled by military requirements – and military money. In this particular respect, the all-weather, day/night capability of the SAR technology is paramount, whatever the shortcomings or limitations in the quality of its radar imagery of the terrain.

Compared with the intense military interest, civilian interest is relatively small, but is definitely increasing – as may be seen with the operation of airborne SAR imagers by a small number of commercial mapping companies such as Intermap (Canada), EarthData (USA) and Aero-Sensing Radarsysteme (Germany). Recent developments in interferometric SAR for generating DEMs from both airborne and spaceborne platforms have raised the level of civilian interest in SAR imagery.

Spectral aspects

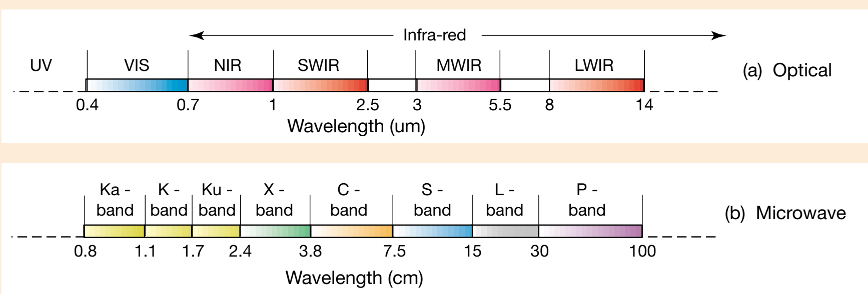
The spectral aspects of imagers are also an important consideration in any overview of the terrain imaging field (see figure 2).

Optical spectral bands

Most optical imagers – whether using photographic film or electro-optical digital sensors – operate in the visible (VIS) and near infrared (NIR) parts of the electromagnetic spectrum. Panchromatic sensors producing black-and-white imagery give the highest resolution as required; for example, for topographic mapping. However, colour or colour infrared (CIR) images may be preferred or indeed required if the emphasis is on image interpretation or thematic mapping for field science or environmental purposes. Beyond the VIS/NIR region, the use of photographic film is not possible: thus all the optical imagers operating in this region are of the electro-optical type. The short-wave infrared (SWIR) is mainly the domain of line scanners.

However, when one reaches the medium-wave infrared (MWIR) and long-wave infrared (LWIR) regions, one enters a totally different domain, full of unusual materials and technologies. Silicon-based detectors are replaced here by detectors using exotic materials such as mercury-cadmium-telluride (HgCdTe) and indium antimonide (InSb). Optical glasses are typically made of germanium or zinc sulphide. While purely framing and linescan imagers do exist in the MWIR and LWIR regions, many of the imagers are frame scanners. These are hybrid devices that utilise high-speed scanning techniques, but produce frame images, usually at video rates. Nowadays there is also much interest on the part of geologists, ecologists and military personnel in increasing the number of discrete spectral bands that can be imaged simultaneously by a single imager over a wide range of wavelengths. Thus, for example, the number is being raised from the usual four to seven channels (with multispectral imagers) to 10 or more (super-spectral) and then up to 200 or more (hyperspectral).

Figure 2: Electromagnetic Spectrum – above (a) Optical wavelengths, below (b) Micro wavelengths. (Drawn by M. Shand)



> Using its STAR-3i X-band interferometric SAR (InSAR) system installed in a Learjet aircraft, Canada's Intermap Technologies has been especially successful in obtaining substantial contracts from NIMA and NASA (via Digital Globe, formerly EarthWatch) to map large areas of cloud-covered terrain in North America (Alaska), Central America (Panama) and the Caribbean (Puerto Rico) where difficulties have been encountered in acquiring coverage using optical imagers. Now a similar project, NEXTMap Britain, is being undertaken by Intermap to cover the whole of the UK with InSAR imagery from which DEMs can be produced. The DEM data will then be used by Getmapping to help produce orthophotos from its air photo coverage of the UK.

