Autonomous Onboard Classification Experiment for the Satellite BIRD

W. Halle[1] K. Brieß, M. Schlicker, W. Skrbek, H. Venus
German Aerospace Centre, Institute of Space Sensor Technology and Planetary Exportation
Rutherfordstraße 2, 12489 Berlin, Germany

ABSTRACT

The general trend in remote sensing is on one hand to increase the number of spectral bands and the geometric resolution of the imaging sensors which leads to higher data rates and data volumes. On the other hand the user is often only interested in special information of the received sensor data and not in the whole data mass.
Concerning these two tendencies a main part of the signal pre-processing can already be done for special users and tasks on-board a satellite.
For the BIRD (Bispectral InfraRed Detection) mission a new approach of an on-board data processing is made. The main goal of the BIRD mission is the fire recognition and the detection of hot spots.
This paper describes the technical solution and the first results, of an on-board image data processing system based on the sensor system on two new IR-Sensors and the stereo line scanner WAOSS (Wide-Angle-Optoelectronic-Scanner). The aim of this data processing system is to reduce the data stream from the satellite due to generations of thematic maps. This reduction will be made by a multispectral classification. For this classification a special hardware based on the neural network processor NI1000 was designed. This hardware is integrated in the payload data handling system of the satellite.
Keywords: Neural Network Classificator, Multi-spectral Classification, Small Satellite BIRD, On-Board Data Processing

1. INTRODUCTION

The BIRD mission (Bi-spectral Infrared Detection) is a small satellite mission funded by DLR. The BIRD satellite was launched with the Indian PSLV-C3 on 22 October 2001 into a 572 km circular Sun-synchronous Low Earth Orbit. The mission was designed to give answers to different technological and scientific questions related to detection and assessment of hot spot events like vegetation fires, volcanic activities, burning oil wells and coal seams using push-broom sensors on board of a micro satellite.

The 3-axes stabilized BIRD satellite has a total mass of 94 kg. The size of the box-shaped main body is 620 x 620 x 550 mm³. The satellite assures a peak power consumption of 200 W for the duty cycle. It is an experimental satellite. The duty time of the payload is 10 minutes in one orbit. The data of one duty cycle can be stored in the 1Gbit mass memory and will be transmitted during the next pass to a German ground station. Simultaneously data take and down-link are possible, too.

	WAOSS-B	Infrared Sensor System
Spectral bands	VIS: 600-670nm NIR: 840-900nm (nadir)	MIR: 3.4-4.2µm TIR: 8.5-9.3µm
Focal length	21.65mm	46.39mm
Field of view	50°	19°
f-number	2.8	2.0
Detector	CCD lines	CdHgTe Arrays
Detector cooling	Passive, 20°C	Stirling, 80-100 K
Pixel number	2880	2x512 staggered
Quantisation	11bit	14bit (for each exposure)
Sampling step	185m	185m
Swath width	533km	190km

Table 1.1: Characteristics of the instruments of BIRD's main sensor payload

[1] Correspondence: Tel. 49 (0)30 67055559, E-Mail: Winfried.Halle@dlr.de
More Information: http://www.dlr.de/bird

2. THE ON-BOARD CLASSIFICATION EXPERIMENT

2.1. Main idea

The aim of this data on board processing system is to reduce the downlink data stream by generation of thematic maps. This reduction will be made with a multispectral classification of the available sensor signals on board BIRD. The classification process will be done by a neural network implemented in the neuro-chip "Recognition Accelerator NI1000" from *Nestor Inc*.

The new on-board signal processing system is able to resolve the two following demands:

- reducing the data rate due to the generation of thematic maps
- providing the user with results immediately without large processing and distribution efforts and time delay

In general, this kind of on-board processing is needed in cases if users must obtain information with strong time restrictions. Special tasks could be for example fire warning or managing, gale warning or detection of pollution of the environment.
The classificator of BIRD is trained to detect fire directly on-board. Further it is possible to detect other terrain classes. They must be chosen under the condition that they will be separable from the available spectral bands.
The experiment should start with the task to classify a scene within few classes. They are hot spots (fire), water, bare soil, cloud and urbanisation areas.
In the case of an unclear decision for a class a rejection class „unclassified" must be defined. The on-board classified scenes will be processed to a high-level data product. A further experiment goal consists in the generation of a geocoded thematic map which will be transmitted to the ground station.

