# The CHIPS System for Satellite Image Processing

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*CHIPS, a software system for satellite image processing and analysis has been developed at The Institute of Geography, University of Copenhagen. The background, philosophy and objectives of this development effort will be briefly presented. In recent years emphasis has been put on the development of methodologies for remote sensing of environment and agriculture in Third World countries. This includes both land cover/use mapping using high resolution satellite images and applications of low resolution satellite data. This paper will give examples of research applications of CHIPS within different fields, and illustrate how the requirements, defined by this research, influence its contents and development. The presented examples include the use of SPOT, Landsat and ERS-1 SAR data for land cover mapping in Denmark and Third World countries, and monitoring of agroclimatic parameters, vegetation, crops and bush fires based on NOAA AVHRR data. Finally, the current plans for the development of CHIPS will be presented.*

Keywords: *Satellite image processing, remote sensing, land cover mapping, environmental monitoring.*

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The development of the Copenhagen Satellite Image Processing System (CHIPS) was initiated in 1985. The objective was to provide the Institute of Geography, University of Copenhagen (IGUC) with the necessary tools for remote sensing research and education. Over the years objectives have changed, as the group of users has expanded and the financing of the development has shifted. CHIPS is developed mainly for users involved in the use of remote sensing for agricultural and environmental monitoring. Particular emphasis is placed on providing a system suitable for small institutions in the Third World with limited technical and economic resources. It has, however, turned out that CHIPS in its present form is well-suited for training, research and operational applications, since it provides the necessities for satellite image processing at low-costs. Thus, it is now used in approximately 100 institutions all over the world. The present paper outlines the philosophy of the CHIPS development, its structure and elements of its contents, and it exemplifies its applications and presents plans for the future development. For a more detailed description of CHIPS, see Andersen et al. (1992).

## Philosophy and Objectives of the CHIPS Development

Since 1987 the development of CHIPS has mainly been determined by the requirements of 'Centre de Suivi Écologique' (CSE), Dakar, Senegal. The CSE is a parastatal environmental monitoring centre, established by the Senegalese government and United Nations Sudanian-Sahelian Office (UNSO), and largely financed by The Danish Agency for International Development (DANIDA). The CSE carries out a range of agricultural, environmental mapping and monitoring activities. The centre supports national and local public services, such as the Ministries of Agriculture and the Environment, and from other organisations, e.g. development projects. The CSE has relied heavily upon the use of satellite images, in combination with aerial photos and very substantial field work, and the use of 'geographical information systems' (GIS) technologies. DANIDA has provided a special grant to the IGUC, allowing development of methodologies and software in support of the CSE's activities. This has had a strong impact on the design objectives of CHIPS, which may be described as follows:

(a) The system must support basic operations applied to digital satellite images, in particular those related to multispectral image display, delineation of areas of special interest ('training areas'), statistical analysis, spectral transformations, filtering and geometrical correction.
(b) It must support applications of high-resolution data, such as Landsat and Système Probatoire d'Observation de la Terre (SPOT) images, for land cover mapping, including a choice of classification algorithms and methodologies.
(c) It must support environmental and agricultural monitoring applications, based on low resolution data, i.e. NOAA AVHRR (National Oceanographic and Atmosperic Administration's Advanced Very High Resolution Radiometer) and similar data. This includes monitoring of biomass production in semi-arid grasslands, crop yield assessment, bush fire monitoring and estimation of energy and water balance components.

(d) The structure must be open and flexible, allowing modification and addition of new routines, and interfacing to other software, not the least GIS's.
(e) The hardware basis of CHIPS should be as simple, easily serviceable and inexpensive as possible, without compromising on the capacity for the processing of full scenes of satellite images and for multispectral image display. It is preferable to use standard hardware and operating systems, also allowing use of other image processing and GIS.

These design objectives should make CHIPS widely applicable, and allow that systems for satellite image processing could become a 'desk-top' facility for those involved in agricultural and environmental research and monitoring. By moving this technology from specialized centres into the offices of 'end-users', it is believed to be possible to remove some obstacles, presently hindering full use of the potential of satellite images as a data source in environmental and agricultural monitoring in developing countries.

CHIPS differs from most other systems for satellite image analysis, as it is developed in a scientific environment where research in various fields defines demands for the image processing system. This will be illustrated by several examples of how ongoing research, at IGUC and elsewhere, influences the present contents and future development of the system.

It was decided from the outset to develop CHIPS for standard PC-equipment with the PC-DOS operating system. The only additional equipment required is a 'display adapter', particularly suited for multispectral image display, and an image display monitor. This hardware is identical to that used by major manufacturers of commercial image processing systems. However, CHIPS status as a low-cost shareware product allows utilization of it in institutions without large financial resources.

