

Computer assisted detection and classification of possible cultural heritage sites

User requirements and conceptual design

Note no

SAMBA/11/05

Authors

Lars Aurdal, Rune Solberg, Joachim Lous

Date

May 9th 2005

Norsk Regnesentral

Norsk Regnesentral (Norwegian Computing Center, NR) is a private, independent, non-profit foundation established in 1952. NR carries out contract research and development projects in the areas of information and communication technology and applied statistical modeling. The clients are a broad range of industrial, commercial and public service organizations in the national as well as the international market. Our scientific and technical capabilities are further developed in co-operation with The Research Council of Norway and key customers. The results of our projects may take the form of reports, software, prototypes, and short courses. A proof of the confidence and appreciation our clients have for us is given by the fact that most of our new contracts are signed with previous customers.

Title	Computer assisted detection and classification of possible cultural heritage sites: User requirements and conceptual design
Authors	Lars Aurdal, Rune Solberg, Joachim Lous
Date	May 9th
Year	2005
Publication number	SAMBA/11/05

Abstract

The increasingly intensive use and modification of the landscape as a result of modern demands for efficient infrastructure and land use (agricultural production, mining, energy sources, leisure/tourism facilities) exerts growing pressure on areas and sites associated with our cultural heritage. The use of modern support technologies is imperative if such rapid changes are to be balanced against the sustainable management of this resource. This pilot project directly addresses these issues by initiating the development of a basis for a sustainable, up-to-date and cost-efficient decision-support methodology which relies upon satellite remote sensing, mapping and monitoring of cultural heritage sites.

This report contains the system specification for a prototype system that will provide computer assistance to the user when searching satellite images for the presence of possible cultural heritage sites.

Keywords	cultural heritage satellite image classification
Target group	Users and developers
Availability	Open
Project number	SAMBA/11/05
Research field	Remote sensing
Number of pages	66
© Copyright	Norsk Regnesentral

Contents

1	Introduction	8
1.1	General background and project history	8
1.2	Basic assumptions	9
1.3	Users	9
1.3.1	General archaeologist.....	9
1.3.2	Remote sensing archaeologist.....	9
1.4	Funding.....	9
2	The Software Development Process	11
2.1	Software engineering approaches.....	11
2.2	The iterative development process	12
3	Use scenarios	14
3.1	General archaeologist	14
3.2	Remote sensing archaeologist.....	16
4	User requirements	17
4.1	General archaeologists	17
4.1.1	File input requirements	17
4.1.2	Input display requirements.....	17
4.1.3	Preprocessing requirements.....	18
4.1.4	Processing requirements	18
4.1.5	Detection display requirements.....	18
4.1.6	Detection editing requirements	18
4.1.7	File output requirements	18
4.1.8	Analysis requirements.....	18
4.1.9	System requirements	18
4.2	Remote sensing archaeologists	19
4.2.1	File input requirements	19
4.2.2	Input display requirements.....	19
4.2.3	Preprocessing requirements.....	19
4.2.4	Processing requirements	19

4.2.5	Detection display requirements.....	19
4.2.6	Detection editing requirements	19
4.2.7	File output requirements	19
4.2.8	Analysis requirements.....	19
4.2.9	System requirements	19
5	Use cases	20
5.1	General archaeologist use cases	26
5.2	Remote sensing archaeologist use cases.....	47
6	Conceptual design.....	53
6.1	Introduction.....	53
6.2	System operation.....	54
6.3	File input/output.....	55
6.3.1	Satellite file input.....	56
6.3.2	Field mask input.....	56
6.3.3	Detection input	56
6.3.4	Detection output.....	56
6.4	Satellite image display.....	57
6.5	Field mask display	57
6.6	Detection display	57
6.7	Preprocessing algorithms.....	58
6.8	Detection algorithms.....	58
6.9	Analysis algorithms	60
7	References	61
8	Appendix: Simulated screen snapshots	62
8.1	Display of input satellite image.....	62
8.2	Display of field polygons on top of satellite image	63
8.3	Classification output and list of detections	64
8.4	Retained classifications	65
8.5	Zoom and contrast enhancement of detection.....	66

List of abbreviations

CHDS	Cultural heritage detection software
GB	Gigabyte
GIS	Geografisk informasjonssystem, Geographic information system
GUI	Graphical user interface
MOS	Minimal Operational Sub-system
NIKU	Norsk institutt for kulturminneforskning, Norwegian institute for cultural heritage research
NOK	Norske kroner, Norwegian crowns
NR	Norsk Regnesentral, Norwegian Computing Center
NRS	Norsk Romsenter, Norwegian Space Center
RA	Riksantikvaren, Norwegian Directorate for Cultural Heritage
ROI	Region of interest
SWE	Software engineering
TBD	To be defined
UCL	University College of London
UP	Unified software development process

1 Introduction

1.1 General background and project history

It is generally recognized that the increasingly intensive use and modification of the landscape resulting from modern demands for efficient infrastructure and land use (agricultural production, mining, energy sources, leisure/tourism facilities etc.) exerts growing pressure on cultural heritage in the landscape.

In recognition of this, the Norwegian directorate for cultural heritage research (Riksantikvaren, RA), in collaboration with several other research institutes (The Norwegian institute for cultural heritage research, NIKU, The Norwegian Computing Center, NR, and The University College of London, UCL) has undertaken a project with the overall aim of developing a cost-effective method for surveying and monitoring cultural heritage sites on a regional and national scale.

Given the enormous costs of surveying the tracts in question by traditional field work, alternatives must be sought. One possible approach is through the use of satellite images. Current experience with the manual analysis of these images indicates that cultural heritage sites with no apparent above ground manifestations still may be observable in such images. The costs of acquiring and analyzing such images is not negligible, and it is not reasonable to assume that such an approach can entirely replace traditional field work. Nevertheless, it is clear that if the potential of satellite images for detecting such sites could be clearly established, this would be an invaluable addition to the traditional methods that would be very useful in monitoring this important resource on a regional and national scale.

The work has so far been split in two main directions. One is the manual analysis of satellite images followed by chemical profiling of sites observed in these images in order to gain experience as to how cultural heritage sites really manifest themselves in satellite images. The other main direction of work is the development of automated methods that will eventually be useful in detecting possible cultural heritage sites. Previous work in the project is reported in [1] and [2]. The work on automated detection of cultural heritage sites has so far resulted in a preliminary study of possible methods that could be applied in such detection.

In order to apply the methods and algorithms described in this previous work on a larger scale and to make end user involvement possible at an early stage in the development process, a functional prototype implementing these (and possibly other) methods must be made. The purpose of this software is to provide computerized assistance to the operator in the analysis of satellite images. In particular the software is expected to mark and rank possible sites for further inspection by the operator. **This report contains the user requirement specification and conceptual design for such a prototype system. For brevity we will refer to the software to be developed as the Cultural Heritage Detection Software, CHDS.**

1.2 Basic assumptions

The working assumption is that cultural heritage sites with no visually apparent manifestations above ground will be detectable in satellite images due to alterations in the spectral signature of the bare soil or that of smaller plants growing out of the soil. The project is currently limited to sites located in agricultural fields, detecting such sites in forests is expected to be a much more complicated problem. We therefore assume the availability of masks delineating agricultural fields.

Cultural heritage sites obviously encompass sites of very different age, type and size. We will assume that the satellite images we use have a resolution (spatial and spectral) relevant to the type of site studied. Given Norwegian conditions, it seems that a resolution of 2.5m or better is required [1], [2].

1.3 Users

Although there are many possible users of the CHDS we will distinguish between two main types of users, the general archaeologist and the remote sensing archaeologists.

1.3.1 General archaeologist

The general archaeologist user will typically work in a **local county administration**. These users will normally have their basic education in the fields of archaeology and history. They will use the CHDS in a result oriented fashion where the main aim is to produce maps of possible cultural heritage sites. They have much local knowledge and are typically involved in the counties administration, protection and excavation of cultural heritage sites. These users are not necessarily very familiar with sophisticated GIS and remote sensing software.

1.3.2 Remote sensing archaeologist

The remote sensing archaeologist user may work in a **local county administration, in national administrative bodies such as Riksantikvaren or in universities or research institutes such as Norsk Institutt for Kulturminneforskning**. These users will also normally have their basic education in the fields of archaeology and history, but might have a technical background at least through their work experience. These users are very familiar with GIS and have some knowledge about remote sensing. They will use the system much as does the general archaeologist, but will go to greater lengths in exploring each particular site not only from an archaeological point of view, but also from a remote sensing viewpoint. These users will therefore need more analysis tools in order to analyze the underlying remote sensing data.

1.4 Funding

The project is funded by The Norwegian Space Center (NRS) (<http://www.spacecentre.no>) and the Norwegian Directorate for Cultural Heritage (RA) (<http://www.riksantikvaren.no>). The

University College of London and the Norwegian Computing Center (www.nr.no) all contributed match funding.

2 The Software Development Process

Development of successful, complex software systems to be applied by many users, often representing rather heterogeneous user requirements, is a challenging task. Decades of trials and errors combined with scientific research on software development methodology have resulted in well-documented approaches that significantly increase the chances of developing successful systems.

The current project is rather small compared with most software development projects. However, there are elements of best practices for software development that should be taken into account here as well. The following sections give a brief introduction to the most important elements of iterative and incremental software engineering.¹

2.1 Software engineering approaches

Software engineering (SWE) research has proposed many tools, methods, and techniques for improving the software development process. It has long been recognized that the linear “waterfall” model of *requirements* → *design* → *implementation* → *testing* → *evaluation* simply does not work in practice for complex systems. The most successful models suggest an approach to closely incorporate the evaluators and the developers by taking a more incremental approach. This incremental approach seeks to implement a scaled-down version of the system as soon as possible (its skeleton) and then build the appropriate functionality in increments onto that skeleton. During each increment, the system is evaluated and modifications can be implemented while the development proceeds rather than after final implementation. The result is the development of large-scale systems with greater user satisfaction, better working quality, and providing system managers with an improved ability to estimate production cost and delivery times.

A solution to the known problems of traditional large-scale software systems engineering is the Unified Software Development Process (UP) [3]. The UP approach concentrates on three areas:

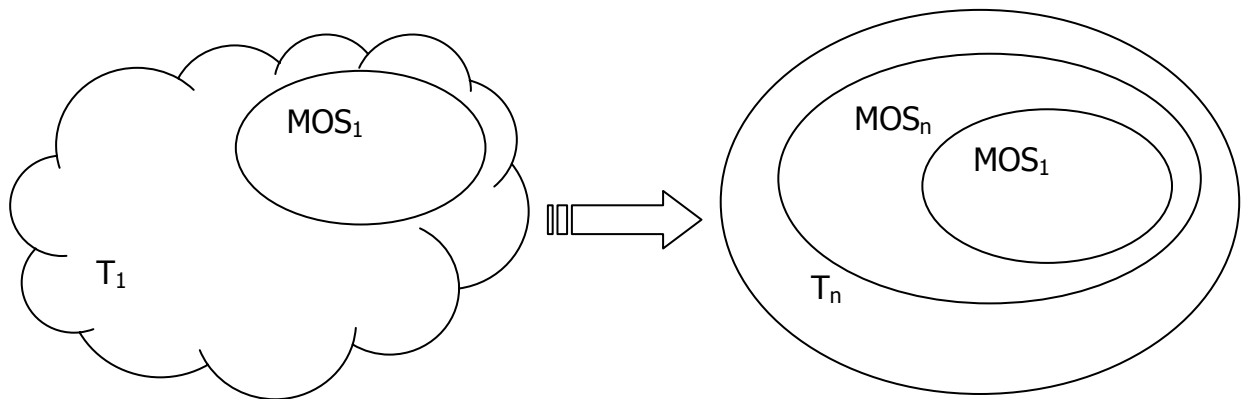
- Use-case driven
- Focus on architecture
- Iterative and incremental development

This process gives the system development much better ‘visibility’ to enable modifications and improvements based on user-driven evaluation. Furthermore, the UP improves the ability to specify important issues such as time-to-delivery and development costs. It also improves the ability to deal with changing requirements, which is a serious problem in large-scale development and research-based projects.

