Knowledge-Based Interpretation of SAR Imagery

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Abstract

The Elektronik-System-GmbH (ESG) is currently developing a system for knowledge-based interpretation of airborne and satellite digital imagery employing off-the-shell hardware and software components.

The first prototype shall be used to transfer knowledge acquired from visual interpretation of airborne SAR data to computer assisted classification of digital SAR signatures.

In order to apply the necessary procedures to SAR images during the process of knowledge-based interpretation, the "EASI/PACE" software system from "PCI Inc." has been selected as the standard toolbox providing all basic tools for image manipulation.

The present software development at ESG aims at the implementation of the existing knowledge representation which correlates the "real-world objects" (i.e. objects to be detected and classified) with their corresponding Radar signatures. For this task, "PROKAPPA" has been selected, a C-based object-oriented software development environment from "Intellicorp".

The paper describes the major hard- and software components of the knowledge-based system prototype, the process of knowledge acquisition, the structure of the data base with its derived objects and rules (representing the problem domain) and the method used for interfacing PCI's software tools to the knowledge-base implemented with PROKAPPA.

1. Introduction

Despite fast image processing workstations, the interpretation of SAR images is still a very time consuming task. It requires highly specialized personnel. Only a very small group of experts has the skill required for a reliable SAR interpretation.

The requirements of the users concerning a modern, high-performance interpretation station are manifold. The high volume of SAR data generated by spaceborne sensors such as ERS-1 has to be analysed in a short time. Dealing (for example) with time series investigations, it is highly desirable to achieve a consistent interpretation result even in the case that various SAR image analysts with different interpretation behaviour are involved.

A new approach may be, to assist the analysts by means of a knowledge-based interpretation. Knowledge-based interpretation of satellite data concerning recognition and classification of objects means the removal or at least the reduction of uncertainties regarding the classification of objects. Furthermore, it means that the interpretation of an object is based upon information regarding the object environment and its location compared to similar objects. The knowledge of the expert, which is used to reduce the search space for the object classification, has to be prepared for the system in form of facts and rules.

Very often, a lot of interpretation work is just routine. By implementation of standard interpretation procedures on a knowledge-based system, the experts can concentrate on new features requiring human intelligence.

In a first step, the feasibility of such a development must be demonstrated. ESG therefore decided to start with a prototype development in order to transfer some of the knowledge of an expert for visual SAR interpretation into a computer programme.

Image Processing Software

The EASI/PACE (Engineering Analysis and Scientific Interface/Picture Analysis, Correction and Enhancement) software system from the Canadian company PCI Inc. has been selected by ESG as the most suited software package providing a complete range of digital processing modules for geoscience application.

The software is designed around an open architecture. Large parts of its source code is available, the database (which has virtually no limitations on the image size), is published and the software runs on a wide variety of operating systems, CPUs and displays. The software combines in a loosely coupled structure a X-Window based complete user environment, an extensive toolbox of independent executable files (application programmes for image processing and analysis of remote sensing data) and as the connecting link a parameter file on disc allowing parameter data storage by EASI and data access by PACE.

The modular software structure and the extensive application package which provides a basic set of programmes for radar data analysis, were the main drivers for ESG to select PCI's EASI/PACE.

Expert-System Software

PROKAPPA, a C-based object-oriented software development environment from Intellicorp Inc. has been selected by ESG as the most suited software package for the SAR image interpretation prototype. It is used to create the objects which represent the so called problem domain. PROTALK, a complete general-purpose programming language specifically designed for use with PROKAPPA, is itself part of the PROKAPPA software and provides a complete backward and forward-chaining rule system for developing knowledge-based programmes.

The objects, which represent the problem domain, are entities containing data and behaviour. Their properties are described using so-called slots. Besides single or multiple valued slots which are used to store values such as symbols, strings or numbers, method slots are used to implement the behaviour of an object.

PROKAPPA provides a multiple inheritance scheme and three major types of monitors to check for slot value changes. Furthermore, PROKAPPA code translates directly into ANSI C. Thus, the result of the object-oriented software development is a C-programme.