Microwave bands

On the microwave side, the highest resolution SAR imagers operate at the shortest wavelengths (for example, in the Ka, Ku and X-bands), while the longer wavelengths (such as those in the L-band) are those least affected by rain. The intermediate C-band has been much used by SAR imagers mounted on satellites (such as ERS and Radarsat). Now SAR imagers operating at still longer wavelengths (for example, in the P-band) are being used experimentally to penetrate foliage and image the ground lying beneath its vegetation cover, although with a reduced ground resolution.

IMAGING FROM AIRBORNE PLATFORMS

Airborne platforms range from blimps, kites and model aircraft operating at altitudes of a few hundred feet, through conventional small single and twin-engined propeller-driven aircraft and helicopters operating at low to medium altitudes, through business jets operating at high altitudes, and finally to ultra-high-flying military reconnaissance aircraft such as the piloted U-2 and the SR-71 or the robotic (unmanned) Global Hawk that can operate at altitudes of up to 70,000 feet (21 kilometres).

Quite different types of imager will be

Figure 3: LH Systems RC30 metric film frame camera. (Source: LH Systems)

required depending on the operating altitude and the carrying capacity of the aircraft, besides satisfying the user requirements for images of a certain scale or ground resolution. Tiny digital or video frame cameras may be used at the one end of the scale, while large-format frame cameras equipped with high-quality long focal length telescopic optics may be employed at the other end. The latter need a fairly large high-flying aircraft as their platform.

Airborne frame cameras

The airborne side is dominated by frame cameras. The pre-eminent airborne imagers used for mapping applications are the photographic frame cameras. However, currently there is an intensive and widespread development of digital frame cameras designed specifically for use on airborne platforms.

Photographic frame cameras

The Z/I Imaging RMK-TOP and LH Systems RC30 metric film cameras (figure 3) and their predecessors, used almost universally for topographic mapping, are equipped with high-quality, low-distortion lenses and feature image motion compensation. They are usually operated with gyro-controlled mounts. Using films with fine grained high-resolution panchromatic (black-and-white) or colour emulsions, they can deliver images with resolutions of up to 60lp/mm (0.017mm) on the negative film. Translated into digital terms, this allows a smallest pixel size of 8.5µm to be generated during the subsequent high-precision scanning of the film after its development. With the standard image format of 23 x 23 centimetres, this gives a square image of 27k x 27k pixels = 729 Megapixels for a single image. With a 10µm pixel size, the image size is 23k x 23k pixels = 529 Megapixels. No digital imager comes anywhere near this level of performance.

Indeed, the combination of large format, wide coverage, high resolution and low lens distortion of these metric film cameras is at present unrivalled. So they continue to sell well and will continue to serve the mapping community for quite some time. The down side of this high-resolution film imagery is of course the inconvenience of first having to chemically process the negative film and then having to scan it in an expensive high-accuracy photogrammetric film scanner before the images can be used in a digital image processing system or a digital photogrammetric workstation. For civilian users, this may not be too much of a hindrance, since it is offset by the substantial advantages mentioned above. However, for military reconnaissance, where user demands are for real-time or near real-time imaging, film is not convenient, though it is still used widely by many air forces.

Small-format digital frame cameras

Which brings us next to airborne digital frame cameras. In recent years, small-format digital cameras have become popular with certain groups of users. Especially popular have been the Kodak DCS 420 and 460 CIR cameras – which have now gone out of production and been replaced by the DCS 560 and 660 models. The DCS 460 cameras are fitted with 2k x 3k = 6 Megapixel CCD areal arrays (with each pixel 9.2µm in size) and incorporate integral filters giving (via an interpolation procedure) an 18 Megapixel image for the three bands needed to produce colour infrared (CIR) images (figure 4a). A larger-format version of this type of camera (called AirRECON III) producing a 36 Megapixel colour image has been built and is being used commercially by Visual Intelligence Systems based in Houston, Texas.