¹ We gratefully acknowledge the indirect contribution of Jason Baragry, former employee of NR, in writing this chapter.

2.2 The iterative development process

Changing requirements is destructive to development even when change is inevitable, and no matter how well change is managed. Thus, an iterative process of gradual refinements to the requirements itself should be devised and implemented. One scenario is to specify the requirements for a well understood, minimal and operational sub-system (MOS_1) within the overall “vague” target system (T_1) and revisit/refine the requirements in iterations after designing and implementing the MOS at each iteration.



At each iteration, the MOS (the well-understood and specifiable sub-system) will build upon the previous MOS and will cover more of the target system, uncovering requirements and issues along the way, thus making it possible to specify the target system better and better.

At each requirements/design/implementation iteration, the requirements for the current MOS will then be possible to freeze against changes. Still, there will be changes in requirements for the target system, and (to a lesser degree) for the current MOS also. To avoid or reduce the impact of changes in ongoing work, a two-tier change management scheme should be devised and implemented. This implies that all change requests (to current MOS, the target system or other iterations) are logged and pre-evaluated by a separate team (typically by requirements engineering, project management and test management teams, often termed the Change Control Board (CCB)) regularly. **Changes that do not concern the current MOS will be assigned to future iterations. Only changes that belong to the current MOS will involve development staff, who then evaluates the impact of these changes and help re-plan current activities (and hence the current project plan).**

Projects involving many users, often also geographically spread, add an additional constraint of communicating unambiguously across the distributed virtual team members/sub-groups. This is a contradicting requirement, requiring a more linear (non-situated) planning and execution model.

A possible solution to this kind of complexity (and the need to reduce uncertainty in communication across borders and cultures) is sketched below:

- To employ well-described mock-ups in requirements and design (sketches showing what the end product may look like and how it will behave approximately etc.). It may be recommended to go through a phase where a functional (maybe throw-away) prototype is developed to discover the requirements. This will reduce ambiguity in communicating across the virtual team and will increase chances to capture requirements.
- To evolve a prototype through to the end product as a technique in general. This will help discovering and incorporating technologies and results of research, especially if change can be managed as described in the previous section. Full-scale prototyping is sometimes impossible or impractical, especially in software that is highly distributed, and if the team does not have control over some components, or when some components simply do not allow for experimenting. In such cases a prototype of sorts may still be possible if problem components can be simulated.

3 Use scenarios

In order to define the user requirements for the system we will begin by describing use scenarios. The use scenarios will make it possible to see how the different users will use the CHDS in a larger setting. It also makes it possible to see how the CHDS can (and cannot) contribute in the users work tasks. Based on the use scenarios we will derive user requirements, these are detailed in the next chapter.

3.1 General archaeologist

Along the Lågen river in Vestfold County there are many known cultural historical sites in agricultural fields. Some of these have been known to archaeologists for a long time and are currently being excavated. This is done by field archaeologists associated with the Vestfold county administration. Although all excavation efforts are focused in one particular field, it is considered to be of interest to examine other fields for visible traces that could indicate the position of unknown cultural heritage sites.

It is decided that an analysis is to be made of images of the interesting agricultural fields using local human and computer resources. The personnel assigned to the task are general archaeologists with detailed field knowledge of the study area. The local computer resources comprise ordinary desktop computers running Windows based operating systems. In addition to ordinary office software these computers have GIS systems such as ArcView installed. For this purpose a Quickbird Satellite image covering the interesting study area has been acquired. This image comprises a panchromatic image with a resolution of 0.6 meters and 4 spectral bands (red, green, blue and near infrared) with a resolution of 2.4 meters. The image is georeferenced to high precision.

As part of the local administrative GIS tools the County owns the digital version of the economical (1:5000) maps made by the Norwegian Mapping Authority. In particular the mask for agricultural fields is at the disposal of the project team.

Using the Cultural Heritage Detection Software the image is opened and displayed to screen. The screen display might look as in figure 1 in the appendix providing navigation and zoom capabilities. Using the navigation tools an initial visual inspection of the panchromatic image is performed revealing the presence of numerous interesting sites.

Analyzing all the interesting fields in this fashion is a large and tiresome task. Using local GIS software the agricultural field mask is loaded. A selection is made among all the fields and only those in reasonable proximity to Lågen are retained. The result is saved to file. Loading this modified agricultural field mask using the Cultural Heritage Software it becomes possible to do an automated scan for interesting sites located in the specified agricultural fields. Having loaded the field mask it is displayed for inspection, the screen display might look as in figure 2 in the appendix.

Having loaded the panchromatic satellite image along with the modified field mask, an automatic scan of the given fields is initiated. Upon termination of the scan the possible sites

are displayed. The screen display might look as in figure 3 in the appendix. As before the display provides navigation and zoom capabilities, in addition a list of all the detections and a suggested interpretation (grave, house, etc.) is displayed. The detections will be local regions that have shapes and intensities that make it reasonable to assume that they may be representative of cultural heritage sites. The suggested interpretation will be based on each detections size and other shape parameters. The system is designed in such a way that its threshold for including a region in the list of possible detections is low, this is done in order to reduce the risk of missing possibly interesting sites. For this reason the result must be scanned and sorted by the general archaeologists. Clicking on each detection in the list of detections takes the focus of the display to that site. Having decided whether a site should remain on the list or not, it can be deleted or, if necessary, modified as the operator pleases. If necessary the operator can add sites in a fully manual fashion if the system has omitted a possible site. After a manual deletion of detections the screen display might look as in figure 4 in the appendix.

Having decided upon what detections to keep the result can be saved to file and eventually reloaded in order to continue the analysis at a later point. The result can also be saved to a file format compatible with local GIS software. This makes it possible to display the detections on top of the different layers composing the economical maps and to analyze possible sites in relation to terrain and infrastructure features.

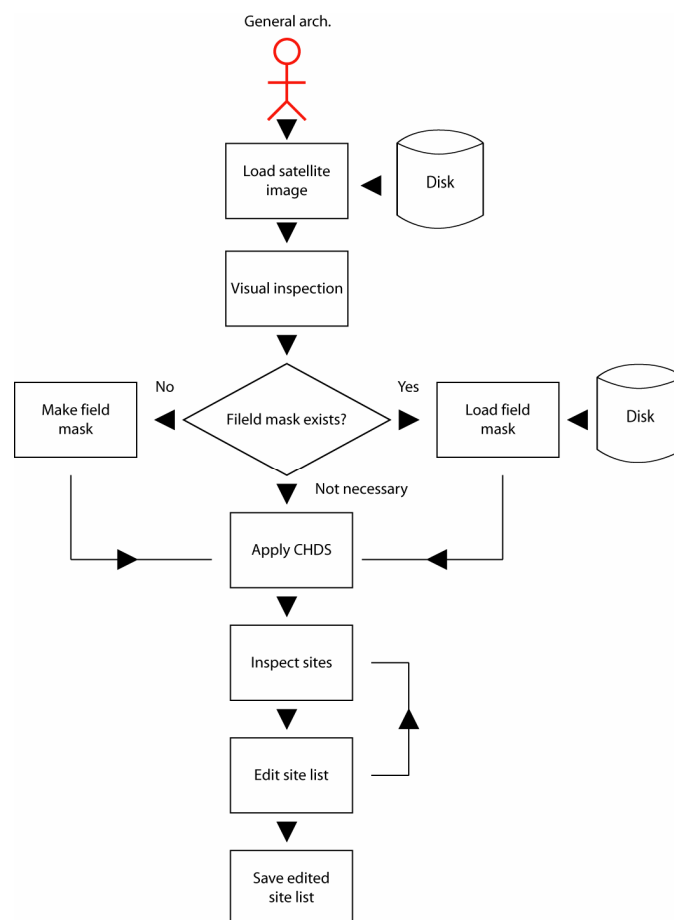


Figure 1: The work flow of the general archaeologist user.

3.2 Remote sensing archaeologist

After the general archaeologists have found possible sites along Lågen as described in section 3.1, a careful inspection of the sites is carried out. Some turn out to correspond to known and inventoried cultural heritage sites, most of the sites however are previously unknown. It is expected that many of the sites have nothing to do with the local cultural heritage. In an attempt to distinguish between truly interesting sites and those that can safely be ignored, an in-depth analysis of the available remote sensing data is performed.

For this purpose an archaeologist specializing in remote sensing is engaged in the project. In a first attempt to distinguish between interesting and uninteresting sites a spectral analysis of the detections is carried out. This consists in using the CHDS to analyze the values of the different spectral bands in order to look for patterns. The remote sensing archaeologist also suggests using different preprocessing options (for instance noise and plow furrow removal) available in the CHDS to see if this changes the detections. In an attempt to further narrow down the list of detections it is decided that the criteria the CHDS uses for including or excluding sites should be adapted to match local conditions better. In particular, remains of houses are found to have deviating forms in Vestfold County. Working in close cooperation with remote sensing experts the CHDS is modified so as to work optimally under the local conditions in Vestfold County. This modification is done by editing the ground truth description used by CHDS. This consists of a list of shape and size criteria that recapitulate what is known about cultural heritage sites observed in satellite images. Having tried these approaches the list is narrowed down and consolidated.

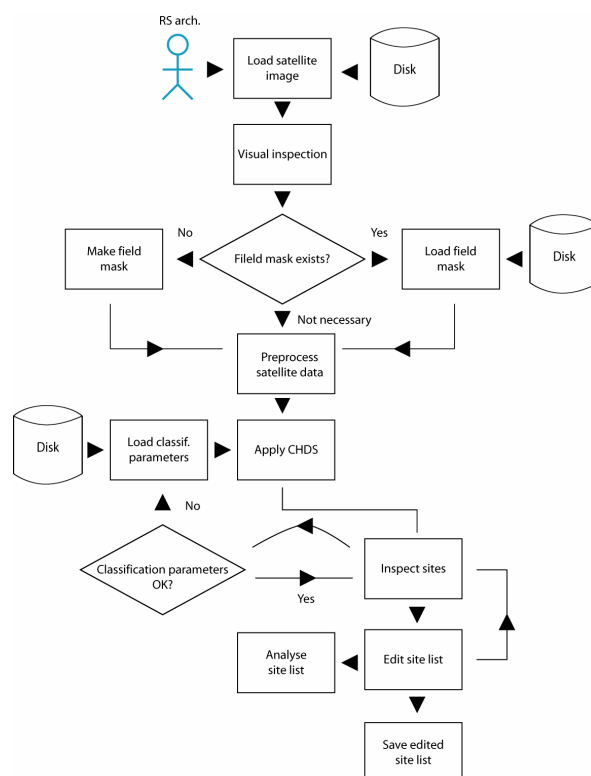


Figure 2: The work flow of the remote sensing archaeologist user.

4 User requirements

The following sections summarize the user functional and system requirements. The **user functional requirements** are the requirements imposed on the system by its final users concerning the functionality provided by the system. This is distinct from the **user system requirements** which are the requirements imposed on the system by its final users concerning the hardware and software environment in which the system must be operational.

The user functional requirements will be expressed in the user's terminology, thus making it possible for the end users of the system to fully comprehend all the imposed requirements. This makes it possible for the end users to verify that all user requirements are met and furthermore it makes end user interaction in the specification process possible.

The user system requirements summarize the requirements imposed on the system by its final users concerning the hardware and software environment in which the system must be operational.

As for the user functional requirements, the user system requirements will be expressed in the user's terminology, thus making it possible for the end users of the system to fully comprehend all the imposed requirements.

4.1 General archaeologists

4.1.1 File input requirements

1. The CHDS must be able to read all satellite image formats that are relevant for the project. Currently, the relevant formats are Quickbird and Ikonos satellite image formats, but it is highly desirable that more formats can be read. The input satellite image files must be georeferenced to a standard geographic reference system.
2. THE CHDS must be able to read field masks in the form of SHAPE files, the de facto standard format used by the ArcView GIS system. The input field mask files must be georeferenced to a standard geographic reference system.
3. The CHDS must be able to load previous cultural heritage site detections in the form of SHAPE files.