## The Structure

The overall structure of CHIPS, as seen from the user's point of view, is reflected in the main menu, shown in figure 1. The main entries in this menu are ordered according to the 'natural' sequence in which satellite image processing routines are often applied: Image display and contrast stretch, pointing out of 'areas of interest'/'training areas', statistical analysis of spectral properties of such areas or the entire image, spectral transformation and classification. In addition, there are entries for operations such as filtering, geometrical correction and specific application areas, e.g. vegetation monitoring using NOAA AVHRR. Export and import of widely used rater image formats are also available, see Andersen et al. (1992).

CHIPS-menus display status information in the rightmost section of the lower 'bar' (e.g. the location of the cursor and image values at the cursor position), as shown in figure 1. The leftmost section of the lower 'bar' enables the user to access basic CHIPS routines and DOS commands. The upper bar gives information to the user about processing status and the availability of routine specific functions.

Most CHIPS routines may be invoked interactively using the menu system or as stand-alone modules with direct access to basic routines. Many modules also exist in 'command line' versions. These are suited for use in unattended 'production line' processing of large amounts of satellite data, which is of specific interest to operational users, such as the CSE.

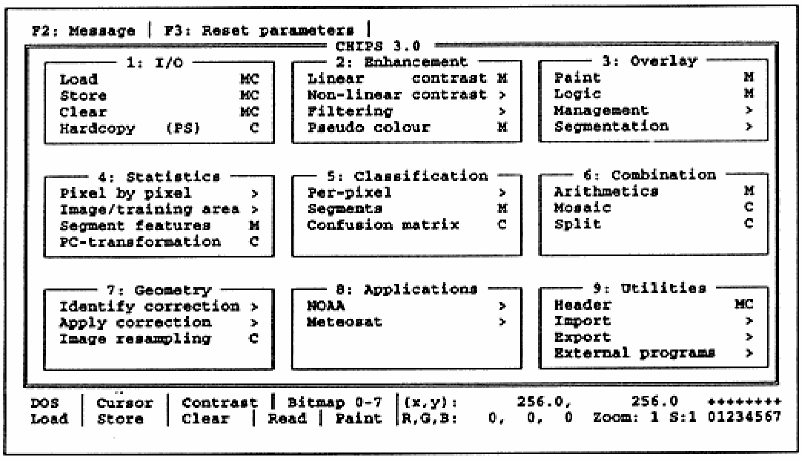


Figure 1. CHIPS main menu.

## Land Cover Mapping

Both research projects at IGUC and practical applications at the CSE and the Danish Ministry of Agriculture apply high resolution satellite data to map land cover and to identify land cover change. The basis for mapping will often be several satellite images, acquired in different seasons.

In the following an overview of the relevant CHIPS modules will be presented, and the demands, defined by typical applications, will be discussed, taking research projects at IGUC as the point of departure.

### *Statistical description of spectral signatures*

In many applications of high resolution satellite images for mapping and monitoring the Earth's surface, classification of pixels based on their spectral reflectance properties plays an important part. This presumes that classes are described statistically in the first place. Since satellite images contain (presently) up to 7 bands, and since the datasets analysed sometimes comprise several images, a substantial number of bands has to be dealt with. The statistical description of a class will usually be based on analysis of known, supposedly representative, "training areas". CHIPS contains a number of routines allowing such statistical analysis, such as Euclidean and Jeffries-Matusita Distance separability measures.

### *Per-pixel classification methods*

Classification based on spectral signatures alone may be carried out using a variety of methods (Rasmussen, 1994):

(a) Parallel-epiped, or "box"-classification, assumes that decision boundaries are parallel to the axes of the feature space.

(b) In scattergram-based classification an area in a two-dimensional sub-feature-space determines the decision boundaries. Thus the method is limited to two bands/features at a time, but no assumptions are made with respect to the statistical distribution of the class.

(c) The "Minimum Distance" classification algorithm allocates a pixel to the class to which the Euclidian (or "city block") distance to the class mean value is smallest. Thus the statistical distributions and the variances of the classes are not taken into account.

(d) In "Maximum Likelihood" classification a pixel is allocated to the class, usually among several, which it has the highest probability of belonging to, assuming (n-dimensional) Gaussian distributions of pixel values. Probabilities are then weighted with a priori probabilities for each class. This classification method is generally considered the statistically most satisfactory.

### *Hierarchical classification*

Application of the above-mentioned standard classification methods on multitemporal datasets involves several problems:

(a) All bands will be used to identify all classes, even though this may not make sense: Some classes may be identifiable on the basis of just a few bands in a given image, and inclusion of bands from other images will make classification more difficult.
(b) Masking out of irrelevant, temporary classes, such as cloud cover, is difficult.
(c) The most complex and time-consuming methodologies, such as maximum likelihood classification, necessary to identify some classes, is applied to all pixels.
(d) Registration of all image bands to a commom coordinate systen.

One way of circumventing these problems is to utilize a 'hierarchical' classification approach, as illustrated in figure 2. This involves objects which may be easily identified on the basis of spectral signatures in one image, in being classified using simple and fast methods, such as the parallel-epiped method, while progressingly complex algorithms and more images/bands are used to solve the more intricate classification problems. The CHIPS software allows establishment of this sort of "decision trees".