2.2. Operation Method

The whole classification system is split into two parts (s. fig. 2.2): the classification module on the satellite "On-Board-Classification", and the classification test and verification module at the ground station "On-Ground-Classification". Each module contains a unit for the data pre-processing like a feature extraction from the available sensor image data. For this experiment, the features are the radiation values of the sensors. They are the inputs of the classification process. In the centre of the classification process is the Neuro Chip *NI1000*, which works internally with so-called „Radial Basis Function Networks".

The user is able to use the common RCE (Restricted-Coulomb Energy) or PNN (Probabilistic-Neural-Network) training paradigms. The principle function of the paradigms is the mapping of the class distributions in the feature space with different hyper-spheres (s. fig. 2.1.): During the autonomous training process the NI1000 stores "representative" vectors w_i of the training-data-set as prototypes (reference vectors) for each selected class. By using a hyper-radius r_i around each reference vector the mapping of the class-distribution is reached. This process is controlled by different kinds of learning parameters. The classification of the NI1000 is done by a minimum distance calculation between each reference vector and the vector to be classificd.

At the end of the classification process on-board BIRD, images with so called "class maps" are the results. They will be labelled with the time-code of the data-take of the corresponding row-data image. Theses class maps are directly available for the user at the ground station.

The "On-Ground-Classification" (s.fig 2.2.) is used for two principal tasks:

1.) Before classifying the sensor data, the classifier must be trained with the ground-truth classes which will be detected. This process will be done interactively between the on-board and the on-ground classification module.
2.) At the beginning of the system operation time it is useful to verify the performance of the on-board system by comparing its results with the results from the on-ground system. In this case it is possible to obtain the classification results and the untreated sensor image data together from the same scene. The results can also be compared with ground-truth measurements.

At the first step, the on-ground-classification-module will be configured by training with several selected image points from each of the desired class. Each training point is selected from the already stored sensor raw data and consists of the dimensions of the feature-extraction sensor data.
The configured on-ground classifier can be verified by the comparison of the classification results and the known class categorisation taken from ground-truth measurements.
With this method, the selection of the training points and other parameters of the classifier, like learning rate and threshold values, can be optimised interactively at first on the on-ground module. The training points with the concerning features and their associated classes will be put into a learn-matrix. This learn- matrix and parameters of the classifier will be sent via the satellite telemetry to the on-board classification system, which will be configured autonomously with the transferred parameters. After this procedure, the on-board classifier is ready for the classification of the sensor data.