When placed on special anti-vibration mounts and integrated with small inexpensive GPS receivers, the small-format Kodak cameras have been used very successfully from light aircraft for local use where rapid response is the key issue, for example during flooding and forest fires and for disaster relief, or in situations where frequent flights are being undertaken over limited areas, for example for coastal zone monitoring. The users are mainly environmental agencies, universities and research organisations.

However, a large American company, Landcare Aviation, operates no fewer than 15 small Cessna aircraft, each of which is equipped with a Kodak DCS 460 or 560 camera, together with a dual channel GPS receiver and an inertial measurement unit. These systems are mainly operated on behalf of the Emerge company, which is concerned with land use management and with agricultural applications of the imagery. The ground coverage of each DCS frame image is

Figure 4: Airborne digital frame cameras from GeoTechnologies, Bath Spa University College.

top (a): The ADPS (Airborne Digital Photographic System) based on the Kodak DCS 460 CIR camera.

right (b): The MF-DMC (Medium Format Digital Mapping Camera) based on the Hasselblad 555 ELD camera equipped with a 4k x 4k CCD areal array back.

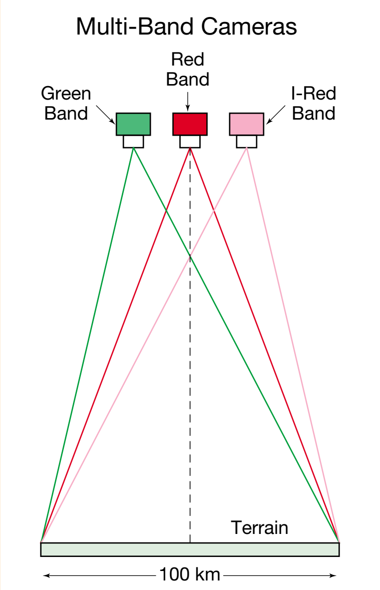
Figure 5: The Z/I Imaging DMC (Digital Modular Camera) – left (a): the actual camera in its gyro-controlled mount, and right (b): the camera in cross-section. (Source: Z/I Imaging)

tiny, so very large numbers of images need to be taken to cover any substantial area of terrain. In response to this, image processing software packages, such as COBRA from Inpho in Germany and DIME from Positive Systems in the USA, have been developed that can handle the huge number of small-format images in a highly automated manner to generate a single large and homogeneous ortho-image mosaic in digital form for the end users.

Medium-format digital frame cameras

The matter of using larger CCD areal arrays in digital frame cameras is one that manufacturers and agencies in various countries are actively pursuing. Most cameras falling into this category use 4k x 4k = 16 Megapixel arrays. Typical examples are the airborne digital cameras constructed by the French national mapping agency and by Ohio State University (with its AIMS system), Emerge (with its Digital Sensor System) and EarthData (with its Kodak MegaPlus 16 camera) in the USA. Other similar digital cameras have been built by Rollei and by Linhof in Germany and by the Swiss iMetric company – though these seem to be oriented more towards close-range industrial photogrammetric applications than airborne use.

Figure 6: The multiple camera solution for the generation of colour and false-colour digital frame images. (Drawn by M. Shand)



In the UK, a similar development, designed specifically for airborne use, has been undertaken by the GeoTechnologies consultancy based on Bath Spa University College, which has previously produced a number of its ADPS systems based on the Kodak DCS 420/460 series (figure 4a). Its new MF-DMC (Medium Format Digital Mapping Camera) systems (figure 4b) are based on the Hasselblad 555ELD single lens reflex camera, equipped with a 4k x 4k CCD areal array supplied either by Dicomed or Kodak. These cameras are fitted with colour filter arrays to allow the production of digital images in colour using interpolation techniques.

