

SI-35  
111659

CIRES  
N88-13756

THE PORTABLE INSTANT DISPLAY AND ANALYSIS SPECTROMETER (PIDAS)

P.10

ALEXANDER F. H. GOETZ  
Center for the Study of Earth from Space (CSES)  
Cooperative Institute for Research in Environmental Sciences  
(CIRES)  
University of Colorado, Boulder, Colorado 80309

ABSTRACT

A field spectrometer covering the range 0.4-2.5  $\mu\text{m}$  has been developed that acquires spectra in 2 seconds at 872 points within the spectrum. The Portable Instant Display and Analysis Spectrometer (PIDAS) can acquire spectra every 8 seconds and stores up to 288 spectra in bubble memory. A hand-held display unit allows for display of the current spectrum acquired and superimposed, one of 128 permanently stored library spectra. PIDAS represents a major advance in the technology of field spectral data acquisition and for the first time makes possible the acquisition of enough spectra to characterize the mean and intraclass variance within a Landsat MSS or TM pixel.

INTRODUCTION

The need and the idea for the Portable Instant Display and Analysis Spectrometer (PIDAS) developed beginning at the time of completion of the first Portable Field Reflectance Spectrometer (PFRS) (Goetz et al., 1975). One of the major goals in *in situ* spectrometric measurements that has eluded us until now is the ability to define the average spectral reflectance characteristics within one Landsat MSS or TM pixel and to define the intraclass variance within a pixel. Another major goal is to be able to make *in situ* spectral measurements with a resolution comparable to or higher than the new class of imaging spectrometers such as the Airborne Imaging Spectrometer (AIS) and the Airborne Visible and Infrared Imaging Spectrometer (AVIRIS). Most laboratory instruments do not have adequate spectral resolution beyond 2.0  $\mu\text{m}$  (Inouye et al., 1987). A field spectrometer with sufficient resolution is available commercially (GER Corporation) but the 3- to 4-minute scan time required for a single spectrum is not ideal. PIDAS achieves these long awaited goals with the addition of near-real-time display of spectral reflectance.

Support for the construction of PIDAS was obtained from the W. M. Keck Foundation with grants in 1983 and 1984. The instrument was field tested in July 1986.

## REQUIREMENTS

The main requirement arising from previous experience with field instruments was for a lightweight, rugged spectrometer covering the 0.4-2.5  $\mu\text{m}$  region at high resolution, able to acquire and store complete spectra in several seconds, and display the results for immediate viewing. In addition, there was a need to display a set of stored spectra for comparison with the field-acquired spectra. The display and the ability to call up stored spectra comprise the "analysis" aspect of the instrument. The display capability is a major advance in field measurements because many of the spectral characteristics of surface materials are found in the spectral region beyond the sensitivity of the human eye. Proper sample location and identification is made possible by a near real-time display.

## DESIGN

In order to meet the requirements discussed above, it was necessary to develop a spectrometer with features not available in existing instruments. In particular, the implementation required the use of very fast, lightweight rugged spectrometers and an optical head connected to the spectrometers with optical fibers. Table 1 lists the new features required for the design.

Table 1. Design features

---

Hand-held liquid crystal display  
Silica and "exotic" fluoride fibers  
Fast (f/1.2) solid silica spectrometers  
Stored library of spectra  
Spectral resolution greater than most laboratory  
instruments  
2-second data acquisition time

---

Figure 1 shows the PIDAS in operation; Figure 2 shows the major features of the instrument. The requirement for high spectral resolution could only be met by using grating spectrometers. A great saving in weight and volume could have been achieved by using circular variable filters, as used in the PFRS, but these filters have a limitation in spectral performance, particularly in the visible portion of the spectrum. The  $\Delta\lambda/\lambda$  values in the visible are approximately 0.04 and 0.015 in the short wavelength infrared (SWIR). At 2.2  $\mu\text{m}$  this translates into a resolution of



Fig. 1. PIDAS during field trials in Cuprite, Nevada.