### *Urban land cover mapping*

Detailed mapping of the smallest objects of the urban scene (e.g. the housing unit) is not achievable with current satellite images mainly because the spatial resolution is too low. However, if aiming at a more general or synthesizing land cover map of built-up urban areas, e.g. extension of low-density residential areas, the use of satellite images may be considered, especially if frequent map updating is desirable (Møller-Jensen, 1990). These areas, however, constitute spectrally heterogeneous land-cover classes and call for the application of specific image processing methods.

The appearance of such heterogeneous land-cover classes in digital imagery is closely related to the spatial resolution of this image, i.e. significant changes occur as a result of increased/decreased spatial resolution. This can easily be realized by looking at a specific land cover class in different types of images, see figure 3.

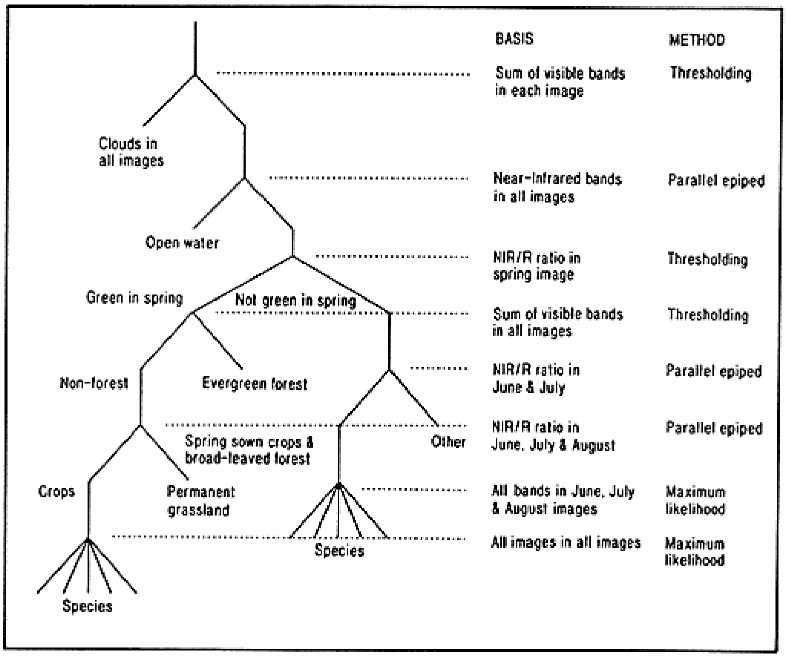


Figure 2. An example of a decision tree for multitemporal classification of landcover in Denmark.

The corresponding spatial model of this area (figure 4) describes the basic objects which make up the general land cover class (the "subparts") and the spatial relations between these. It is possible for a specific spatial resolution to draw a horizontal line in the model indicating that objects below are not directly recognizable due to mixed pixels effects. Some information about the objects is, however, present in the scene. Land cover classification of areas "above the line", whether human or computer-based, must use information about the spatial distribution (or texture) of the subparts "below the line". In other words, the use of texture-based methods makes it possible to classify general urban land cover classes although their basic subparts cannot be clearly seen. It is obviously not possible to make a classification of the general land cover class by examining the reflectance properties of each pixel in isolation from the neighbouring pixels.

The human brain is excellent at incorporating context and texture when making a decision concerning the class label of a certain area. TCorrespondingly a computer-based image processing method must be applied, which is capable of extracting information from the complex pixel pattern that characterizes the urban area. Texture-based classification in CHIPS is done by establishing co-occurrence matrices which hold information about the frequency of pairs of pixels with specific values. A number of texture describing features can be extracted from the matrix and used e.g. for maximum likelihood classification. A problem associated with the use of texture is that the minimum image segment, over which the texture is computed, must be of a certain minimum size and contain only one land cover class. A large segment will enable the most reliable computation of texture, but a class segment is often limited to only a few pixels which may cause unreliable texture information. Segmentation is not one of the strongest features in CHIPS; however, there is a possibility of creating connected segment borders from linear features, such as roads, in an image. Incorporation of contextual information will be considered in the future.

### *Combined use of optical and microwave satellite images for crop mapping*

Today optical satellite data are applied operationally in land use and crop monitoring in Denmark. The data sources are SPOT and Landsat Thematic Mapper (TM) data, and the methodology used is multispectral and multitemporal classification, also using information stored in a GIS. Optimal identification of crops requires satellite data from three periods of the growing season. For Danish climatic conditions, this is not always possible because of cloud cover. This has lead to the initiation of a research project aiming at investigating the extent to which data from space-based 'synthetic aperture radar' (SAR) may be applied in combination with optical satellite data for crop

