METHODOLOGY OF FEATURE CLASSIFICATION BY THE SMART SENSOR ON BOARD THE ROHINI RS-D2 SATELLITE

S. RAMANI, G. NAGENDRA RAO, K. LAKSHMI and V. ARUNA RAO
Image Analysis Group, Sensors Section, ISRO Satellite Centre, Bangalore 560 058, India.

ABSTRACT

On-board feature classification has been attempted for the first time in the Rohini (RS-D2) satellite using the two band optical Smart Sensor. The on-board feature identification circuit takes the outputs from the two cameras together with a given threshold and two slopes and generates a two bit code representing one of the four broad terrain classes: water, bareland, vegetation and cloud/snow.

The feature classification obtained during the course of the mission are described with examples. The accuracy of feature classification using the ratio and threshold method is found to be above 99 % for water, 93 % for vegetation, 90 % for cloud and 83 % for snow.

Suggestions for improving the accuracy and confidence level of feature classification are made for the two-band case, using a modified algorithm for biomass area estimation by remote sensing.

1. INTRODUCTION

A LARGE amount of remotely sensed data from Earth Observation Satellites are generally collected in any Space mission. These data have to be analysed rapidly to generate accurate and timely information about the Earth's resources.

In order to reduce the volume of data at the ground, techniques to compress the data or carry out classification of the different Earth features on-board the satellite have been developed[1, 2] in recent times.

The Rohini Series Development 2 (RS-D2) Satellite launched recently from Sriharikota in Andhra Pradesh had a 'Smart Sensor'—a two band solid-state camera with bands in the visible and near-infrared parts of the spectrum. The sensor had a capability to carry out on-board classification of Earth features into water, bare land areas, vegetated areas and cloud/snow-covered areas (the four broad classes of surficial features on the Earth), in an attempt to reduce the time lag in providing feature identification and location information to the users of remote sensing data.

This is the first time that an on-board classification process has been implemented next only to the Feature Identification and Location (FILE) Experiment flown on the U.S. Space Shuttle STS-3 flight in 1982.

The FILE experiment comprised of imaging the Earth in two bands, at 650 and 850 nm, over a ground swath of 113 km width, with picture element (pixel) resolution of 1.13 km along the ground track of the shuttle, and carrying out feature identification and classification therefrom.

The objectives of the Rohini (RS-D2) Smart Sensor experiment were: (i) To provide single band Earth imagery for remote sensing applications. (ii) To identify landmarks from the imagery and use the data for Satellite orbit and attitude parameter refinement. (iii) To carry out feature identification and classification on-board and generate land cover maps.

The Sensor provides imagery nominally of an area 250 km wide and 80 km along the sub-satellite track. The spatial resolution[3] (picture element size) was nominally 1 km × 1 km. However, the satellite was in an elliptical orbit and its swath and spatial resolution varied about the nominal value.

The present paper, describes a study to evaluate (i) the feasibility of on-board classification of major earth features: water, bareland, vegetation and cloud/snow-cover, and (ii) the accuracy of feature classification using the on-board hardware.

2. DATA AND ANALYSIS METHODOLOGY

2.1 *Data source*

The satellite was launched on 17 April 1983 from Sriharikota by the SLV-3 (D2) rocket into an elliptical orbit with a perigee height of 388 km and an apogee height of 852 km, an orbital inclination of 46.1° and a period of 97.1 min. The satellite was spin stabilized at nominally 10 rpm with its spin axis perpendicular to the orbital plane. On April 20th 1983, in orbit 45 the first imagery from the Smart Sensor was obtained.

The Smart Sensor[3] images the Earth in two bands using two linear photodiode arrays, with band pass filters, one in the visible band (634 to 675 nm) and the second in the near infrared band (from 798 to 883 nm). The image along a line perpendicular to the ground trace consists of 249 picture elements exposed within a time of 2 millisec., nominally. The alongtrack scan is carried out 80 times under the spinning satellite, aided by the spinning motion. The imaging is then inhibited until the sensor again looks down ward in the next spin. The outputs are digitized in 5 bits (32 grey levels). Either one of the two band imagery are selectable (by ground command) for transmission to the ground.