Larger-format digital frame cameras

The strongest move to overcome the limited size of the CCD areal arrays available today can be seen in the Digital Modular Camera (DMC) under development by Z/I Imaging (figure 5). To generate pan (black-and-white) images, the DMC integrates four individual cameras tilted outwards in a star-type configuration. The resulting four individual tilted images overlap slightly and are exposed simultaneously. They are then processed to form a single perspective image. Each of the four component cameras is fitted with a 7k x 4k CCD areal array manufactured by Philips. In combination, this configuration produces a 13.5k x 8k = 108 Megapixel image giving an angular coverage of 74 degrees by 44 degrees over the ground.

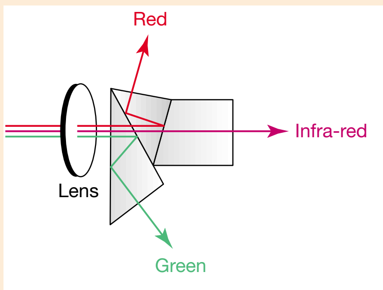
The first production versions of the DMC are scheduled to be delivered later this year. The results are eagerly awaited. However, BAE Systems in North America (having acquired Lockheed's Fairchild subsidiary) has now produced a new larger format electro-optical camera, developed for the US Navy for both reconnaissance and mapping applications. This uses a single 9.2k x 9.2k = 85 Megapixel CCD areal array with an astonishing two-frames-per-second readout. This single lens camera obviates the need for multiple cameras and lenses and the consequent need for the processing of multiple tilted images into a single virtual image as with the DMC.

Colour imagery from digital frame cameras

For the acquisition and generation of colour (RGB: red, green, blue) and false-colour (RGB + NIR) frame imagery, Z/I Imaging's solution again uses multiple cameras. However, in this case, these are arranged with parallel optical axes to cover the same piece of ground (figure 6). Each individual camera has a filter defining a different spectral band placed in front of it. The size of the individual CCD areal arrays used in these cameras is smaller – 2k x 3k = 6 Megapixels – than those used in the DMC pan camera. So the cameras have been fitted with short focal length (f = 25mm) wide-angle lenses to provide a reasonable ground coverage. The penalty for this is, of course, a very considerable reduction in the ground resolution (cf. f = 25mm v. f = 120mm) compared with the DMC pan camera when operating from the same flying height. The final colour or false-colour image is formed later through the co-registration and fusion of the individual images recorded by each of the component cameras.

Similar multiple camera systems have been developed in the USA in parallel with this Z/I Imaging development. These include the Spectra-View camera from Airborne Data

Figure 7: Diagram of the DuncanTech MS3100 multispectral camera showing the beam-splitting and colour-separating prism located behind the camera lens. (Drawn by M. Shand)



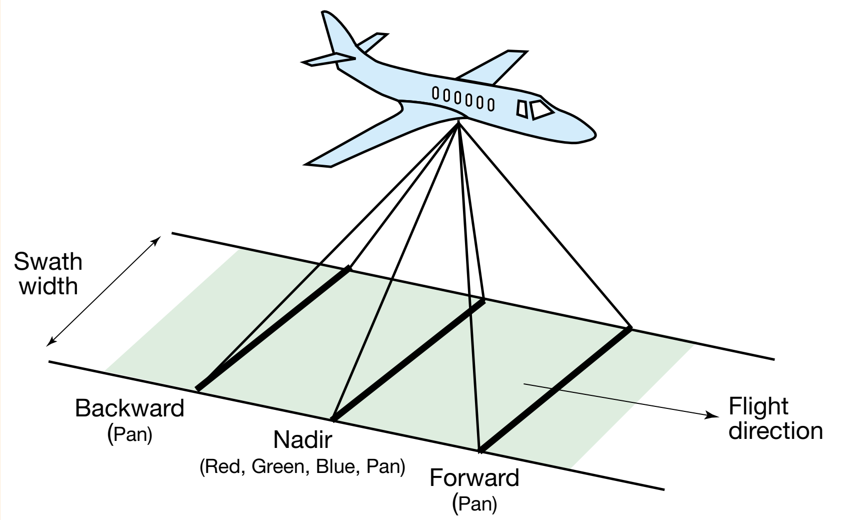


Figure 8: (a) The airborne pushbroom scanner based on the three-line imaging principle. (Drawn by M. Shand)

Figure 8: (b) The HRSC-AX (Source: DLR)

Figure 8: (c) The ADS40 (Source: LH Systems) airborne pushbroom scanner system.