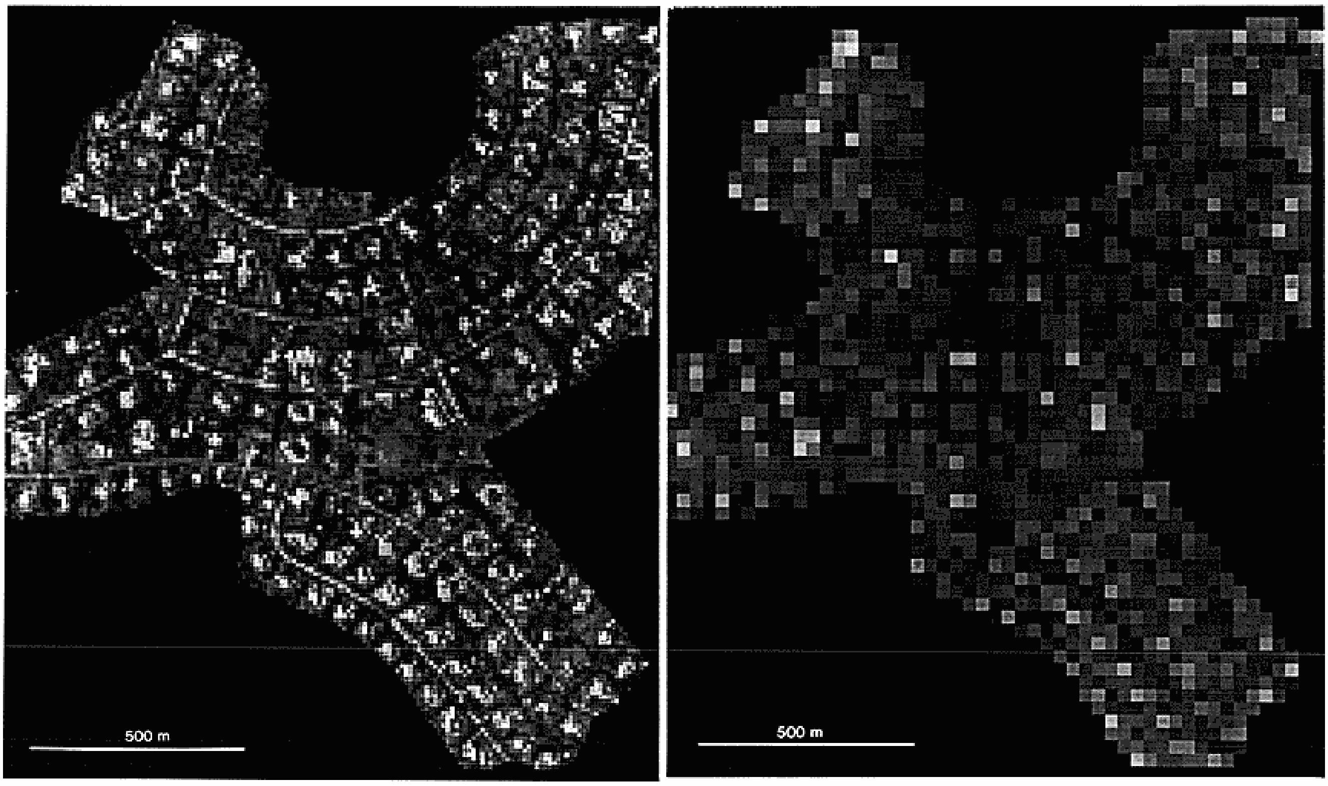


Figure 3. The appearence of a low-density residential area with large building units in a digital image with 10x10m (a) and 30x30m (b) pixel spatial resolution. (Accra, Ghana)

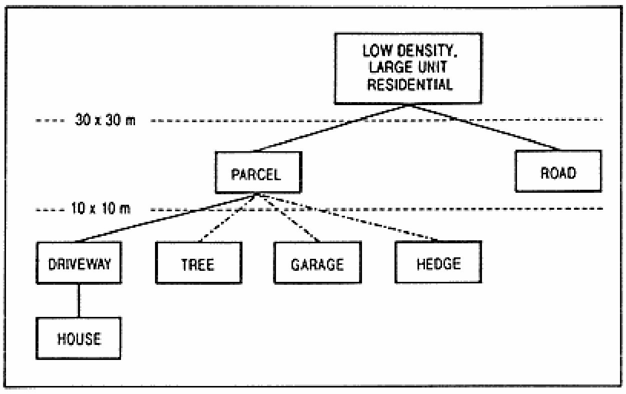


Figure 4. A spatial model of a residential area (figure 3). Objects below the horizontal lines are not directly recognizable at the specified spatial resolution due to mixed pixels effects, and texture-based methods must be applied.

monitoring purposes. The advantage of SAR-data is that they may be acquired independent of clouds and time of the day. On the other hand, the presently available space-based SAR, the ERS-1 SAR, operates at one frequency and with one polarization, which means that only a one-band image is produced. Other factors than those relevant in crop/land cover applications affect this one-band image, notably soil moisture and surface roughness. Also the 'effective spatial resolution', taking the radar speckle into account, is lower than those of SPOT and Landsat TM. Thus, there is scope for a combination of optical and SAR data. A preliminary study, financed by the Danish Space Science Board, was carried out in 1993 in order to explore these potentials. The results of this study are presented in Fog et al. (1993). The study has led to the definition of a new CHIPS-module, containing routines particularly targeted towards the processing of SAR-data, which have properties distinctly different from those of optical data.