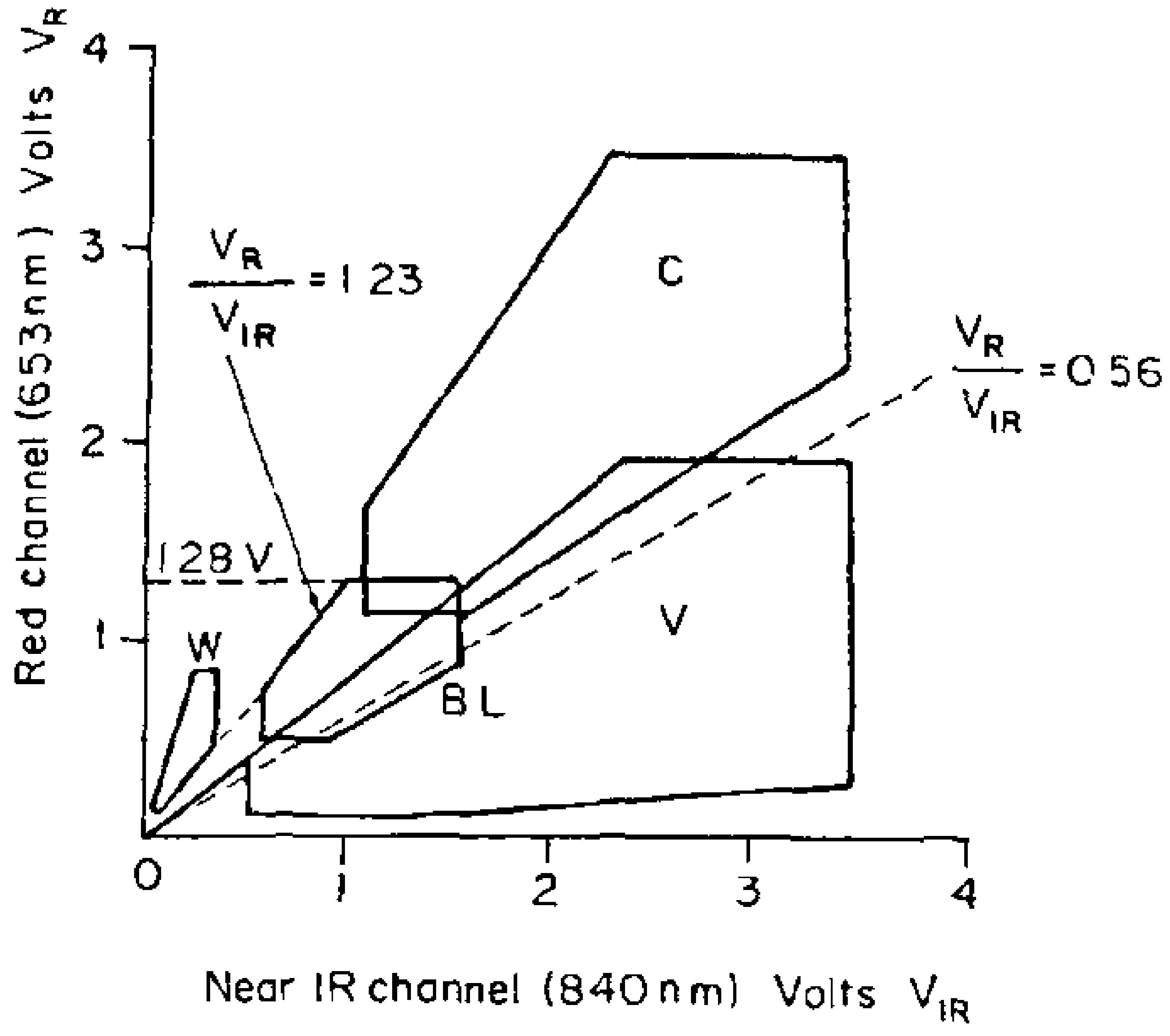

Figure 1. Confidence polygons for the four features, used in the on-board classification algorithm.