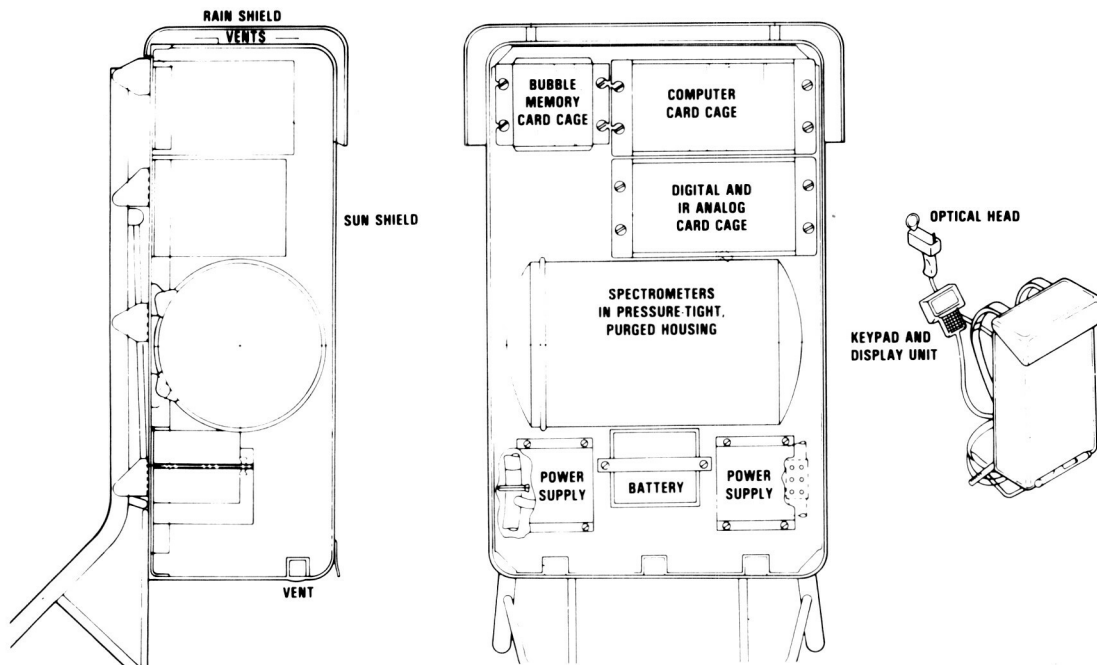


Fig. 2. PIDAS configuration.

approximately 33 nm or a resolution 60% poorer than that available from AVIRIS. The spectral resolution of PIDAS in the SWIR is defined by the 4.8 nm sampling interval and is approximately 10 nm. The sampling interval in the visible portion of the spectrum is 0.88 nm.

A major design goal was to make the optical head as lightweight as possible which meant that the spectrometers had to be separated from the fore-optics. Therefore, the optical head consists solely of the fore-optics, a shutter and a chopper, and the incoming energy is transmitted to the spectrometers by means of optical fibers. Figure 3 shows a block diagram of the spectrometer system. The optical components consisting of three spectrometers with detectors, the amplifiers, and grating drives are contained in a pressure vessel shown in Figure 4. The spectrometer covering the VNIR portion of the spectrum consists of a camera lens, a fixed grating and a 512-element silicon detector array. This spectrometer covers the region 0.425-0.922  $\mu\text{m}$ . The VNIR spectrometer assembly is shown in Figure 5.

The spectrometers for the SWIR portion of the spectrum ranging from 0.86 to 2.5  $\mu\text{m}$  posed a more difficult problem. Lead sulfide detectors provided the best compromise between sensitivity and ease of cooling. A disadvantage of lead sulfide detectors is that it is not possible to obtain multiplexed arrays of detectors. This means that each detector requires its own preamplifier and analog circuitry. Unlike the visible spectrometer which contained no moving parts, it was necessary to step the grating in each of the SWIR spectrometers through four positions in 2 seconds. Using 45-element detector arrays in each spectrometer, 360 channels spaced approximately 4.7 nm apart were obtained in the 0.86-2.5  $\mu\text{m}$  region. A very compact spectrometer design was developed employing a solid block of water-free silica incorporating all the optical surfaces in one unit. By this means, the only alignment required was to focus and align the detectors and the optical fibers. This solid-Schmidt design made possible a fast, f/1.2 spectrometer in order to acquire the maximum signal-to-noise ratio. The fast spectrometer design in turn placed a requirement for a high numerical aperture (0.5) for the optical fibers. A further complication arose from the fact that silica optical fibers are not completely water-free and, therefore, exhibited absorption features at 1.4, 1.9 and 2.2  $\mu\text{m}$ . Fluoride optical fibers are used to couple the fore-optics to the SWIR spectrometers. The solid-Schmidt spectrometer optics are shown in Figure 6, and the grating drive assembly in Figure 7. Figure 8 shows the spectrometer enclosure viewed from the side of the SWIR detectors and the 90-channel analog PC boards.