4.1.2 Input display requirements

1. The CHDS must be able to display a satellite image to screen.
2. The satellite image display must allow for navigation in large satellite images.
3. The satellite image display must allow for zooming in satellite images.
4. The satellite image display must allow for contrast and brightness modifications.
5. The CHDS must be able to display a field mask.

6. The field mask display must allow for navigation in large field masks.
7. The field mask display must allow for zooming in field masks.
8. The CHDS must be able to display a field mask on top of a displayed satellite image.
9. The CHDS must be able to display the geographic position of a selected point either in a satellite image or in a field mask.

4.1.3 Preprocessing requirements

None

4.1.4 Processing requirements

The CHDS must be able to perform the following processing operations:

1. Site detection. A site detection comprises a search for site candidates followed by a classification of these.

4.1.5 Detection display requirements

1. The CHDS must be able to display a list of the detection results including the systems interpretation (e.g. grave, building etc.) of the detection.
2. The CHDS must be able to display the detection results in a separate detection result window.
3. The CHDS must be able to display the detection results on top of a displayed satellite image.
4. The CHDS must be able to navigate to each detection result by displaying that part of a satellite image that resulted in the detection.

4.1.6 Detection editing requirements

1. The CHDS must provide capabilities for adding detections to those found automatically.
2. The CHDS must provide capabilities for deleting detections from those found automatically.
3. The CHDS must provide capabilities for modifying the shape of a detection found automatically.

4.1.7 File output requirements

1. The CHDS must be able to save the detections in the form of SHAPE files, the de facto standard format used by the ArcView GIS system.

4.1.8 Analysis requirements

The CHDS must be able to perform the following analysis operations:

1. Distance measurements (between specified points, units are pixels or meters).
2. Area measurements (of polygonal shapes, units are pixels or square meters).

4.1.9 System requirements

The system must be able to run on Windows (2000 and XP) computer systems.

4.2 Remote sensing archaeologists

4.2.1 File input requirements

See 4.1.1.

4.2.2 Input display requirements

1. See 4.1.2.
2. The CHDS must be able to display the spectral values of a selected point either in a satellite image or in a field mask.

4.2.3 Preprocessing requirements

The CHDS must be able to perform the following preprocessing operations:

1. Noise removal.
2. Plow furrow removal.

4.2.4 Processing requirements

See 4.1.4.

4.2.5 Detection display requirements

See 4.1.5.

4.2.6 Detection editing requirements

See 4.1.6.

4.2.7 File output requirements

See 4.1.7.

4.2.8 Analysis requirements

See 4.1.8. The CHDS must be able to perform the following analysis operations:

1. Calculate the statistics of the pixels included in a detection (min, max, mean, variance, band covariance).

4.2.9 System requirements

See 4.1.9. The system must be able to run on UNIX systems.

5 Use cases

Having identified the needs of the different users through use scenarios and textual descriptions of users requirements, the requirements are here formalized as use cases. These are textual descriptions, in the form of tables, of the different uses of the system. Based on these use cases, the system design is developed. A use case is presented in the form of a table as shown below:

Use Case	Textual presentation of the use case, the use case ID.	
Description	Short description of the use case.	
User type	What users are concerned by this use case	
Importance	We state the importance of the use case and distinguish between High , Medium , and Low . Importance is meant to express a combination of how important we consider it to be to provide the use case from an end user's point of view and how realistic it is to provide an implementation.	
Implementation phase	We state in what implementation phase this functionality should be added.	
Formulation of request / Prerequisites	What needs to be specified by the user? When the user enters this use case, what additional information will (s)he have to provide?	
Presentation of results / Post-requisites	How could the result be presented?	
Action Sequence	Step	Action
	1	How is the response produced, step by step?
	:	
	N	
Variations	Step	Branching Action
	1	Small variations that can occur in the use case
	:	
	N	
Exceptions		Branching Action
	2	What if data does not exist, or other exceptional situations occur, such that a proper response cannot be generated? What are the exceptional situations that can occur, and what should be done in each case?
	:	
	N	
Comments	Comments of any kind	
Open issues	Any open issues	

As we have already pointed out the general archaeologist user will use the software in a highly result oriented manner. This user's main focus will be to produce maps of possible cultural heritage sites as quickly and easily as possible with a minimum of user interaction and with a minimal exposure to the underlying system. The remote sensing archaeologist user uses the system in much the same way, but with the addition of using a large range of tools to analyze

the intermediary and final results of the process. The following figures resumes the users and their associated use cases. We point out that the use cases are written with the intention that the system is run and operated through a graphical user interface; this is therefore not specifically stated in any of the use cases. The following table recapitulates all the use cases and identifies their implementation phase.

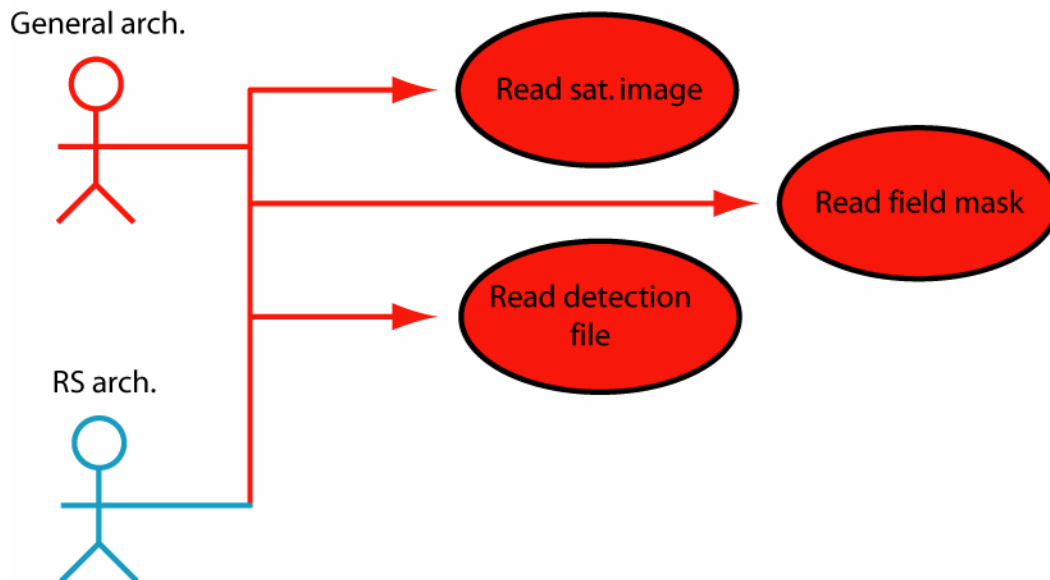


Figure 3: The file input use cases. Use cases marked in red are applicable to all users of the system.

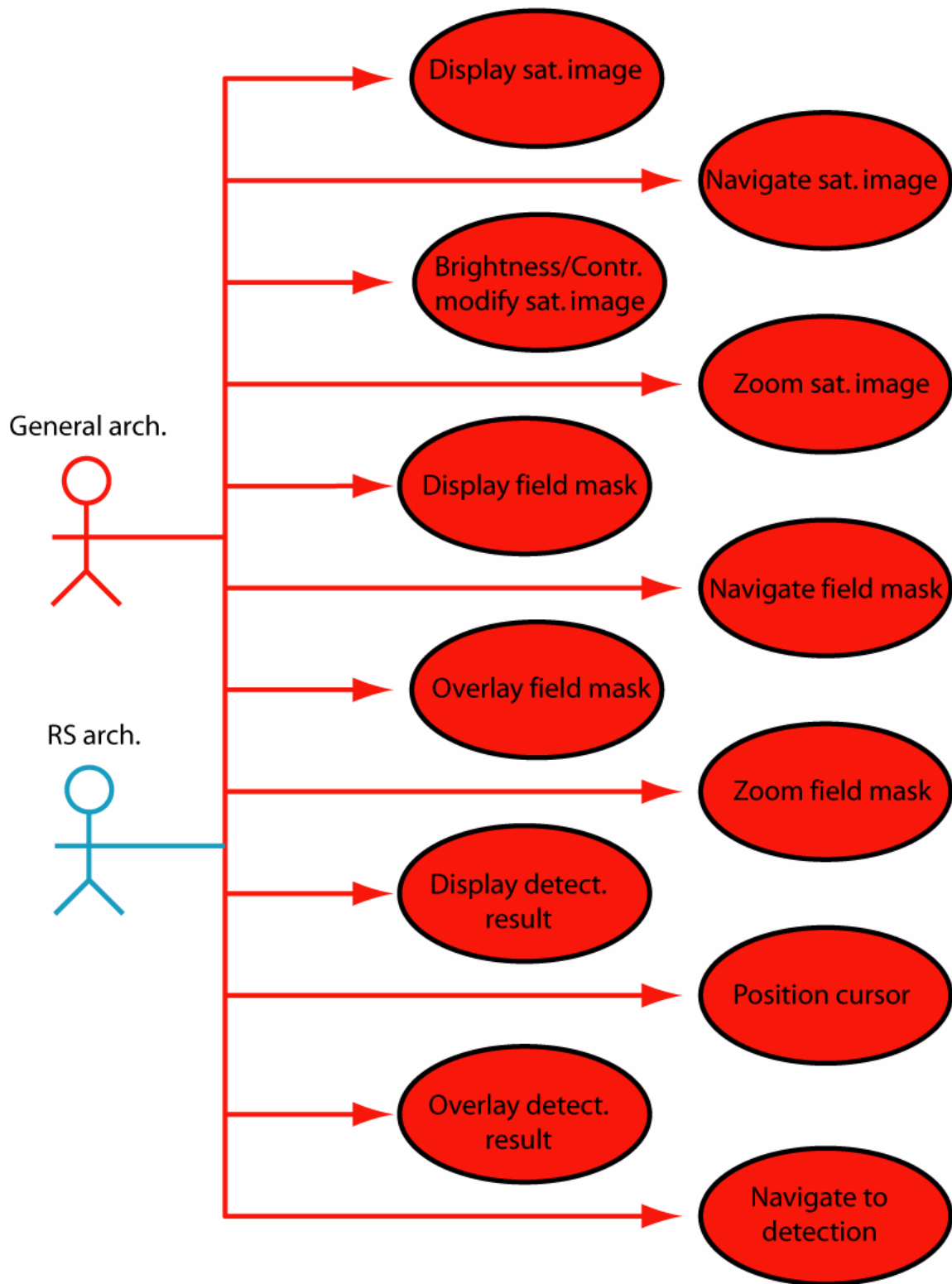


Figure 4: The display use cases. Use cases marked in red are applicable to all users of the system.

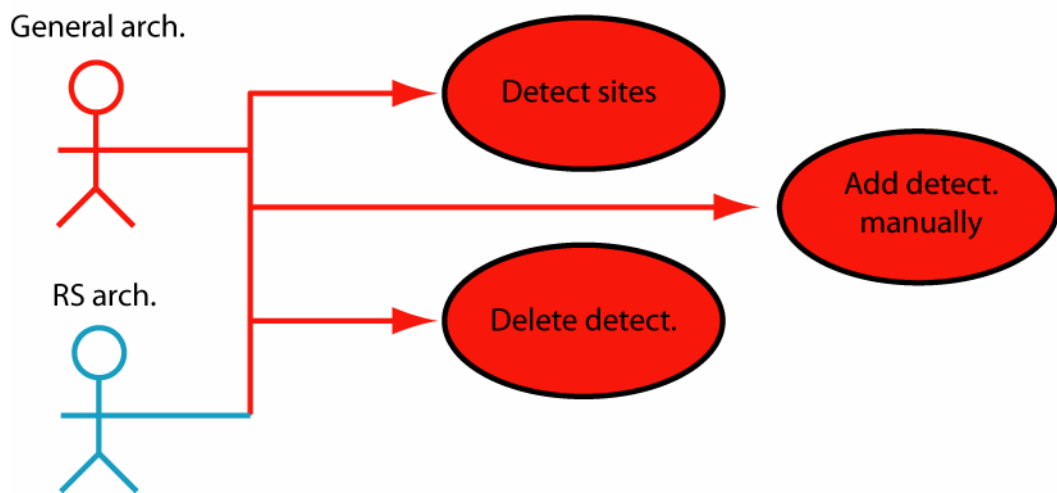


Figure 5: The detection use cases. Use cases marked in red are applicable to all users of the system.