Systems in Minnesota, which offers between four and eight close-coupled cameras with parallel optical axes, all contained in a single case or box. Each camera can be equipped with CCD areal arrays of different sizes – from 1k x 1k to 4k x 7k. TerraSystems from Hawaii also offers its TerraSim four-band camera system, with each of the four component cameras featuring a 2k x 3k areal array – just like the Z/I colour imaging cameras. The same company also offers its Digital Multispectral Video (DMSV) camera system comprising four low-noise video cameras coupled together in a single box. An interesting and quite different solution is offered by Duncan Technologies from California. Its MS3100 camera involves the simultaneous use of three CCD areal arrays collecting the three separate band images making up a CIR composite image through a single lens and incorporating a beam-splitting and colour separating prism located behind the lens (see figure 7 on previous page).

In summary, it does seem that the acquisition and production of colour and false-colour (CIR) images in digital form using these different multiple camera arrangements is far from easy, but will form an important part of the future imaging scene. But larger areal arrays having bigger numbers of detectors need to be developed to provide greater coverage in a single image, otherwise the future development of this important digital frame imaging technology will be curtailed.

Airborne line scanners

As we have already noted, airborne pushbroom scanners with a stereo-imaging capability are now being introduced into the mapping world after a long and protracted development. Their arrival is largely the result of 25 years of steadfast support and development of the technology by DLR – the German Space Agency – and various German manufacturers and universities. As we also noted, the advent of gyro-stabilised mounts and integrated DGPS/INS systems has helped greatly to bring this development out of the research area and into the mapping mainstream.

Starting in 1997, DLR has brought into operation successive models – HRSC-A (with 6,000 pixels per line), HRSC-AX and HRSC-AXW (both with 12,000 pixels per line) – of its three-line airborne pushbroom scanner featuring forward-, nadir- and backward-pointing linear arrays (figure 8). These generate three overlapping pan (black-and-

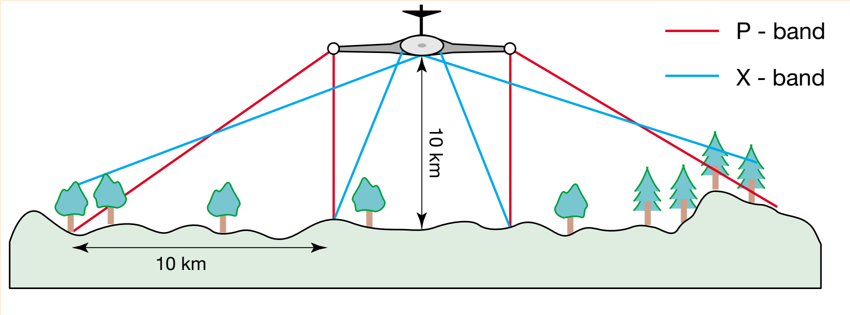


Figure 9: The GeoSAR dual-frequency (X- and P-band) airborne SAR system. (Source: EarthData)

white) linescan images. In cooperation mainly with the French ISTAR mapping company, it has carried out numerous flights and secured extensive coverage of many cities in Europe and North America.

These have served to validate both the technology and the subsequent rather complex processing of the resulting linescan imagery – so much so that LH Systems has now adopted the same approach. With assistance from DLR, the company has developed its own ADS40 pushbroom scanner, which is also based on the three-line imaging principle. This features three 12,000 pixel CCD linear arrays, each of which is duplicated by a second array shifted horizontally with respect to the other by half-a-pixel to provide an improved radiometric and geometric resolution to each imaged line. The rays from the ground are passed through a single semi-wide-angle lens on to the three double linear arrays. Besides these three (forward-, nadir- and backward-pointing) linear arrays that generate pan stereo-imagery, the ADS40 (like the HRSC-AX) has four additional 12,000 pixel linear arrays covering the RGB and NIR spectral bands respectively. These allow the generation of monoscopic colour and false-colour linescan imagery.