The satellite data used in the preliminary study included 4 ERS-1 SAR images from 1992 and 3 from 1993, as well as one SPOT-scene from each of these years, both acquired in mid May.

The preprocessing of the SAR-images involved the following steps:

(a) Compression from 16 to 8 bits per pixel
(b) Filtering and spatial compression
(c) Geometrical correction

These processing steps are all different from the corresponding procedures for optical data. Before merging optical and SAR data it is necessary carried out in a 16-to-8-bit compression of the SAR data. In order to retain as much information as possible in the compressed image, several transformation have been examied. In the present study the logarithm transformation has been applied.

The advantage of the logarithm transformation is that it transforms the Gamma-distribution in SAR images for a homogeneous area into a distribution with shape like a slightly skew Gaussian distribution i.e. the transformed data are well-suited as input to standard classification algorithms. Filtering (of 8- or 16-bit data) is a very important processing step for SAR-images, not the least because of the 'radar speckle', resulting in a very 'noisy' appearance of raw SAR-images. The literature on SAR-processing contains numerous filtering algorithms, see Lopes et al. (1990). Again, these filtering algorithms have been included in a dedicated SAR-module. Geometrical correction with an accuracy comparable to the one that may be obtained for SPOT and Landsat TM, i.e. approximately 10 m, is difficult for two reasons: Firstly, 'ground control points', used as a basis for computing polynomial transformation models, may be very difficult to identify with the necessary accuracy due to the radar speckle. Secondly, ERS-1 SAR is viewing between 20 and 26 degrees off-nadir. In hilly terrain this gives rise to considerable geometrical distortions. It is therefore important to use a digital elevation model (DEM) during the geometrical correction process. Thus, procedures allowing application of a DEM in the correction will be developed and integrated into the CHIPS geometrical correction module.

Once a time-series of ERS-1 SAR images and the SPOT-image have been merged into one data-set, multispectral/multitemporal classification of the set must be carried out. Most classification methods are based on the assumption of a Gaussian distribution of pixel values for each land cover class. This is almost true for the logarithm transformed SAR data. But still, the radar speckle implies that a pixel-by-pixel classification approach is not applicable without an initial segmentation of the data-set based on the SPOT-data or on data held in a GIS. This means that the development of segmentation routines must be given priority.

Results obtained in the preliminary study of data from 1992 and 1993 indicated that combined use of SPOT multispectral and ERS-1 multitemporal data carries great potential for agricultural land use mapping and monitoring. In particular, the combination of a SPOT image from early in the season, where cloud cover very often is limited, and several ERS-1 images from later in the growing season is promising. This would ensure that satellite-based control of EU-subsidies, which are allocated on the basis of the farmer's own accounts of areas cultivated with different crops, could be carried out irrespective of cloud cover conditions, and results of the control could be available relatively early in the season.

### *Multitemporal land cover mapping and change detection in Burkina Faso*

IGUC has carried out a number of studies of agricultural systems in Northern Burkina Faso, using SPOT and Landsat data, in combination with extensive field work, as a basis for mapping and monitoring land cover/use. Agricultural fields in Burkina Faso are small, irregular and inhomogeneous, and the plant density, especially in the case of the dominating crop millet, is very low. This poses considerable problems on the use of satellite images for agricultural applications. On the other hand, agricultural information is scarce, and the increasing local, national and international concern for the environmental conditions and agricultural development trends in the region creates a demand for more precise information on the state and trends of agricultural land use and 'land degradation'. Identification of ways of utilizing satellite data for retrieval of this important information is therefore important.

A multitemporal data-set, encompassing SPOT-data from January, July, September and October 1989, has been analysed in order to study the utility of data from different periods of the year and of different methodologies. Preliminary results from this study are reported in Rasmussen & Reenberg (1993). In the following, a few extracts from this analysis of direct relevance for the CHIPS development will be presented.

Basically, the purpose of the study is to analyse how well a number of land cover classes may be discriminated between, on what data basis it is best done and with which methodology. Analyses of this type are often done by carrying out a number of classification trials, and testing the results against a set of ground data, using a confusion matrix approach. However, the result of this type of analysis is extremely sensitive to a large number of factors, and in particular to the care with which 'training' and 'test' data is selected. Also the number of possible classification procedures which may be tried out is large, and the computing time is considerable for each of them. Thus a more robust and time-economic procedure must be found. Analyses of how the statistical separability of pairs of land cover classes depend on the choice of images/bands allows fast assessment of how the dimensionality of a multitemporal data-set may be reduced, as also discussed in Rasmussen & Hagen-Olesen (1988).