Hardware System

For advanced software development and image processing, ESG decided to purchase a high-performance SPARC (Scalable Processor Architecture) workstation with UNIX operating system.
In detail, the SUN 4/470 GX from SUN Microsystems was chosen. The basic configuration has 32 MB main memory, 669 MB internal hard disc, a 644 MB CD-ROM drive, a VME-bus interface with 12 slots and a 19" colour monitor. Peripherical devices such as a 1,2 GB disc for image data storage and a 2,5 GB Exabyte for back-up and data storage are connected via SCSI.

The basic system has been upgraded in the meantime for an operational dual-monitor configuration. SUN's visualization accelerator (VX-board) has been integrated using the VME-bus interface, a second 21" colour monitor has been installed for displaying the VX-board generated 24 bit colour images.

Prototype Development by ESG

The prototype development covered several engineering aspects. A major topic concerned the systems engineering aspects regarding software and hardware integration (dual-monitor operations, VX-board integration and usage, process communication between PCI and PROKAPPA etc.). Another topic concerned the implementation of the knowledge-base and the development of additional programmes and procedures to be used for the radar image interpretation task.

Subsequently, the SAR image interpretation domain-knowledge and its implementation will be described in more detail.

2. Domain Knowledge as Key to SAR-Signature Classification

Algorithms classify digital image signatures automatically have first been developed for application to remote sensing in the optical range of the spectrum, and are thus traditionally based on spectral signatures of surface elements imaged. Tools change and additionally tools, which classify statistically the image, have been designed and used. These include various filter algorithms and mathematical approaches to separate simple textures. For image enhancement and classification of SAR image signatures, those algorithms derived from multispectral image analysis in the optical range have shown to act imporperly.

SAR image signatures have to be treated as complex compositions of different types of signatures:

- On average uniform grey value image areas, textured by speckle only
- Grey value gradients across the image
- Regular and irregular textures, again composed of patterns of individual radar returns of single natural and man-made targets of largely varying brightness, size, shape, and pixel statistics across each target
- Background signature to textures, by itself composed of "uniform" grey value, or secondary texture respectively.

Separation of SAR image signatures - being a pure representation of radar reflectivities of surface elements - traditionally has been performed as interactive visual image interpretation.

The experience of a human interpreter on different SAR image signatures is the presupposition to perform the different steps of image interpretation: directed by the given task - fast detection and interpretation of specific targets, or a complete image analysis -, he either extracts targets by form and brightness from image backgrounds, then disregards all of the remaining target-returns that do not meet his experienced form features, and interprets the remaining returns for target architecture and type. For the second task, he segments the image into areas of what the human vision "classifies" as "uniform" in brightness and texture, interprets the different image segments as landforms and covers, and then analyses individual returns, often to verify the prior classification of landcover.
The human interface thus performs a step-by-step analysis procedure, often unaware of the systematics in each step of analysis. Such steps can be defined as algorithms and be implemented as a guiding menu to interactive SAR image analysis, and secondly be turned into semi-automatic classification modules. To be added to this first step towards a knowledge based image classification system are specific SAR image variabilities driven by system parameters like imaging geometry affecting radar reflectivity of surface elements and thereby local image statistics, e.g..

Software tools have been designed, tested and described to aid local image correction and interactive feature extraction.

Following target detection and experience based on initial recognition, the human interpreter then uses context information to classify a target on a SAR image finally. The experience of the human interpreter, complemented by his ability to combine features and interpretation rules to interpret SAR signatures in a series of analysis iteration forms, is the domain requirement for a knowledge based digital SAR image analysis software.

The steps of context interpretation have to be formulated into features and rules to form another shell of a knowledge based SAR analysis system. This can be described for a single target example:

A bridge as a radar return resembles a short linear signature on a SAR image. The task is:

1) to detect all possible target returns within the range of bridge signatures against the SAR image background
2) to recognize a target as being a bridge with a high degree of confidentiallity
3) to verify the recognition result from another set of context interpretations as target classification.