The electronics and data handling are designed around a CMOS 8-bit processor with storage in bubble memory. The

ORIGINAL PAGE IS  
OF POOR QUALITY

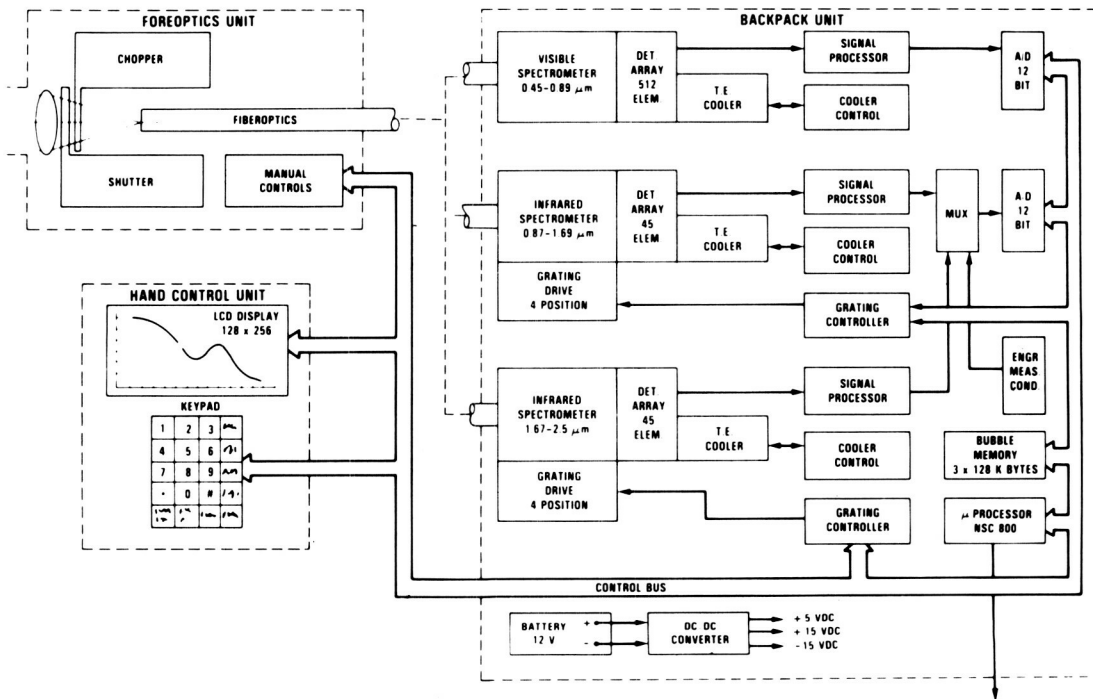


Fig. 3. PIDAS block diagram.

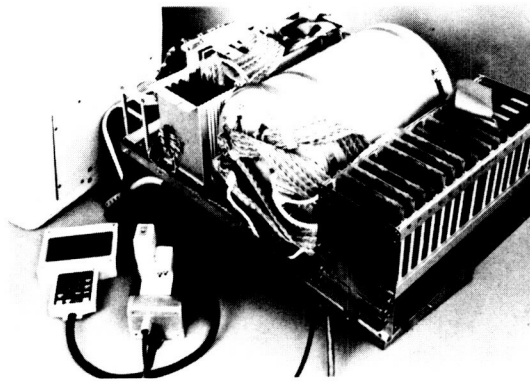


Fig. 4. PIDAS with cover re-  
moved showing the pres-  
surized container hous-  
ing the spectrometers,  
the hand-held display  
unit and the fore-optics  
head.