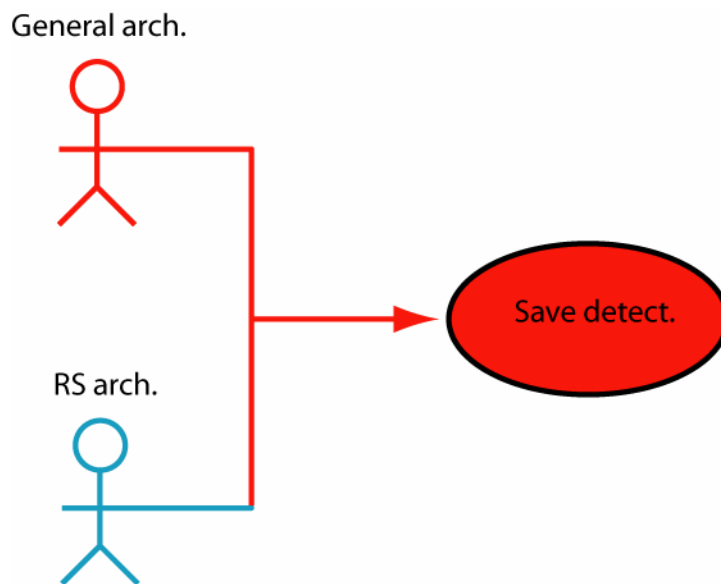


Figure 6: The file output use cases. Use cases marked in red are applicable to all users of the system.

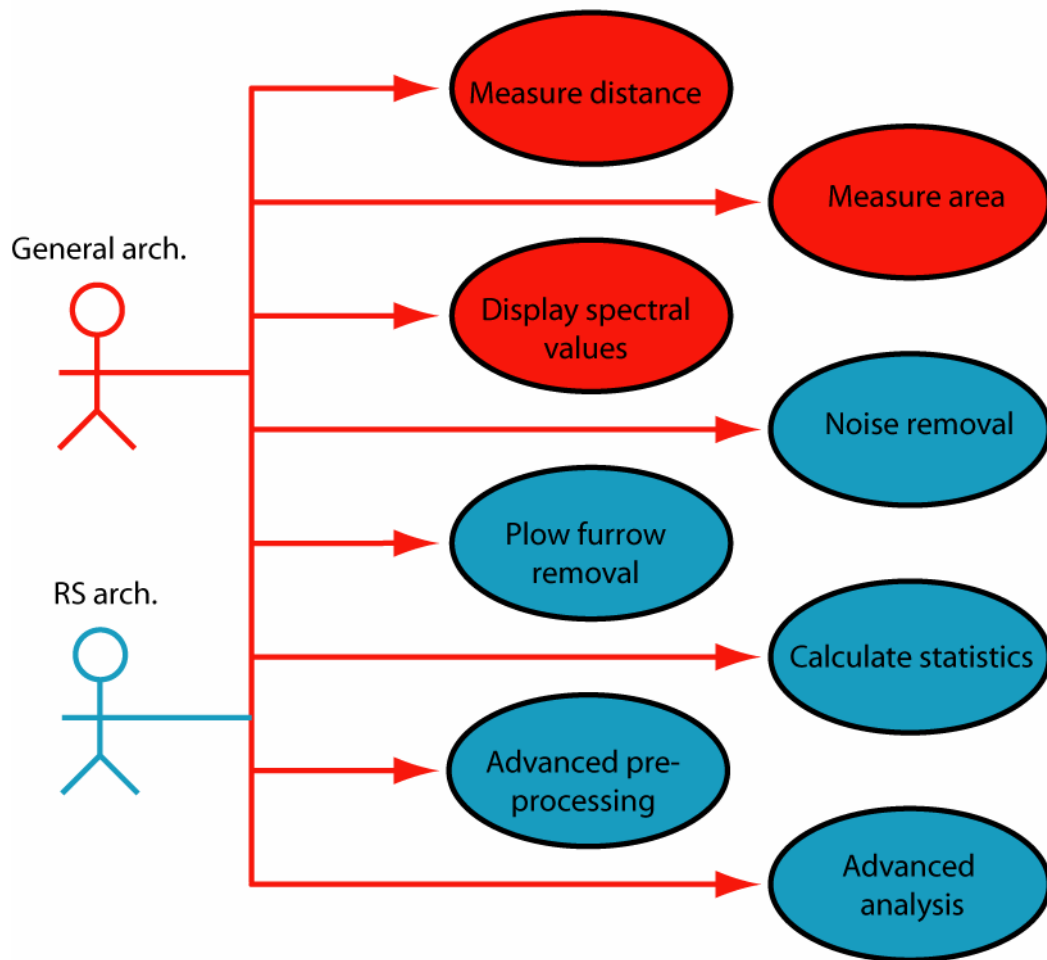


Figure 7: The analysis use cases. Use cases marked in red are applicable to all users of the system, use cases marked in blue are applicable only to the remote sensing archaeologist users of the system.

Use case	User	Implementation Phase	Importance
Read satellite image	Gen. Arch.	MOS1	High
Read field mask	Gen. Arch.	MOS1	High
Read detection file	Gen. Arch.	MOS2	Medium
Display satellite image	Gen. Arch.	MOS1	High
Navigate satellite image	Gen. Arch.	MOS1	High
Zoom satellite image	Gen. Arch.	MOS1	High
Brightness/contrast modify satellite image	Gen. Arch.	MOS2	Medium
Display field mask	Gen. Arch.	MOS1	High
Navigate field mask	Gen. Arch.	MOS1	High
Zoom field mask	Gen. Arch.	MOS1	High
Overlay field mask	Gen. Arch.	MOS1	High
Position cursor	Gen. Arch.	MOS2	Medium
Detect sites	Gen. Arch.	MOS1	High
Display detection result	Gen. Arch.	MOS1	High
Overlay detection result	Gen. Arch.	MOS1	High
Navigate to detection	Gen. Arch.	MOS1	High
Add detection manually	Gen. Arch.	MOS3	Low
Delete detection	Gen. Arch.	MOS1	High
Save detection	Gen. Arch.	MOS1	High
Measure distance	Gen. Arch.	MOS2	Medium
Measure area	Gen. Arch.	MOS3	Low
Display spectral values	Rem. Sens. Arch.	MOS2	Medium
Noise removal	Rem. Sens. Arch.	MOS2	Medium
Plow furrow removal	Rem. Sens. Arch.	MOS2	Medium
Calculate statistics	Rem. Sens. Arch.	MOS3	Medium
Advanced preprocessing	Rem. Sens. Arch.	MOS3	Low
Advanced analysis	Rem. Sens. Arch.	MOS3	Low

Table 1: All use cases and their implementation phase. This table gives an overview of all the use cases, their associated users and the implementation phase. A use case to be implemented in MOS1 will thus belong to the initial Minimal Operating System.

5.1 General archaeologist use cases

Use Case	Read satellite image	
Description	The user selects a satellite image to read. The image file is opened and the image is read into memory. A list of currently loaded images is updated	
User type	All	
Importance	High	
Implementation phase	MOS1	
Formulation of request / Prerequisites	<p>The user must specify:</p> <ul style="list-style-type: none"> • The image file path and name. <p>The prerequisites are:</p> <ul style="list-style-type: none"> • The image must exist and be on a format that is readable by the system. • In order to avoid resampling of the images the images should be georeferenced to a standard geographic reference system. 	
Presentation of results / Post-requisites	The image file is opened and the image is read into memory. A list of currently loaded images is updated	
Action Sequence	Step	Action
	1	Select image file path and name.
	2	•
	3	•
Variations	Step	Branching Action
	1	None
	2	•
	3	•
Exceptions		Branching Action
	1	The image does not exist. Warn the user about this.
	2	•
	3	•
Comments	It is possible that the loading of a satellite image should trigger the display of this image also, not only list it as an available image for display. Currently loading an image and displaying are two different use cases.	
Open issues	None	

Use Case	Read field mask	
Description	The user selects a field mask to read. The field mask file is opened and the field mask is read into memory. A list of currently loaded field masks is updated	
User type	All	
Importance	High	
Implementation phase	MOS1	
Formulation of request/ Prerequisites	<p>The user must specify:</p> <ul style="list-style-type: none"> • The field mask file path and name. <p>The prerequisites are:</p> <ul style="list-style-type: none"> • The field mask file must exist and be on a format that is readable by the system. • In order to avoid resampling of the images the field mask should use a standard geographic reference system. 	
Presentation of results / Post-requisites	The field mask file is opened and the field mask is read into memory. A list of currently loaded field masks is updated	
Action Sequence	Step	Action
	1	Select field mask file path and name.
	2	•
	3	•
Variations	Step	Branching Action
	1	None
	2	•
	3	•
Exceptions		Branching Action
	1	The field mask does not exist. Warn the user about this.
	2	•
	3	•
Comments	It is possible that the loading of a field mask should trigger the display of the field mask also, not only list it as an available field mask for display. Currently loading a field mask and displaying it are two different use cases.	
Open issues	None	

Use Case	Read detection file	
Description	The user selects a detection file to read. The detection file is opened and read into memory. A list of the loaded detections is displayed.	
User type	All	
Importance	Medium	
Implementation phase	MOS2	
Formulation of request/ Prerequisites	<p>The user must specify:</p> <ul style="list-style-type: none"> • The detection file path and name. <p>The prerequisites are:</p> <ul style="list-style-type: none"> • The detection file must exist. 	
Presentation of results / Post-requisites	The detection file is opened and is read into memory. A list of the loaded detections is displayed.	
Action Sequence	Step	Action
	1	Select detection file path and name.
	2	•
	3	•
Variations	Step	Branching Action
	1	None
	2	•
	3	•
Exceptions		Branching Action
	1	The detection file does not exist. Warn the user about this.
	2	•
	3	•
Comments	A detection file is a file containing a list of detections made by the CHDS containing the suggested interpretation of these along with the vectors that mark polygonal regions in the image corresponding to the detections. This file must be compatible with the SHAPE file format	
Open issues	None	

Use Case	Display satellite image	
Description	The user selects a satellite image from the list of loaded satellite images. The selected image is displayed to the screen. The display shows the satellite image along with a navigation window and a zoom window.	
User type	All	
Importance	High	
Implementation phase	MOS1	
Formulation of request / Prerequisites	<p>The user must specify:</p> <ul style="list-style-type: none"> The satellite image from the list of loaded satellite images. <p>The prerequisites are:</p> <ul style="list-style-type: none"> The satellite image must be loaded. 	
Presentation of results / Post-requisites	The selected image is displayed to the screen. The display shows the satellite image along with a navigation window and a zoom window.	
Action Sequence	Step	Action
	1	Select the desired satellite image from the list of loaded satellite images.
	2	•
	3	•
Variations	Step	Branching Action
	1	None
	2	•
	3	•
Exceptions		Branching Action
	1	None
	2	•
	3	•
Comments	It is possible that the loading of a satellite image should trigger the display of this image also, not only list it as an available image for display. Currently loading an image and displaying are two different use cases.	
Open issues	None	

Use Case	Navigate satellite image	
Description	Using the navigation tool the user decides what part of the satellite image is to be displayed to screen.	
User type	All	
Importance	High	
Implementation phase	MOS1	
Formulation of request/ Prerequisites	<p>The user must specify:</p> <ul style="list-style-type: none"> • The part of the satellite image that is to be displayed. <p>The prerequisites are:</p> <ul style="list-style-type: none"> • A satellite image must be displayed. 	
Presentation of results/ Post-requisites	The part of the satellite image specified by the user is displayed to screen.	
Action Sequence	Step	Action
	1	Select the part of the satellite image to be displayed.
	2	•
	3	•
Variations	Step	Branching Action
	1	If the satellite image is small enough to fit the screen then this option should not be available.
	2	•
	3	•
Exceptions		Branching Action
	1	None
	2	•
	3	•
Comments	None	
Open issues	None	

Use Case	Zoom satellite image	
Description	Using the zoom tool the user decides the zoom factor used in displaying the satellite image.	
User type	All	
Importance	High	
Implementation phase	MOS1	
Formulation of request/ Prerequisites	<p>The user must specify:</p> <ul style="list-style-type: none"> • The zoom factor to use. <p>The prerequisites are:</p> <ul style="list-style-type: none"> • A satellite image must be displayed. 	
Presentation of results/ Post-requisites	The satellite image display is zoomed to the desired scale.	
Action Sequence	Step	Action
	1	Select zoom factor.
	2	•
	3	•
Variations	Step	Branching Action
	1	None
	2	•
	3	•
Exceptions		Branching Action
	1	None
	2	•
	3	•
Comments	None	
Open issues	How should the zooming be implemented? Should the zoom apply to the main display window (a la Photoshop) or should there be a separate zoom window (a la ENVI).	