Image manipulation software tools lead to step 1 of "Target Detection" from the variety SAR image signatures. The pixel statistics along the edges of the potential bridge signature verify the target as being hard surfaced and thus man-made architecture. Step 2 and 3, "Target Recognition" and "Target Classification" employ both detailed analysis of cross-target pixel statistics and features and rules of context interpretation: a "leading across" condition complemented by demand for on-connecting linear extensions on both ends of the actual potential bridge signature allow the recognition of the target as a "bridge". Classification then includes the identification of the bridge being a "road bridge leading across a river". In this case the two linear elements of "leading across" and "on-connection" have to be identified as a river and a road by themselves according to signature cross section brightness, then forming the context information to again classify the bridge.

Within a knowledge based SAR image analysis system, radar cross sections (RCS) of relevant target categories form a data base to initially define targets by the signature brightness. The knowledge base, derived from the domain requirement, first provides the analysis basis for pixel brightness distribution patterns being typical for specific target architectures, and second, the context information to separate a given target from others (represented with similarity on the image). Then third, to classify the target in detail. A knowledge base has to be implemented as "objects" describing target signatures, as a set of rules to separate targets into categories. This last step also has to account for target signature variability due to SAR imaging geometry, and due to the target-surface-interface RCS variations. Thus, this step is a crucial factor within the knowledge based interpretation system: the human interpreter's experience compensates for these target specific signature variations with changing imaging parameters. The resulting degree of freedom in signature expression of the same target type for a knowledge based system has to be defined as rules turning the interpreter's experience into individual shells or the knowledge base. The same applies to terrain feature characteristics to be interpreted along with the actual target signature as the target surrounding. Specifically affecting the target signature through alternations of the target-surface-interface RCS of any given target.

The three steps Target Detection, Recognition, and Classification within a knowledge based system are performed along three corresponding levels of interactive, semi-automated digital SAR image analysis. The signature of a given target has to be weighted against objects of the implemented knowledge base on each of the three system levels. Applying the pre-defined rules of the knowledge base, the target is successfully classified through iterative steps.

Being an open system, the knowledge base is implemented in a way open to adding further rules and objectives as the domain requirement grows. Often, neural networks are named as an ideal tool to classify radar image signatures because of such a system being able to "learn" from variations of signature expressions. We feel, however, that such independence of a neural network software would not allow successive implementation of a human interface experience at the present stage. Although neural network software may fulfill the needs of individual pixel pattern recognition processes. And thus be well integrated as module to the overall system architecture. We therefore favor a knowledge based algorithmic design for the overall shells of our SAR image analysis system. Furthermore, starting with a knoweldge based system, the domain requirement can also be employed to design more effective software tools and automated image adaption tools to aid interactive analysis processes to start with. Automated classification algorithms of pixel patterns of target returns are open to fast changes with new domain knowledge in a defined way with a knowledge based system. Such tools offered on a menu drive system during interactive analysis. May be used even by inexperienced interpreters to verify each step of interactive analysis procedure.

Therefore, starting from a simple interactive analysis menu, a knowledge based SAR analysis system will grow along with its knowledge base derived from increasing experience of the human interface as "Domain Requirement" to develop an increasing series of automated steps of signature classification, implemented as modules within an iterative computer driven SAR image signature identification and classification system with the operator finally in a controlling only.

3. Implementation of the Domain Knowledge

3.1 Process of Knowledge Acquisition

The knowledge acquisition for the prototype for SAR-signature classification has been done in a three day workshop with a domain expert. The workshop focussed on bridges as targets to be classified in a SAR-picture. The process of detecting targets on a SAR-picture contains the following two major parts of knowledge:

- The special properties of the target as a signature on a SAR-picture
- The process of target identification itself (how would the expert detect targets?)

The first part is called the domain knowledge which is modelled in the domain layer. In this layer all the 'static' knowledge is stored. The second part handles the inference knowledge which is stored in the inference layer. This layer contains all the possible inferences and the dynamic knowledge.

Both layers of knowledge are interleaved, for the properties of the target have influence on the process of identification and vice versa the identification determines the relevant properties.