Many classification methodologies have been suggested for the analysis of multitemporal data-sets. The use of classical algorithms, such as the 'maximum likelihood' and 'minimum distance' methods, involves problems, since a priori knowledge on the temporal development of spectral signatures of land cover classes is not utilized fully. Also, the occurrence of 'temporary classes', such as clouds, cloud shadows and bush fire scars, increases the number of classes in a multitemporal data-set to a level which is difficult to handle. A 'decision tree approach', as sketched in figure 2, is more appropriate and may be less sensitive to problems of temporary classes. Information from other sources, for instance held in a GIS, may be easily integrated in such an approach, which may, with some right, be categorized as 'knowledge based'.

In some cases, cropped areas may be easily identified by visual interpretation techniques, whereas it is difficult to do the same thing with digital per-pixel classification methods. The reason for this is, of course, that texture, structure and context play a significant role in the classification. Improvement of the performance of digital methods therefore involves that spatial features are introduced in the feature-vector, upon which classification is based. In practical applications, purely visual interpretation methods will be unhandy, if large areas are to be covered, whereas purely digital methods will not be able to provide the required accuracy. Flexible means of combining visual and digital classification techniques are therefore called for.

These methodological conclusions from the study have certain implications on past and future CHIPS development efforts. Firstly, considerable attention has been paid to the inclusion of routines for flexible analysis of spectral/temporal signatures and for the calculation of measures of statistical separability. Secondly, implementation of procedures allowing flexible definition of 'decision tree' classifiers is underway. Thirdly, more advanced classification procedures, including textural, structural and contextual features, are being developed, some based on the concept of 'object models', involving scale-space techniques or utilizing artificial neural nets. Improved facilities for combining visual and digital classification techniques involve mainly two things, better means of editing the contents of classification results, which is basically a computer graphics task, and efficient integration of image processing and GIS systems, which is among the topics which will be given high priority in the future CHIPS development, as indicated below.

## NOAA AVHRR-based Monitoring of Agriculture and Environment

Because of NOAA AVHRR's daily global coverage and spetral configuration , it is of particular relevance for the monitoring of agriculture and environment in the semi-arid tropics, since it is an extremely cost-efficient means of acquiring information on crop and grassland production as well as on a range of environmental themes, including bush-fires and elements of the energy- and water-balances. NOAA AVHRR data may be received locally, using relatively low-cost equipment, and national-scale monitoring may be carried out on PC-based equipment for satellite image processing and -analysis.

NOAA AVHRR data have been used extensively for environmental monitoring at the CSE. The CSE has used AVHRR data operationaly since 1987 and is now in possession of an extremely valuable dataset. The main focus has been on the use of AVHRR data for the monitoring of biomass production in semi-arid grasslands in the northern part of Senegal, but over the years a number of applications have been developed and exploited, notably bush-fire detection and crop yield estimation.

### *Standard AVHRR processing*

During this period, growing attention has been paid to attain a high quality and standardization of the AVHRR processing, see e.g. reports prepared by the International Geosphere-Biosphere Program (Townshend, 1992) and the Observatoire du Sahara et du Sahel (OSS) (Faizoun, 1993), as well as a number of more specific reports on e.g. inflight calibration of the visible and near infrared channels (Teillet & Holben, 1992). These reports underline the need for a standardized processing, i.e. a well-defined set of processing steps.

The obvious reason for this is the need for a homogenization of the AVHRR data both in time and space, which creates enhanced possibilities for direct data comparison within the user and the scientific community. The standard might also serve as a guideline for a common AVHRR data processing software package. However, in order to make this standard dynamic, it is important to create a forum where the different processing steps can be discussed and algorithms exchanged and validated.

The definition of a common processing standard includes both the processing of the AVHRR data itself and the value-added products, e.g. surface temperature maps and normalized vegetation index maps. It must include guidelines for the following main processing steps: Sensor calibration, atmospheric correction, cloud masking, geometrical correction, standards for value added products and standards for data storage formats.

## *AVHRR applications*

As a direct consequence of the collaboration between IGUC and the CSE and the extensive use of AVHRR data within research and education at IGUC, AVHRR processing has always been an important part of CHIPS. Several research projects have utilized CHIPS for AVHRR processing; e.g. vegetation monitoring and primary production (Hansen B., 1989), (Diallo et al., 1991) and (Rasmussen, 1992), bushfire monitoring (Langaas, 1993), estimation of actual evapotranspiration (Søgaard, H., 1988) and (Sandholt & Andersen, 1993) and sea surface temperature monitoring (Hansen et al., 1993).

The NOAA AVHRR modules of CHIPS were from the outset designed to meet the processing demands of the CSE, i.e. primarily sensor calibration, computation of the normalized difference vegetation index, maximum value compositing and temporal integration of the vegetation index and geometrical correction. Since then the modules have been thoroughly changed and is now very close to meet all the specifications proposed in Townshend (1992) and Faizoun (1993).