Use Case	Brightness/contrast modify satellite image	
Description	The user selects the brightness and contrast to be used in displaying the satellite image.	
User type	All	
Importance	Medium	
Implementation phase	MOS2	
Formulation of request/ Prerequisites	<p>The user must specify:</p> <ul style="list-style-type: none"> The gain/offset to be used in modifying the display graylevel lookup table. <p>The prerequisites are:</p> <ul style="list-style-type: none"> A satellite image must be displayed. 	
Presentation of results / Post-requisites	The satellite image display is updated with a new graylevel lookup table.	
Action Sequence	Step	Action
	1	Select gain.
	2	Select offset
	3	•
Variations	Step	Branching Action
	1	None
	2	•
	3	•
Exceptions		Branching Action
	1	None
	2	•
	3	•
Comments	None	
Open issues	Should only this type of linear LUT modification be allowed or do we need more sophisticated LUT management?	

Use Case	Display field mask	
Description	The user selects a field mask from the list of loaded field masks. The selected field mask is displayed to the screen. The display shows the field mask along with a navigation window and a zoom window.	
User type	All	
Importance	High	
Implementation phase	MOS1	
Formulation of request/ Prerequisites	The user must specify: <ul style="list-style-type: none"> • The field mask from the list of loaded field masks. The prerequisites are: <ul style="list-style-type: none"> • The field mask must be loaded. 	
Presentation of results/ Post-requisites	The selected field mask is displayed to the screen. The display shows the field mask along with a navigation window and a zoom window.	
Action Sequence	Step	Action
	1	Select the desired field mask from the list of loaded field masks.
	2	•
	3	•
Variations	Step	Branching Action
	1	None
	2	•
	3	•
Exceptions		Branching Action
	1	None
	2	•
	3	•
Comments	It is possible that the loading of a field mask should trigger the display of the field mask also, not only list it as an available field mask for display. Currently loading a field mask and displaying it are two different use cases.	
Open issues	None	

Use Case	Navigate field mask	
Description	Using the navigation tool the user decides what part of the field mask is to be displayed to screen.	
User type	All	
Importance	High	
Implementation phase	MOS1	
Formulation of request / Prerequisites	<p>The user must specify:</p> <ul style="list-style-type: none"> The part of the field mask that is to be displayed to screen. <p>The prerequisites are:</p> <ul style="list-style-type: none"> A field mask must be displayed. 	
Presentation of results / Post-requisites	The part of the field mask specified by the user is displayed to screen.	
Action Sequence	Step	Action
	1	Select the part of the field mask to be displayed.
	2	•
	3	•
Variations	Step	Branching Action
	1	If the field mask is small enough to fit the screen then this option should not be available.
	2	•
	3	•
Exceptions		Branching Action
	1	None
	2	•
	3	•
Comments	None	
Open issues	None	

Use Case	Zoom field mask	
Description	Using the zoom tool the user decides the zoom factor used in displaying the field mask.	
User type	All	
Importance	High	
Implementation phase	MOS1	
Formulation of request/ Prerequisites	<p>The user must specify:</p> <ul style="list-style-type: none"> • The zoom factor to use. <p>The prerequisites are:</p> <ul style="list-style-type: none"> • A field mask must be displayed. 	
Presentation of results/ Post-requisites	The field mask display is zoomed to the desired scale.	
Action Sequence	Step	Action
	1	Select zoom factor.
	2	•
	3	•
Variations	Step	Branching Action
	1	None
	2	•
	3	•
Exceptions		Branching Action
	1	• The image does not exist. Warn the user.
	2	•
	3	•
Comments	None	
Open issues	How should the zooming be implemented? Should the zoom apply to the main display window (a la Photoshop) or should there be a separate zoom window (a la ENVI).	

Use Case	Overlay field mask	
Description	Having opened a display of a satellite image the user can select a field mask to be loaded and displayed on top of the satellite image.	
User type	All	
Importance	High	
Implementation phase	MOS1	
Formulation of request/ Prerequisites	<p>The user must specify:</p> <ul style="list-style-type: none"> • The field mask to be loaded from the list of available field mask. <p>The prerequisites are:</p> <ul style="list-style-type: none"> • A satellite image must be displayed. • The must be at least partial overlap between the already displayed satellite image and the selected field mask. 	
Presentation of results / Post-requisites	The field mask is displayed as an overlay over the already displayed satellite image.	
Action Sequence	Step	Action
	1	Select field mask from list of available field masks.
	2	•
	3	•
Variations	Step	Branching Action
	1	None
	2	•
	3	•
Exceptions		Branching Action
	1	There is no overlap between the field mask and the displayed satellite image, warn the user about this.
	2	•
	3	•
Comments	None	
Open issues	None	

Use Case	Position cursor	
Description	Whenever a satellite image or a field mask is displayed and the cursor is positioned in such a display the image and geographic position of the cursor is continuously displayed.	
User type	All	
Importance	Medium	
Implementation phase	MOS2	
Formulation of request/ Prerequisites	The user must specify: <ul style="list-style-type: none"> • Nothing The prerequisites are: <ul style="list-style-type: none"> • A satellite image must be displayed 	
Presentation of results / Post-requisites	Whenever the cursor is placed over a pixel in a displayed satellite image the cursor pixel and geographic position is displayed.	
Action Sequence	Step	Action
	1	Position cursor over displayed satellite image.
	2	•
	3	•
Variations	Step	Branching Action
	1	None
	2	•
	3	•
Exceptions		Branching Action
	1	None
	2	•
	3	•
Comments	None	
Open issues	None	

Use Case	Detect sites	
Description	Having loaded a satellite image to memory the user can launch a cultural heritage site detection. If a field mask is loaded it can be used to mask the processing of the image to within the field mask.	
User type	All	
Importance	High	
Implementation phase	MOS1	
Formulation of request/ Prerequisites	<p>The user must specify:</p> <ul style="list-style-type: none"> • A satellite image from the list of available satellite images. • If field masking is desired, a field mask from the list of available field masks. <p>The prerequisites are:</p> <ul style="list-style-type: none"> • A satellite image must be loaded. • If field masking is desired, a field mask with at least partial overlap with the selected satellite image must be loaded. 	
Presentation of results / Post-requisites	The system analyses the satellite image (possibly within the selected field mask) and generates a list of possible cultural heritage sites. A list of detections is displayed.	
Action Sequence	Step	Action
	1	Select satellite image to be processed.
	2	•
	3	•
Variations	Step	Branching Action
	1	If field masking is desired select field mask
	2	•
	3	•
Exceptions		Branching Action
	1	There is no overlap between the field mask and the displayed satellite image, warn the user about this.
	2	•
	3	•
Comments	None	
Open issues	None	

Use Case	Display detection result	
Description	Having loaded a detection file or performed a site detection the user can display the detections in a separate display window.	
User type	All	
Importance	High	
Implementation phase	MOS1	
Formulation of request/ Prerequisites	<p>The user must specify:</p> <ul style="list-style-type: none"> • The user must select display of the detection result. <p>The prerequisites are:</p> <ul style="list-style-type: none"> • A detection file must have been loaded or a site detection must have been performed. 	
Presentation of results / Post-requisites	The detection result is displayed to the screen. The display shows the detections along with a navigation window and a zoom window.	
Action Sequence	Step	Action
	1	Select display of detection result.
	2	•
	3	•
Variations	Step	Branching Action
	1	None
	2	•
	3	•
Exceptions		Branching Action
	1	None
	2	•
	3	•
Comments	None	
Open issues	It is possible that a site detection should open this display by default.	

Use Case	Overlay detection result	
Description	Having loaded a detection file or performed a site detection the user can display the detections on top of an already displayed satellite image.	
User type	All	
Importance	High	
Implementation phase	MOS1	
Formulation of request/ Prerequisites	<p>The user must specify:</p> <ul style="list-style-type: none"> • The user must select overlay of the detection result. <p>The prerequisites are:</p> <ul style="list-style-type: none"> • A detection file must have been loaded or a site detection must have been preformed. • A satellite image must be displayed. 	
Presentation of results/ Post-requisites	The detection result is displayed as an overlay over the already displayed satellite image.	
Action Sequence	Step	Action
	1	Select overlay of the detection result.
	2	•
	3	•
Variations	Step	Branching Action
	1	None
	2	•
	3	•
Exceptions		Branching Action
	1	A satellite image is not displayed. Warn the user about this.
	2	•
	3	•
Comments	None	
Open issues	This could also be a default output from the detection module.	

Use Case	Navigate to detection	
Description	By indicating an element in the list of detections the user can navigate to a particular detection.	
User type	All	
Importance	High	
Implementation phase	MOS1	
Formulation of request/ Prerequisites	<p>The user must specify:</p> <ul style="list-style-type: none"> The part of the detection result that is to be displayed to screen. <p>The prerequisites are:</p> <ul style="list-style-type: none"> A detection result must be displayed in a separate window or as an overlay to a satellite image. 	
Presentation of results/ Post-requisites	The part of the detection result specified by the user is displayed to screen.	
Action Sequence	Step	Action
	1	Select the part of the detection result to be displayed.
	2	•
	3	•
Variations	Step	Branching Action
	1	If the detection result is small enough to fit the screen then this option should not be available.
	2	•
	3	•
Exceptions		Branching Action
	1	None
	2	•
	3	•
Comments	None	
Open issues	None	

Use Case	Add detection manually	
Description	Having displayed a detection result or overlaid a detection result on an already loaded image the user can add a detection manually.	
User type	All	
Importance	Low	
Implementation phase	MOS3	
Formulation of request/ Prerequisites	<p>The user must specify:</p> <ul style="list-style-type: none"> The position and shape of the new detection by drawing it in the display window. <p>The prerequisites are:</p> <ul style="list-style-type: none"> A detection result or a detection result overlaid on a satellite image must be displayed. 	
Presentation of results / Post-requisites	The desired new detection is added to the list of detections. any displays are updated with this new detection.	
Action Sequence	Step	Action
	1	Draw new detection in display window.
	2	•
	3	•
Variations	Step	Branching Action
	1	None
	2	•
	3	•
Exceptions		Branching Action
	1	None
	2	•
	3	•
Comments	None	
Open issues	None	

Use Case	Delete detection	
Description	Having displayed a detection result or overlaid a detection result on an already loaded image the user can delete a detection manually.	
User type	All	
Importance	High	
Implementation phase	MOS1	
Formulation of request/ Prerequisites	<p>The user must specify:</p> <ul style="list-style-type: none"> • The detection to be deleted in the list of detections. • The detection to be deleted in the detection result display or the detection result overlay display. <p>The prerequisites are:</p> <ul style="list-style-type: none"> • The detection list must be displayed. • The detection result or the detection result overlay must be displayed. 	
Presentation of results / Post-requisites	The selected detection is removed from the list of detections. All detection result displays are updated.	
Action Sequence	Step	Action
	1	Select the detection to be deleted from the list of detections or from a display of detection results or from an overlay of detection results on top of a satellite image.
	2	•
	3	•
Variations	Step	Branching Action
	1	None
	2	•
	3	•
Exceptions		Branching Action
	1	None
	2	•
	3	•
Comments	None	
Open issues	It is possible that a functionality allowing only for deletions from the list of detections is sufficient?	