2.1.1 *On-board classification.* The visible (red) and near IR Channel outputs are taken for classification of each individual picture element into any one of the four broad features (figure 1) W: water, B.L.: Bare land, V: Vegetation and C: Cloud/Snow. The 99% confidence polygons for these features, for Sun zenith angles of 41 to 60° are plotted. This two dimensional histogram shown in figure 1 is divided using a red voltage threshold V_R (nominally 1.28 V) and two slopes

$$\left(\frac{V_R}{V_{IR}}\right)_{low}, \text{ nominally} = 0.56$$

and

$$\left(\frac{V_R}{V_{IR}}\right)_{high}, \text{ nominally} = 1.23$$

such that the four polygons are separated using the algorithm:

if $V_R < V_{threshold}$ and $\left(\frac{V_R}{V_{IR}}\right) > \left(\frac{V_R}{V_{IR}}\right)_{high}$

feature = water (W)

$V_R < V_{threshold}$ and

$$\left(\frac{V_R}{V_{IR}}\right)_{low} < \left(\frac{V_R}{V_{IR}}\right) < \left(\frac{V_R}{V_{IR}}\right)_{high}$$

feature = bare land (B.L)

$V_R > V_{threshold}$ and $\left(\frac{V_R}{V_{IR}}\right) > \left(\frac{V_R}{V_{IR}}\right)_{low}$

feature = cloud/snow (C)

$\left(\frac{V_R}{V_{IR}}\right) > \left(\frac{V_R}{V_{IR}}\right)_{low}$

feature = vegetation (V)

Based on the above algorithm, a feature identification/classification circuit is hard wired on-board, and the four classes are coded into two bits per pixel (00,01,10,11) and transmitted to ground along with the selected camera 5 bit output.

To take into account widely varying local times of imaging/sun zenith angle and atmospheric conditions, provision is made for varying the threshold voltage from zero to 2.56 volts (in steps of 160 mV).

The slopes $\left(\frac{V_R}{V_{IR}}\right)_{low}$ and $\left(\frac{V_R}{V_{IR}}\right)_{high}$ were also made variable over the ranges 0.56 to 0.91 and 1.16 to 2.00 respectively by inserting different valued resistors into the circuit. This was done to cater to the range of vegetation/soil types observed[4] over the sub-continent.

2.1.2 *Image production and enhancement.* The transmitted data were received during satellite passes at the Sriharikota telemetry ground station and converted into computer compatible tapes with an accepted format, containing header and annotation data, picture data and the feature images.

The data on the computer compatible tapes were retrieved at Bangalore to first generate Quick Look Imagery on photosensitive paper. These were used in the process of landmark identification and orbit/attitude parameter refinement.

Enhancement of the imagery was carried out by colour coding–assigning a specific colour to a range of irradiance values. The contrast between features in the raw data was increased by stretching the radiance value of each pixel.

2.2 *Field measurements*

A field study was conducted to evaluate the performance of the Smart Sensor cameras. Reflectance measurements were taken of three features: Water (including muddy water), soil–representing bare land, and vegetation. Cloud data could not be obtained from these ground level measurements because of the non-optimal sun-cloud-sensor viewing geometry, the presence of diffuse sky radiation, and cloud motion. The spectral reflectances were measured from 10.00 to 15.00 hr for a period of 20 days simultaneously recording the reflectance of a standard $BaSO_4$ reflector, the total solar irradiance and the sun zenith angle. Using the standard solar spectral irradiance curves, all the measurements were normalized to unit air mass (vertical incidence through the atmosphere). Cluster plots were generated for the water, bare land and vegetation feature classes. These are shown in figure 2 with two representative slope values drawn to demarcate the three feature class clusters.

2.3 *Classification Accuracy.*

The basic problem in remote sensing is the improvement of the accuracy of classification of the various types of earth features present. In order to achieve this several methods of classification have been devised[5] in the past.

In principle, all these methods treat the photo-interpreted classification (from the highest-resolution image of the scene) or the actual ground truth as the basic datum which is considered as 100% accurate.