## *CHIPS processing chain*

The processing of AVHRR data follows the data flow depicted in figure 5.

The AVHRR data input to the modules can be in either raw HRPT, SHARP format as delivered by ESA, the AGRHYMET format as delivered by the receiving station in Niamey or the Dartcom format as delivered by the receiving station in Dakar/CSE. As a first step the image and ancillary data, i.e. calibration data, the sun - satellite geometry and orbital information, are separated and are thereby made available to all the other processing modules. The geometrical correction can be done either in an automatic or semi-automatic mode, depending on the accuracy requirements of the user. Both methods use the orbital (TBUS) information to navigate the AVHRR data, and in addition the semi-automatic method requires a minimum of operator input, e.g. adjustment of a coastline vector to match the image.

The cloud-masking module uses all five AVHRR channels and information about the sun - satellite geometry as input. At the moment it is based on a relatively simple threshold procedure, with the extension that it allows the user to specify temperature and spectral albedo thresholds that vary in time and space. This is particularly useful in regions where the temperature and the spectral albedo background (surface) have pronounced gradients.

The vegetation index module consists of routines for the calculation of the index itself, generation of 'maximum value composites' and integration of the vegetation index over time. It is possible to use either the 'normalized difference vegetation index' (Goward et al., 1991), the 'global environmental monitoring index' (Pinty & Verstraete, 1992), the 'soil adjusted' or the 'modified soil adjusted vegetation index' (Chehbouni et al., 1994). All indices can be computed from calibrated or calibrated and atmosphericly corrected data from AVHRR channel 1 and 2. The spectral albedo corresponding to channel 1

**AVHRR Processing in CHIPS**

| PROCESSING | LEVEL | DATA |
|---|---|---|
| | Level 0 | Raw AVHRR |
| Extraction and generation of image, calibration, geometry and information data from raw AWHRR data | Level 1 | Image Ch1-5, Ancillary |
| Produce cloudmask and update orbital information Update database | Level 2 | Image Ch1-5, Ancillary, Cloudmask, Database |
| Generate vegetation index, reflectance and temperature maps. Resampling into map projection | Level 2a | Thematic maps |
| Generate maximumvalue composite and integrated vegetation index | Level 3 | Multitemporal maps |

Figure 5. Main steps in the CHIPS AVHRR processing chain.

and 2 can be computed with either calibrated and normalized or calibrated and atmosphericly corrected data. The atmospheric correction procedure used in the case of visible and near infrared data is the 5S model developed by Tanré et al. (1990), and the implementation is based on Dedieu and Rahman (1994). As is the case with visible and near infrared data, thermal infra-red data can either be transformed into surface temperature by simple calibration or by combined calibration and atmospheric correction. The atmospheric correction procedure is in this case carried out by using the so-called split window method e.g. (Price, 1984).

Two modules are available to update and maintain databases, including an image information database and a database which consists of extracted data from all five AVHRR channels and geometry data. The extracted data can be from user specified sites. Both databases include all relevant information and can be useful when testing for new AVHRR processing algorithms.

The AVHRR processing modules are continuously being improved and enhanced. This is possible through the research efforts at IGUC and the close contact between IGUC and other major research institutions and operational centres, notably the CSE.

An improved version of the processing chain is going to be used at the CSE throughout the 1994 growing season. It is expected that up to date information about the atmospheric state, i.e. the water vapour and aerosol content, will be routinely available to CSE from the newly established West African sunphotometer network. This will, amoung other things, enable analysis of the effect of atmospheric correction on the relation between integrated vegetation index and biomass.

## CHIPS Development Plans

As user requirements as well as computer technologies evolve, CHIPS must undergo constant revisions in order to live up to standards. A 'CHIPS development plan', describing the planned development activities for the next few years, has recently been finalized, and the main tasks will be as follows:

(a) To transfer the functionality of CHIPS version 3.0 to a platform (operating system) independent version, making it possible to run the software on a variety of hardware, ranging from a standard PC to a workstation.

This would allow a user to move from a very low-cost PC-based system to an extremely powerful, yet much more costly, workstation-based system without experiencing changes in the functionality, but certainly in the performance, of the software.

(b) Expansion and modification of the present NOAA AVHRR processing modules, along the lines suggested by the standardization working group of the OSS for NOAA AVHRR processing in Africa.

This involves the perspective of CHIPS becoming the standard software to be applied in the quickly expanding field of NOAA-based environmental and agricultural monitoring in Africa. Seen in the context of the future platform independence of CHIPS and the advent of very low-cost receiving station's for NOAA, this will probably be an important contribution to the spread of the cost-efficient use of remote sensing in Third World countries.

(c) Development of a proper 'CHIPS-GIS', as a complement to the GISs to which interfaces are provided in CHIPS. This GIS should be integrated with the image processing part of CHIPS, and should be designed with the application fields, mentioned above in mind. The user-interface should match that of CHIPS, and it should contain intelligent user support.