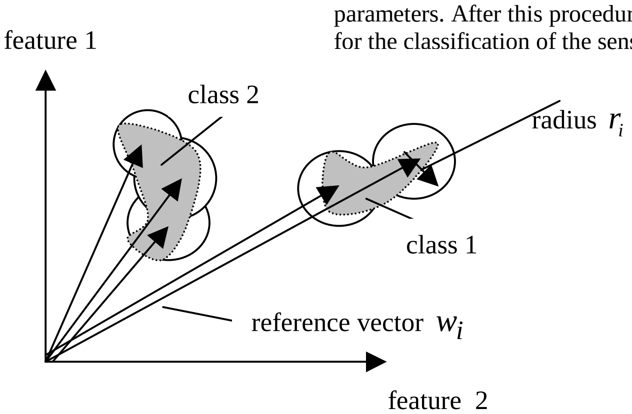

Fig. 2.1.: RCE- configuration in a two-dimensional feature space

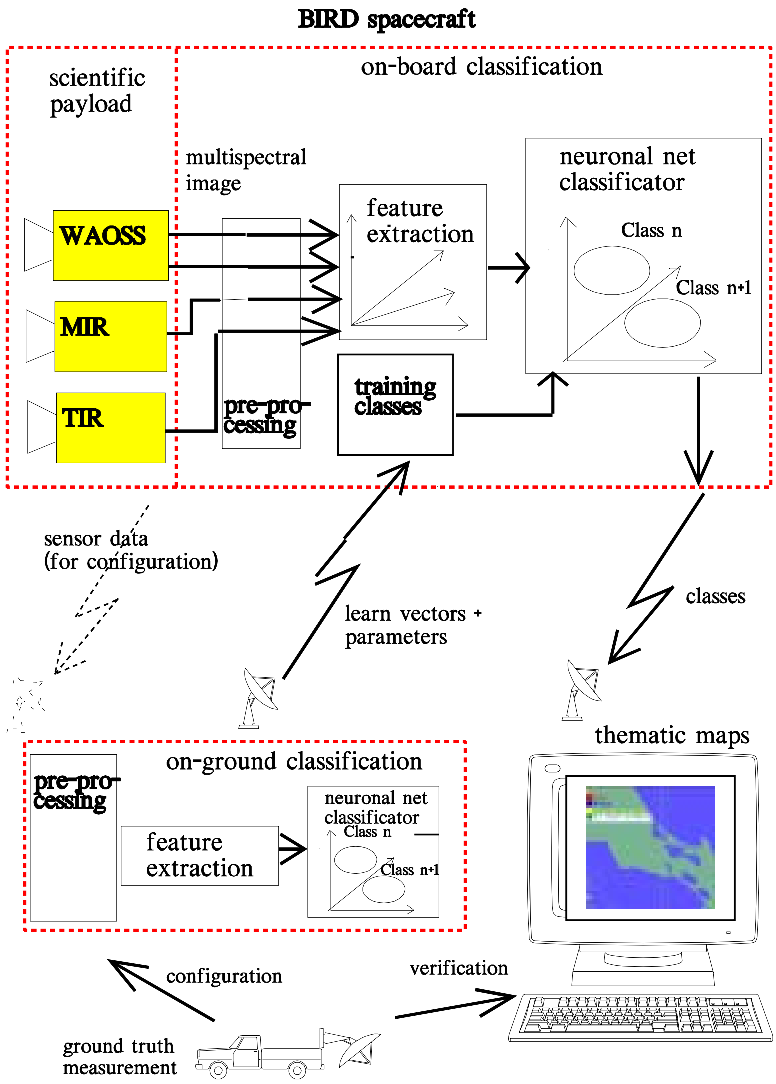

Fig. 2.2.: Overview of the classification process

3. PALYLOAD DATA HANDLING SYSTEM

The on-board classification system is fully integrated in the Payload Data Handling System (PDH). The PDH is a dedicated computer system responsible for the high level command distribution and the science data collection between all payloads at the BIRD satellite. The PDH has data interfaces to all payloads, the spacecraft board computer (SBC) and the down-link telemetry channel. An overview of the PDH with the connections to all systems is shown in figure 3.1.
The tasks of the PDH can be divided into three groups :

- high level command of the attached payloads and housekeeping extraction out of the payload science data stream
- data storage, telemetry frame generation and down-link via the telemetry channel
- on-board thematic data compression in form of a multi-spectral classification.

Furthermore, several technological experiments will be carried out at the PDH. It will be tested the on-board geo-coding facility as well as miscellaneous technical approaches, like fiber optic interconnects between the IR Sensors and the PDH, high density multi-chip modules or on-line real-time parallel processing.
Table 3.1. presents the interface and science data relevant technical parameters to the connected instruments or subsystems. Further constraints are given by the satellite operation modes and the limited resources (mass, volume, power and budget).
The PDH was built on standard European Size printed circuit boards. A PDH system contains four different modules. These modules are: the DPU (digital processing unit), the neural network classification chip NI1000 for this classification experiment, the WAOSS MIL1553 and telemetry interface (W/TM-IF) and the command and data interface to the infrared sensor heads (IRL/M-IF). To built the DPU module, it is used an advanced multi-chip module (MCM) technology for the processor core and the mass memory (1 GBit). The system support hardware (decoders, bus-arbiter, interrupt controller,..) as well as the standard PCI system bus will be integrated into field-programmable gate arrays (FPGA).

Payload	interface type	average data rate[kbps]	peak data rate [kbps]	data volume (9 minutes at 450 km orbit)[Mbit]
WAOSS	MIL 1553	597	600	315
IR-1 command	RS 422	19.2	19.2	0
IR-1 data	fiber cable	693	4790	365
IR-2 command	RS 422	19.2	19.2	0
IR-2 data	fiber cable	693	4790	365
SBC	RS 422	19.2	100	1
Sum		1720	10264	1045