Fig. 5. VNIR spectrometer  
assembly.

ORIGINAL PAGE IS  
OF POOR QUALITY.

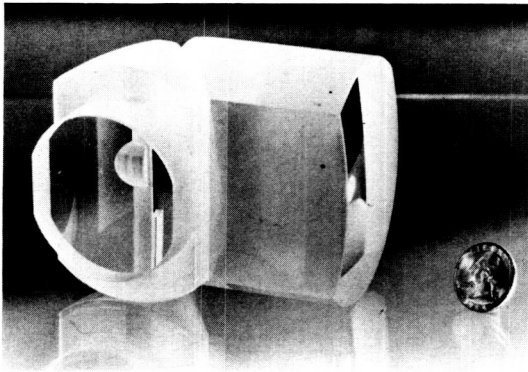


Fig. 6. Solid Schmidt SWIR spectrometer optics.

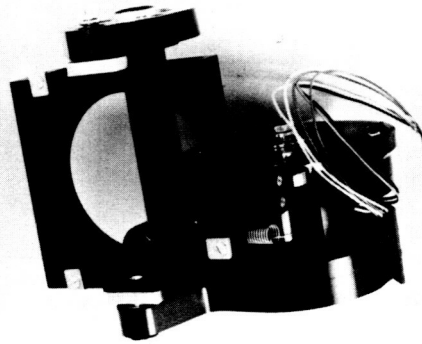


Fig. 7. SWIR grating drive assembly.

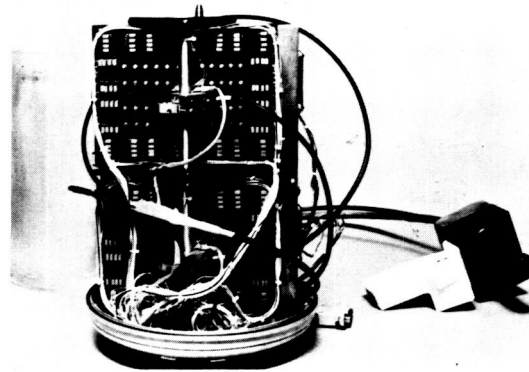


Fig. 8. Pressure vessel with the housing removed showing the detector preamplifier boards.

processor handles all the input/output functions and provides the data acquisition sequence, display and memory access. The hand-held terminal consists of a key pad and a 128- x 256-element liquid crystal display. Software stored on a prom allows the display of engineering data and individual spectra at various magnifications. Data from a 128-spectra bubble memory library can be superimposed upon the current data acquired or stored in the 288 spectra data bubble memory. The software features include the ability to expand the scale by use of gain and offset functions so that the full 8-bit resolution can be displayed.

PIDAS is a single channel instrument, and, therefore, spectra of standards and samples are collected separately. In normal operation, a spectrum of a standard is collected and encoded to 12 bits. The most significant 8 bits are stored as a reference spectrum for all subsequent sample spectra until a new standard spectrum is acquired. When the sample spectrum is acquired, the instrument automatically creates a

ratio of sample to standard before storing the spectrum in bubble memory. The advantage of this method is that no gain changes are required and storage is optimized. The disadvantage is that, particularly for dark samples, digitization error becomes a major factor and limits the ability to increase the signal-to-noise ratio by averaging sample spectra. A summary of the major instrument characteristics is given in Table 2.

Table 2. PIDAS characteristics

---

Portable, backpack, self-contained, approx. 67 pounds  
Spectral range - 0.45 to 2.5  $\mu\text{m}$   
Sampling interval  
    Visible - 0.88 nm (512 channels) 0.425-0.922  $\mu\text{m}$   
    Infrared - 4.7 nm (360 channels) 0.856-2.490  $\mu\text{m}$   
Fore-optics - f/1.2, 6 degree circular FOV  
Spectrometers  
    VIS - Nikon optics, f/2.8, 512 Si.  
    IR-2 - solid Schmidt, f/1.2, 45 PbS.  
Processor-low power Z80 type, 16K RAM, 8K ROM  
Data Memory - bubble, 288 spectra, 128 spectra  
    sample library  
Hand-held terminal-display 128 x 256 element LCD  
    keypad-custom numeric and command entry  
Data acquisition time: 2 sec., repeat interval: 8 sec.