3.2 Structure of the Knowledge-Base

Domain layer
The knowledge modelled in the domain layer contains the following major categories of objects:

RealWorldObjects:
This object class contains all the objects which exist in the real world and which are relevant for the problem of classification of targets in a SAR-picture. These are for instance bridges (with instances trainbridge, riverbridge, etc.) and waterlines like rivers, channels, ditches, etc. Each object is defined by several attributes and relations to other objects.

Signatures:
This object class contains all different kinds of signatures which can appear on a SAR-picture. The class models the structure and form of a signature, not the brightness and intensity, for these are depending on the way the 'real world' object reflects the radar (see ObjectType).

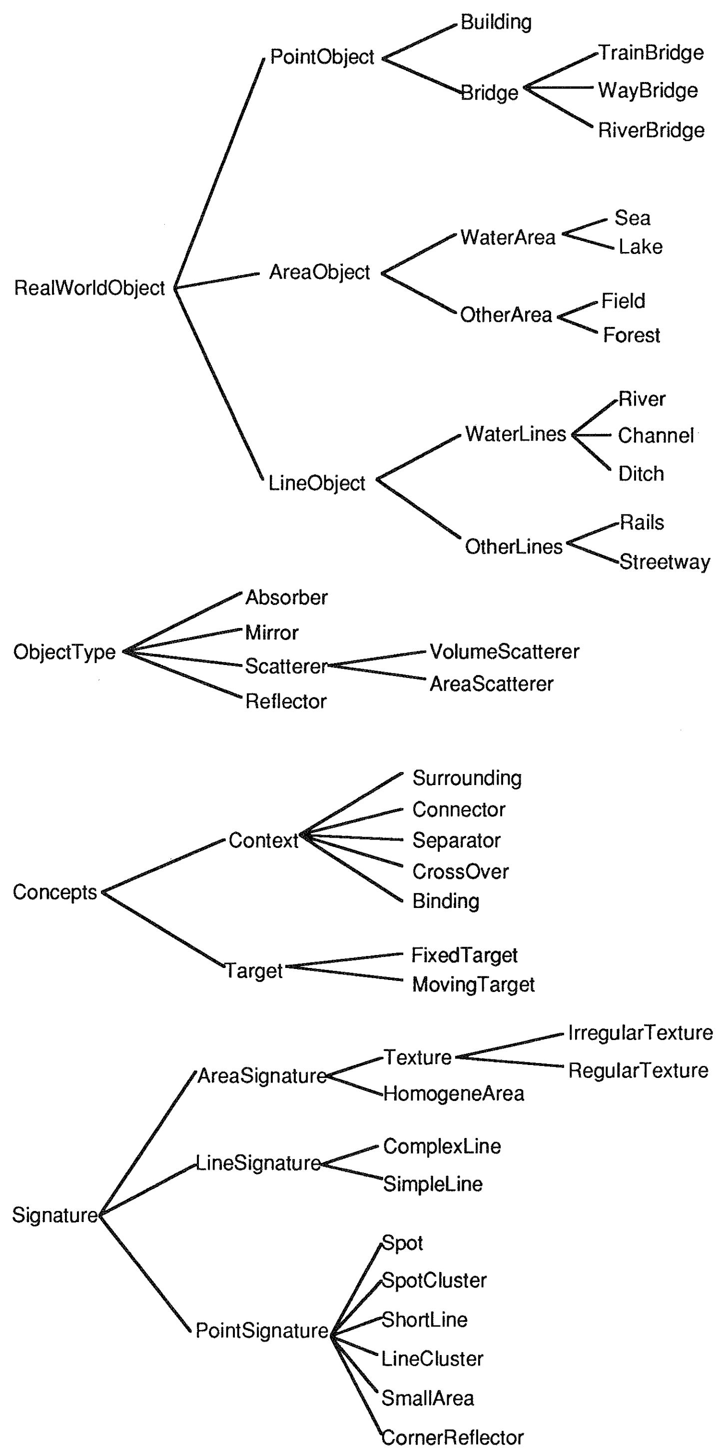

Fig. 1: Domain Layer IS-A Hierarchies

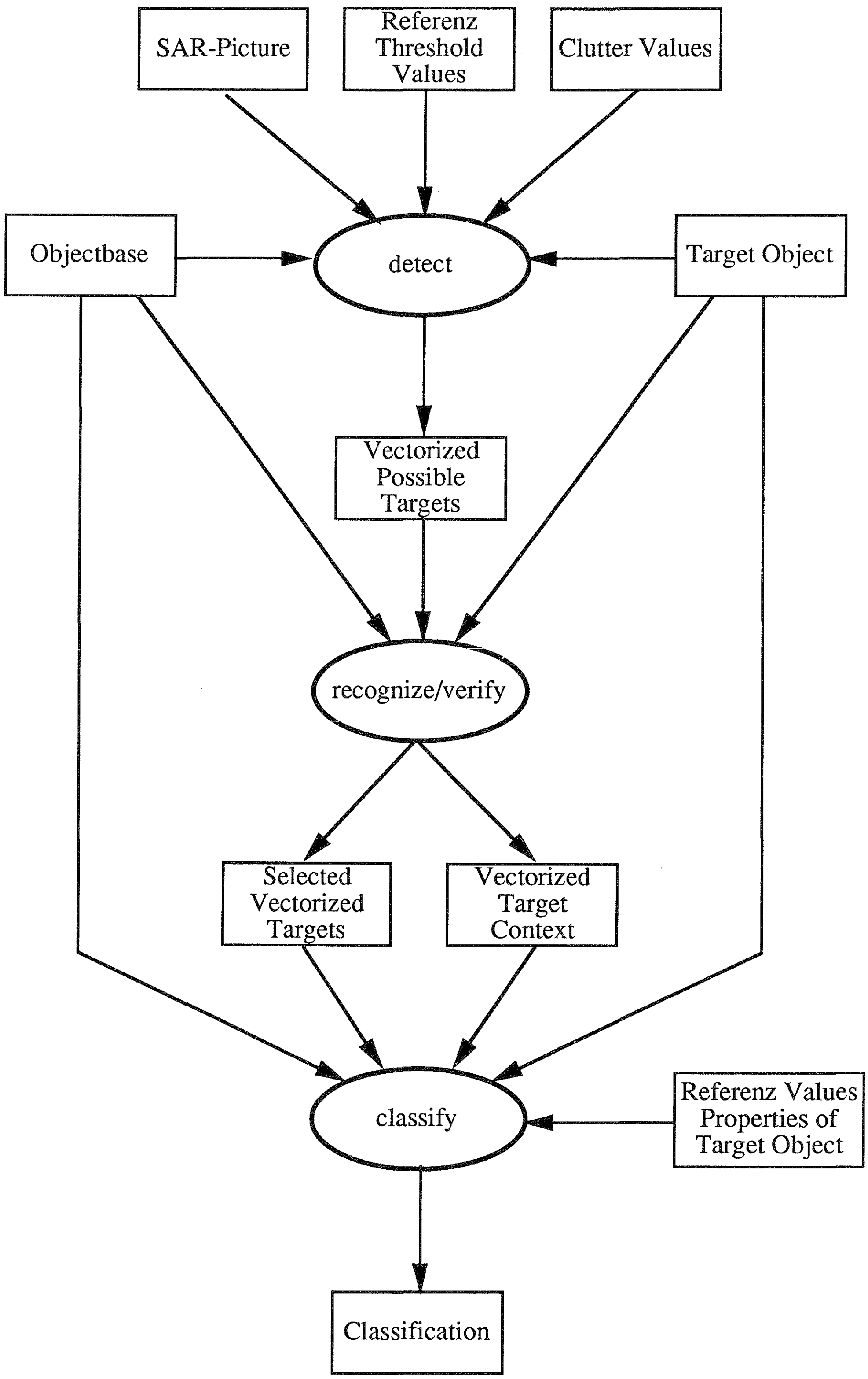

Fig. 2: Top Level Inference Layer

ObjectType:
Each 'real world' object has a characteristical way of reflecting the radar. Depending on the material and the construction, the object can absorb, scatter or reflect the radar rays. This class models the different ways an object can reflect the radar and hence how it may appear on the SAR-picture.