The first deliveries of the ADS40 were made to the PASCO air survey company in Japan late last year. It will be interesting to see how quickly this new imaging technology will spread among the mapping community in the coming years.

Hyperspectral imagers

The credit for much of the pioneering work on the generation of hyperspectral imagery based on imaging spectroscopy must go to NASA, which sponsored the construction of various prototypes based on this technology. Prominent among these was the Advanced Visual Infra Red Imaging Spectrometer (AVIRIS) built by the Jet Propulsion Laboratory in the early 1990s and flown extensively in one of NASA's high-flying ER-2 (Lockheed U-2) aircraft.

Since then, a small number of airborne hyperspectral pushbroom line scanners have also been constructed and operated commercially for some years, including those built by ITRES Research (in Canada), Specim (in Finland) and Integrated Spectronics (in Australia). The ITRES Research CASI can produce images with up to 288 separate spectral channels; the Specim AISA can provide up to 186 channels; and the Integrated Spectronics devices operated as the Probe-1 in the USA and HyMap in Australia have 96 or 128 individual channels. These hyperspectral imagers have mainly been used for geological purposes, especially mineral exploration, and for environmental monitoring and agricultural and forestry applications.

In the UK, NERC (Natural Environment Research Council) and the Environment Agency have operated CASI imagers for some years. More recently, NERC and the British National Space Centre have sponsored the SAR & Hyperspectral Airborne Campaign (SHAC) using a HyMap imager in conjunction with DLR's E-SAR over a number of UK test sites.

Airborne microwave imagers

As we have seen, SAR technology has begun to mature and come out of the hands of the research agencies and military organisations who have been its principal users until now. In the civilian domain, new SAR imagers have mostly been mounted on high-performance business jet or turbo-prop aircraft. Using its STAR-3i X-band interferometric SAR (InSAR) system installed in a Learjet aircraft, Canada's Intermap Technologies has been especially successful in obtaining substantial contracts from NIMA and NASA (via Digital Globe, formerly EarthWatch) to map large areas of cloud-covered terrain in North America (Alaska), Central America (Panama) and the Caribbean (Puerto Rico) where difficulties have been encountered in acquiring coverage using optical imagers.

Now a similar project, NEXTMap Britain, is being undertaken by Intermap to cover the whole of the UK with InSAR imagery from which DEMs can be produced. The DEM data will then be used by Getmapping to help produce orthophotos from its air photo coverage of the UK.

A similar SAR capability has been offered in Europe by Aero-Sensing Radarsysteme, a spin-off from DLR's extensive research activity in SAR imaging. Aero-Sensing's aircraft can be fitted with X-, C-, L- or P-band SARs. However, the company has now been acquired by Intermap. In addition, DLR's own E-SAR multi-frequency system, which operates in the same bands and which is mounted on a Dornier DO 228 aircraft, is also being operated over the UK under contract to NERC.

In the US, EarthData has fitted dual X- and P-band SARs to a Gulfstream jet aircraft and is undertaking a large project (GeoSAR) in California in collaboration with NASA-JPL and the state's Department of Conservation (figure 9).

The Swedish Defence Research Establishment (FOA) has also developed similar dual-band SARs, called Carabas, to take advantage of the vegetation penetration of a P-band SAR in combination with the high resolution of an X-band SAR.

Finally, one must note again the strong military interest in airborne SAR imagers as evidenced by the serial production of the TESAR and Lynx SARs for the Predator and Gnat UAVs, the ASARS-2 for the Lockheed U-2 reconnaissance aircraft and the HISAR for the Global Hawk UAV.

NEXT MONTH:

Imagery from spaceborne platforms

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