Use Case	Save detection	
Description	Having generated a detection result the user can save the result to file.	
User type	All	
Importance	High	
Implementation phase	MOS1	
Formulation of request/ Prerequisites	<p>The user must specify:</p> <ul style="list-style-type: none"> • The detection result file path and name. <p>The prerequisites are:</p> <ul style="list-style-type: none"> • A detection result must exist. 	
Presentation of results/ Post-requisites	The detection result is written to the specified file.	
Action Sequence	Step	Action
	1	Select detection result file path and name.
	2	•
	3	•
Variations	Step	Branching Action
	1	None
	2	•
	3	•
Exceptions		Branching Action
	1	• The detection result file already exists. Warn the user about this.
	2	•
	3	•
Comments	None	
Open issues	None	

Use Case	Measure distance	
Description	In any image, field mask or result image display the user can measure distances in a set of specified units (pixels or meters) by indicating a from and to position.	
User type	All	
Importance	Medium	
Implementation phase	MOS2	
Formulation of request/ Prerequisites	<p>The user must specify:</p> <ul style="list-style-type: none"> • Two points in the display of interest. <p>The prerequisites are:</p> <ul style="list-style-type: none"> • A satellite image, field mask or detection result display must be open. 	
Presentation of results / Post-requisites	The distance in pixels and meters between the points is displayed.	
Action Sequence	Step	Action
	1	Select from point in the display of interest.
	2	Select to point in the display of interest.
	3	•
Variations	Step	Branching Action
	1	None
	2	•
	3	•
Exceptions		Branching Action
	1	None
	2	•
	3	•
Comments	None	
Open issues	None	

Use Case	Measure area	
Description	In any image, field mask or result image display the user can measure areas in a set of specified units (pixels or square meters) by indicating the polygon for which the area should be calculated.	
User type	All	
Importance	Low	
Implementation phase	MOS3	
Formulation of request/ Prerequisites	<p>The user must specify:</p> <ul style="list-style-type: none"> • A polygon in the display of interest. <p>The prerequisites are:</p> <ul style="list-style-type: none"> • A satellite image, field mask or detection result display must be open. 	
Presentation of results / Post-requisites	The area in pixels and square meters of the given polygon is displayed.	
Action Sequence	Step	Action
	1	Draw a polygon in the display of interest.
	2	•
	3	•
Variations	Step	Branching Action
	1	None
	2	•
	3	•
Exceptions		Branching Action
	1	None
	2	•
	3	•
Comments	None	
Open issues	None	

5.2 Remote sensing archaeologist use cases

Use Case	Display spectral values	
Description	In any image, field mask or result image display the user can display the spectral values of the underlying satellite image data by indicating the position for which the spectral values are sought.	
User type	RS archeologist.	
Importance	Medium	
Implementation phase	MOS2	
Formulation of request/ Prerequisites	<p>The user must specify:</p> <ul style="list-style-type: none"> The point in the image for which the spectral values should be displayed. <p>The prerequisites are:</p> <ul style="list-style-type: none"> A satellite image, field mask or detection result display must be open. 	
Presentation of results/ Post-requisites	A plot window is opened and the spectral values of the underlying satellite image data is plotted as a function of wavelength.	
Action Sequence	Step	Action
	1	Select a point in the display of interest.
	2	•
	3	•
Variations	Step	Branching Action
	1	None
	2	•
	3	•
Exceptions		Branching Action
	1	None
	2	•
	3	•
Comments	None	
Open issues	None	

Use Case	Noise removal	
Description	Prior to site detection a noise removal can be performed on the satellite image to be processed.	
User type	RS archeologist.	
Importance	Medium	
Implementation phase	MOS2	
Formulation of request / Prerequisites	<p>The user must specify:</p> <ul style="list-style-type: none"> • A satellite image from the list of available satellite images. • If field masking is desired, a field mask from the list of available field masks. • A noise removal method. <p>The prerequisites are:</p> <ul style="list-style-type: none"> • A satellite image must be loaded. • If field masking is desired, a field mask with at least partial overlap with the selected satellite image must be loaded. 	
Presentation of results / Post-requisites	The specified noise removal is performed on the given satellite image. If field masking is specified, the processing is limited to the field mask.	
Action Sequence	Step	Action
	1	Select satellite image.
	2	Select field mask.
	3	Select noise removal algorithm.
Variations	Step	Branching Action
	1	None
	2	•
	3	•
Exceptions		Branching Action
	1	None
	2	•
	3	•
Comments	None	
Open issues	It is uncertain whether it is necessary to allow for a masking of this operation.	

Use Case	Plow furrow removal	
Description	Prior to site detection a plow furrow removal can be performed on the satellite image to be processed.	
User type	RS archeologist.	
Importance	MEDIUM	
Implementation phase	MOS2	
Formulation of request / Prerequisites	<p>The user must specify:</p> <ul style="list-style-type: none"> • A satellite image from the list of available satellite images. • If field masking is desired, a field mask from the list of available field masks. <p>The prerequisites are:</p> <ul style="list-style-type: none"> • A satellite image must be loaded. • If field masking is desired, a field mask with at least partial overlap with the selected satellite image must be loaded. 	
Presentation of results / Post-requisites	Plow furrow removal is performed on the given satellite image. If field masking is specified, the processing is limited to the field mask.	
Action Sequence	Step	Action
	1	Select satellite image.
	2	Select field mask.
	3	•
Variations	Step	Branching Action
	1	None
	2	•
	3	•
Exceptions		Branching Action
	1	None
	2	•
	3	•
Comments	None	
Open issues	It is uncertain whether it is necessary to allow for a masking of this operation.	

Use Case	Calculate statistics	
Description	The user can specify a particular detection and calculate the statistics of the pixels belonging to this detection.	
User type	RS archeologist.	
Importance	Low	
Implementation phase	MOS3	
Formulation of request / Prerequisites	<p>The user must specify:</p> <ul style="list-style-type: none"> • The detection for which to calculate statistics. <p>The prerequisites are:</p> <ul style="list-style-type: none"> • A satellite image must be loaded. • A detection result with at least a partial overlap with the satellite image must exist. • A detection result list or a detection result display or a detection result overlaid on a satellite image must be open. 	
Presentation of results / Post-requisites	A window reporting certain statistics of the pixels belonging to a specified detection is opened.	
Action Sequence	Step	Action
	1	Select the interesting detection from a detection result list or a detection result display or a detection result overlaid on a satellite image
	2	•
	3	•
Variations	Step	Branching Action
	1	None
	2	•
	3	•
Exceptions		Branching Action
	1	No overlap between the detection result and the satellite image. Warn the user.
	2	•
	3	•
Comments	None	
Open issues	It is uncertain whether it is necessary to allow for a graphical selection of the interesting detection. It is possible that it suffices to allow for a selection of the detection from the list of detections.	

Use Case	Advanced preprocessing	
Description	The RS archeologist user will need a set of advanced preprocessing routines.	
User type	RS archeologist.	
Importance	Low	
Implementation phase	MOS3	
Formulation of request/ Prerequisites	Depending on the implementation of the system it is doubtful if this functionality should be included in the final system or not. If the final system is implemented as an extension to a library of image processing and GIS functionality then this functionality might be an added benefit.	
Presentation of results/ Post-requisites	Not applicable.	
Action Sequence	Step	Action
	1	Not applicable.
	2	•
	3	•
Variations	Step	Branching Action
	1	Not applicable.
	2	•
	3	•
Exceptions		Branching Action
	1	Not applicable.
	2	•
	3	•
Comments	None	
Open issues	None	

Use Case	Advanced analysis	
Description	The RS archeologist user will need a set of advanced analysis routines.	
User type	RS archeologist.	
Importance	Low	
Implementation phase	MOS3	
Formulation of request/ Prerequisites	Depending on the implementation of the system it is doubtful if this functionality should be included in the final system or not. If the final system is implemented as an extension to a library of image processing and GIS functionality then this functionality might be an added benefit.	
Presentation of results/ Post-requisites	Not applicable.	
Action Sequence	Step	Action
	1	Not applicable.
	2	•
	3	•
Variations	Step	Branching Action
	1	Not applicable.
	2	•
	3	•
Exceptions		Branching Action
	1	Not applicable.
	2	•
	3	•
Comments	None	
Open issues	None	

6 Conceptual design

6.1 Introduction

Having identified the user requirements and analyzed them through use cases, we will now propose a system conceptual design of the CHDS. By conceptual design we mean design issues related to the system architecture and the overall operation of the system such as the users interaction with the system, the system main modules and their interaction and finally a high level description of the algorithms and methods that the system will employ in order to carry out its assigned tasks.

We will therefore not discuss issues related to the exact layout of the user interaction tools, the implementation language or specifics of any algorithms. Rather, we will try to identify the high level functionality the system must provide in order to meet the user requirements. Figure 7 on the next page gives a graphical view of the operation and interdependence of the different modules making up the CHDS.

6.2 System operation

The system operation is as described in the following figure. All users will operate the software through a graphical user interface (GUI). The GUI gives access to file input/output functionality as well as the different processing options.

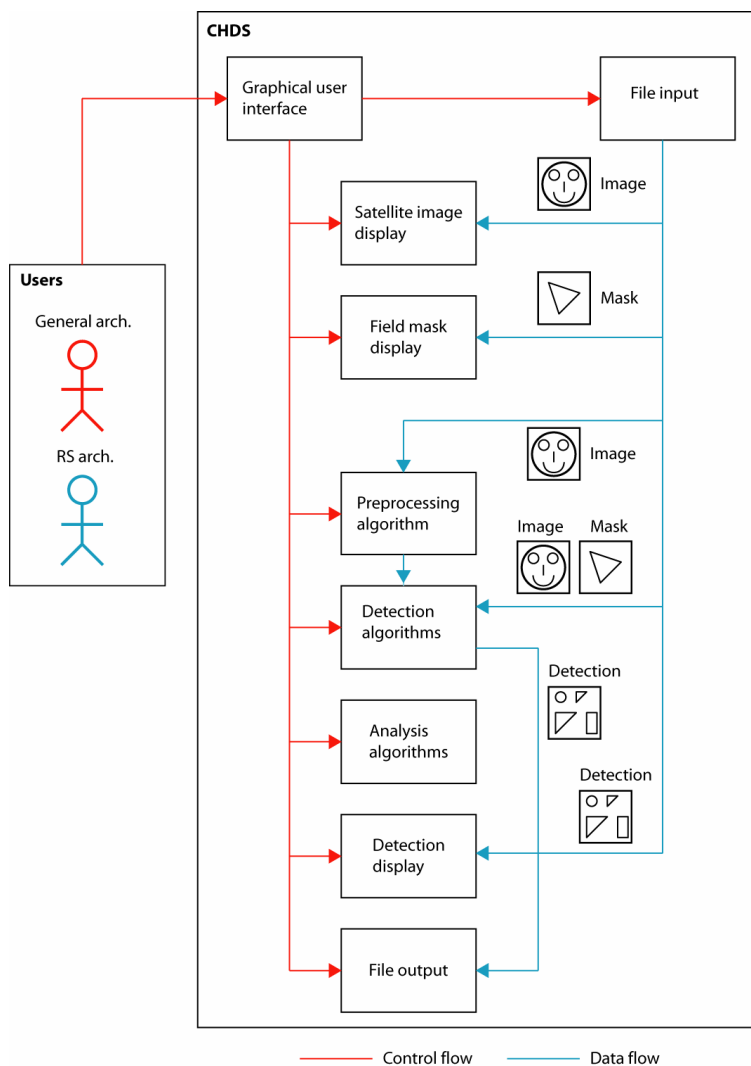


Figure 8: Overall system operation and module interdependence. Through the graphical user interface both users operate all the functionality of the CHDS. The file input module provides the different data inputs as illustrated in the figure, the symbols indicate the type of objects that flow between the different modules.