---

Data stored in the bubble memories are downloaded onto a floppy disc across an RS 232 interface to a PC. Battery power consists of ten NiCd D cells. One charge will run the instrument for approximately two and a half hours, sufficient time to collect a full memory load of 288 spectra. The bubble memories as well as the batteries are exchangeable in the field.

The initial target instrument weight was 42 pounds. The present weight is 67 pounds; however, it is anticipated that in subsequent versions of the instrument the weight will be reduced significantly.

#### TEST RESULTS

In the last year, PIDAS has acquired thousands of spectra for applications in mineralogy, botanical stress, AVIRIS calibration, BRDF measurements of snow and ice and non-destructive testing of artifacts in the National Museum of Guatemala. Transportation and field use have not brought about any major instrument failures, and it can be assumed that it will continue to be reliable in the field.

The signal-to-noise characteristics of the instrument are shown in Figure 9. These data were acquired at Rogers

Dry Lake during an AVIRIS calibration test. The low signal-to-noise ratio at 1.4 and 1.9  $\mu\text{m}$  is associated with the atmospheric water absorption features. The effects of other minor water and  $\text{CO}_2$  bands are also visible. The rapid variation in the signal-to-noise values is caused by the variation in detector characteristics within the 45-element arrays.

PIDAS measurements in the field have been compared with laboratory spectra reflectance curves of the same samples. Figure 10 shows such a comparison for alunite. The combination-overtone absorption feature in alunite at 2.22  $\mu\text{m}$  has a true absorption band in the PIDAS data (upper curve) but shows only as a shoulder in the laboratory data. The Beckman 5240 spectral resolution in this region is approximately 25 nm (Inouye et al, 1987). The PIDAS resolution of approximately 10 nm is sufficient to reproduce essentially all the spectral features of solids in the 0.4-2.5  $\mu\text{m}$  region and has about twice the resolution of the current and proposed imaging spectrometer systems.

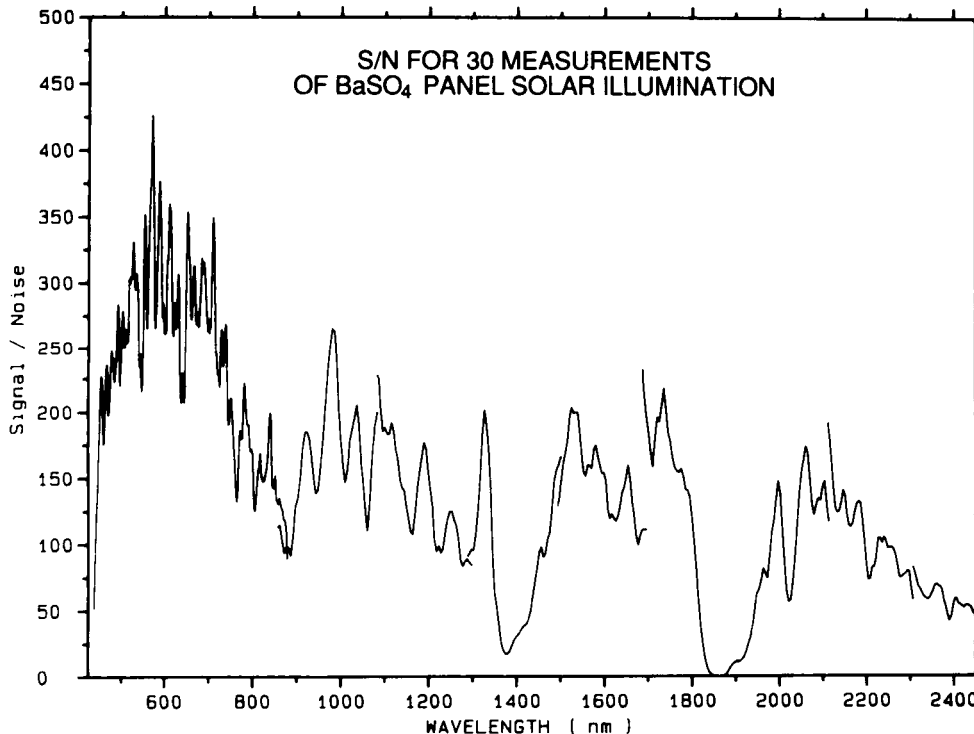


Fig. 9. Signal-to-noise as a function of wavelength obtained from 30 sequential measurements of Rogers Dry Lake. S/N is defined as the mean/std. deviation for each wavelength.