In the case of imagery from the Smart Sensor on the RS-D2 Satellite two images of each scene were provided. One was the basic camera image selectable either from the visible (red) or the near-infrared camera while the other was the 'feature-classified' image. Since the selected main image

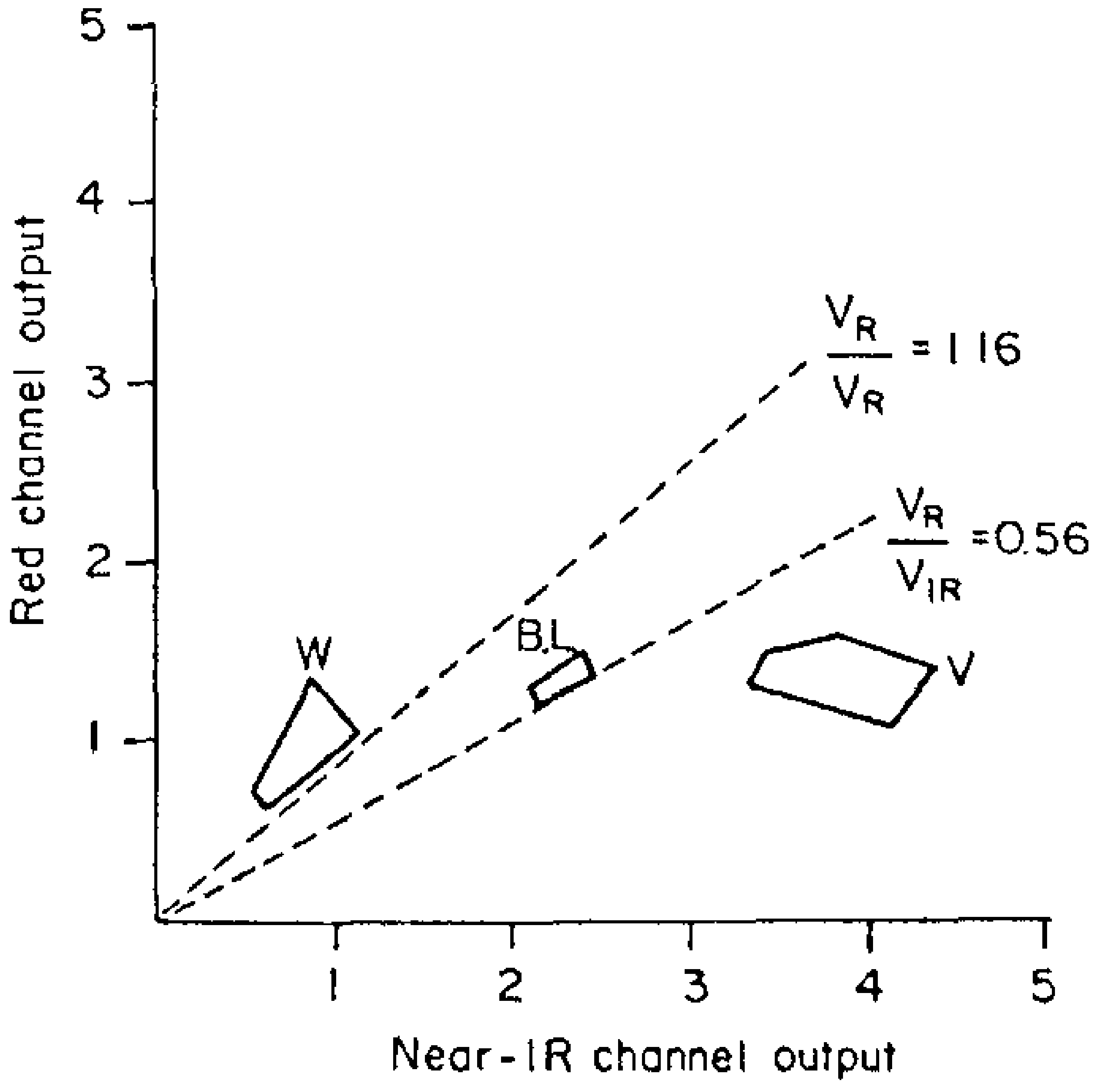

Figure 2. Feature classification data from field spectro-radiometric measurements.

was a clear image, the main image was considered the basic datum against which the accuracy of feature classification by the above algorithm as obtained in practice, was checked.