6.3 File input/output

There are three types of file input to the CHDS system, these are satellite images, field masks and detection files. The only file output is the detection file. In this section we will discuss the handling of all of these file inputs and outputs. The following figure shows the interaction of the modules involved in the file I/O process. Notice that the navigation tool associated with the satellite image display functionality also must have access to the satellite image file input functionality, this is also illustrated in the figure.

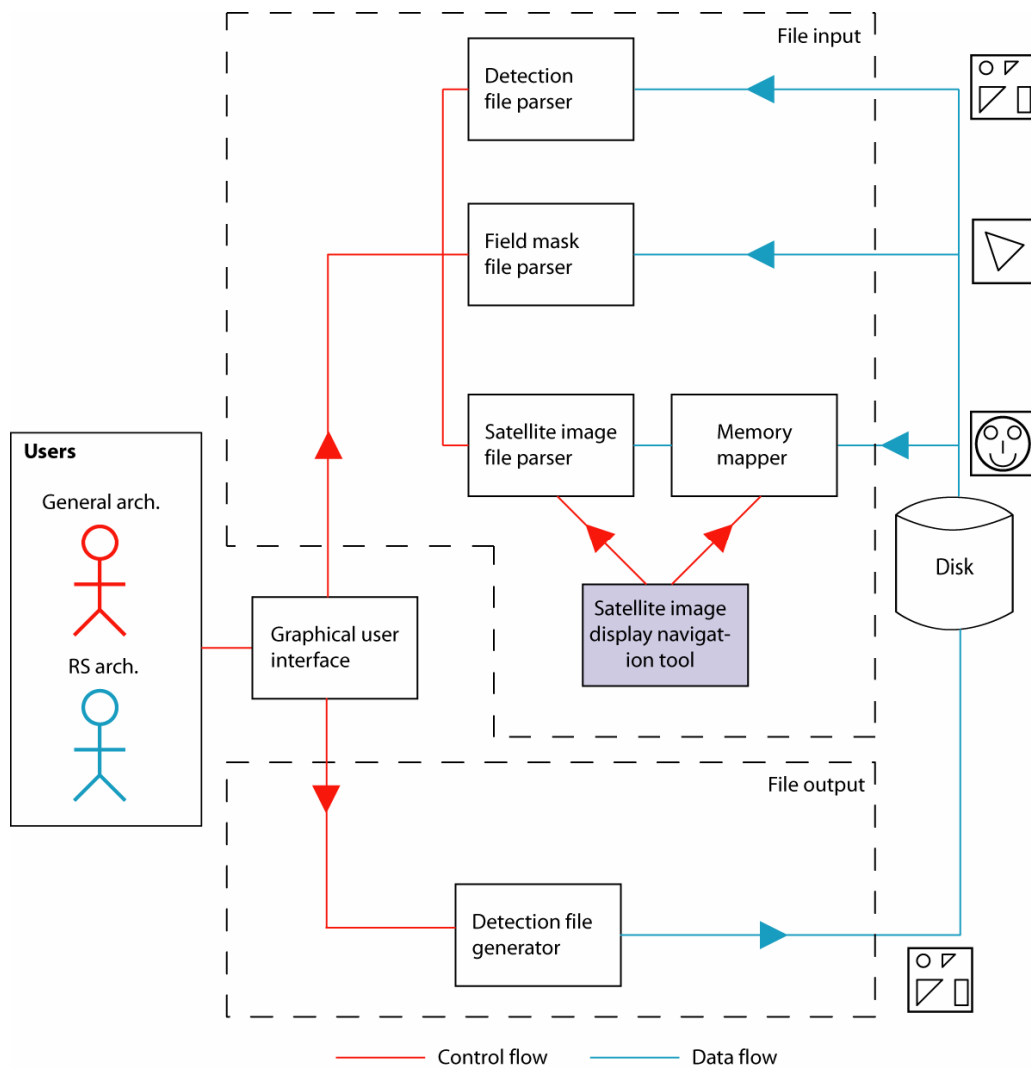


Figure 9: The file input and output functionality. Both users control this functionality through a user interface. Input files can be satellite images, field masks or detection files. Output files are only detection files. The handling of these three file types is described in the text.

6.3.1 Satellite file input

Satellite image files are normally binary files containing the satellite image data possibly along with metainformation of various types. The satellite image data are typically multi- or hyperspectral. There are many possible types of metainformation, the most common are:

- Image size and number of spectral bands
- Spectral bandwidths
- Projection and georeferencing information
- Acquisition information (satellite type, date, time etc.)

Satellite image files have two particularities that require special handling, they are typically stored on a binary, proprietary format and secondly they are often very large (~1GB). The specific file format obviously requires an adapted parser; their size makes it impossible to load them in their entirety into the memory of the computer used to process them. The parsing problem is typically resolved by including a library of satellite image file parsers; these are available both as freeware (e.g. GDAL) and as commercial libraries. The file size problem makes it necessary to dynamically load only the part of the file that is currently needed for display or processing. The standard way of doing this is by memory mapping the file.

6.3.2 Field mask input

The field masks that the CHDS will load will be represented on a vector format (the most common of these being the SHAPE-file format used in programs such as ArcView). These files are built up of the actual vector information along with metainformation. The vectors describe geometric primitives (typically lines) that are used to draw the desired features. The metainformation will typically contain the georeferencing information.

Typically smaller than the satellite image files, their contents can be read into memory directly. Most vector file formats (such as the SHAPE-file format) are proprietary binary formats whose parsing should be resolved by including an appropriate library.

6.3.3 Detection input

The detection files will be represented on a vector format just like the field masks and the comments concerning the field masks also apply to the detection files. These files essentially contain polygons describing the shape and size of the detections along with metainformation, in particular metainformation describing what the CHDS considers to be the most likely interpretation of a detection.

These files will in all practical situations be small and the entire contents can be loaded into memory.

6.3.4 Detection output

The only type of file output generated by the system is detection files. See the comments in section 6.3.3 concerning these files.

6.4 Satellite image display

The display of satellite images will typically be closely linked to the satellite image file input since it is normally impossible to load the entire satellite file into memory for display or processing. As stated previously the display must comprise a navigation and a zoom tool as well as functionality for modifying the brightness/contrast of the satellite image display (see the appendix for examples of this) and the navigation tool actually decides what part of the total file is displayed to screen. The functionality of this module is summarized in the following figure:

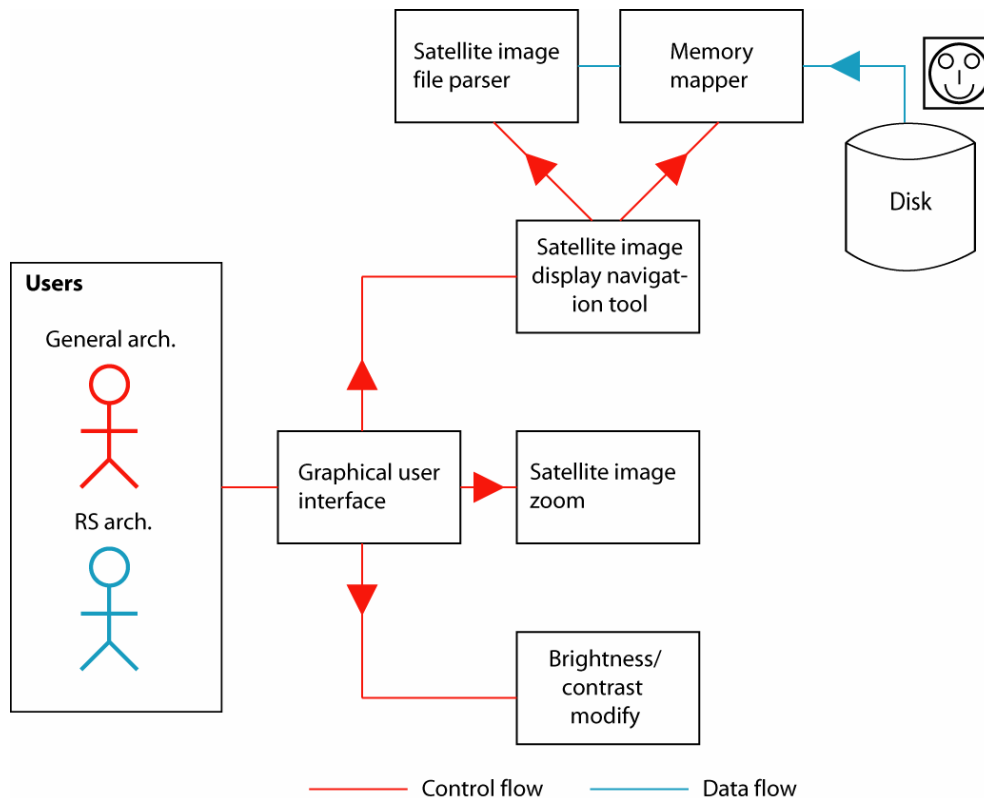


Figure 10: The satellite image display functionality. Both users control this functionality through a user interface. Input files are satellite images. Again, the complexity of displaying image data to screen makes use of imaging libraries the only viable alternative for this operation.

6.5 Field mask display

The display of field masks can be done either in specialized vector display windows or on top of satellite images. For both types of displays a navigation and zoom tool must be available. See the appendix for an example of a field mask displayed on top of a satellite image.

As for the satellite images, the complexity of displaying such vector data to screen makes use of imaging libraries the only viable alternative for this operation.

6.6 Detection display

The display of detections can be done either in a specialized vector display windows or on top of satellite images. For both types of displays a navigation and zoom tool must be available. See the appendix for an example of detections displayed on top of a satellite image.

As for the satellite images, the complexity of displaying such vector data to screen makes use of imaging libraries the only viable alternative for this operation.

6.7 Preprocessing algorithms

The preprocessing algorithms that should be available under the CHDS system are noise and plow furrow removal. The functionality of this module is described in the following figure:

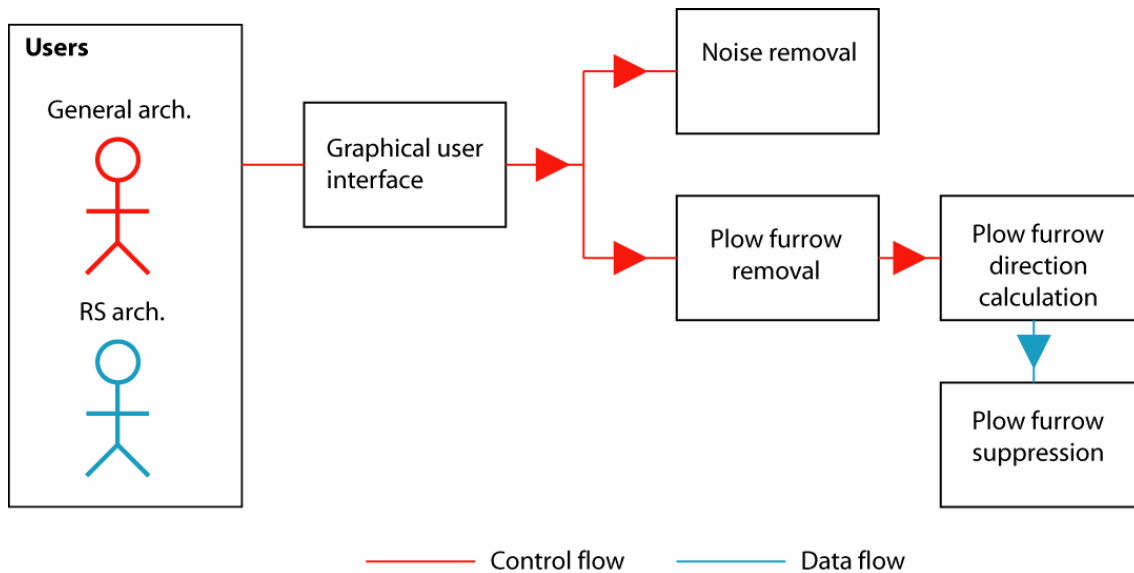


Figure 11: The preprocessing functionality. Both users control this functionality through a user interface.

The noise removal algorithms should allow for simple spatial domain filtering. The plow furrow removal depends on detecting the local plow furrow direction followed by a filtering to suppress the plow furrows.