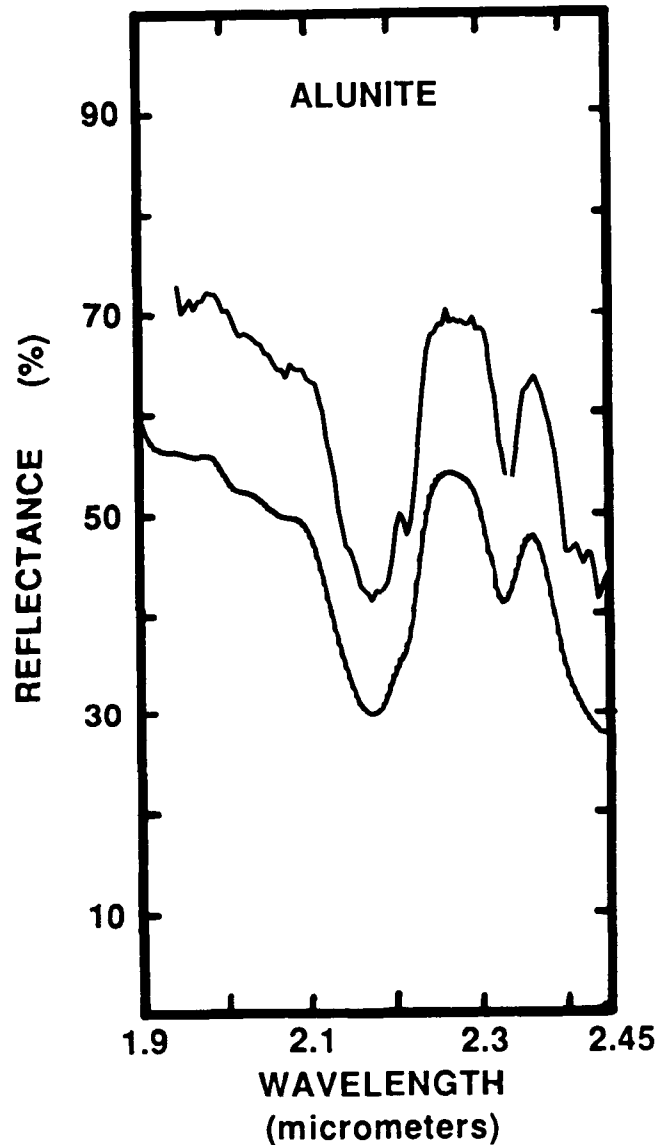


Fig. 10. Reflectance spectra of alunite taken by PIDAS (upper) and the Beckman 5240 (lower). The superior resolution of PIDAS is shown for the absorptive feature at 2.22  $\mu\text{m}$ .

#### ACKNOWLEDGEMENTS

The development of PIDAS could not have taken place without the support of many individuals at JPL, among those Harry Enmark, Project Manager, Bob Irigoyen, Project Engineer, and Norm Page, Optics Designer. Arden Albee was the Caltech Principal Investigator, Brian Curtiss of Caltech provided invaluable support in the latter phases of instrument development and developed all the data analysis software. PIDAS is covered by U. S. Patent #4,560,275 issued to the California Institute of Technology. This research was

supported in large part by a grant from the W. M. Keck Foundation.

#### REFERENCES

- Goetz, A. F. H. 1975. Portable Field Reflectance Spectrometer, Appendix E in Application of ERTS Images and Image Processing to Regional Geologic Problems and Geologic Mapping in Northern Arizona, JPL Technical Report 32-1597.
- Inouye, C., A. F. H. Goetz and S. Schultz. 1987. Reflectance Spectra of 156 minerals, 0.4-2.5  $\mu\text{m}$ . JPL Technical Report, in press.