Tab. 3.1.: Interface Requirements

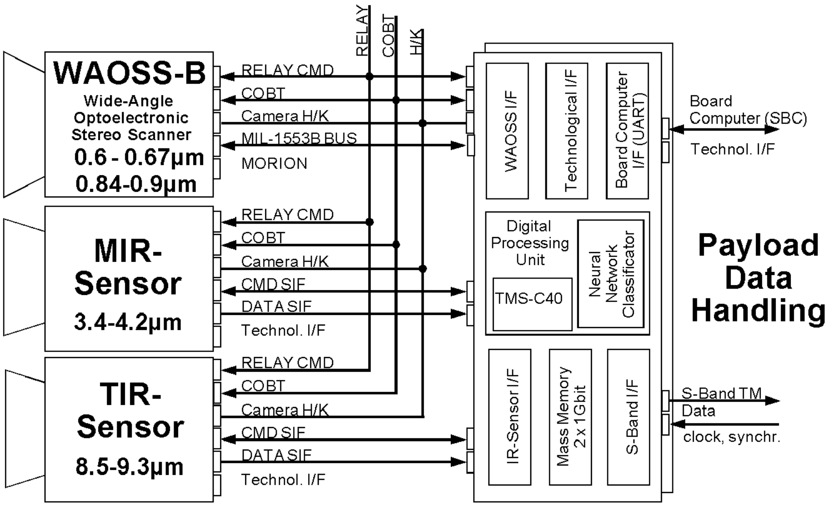

Fig. 3.1.: Payload System of BIRD with Sensors and Data Handling System

4. REQUIREMENTS ON PRE-PROCESSING FOR THE ON BOARD PROCESSING

As explained, the main inputs for the classification system could be in principle the four available spectral bands of the imaging system of BIRD. For the first experiments only the three nadir pointing channels will be taken for the classification process. The wavelength for WAOSS 840-900, for MIR: 3.4-4.2µm and for TIR: 8.5-9.3µm.

The on-board classification process will run for this technological experiment in an off-line state, the classification module will take the already stored image data from the mass memory of the PDH.

The stored sensor signals cannot be used directly for the classification process. They must be pre-processed in different ways:

1.) The first pre-processing step is the **multi-sensor pixel-co-registration** of the different spectral channels.

This is made by simple geometric calculations. In knowing the geometric constellation between the three camera systems, measured in the lab before launch, it is possible to calculate the geometric corresponding pixel to each other. After calculation of each line the data are stored in a three dimensional array. Because the three cameras system are designed with nearly same ground sampling distance the co-registration is done on-board for the first experiment without a pixel re-sampling to reduce the pre-processing time.

2) The next step of the pre-processing is the **radiometric calibration** of the sensor data. The two IR channels deliver raw data. Because of the high non-uniformity of the IR-sensors, the two cameras must be calibrated pixel by pixel [LORENZ]. For this on-board calibration process only a simple linear model is used (gain and the offset). Theses coefficents are stored in a special sector of the PDH–ROM. The WAOSS camera delivers an optical signal which is already PRNU (Photo Response Non-Uniformity) and offset corrected. For the radiometric calibration only one calibration coefficient has to be considered. After all steps of this process the image data of all channels are calibrated in units of radiance [W/m^2 *sr*µm] and can be used as inputs for the neural-net classificator NI1000.

3.) Because the NI1000 has only a 5 Bit resolution for each input feature, each of physical features (wave- length) must be split to several NI1000 feature. (The NI1000 has maximal 64 input features). The explained pre-processing and the control of the learning and classification is realised in a software which runs on the PDH signal processor TMS-C40 from *Texas Instruments*.

The software tool is able to change different parameters by special commands which can be given from the ground station these are e.g. for the classification itself the number of lines, the swath with of the selected scene and the kind of classification algorithm. By using different memory sectors for the storage of the learning vectors and parameters it is possible to change easily the configuration of the classifier. This option can be used for example if several users want to have the classifier for different applications

After the classification process the data are stored the mass memory of the PDH and can be linked down to earth through the telemetry interface.

5. THE ON BOARD CLASSIFICATION EXPERIMENT AT WORK

After the launch the neural network hardware was tested in the commissioning phase of his electrical functions. Tests about the learning and classification are done with a test-data-set for checking the connections between the PDH and the processor NI1000 and the NI1000 itself. The first test with real data from the BIRD sensors was done at the Jun 2002.

5.1. Configuration and test of the classifier Experiment Scenarios

For the fist step the classificator was configured with 4 different classes: This classes are water, bush fire , warm clouds and cold clouds. Training points were taken of a BIRD scene of Australian bush-fires of the 4. Jan 2002 (s. fig 5.1.a). For each class some representative pixels were selected to describe the distribution of the classes in the feature space. The spectral significances of the classes are shown in figure 5.2. (mean values of the training points for each class, corresponds to radiance, normalized for NI1000 input). With this training points the on-ground-classification-module was trained. Learning parameters like smoothing factors and threshold values for the radial-basis-function neural network are optimised. After this process the verification and validation of all parameters was done by an on-ground-classification of different raw-data taken form the BIRD satellite in combination ground-truth of the chosen classes.