Concept:
This object class modells all the roles an 'real world' object can play in the classification of targets on a SAR-picture. For instance an object can be a target we look for on a SAR-picture as well as the context of another target. A bridge can be the object we want to classify on the SAR-picture and the possible context of such a bridge can be a river crossed by the bridge and a railway crossing the bridge (see fig. 1 for Domain Layer IS-A hierarchies).

Each of the noted object classes has a special attribute called Ruleset containing a set of rules which verify the defined properties of the object. A signature ruleset checks the form of the signature if it matches the special characteristics for that signature form. For instance a LineSignature ruleset will check whether the object in focus is any kind of line while the ComplexLine ruleset additionally checks the structure of the line.

Inference layer
The inference layer contains the inferences which are possible on the given domain knowledge. This layer can be seperated into two different object classes.

First metaclasses represent the information which is available at a certain moment during the classification process and second the knowledge sources represent the methods using the metaclasses and producing new ones. A knowledge source can be divided into several other knowledge sources which are called the knowledge source.

The process of classifying targets on a SAR-picture can be divided into three major phases (see also fig. 2):

Detection:
First of all the possible targets must be detected. This set of possible targets can contain several objects which dont meet the characteristics of the target in focus. To detect the possible targets the only needed information is the type of object we are looking for. From this information the system can derive using the knowledge sources, what kind of reflector type and what form of signature the user (or the system) should look for on the SAR-picture. The detected possible target should be vectorized so they can be handled easier in the further operations.

Recognition:
During the recognition phase the detected targets are checked against more specific properties of the target in focus. This is for instance the context of the target object. This additional information is used to verify or discard the possible targets. If a possible target has been verified, the context is vectorized for the classification phase.

Classification:
In this phase, which is not implemented yet, the pixel structure of both the target and its context is analysed to classify the target. The information needed for this phase can be provided by the domain layer and by databases storing information about pixel structures.

The inference layer is controlled by the task layer which defines which inferences shall be used and when they shall be used. This task layer checks the existing and produced metaclasses (existing information) and selects a knowledge source which can be run with the given information.

3.3 The Implementation Environment and Interface to EASI/PACE

The prototyp is implemented in an object oriented shell called PROKAPPA.

In this shell the domain layer and inference layer object hierarchies are defined. The knowledge sources of the inference layer which perform activities on or using the image call the image processing software EASI/PACE from PCI. These function calls are implemented in two different ways:

- Using the interactive shell EASI
  The PROKAPPA method of the knowledge source calls the UNIX system to start the EASI shell and redirects the input for this shell using the UNIX features. Any command or image processing action is redirected into the EASI shell, which interpretes and performs the action.

- Using the parameter file PRM.PRM
  The PCI library containing all functions to manipulate the PRM.PRM parameterfile is linked to the runtime shell of PROKAPPA. All parameters which are needed for the image processing action are set using these PCI library functions. The action itself is a executable file in the PCI system and is called via a system call to UNIX.

4. Conclusion

The first phase of the prototype development has been successfully concluded. The interpretation workstation works operationally in a dual-monitor configuration, several new radar image interpretation tools (mainly for LUT adaptation) have been developed, the expert system prototype guides an operator to detect an object and performs via process communication automatically the correct EASI/PACE procedures.

The internal project is now continuing with the investigation regarding the most suited Geographical Information System (GIS) (which will be the functional superstructure) and the prototype development of a customer optimized user interface.

5. References

1) PCI Inc.: "PCI Software Overview, EASI/PACE Version 5.0", September 19, 1991

2) Intellicorp Inc.: "PROKAPPA, Development and Runtime Systems", Product Description, 1991

3) J.R. Bennett & W. Geile: An Introduction to Imaging Radar and its Applications to Reconnaissance; MDA-Document for image analysis training, MacDonald-Dettwiler Ass. 1986