In relation to applications in Third World countries, it is particularly relevant to ease combined use of CHIPS (incl. CHIPS-GIS) and widely used standard systems, such as ARC/INFO and IDRISI. CHIPS and ARC/INFO are being widely used in combination, both at the CSE and in Denmark.

(d) Addition of a module containing routines for the processing of 'synthetic aperture radar' (SAR) images. This includes images from both the ERS-1 and other upcoming space-based SARs and from SARs onboard aircraft, such as the Danish EMISAR (Madsen, 1991)

As mentioned in section 4.5, SAR-images differ from optical ones in several respects, and a special suite of routines will be required to allow state-of-the-art processing of such data. Through collaboration with the Electromagnetics Institute (EMI), The Technical University of Denmark, which has great experience in the processing of SAR-images, it will be possible to include a 'SAR-module' in CHIPS, which will both support the preprocessing and the application-specific processing of simple, multifrequency, polarimetric and interferometric SAR-data.

(c) Further development of methodologies for interpretation and classification of high-resolution images, acquired from satellite or aircraft. These additions to the presently available methodologies will include the use of objects-models, describing spectral, spatial, contextual and temporal properties of classes/objects, and the use of scale-space techniques and artificial neural nets. Also, the application of data stored in a GIS in the interpretation or classification process will be supported.

Such methodologies are relevant when applicating high resolution data both in Africa and in Denmark. In relation to the CSE, the development will be particularly important in ongoing and future land cover and forest mapping activities, and in Denmark the methods will be applicable both to crop identification and nature type monitoring.

(f) Establishment of a training package, including the CHIPS software in the planned platform independent version, running on very low-cost hardware. User-friendly on-line help- and advice facilities, a user manual (in English and French), a text-book, introducing the basic theory of satellite image processing, and an exercise book with sample data will be available.

This package will make CHIPS easily applicable to training courses both at universities, in international training centers and in private companies.

## Conclusion

Technological development in the field of computer hardware and software has made it realistic to make facilities for satellite image processing readily available to researchers and 'end-users' of remote sensing data, as 'desktop systems'. This will allow these data sources to become far more widely applied in many fields and contribute to overcome the apparent underutilization of remote sensing techniques. This is particularly true in the case of NOAA AVHRR and similar 'meteorological' satellite data, which may be received locally at low cost, and which have important environmental and agricultural applications, not the least in the Third World. CHIPS has been designed as a means of furthering this development.

Once the use of remote sensing techniques for environmental monitoring becomes more widespread, e.g. in Africa, the need for validating, and probably standardizing, the methodologies applied by many small institutions will rise. The activities of the OSS aim at carrying out such validation and standardization, and the choice of CHIPS as the software basis for OSS-activities in Africa will be a great challenge to CHIPS development efforts.

In a Danish context, the combined use of remote sensing data from satellite and aircraft and other spatial data, stored in GISs, will probably increase very substantially in the next few years. As major Danish institutions, involved in practical application of satellite data at present, utilize CHIPS in combination with GISs, there will be a substantial interest in further development of the relevant CHIPS-modules, not the least those used in land cover mapping and the proposed 'CHIPS-GIS'.

In general, direction of the development of CHIPS has been and will continue to be determined by requirements of users, e.g. in-house research projects or the CSE. As major users will tend to diversify with respect to the type of computer hardware and operating systems used, development of a 'platform-independent' CHIPS version is of critical importance, and considerable efforts will be invested in this task.

## Summary

CHIPS, a software system for satellite image processing and analysis has been developed at The Institute of Geography, University of Copenhagen, in the period 1985 to date. Background, philosophy and objectives of this development effort have been briefly presented. In recent years emphasis has been put upon the development of methodologies for remote sensing of environment and agriculture in Third World countries. This includes both land cover/use mapping using high resolution satellite images and application of NOAA AVHRR data. This paper has given examples of research applications of CHIPS within different fields. CHIPS differs from most other systems for satellite image analysis, as it is developed in a scientific environment, where research in various fields defines demands for the image processing system. It is important to emphasize how requirements, defined by ongoing and future research, affect the contents and development of CHIPS. This will be illustrated by several examples of ongoing research at IGUC and elsewhere. The presented examples included use of SPOT, Landsat and ERS-1 SAR data for land cover mapping in Denmark and Third World countries, and monitoring of agroclimatic parameters, vegetation, crops and bush fires based on NOAA AVHRR data. Technological development in the field of computer hardware and software has made it realistic to make facilities for satellite image processing readily available to researchers and 'end-users' of remote sensing data as 'desk-top systems'. This will allow

these data sources to become more widely applied in many fields and contribute to overcome the apparent underutilization of remote sensing techniques. In general, direction of the development of CHIPS has been and will continue to be determined by requirements of users, at the IGUS or the CSE. Since major users will tend to diversify with respect to the type of computer hardware and operating systems used, the development of a 'platform-independent' CHIPS version is of critical importance, and considerable efforts will be invested in this task.


## Acknowledgements

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