One of the results is shown in fig 5.1.b.: The Australian scene (fig.5.1.a) was classified with the explained configuration, the bush fire fronts are detected. This results of classified points have been compared with the conventional hot spot recognition method explained in *SKRBEK* [2002].

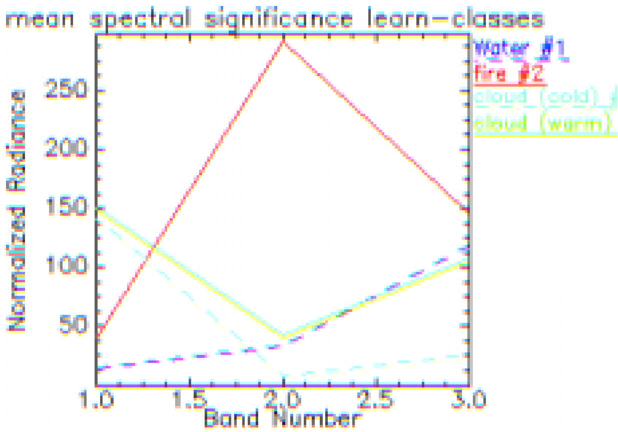

Fig. 5.2.: Spectral distribution of the chosen classes
Band Number:
1: WAOSS 0.87 µm; 2: MIR 3.7 µm ; 3: TIR 8.9 µm

Fig.:5.1.a: BIRD MIR image, Australia, 4. Jan, 2002

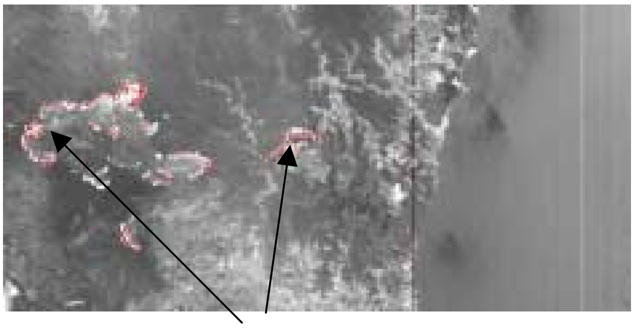

Fig.:5.1.b: BIRD MIR with On-Ground-Classification (overlay hot spots)

At the next step all the learning vectors and parameter are put in a special learn matrix to send them to the satellite BIRD. The matrix is stored in a special sector of the PDH–ROM. Up to 12 different learning matrices can be stored on-board in parallel.
Now the on-board-classificator is able to learn itself autonomously the configuration by an uplink of a special command form ground with corresponding sector number of the learn matrix which is desired. When the classificator NI1000 has learned ones the vectors of the NI1000 is able to store the internally configuration. This advantage is used every time when the classification should take the same learning matrix after a new power-on of the on-board-classifier. A simple "restore" refreshes the NI1000 and the "normal" learning procedure can be omitted. After the self configuration of the module it is able to classify any scenes on-board after a data-take.

5. 2. First results of on-board classification

One of the first test of the on-board-classification was done from the data-take of the 26.Jun. 2002. In the fig 5.3.a scene of the island Sachalin near Japan is shown (MIR channel). The result of the classification (fig 5.3.b) shows clearly the distribution of the detected water and no-water areas. The fist visual comparison with the original image gives the same principle impression of geographic constellation of the scene. Further two hot spots are classified from the original scene. Theses two points are visible in the original scene of the MIR channel (s. Zoom fig 5.3.a). The real verification of the classification results must be done later by the analyses of selected points in comparison with ground truth measurements. An other example of the on-board classification capability is the result after the data-take in South-West Australia at 1 Jul. 2002 (s. fig 5.4.a.). The onboard classifier has detect a huge fire frond in a forest nearly the Vancouver bay. (s. fig 5.4.b.).