From the digital data in the form of computer print-outs, sub-scenes, were randomly selected. The number of pixels in each class both in the main image sub-scene(s) and in the feature classified sub-scene(s) were totalled and compared.

These data were used in determining the accuracy of feature classification. The results of the analysis are presented below.

2.4 *Payload Operations*

Various payload settings for the thresholds and the two slopes were tried out on the basis of the polygons calculated, for different local times and Sun elevations. Table 1 lists the payload and imaging conditions in different orbits when the feature imagery were analysed to assess the working of the feature classification algorithm. For the classification studies, only features greater than one pixel in extent were identified and within each pixel if at least 30% of the area had vegetation, it was taken as a vegetated area.

3. RESULTS OF FEATURE CLASSIFICATION ACCURACY ESTIMATION

The accuracy of feature classification for each of the different features was calculated for each of

Table 1 *Imaging Conditions in different orbits of the RS-D2 Smart Sensor*

Orbit	45	375	624	746
Features classified	Bare land*	Water Vegetation	Snow	Cloud
Date and time	April 20, 1983. 10.20 hrs	May 12, 1983 15.12 hrs	May 20, 1983 09.45 hrs	June 6, 1983 5.33 hrs
Sun Elevation (deg)	61	46	57	57
Camera ON	1 (visible)	2 (near-IR)	1 (visible)	1 (visible)
Altitude of imaging (km)	422	746	548	800
Scene details				
Serial No.	*	145	34	58
Scene centre location:				
Latitude	*	14° 18′	30° 23′	11° 50′
Longitude	*	78° 48′	78° 16′	78° 31′

* ground data insufficient due to cloud-cover.

Table 2 *Feature classification accuracy determination for vegetation and water from orbit 375*

Feature	Sample plot no.	Classification		
		as vegetation	% as water	as cloud
Water	1	1	99	0
	2	1	99	0
	3	1	99	0
Average	—	1	99	0
Vegetation	1	89	8	3
	2	93	3	4
	3	98	2	0
Average	—	93	4	3

the four features, using the available data prepared as described in section 2 above.

The results are presented and discussed below:

(i) *Water*:

The automatic classification of water carried out in orbit 45 (visible camera imagery) and 375 (near-IR camera imagery) was analysed.

In orbit 375 the near-IR Camera was 'ON' while the slopes were set at 0.56 and 2.0.

Water has a low reflectance in the near-IR, and is easily separated from the other classes.

The accuracy of feature classification, using the method described above, was found to be 99 % or higher (table 2).

(ii) *Bare land*:

This feature is not classified. This is attributable to the lack of ground data on bare land. In the case of orbit 45, clouds covered most of the areas of bare land in the interior areas. In orbit 375 the clear scenes were in the coastal areas where bare land pixels were again difficult to pinpoint. The increase of cloud cover and the reduction in the area of bare land areas with time subsequently, precluded the estimation of bare land classification accuracy.

(iii) *Vegetation*:

The vegetation feature classification was studied from imagery in orbit 375 for three subscenes on the West Coast (Kerala). The average accuracy of classification was found (table 2) to be 93 %.

(iv) *Snow/cloud*:

Figure 3 shows a typical photo-graph of the snow feature classification carried out by the on-

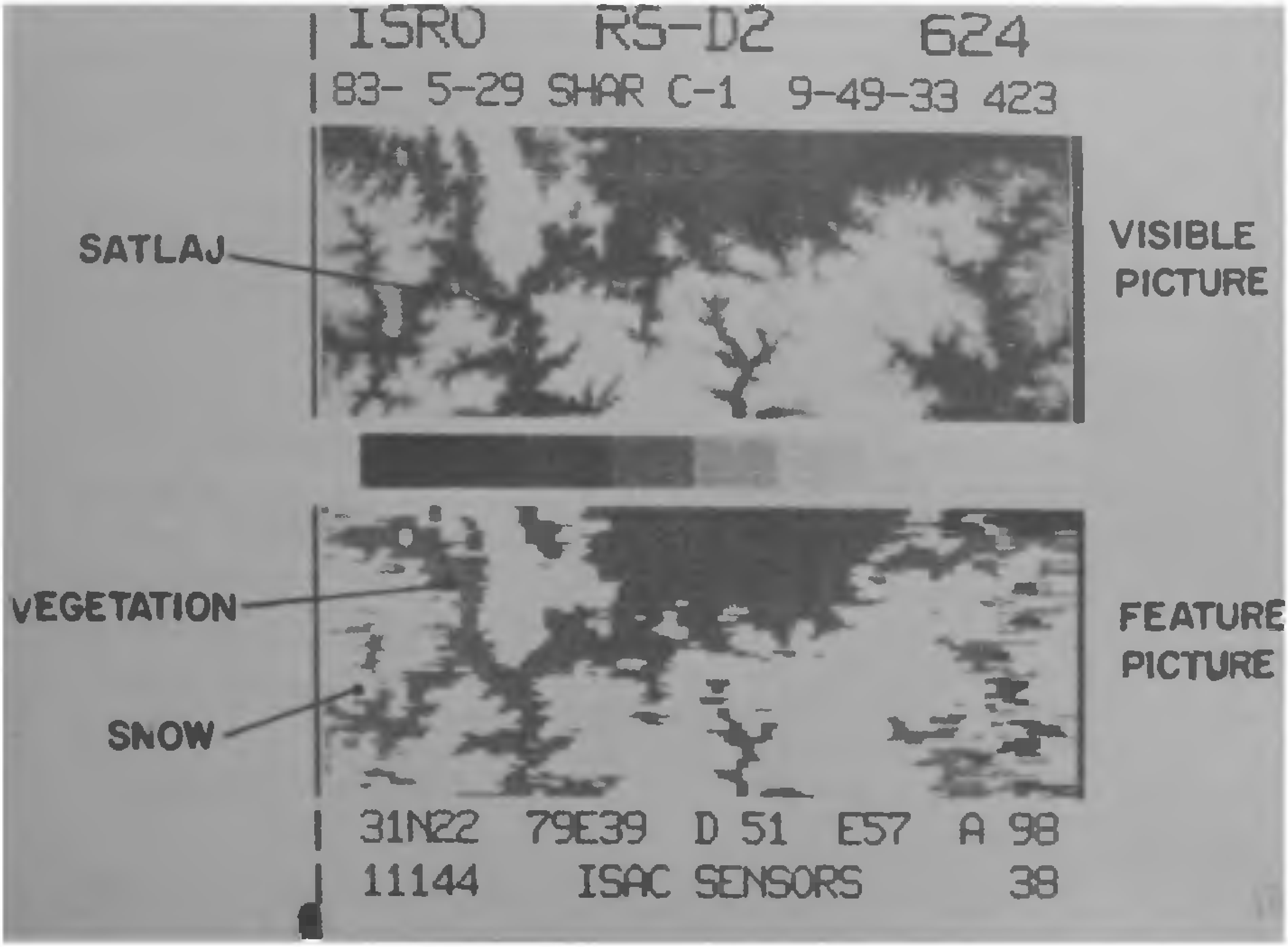

Figure 3. A typical image of snow feature classification.

Table 3 *Feature classification accuracy determination for snow from orbit 624*

Feature	Sample plot no.	Classification as snow	as Bare land	% Vegetation	as water
Snow	1	81	5	14	2
	2	84	12	0	4
	3	84	16	0	0
Average	—	83	10	5	2

board hardware in orbit 624. The conditions of imaging are as in table 1 and the results are in table 3.

The accuracy of feature classification in the case of snow was estimated from three subscenes to have an average value of 83%, which is reasonably high. Cloud classification accuracy was determined from image analysis of orbit 746 data imaged with the conditions listed in table 1. The average accuracy of cloud classification determined using the method described above was found to be 90%. This too is a substantially high value.