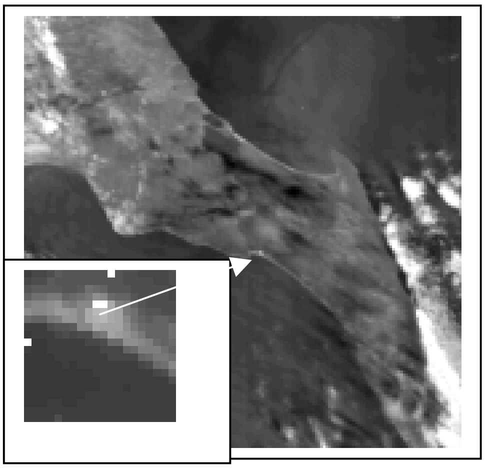

Fig.:5.3.a: BIRD MIR image, 28. Jun 2002 ;

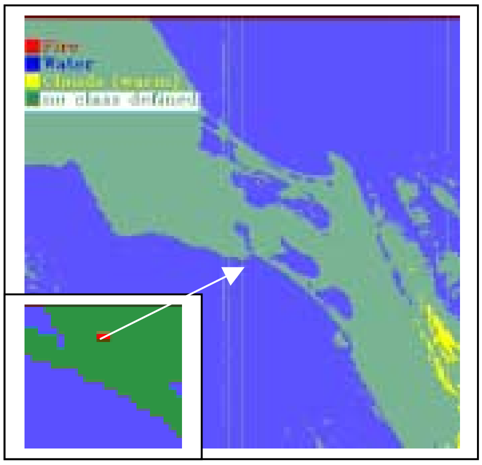

Fig.:5.3.b: Classification result with 4 classes

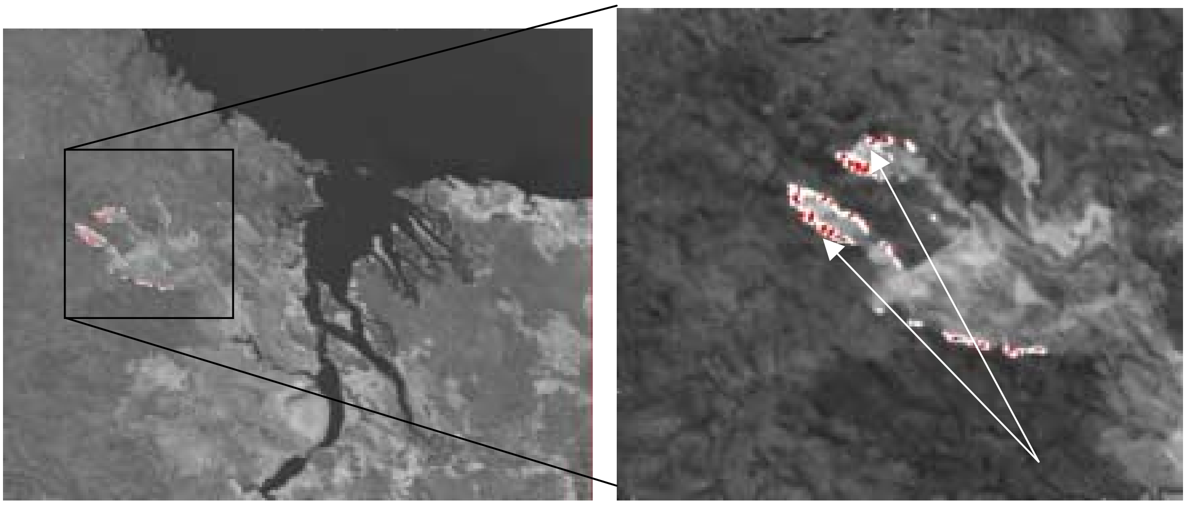

Fig.:5.4.: Area of bush fires in the area of Sydney in Australia obtained by BIRD at January 4, 2002; MIR with overlay bush fire

6. SUMMARY

In this paper we presented a new on-board processing system with a neuronal network as a technological experiment on the small satellite BIRD. The aim of this project is to get an on-board thematic data reduction through a multispectral classification. The advantage of this kind of system is on one hand the up-speeded availability of the required information for the user in the cases of fire detection, because the time consuming on-ground data processing procedure which is performed usually in a "user data centre" becomes obsolete. On the other hand the on-board data reduction lowers the costs for data transmission to the ground. The first results has shown that the trained classifier is able to full-fill two main requirements:

- classification of vectors from learning points of equivalent classes as determined by ground-truth measurements. This shows the interpolation and convergence of the learning algorithm.
- classification of any image-scenes of non non-training data areas. This shows extrapolation capability of the classifier.

With this pioneering satellite experiment for civil application in the proposed manner, the principle feasibility and usefulness of such on-board classification systems on satellites is demonstrated. The proposed system should be a precursor prototype demonstration system, which give a direction for prospective operational small satellite systems probably for a WEB based information service .

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