4. DISCUSSION

Based on the above results on the accuracy of feature classification using the basic algorithm described it can be stated that the classification is sufficiently accurate. However, the following points emerge from the analysis of image data from other orbits.

1. Water bodies and coastal sea water are sometimes incorrectly classified as bare land. This can be corrected by selecting a near-IR threshold which will separate water types from land/vegetation with far greater accuracy.
2. The effect of variable soil reflectance on vegetation (biomass) estimation can be taken into account by considering a 2-dimensional plot of $(V_R - V_{IR})$ *vs* $(V_R + V_{IR})$, which would provide a more accurate map of biomass, directly from the payload. Since cloud is eliminated by the visible thresholding and water by the near-IR thresholding, inverting the negative values of $V_R - V_{IR}$ and counting the resulting pixels will provide a biomass map.

5. SUMMARY AND CONCLUSIONS

This paper has presented the details of the method of classification on-board the Rohini-RS-D2 Space-craft which had a 2 band 'Smart Sensor' on board. The results of the feature classification experiments for the four broad features water, bareland, vegetated areas and cloud/snow covered areas have been presented and discussed.

The following conclusions are drawn from the present study:

1. The accuracy of classification of water, vegetation and cloud/snow is high and highly significant. The present algorithm is capable of resolving these features with 1–2 km resolution for use by interested mapping agencies.
2. Bare land areas could not accurately be classified due to inadequacy of ground data and cloud cover over the selected bare area.

6. ACKNOWLEDGEMENTS

The authors wish to thank the Director, ISRO Satellite Centre and Dr K. Kasturirangan, Project Director, IRS for their encouragement in this work. Thanks are also due to Shri. T. K. Alex, Head Sensors Section and Shri. Y. K. Jain, Dy. Head Sensors Section. and Shri. K. K. Kurian for their support.

26 December 1983; Revised 21 January 1984

---

1. Schappell, R. T. and Tietz, J. C., In *Remote Sensing of Earth from Space: Role of Smart Sensors*, (ed.) R. A. Breckenridge, AIAA, New York, 1979.

2. Thomas, H. *IEEE International Geo-science and Remote Sensing Symposium Digest*, Vol. 1 TP—8, IEEE, New York 1982.
3. Alex, T. K. *et al.* In *Proc. SPIE Symposium, San Diego*, U.S.A. August 1982. Paper No. 363.
4. National Atlas of India: Soil types, Vegetation, National Atlas and Thematic Mapping Organisation (NATMO), Calcutta, 1977.
5. American Society of Photogrammetry, "*Manual of Remote Sensing*". ASP, New York, 1983.

NEWS

SCIENCE NOBELS: DO THEY ALWAYS GO TO THE BEST?

. . . "Probably the chief complaint against the science prizes is that Alfred Nobel's will and supporting statutes and traditions exclude some of the world's best scientists. The prizes are limited to the three fields that interested Nobel; namely, Chemistry, Physics and Physiology or Medicine. Although the Swedes in recent years have tried to interpret these fields broadly, vast areas of important work remain explicitly excluded or ignored. John von Neumann, probably the greatest mathematician of the century and creator of the theory of the computers that are revolutionizing the modern world, never received a Nobel Prize because mathematics is explicitly excluded. However, the inventor of a trivial device to regulate lighthouses was duly honoured in 1912. Sigmund Freud, the father of modern psychiatry, never received a Nobel Prize because psychiatry and psychology have not thus far been included under the rubric of physiology or medicine. And some of the hottest fields of modern science have thus far been ignored. The key figures in discovering continental drift and the theory of plate tectonics that has revolutionized modern geology have been shunned because geology, for the most part, falls outside the Nobel fields. The leaders of modern evolutionary biology, who synthesized Darwin's theory with later advances in genetics and other fields, have thus far been neglected. And so have the top scientists in such fields as archeology, botany, environmental science, much of astronomy, oceanography, cosmology and most of the behavioural sciences, to name a few." (*New York Times, 18 Oct. '83*)