6.8 Detection algorithms

The detection algorithm is a two-step procedure (see [2]) consisting of detection of regions with deviating gray levels or spectral values in the image followed by a classification step that sorts and keeps/discards the initial detections according to size, shape and other criteria. The functionality of this module is as described in the following figure:

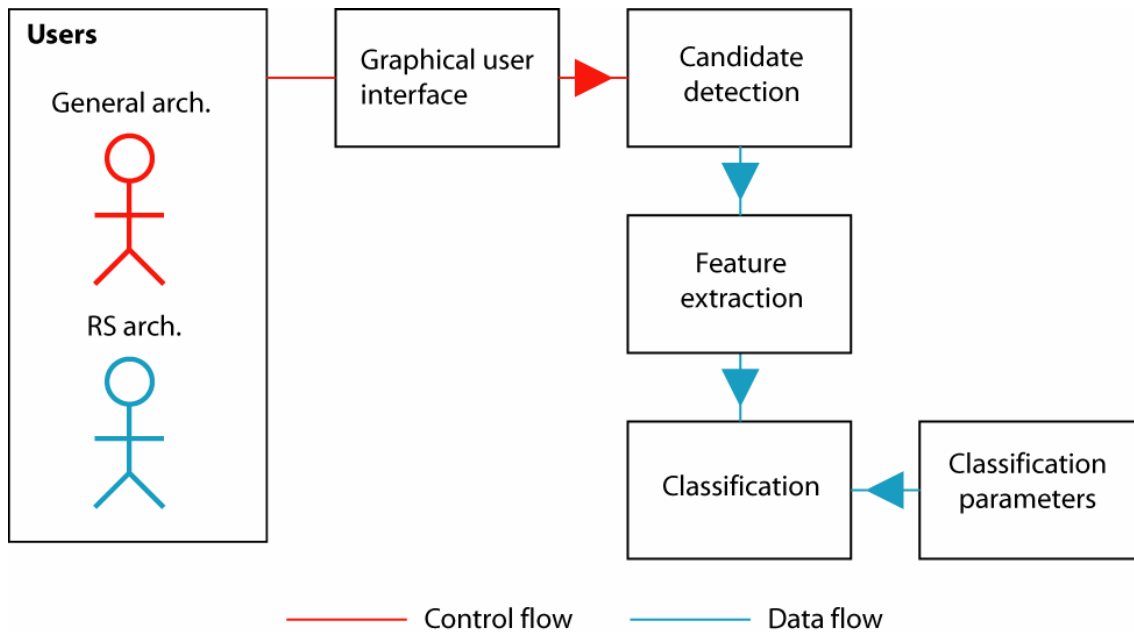


Figure 12: The detection functionality. Both users control this functionality through a user interface.

The candidate detection module will extract regions from the image that have deviating spectral properties compared to their local background. This can either be done using locally adaptive thresholding algorithms or by using an unsupervised clustering of each field (as described in [2]). Once the candidate regions are found, features describing these regions must be extracted. As described in [2], these features can for instance be:

- Size
- Degree of rectangularity
- Compactness
- Aspect ratio
- Grouping (contextual information)
- Location in the terrain

The classification module will most likely be implemented using a trained classifier. Since the interesting classification parameters are likely to change (for instance as the CHDS is applied in different regions or as experience is gained in the project) it is probably necessary that the classification parameters are read from file to allow for simple updating.

The necessary algorithms for carrying out these steps are found in many image processing and pattern recognition libraries.

6.9 Analysis algorithms

The analysis algorithms that should be available are algorithms for computing statistics, and for advanced preprocessing and analysis. It is impossible at the current time to determine what algorithms and tools should be made available to the user as part of the analysis algorithms. Most image processing and pattern recognition libraries contain a wealth of such algorithms, and the use of such a library will make it simple to offer extensive functionality to the user.

7 References

- [1] O. Grøn and a. Loska, "Development of methods for satellite monitoring of cultural heritage sites," NIKU December 2002.
- [2] O. Grøn, L. Aurdal, F. Christensen, H. Tømmervik, and A. Loska, "Locating Invisible Cultural Heritage Sites in Agricultural Fields: Evaluation of of Methods for Satellite Monitoring of Cultural Heritage Sites-Results 2003," NIKU ISBN: 82-7574-033-9, March 2004.
- [3] I. Jacobson and G. Booch, *The Unified Software Development Process*: Addison Wesley Longman, 1998.

8 Appendix: Simulated screen snapshots

In order to provide a preliminary impression of what the screen output during the different stages of a typical use case will look like we provide the following illustrations. The illustrations are made using ENVI in conjunction with manual drawing to produce an impression of what a final result may look like.

8.1 Display of input satellite image

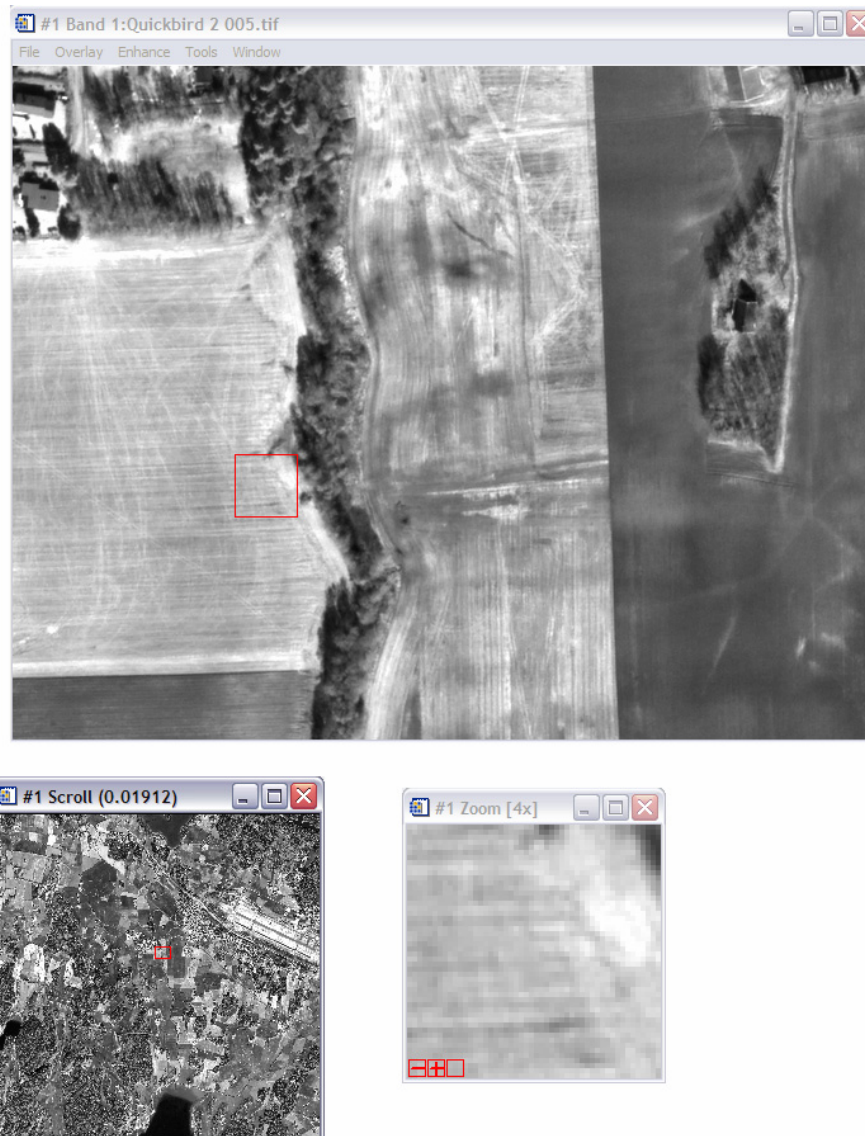


Figure 1: Conceptual satellite image display. The lower left window shows the navigation (scroll) window, displaying a subsampled version of the entire image. The upper window shows a part of the total scene (that marked by a red box in the navigation tool) in 1:1 scale (that is, one satellite image pixel is mapped to one screen pixel). The lower right image shows a 4:1 scale zoom of the part of the image marked by the red box in the 1:1 display.

8.2 Display of field polygons on top of satellite image

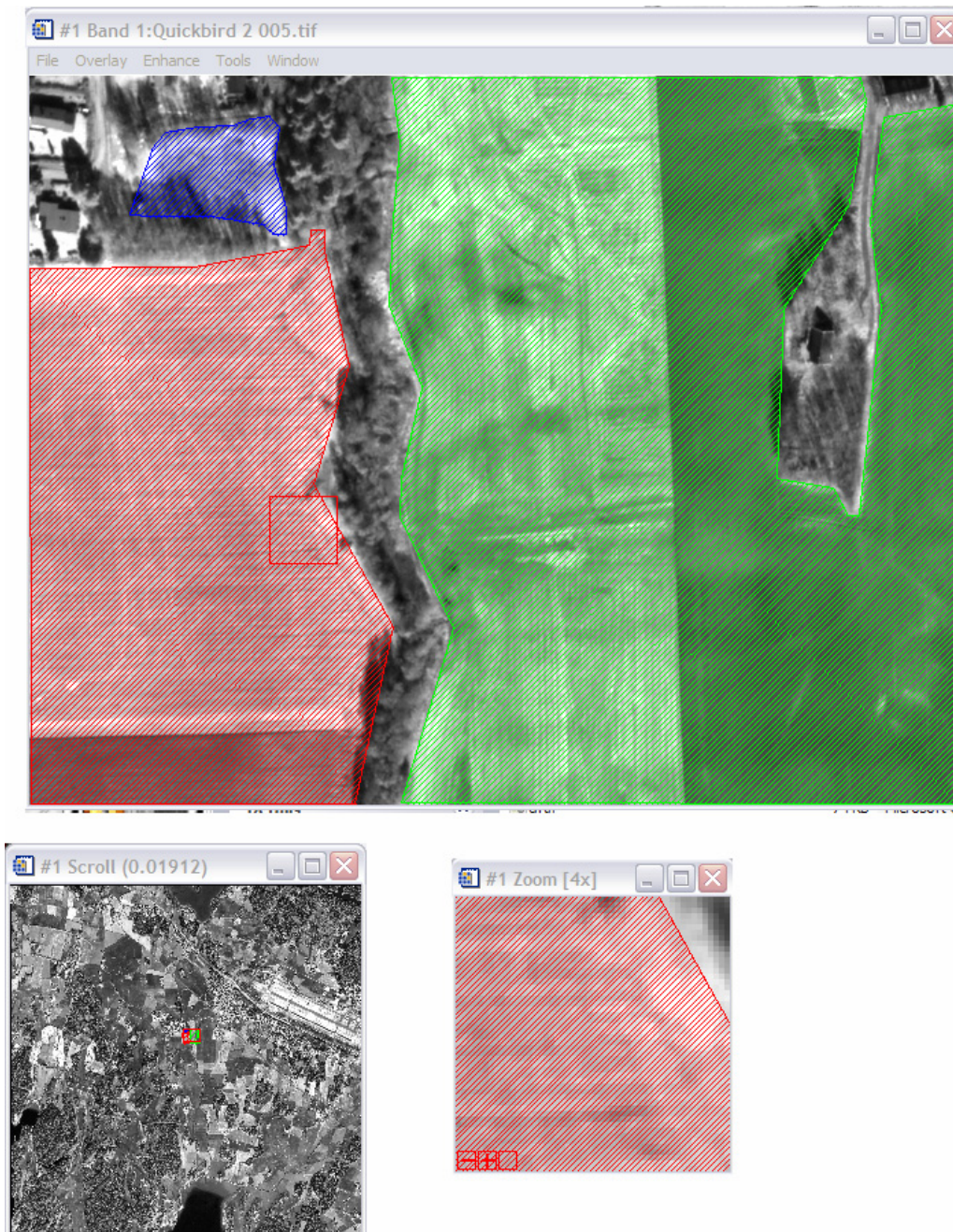


Figure 2: Conceptual display of field masks. Three field masks have been loaded and are displayed on top of the satellite image. As before a navigation and zoom tool is available.

8.3 Classification output and list of detections

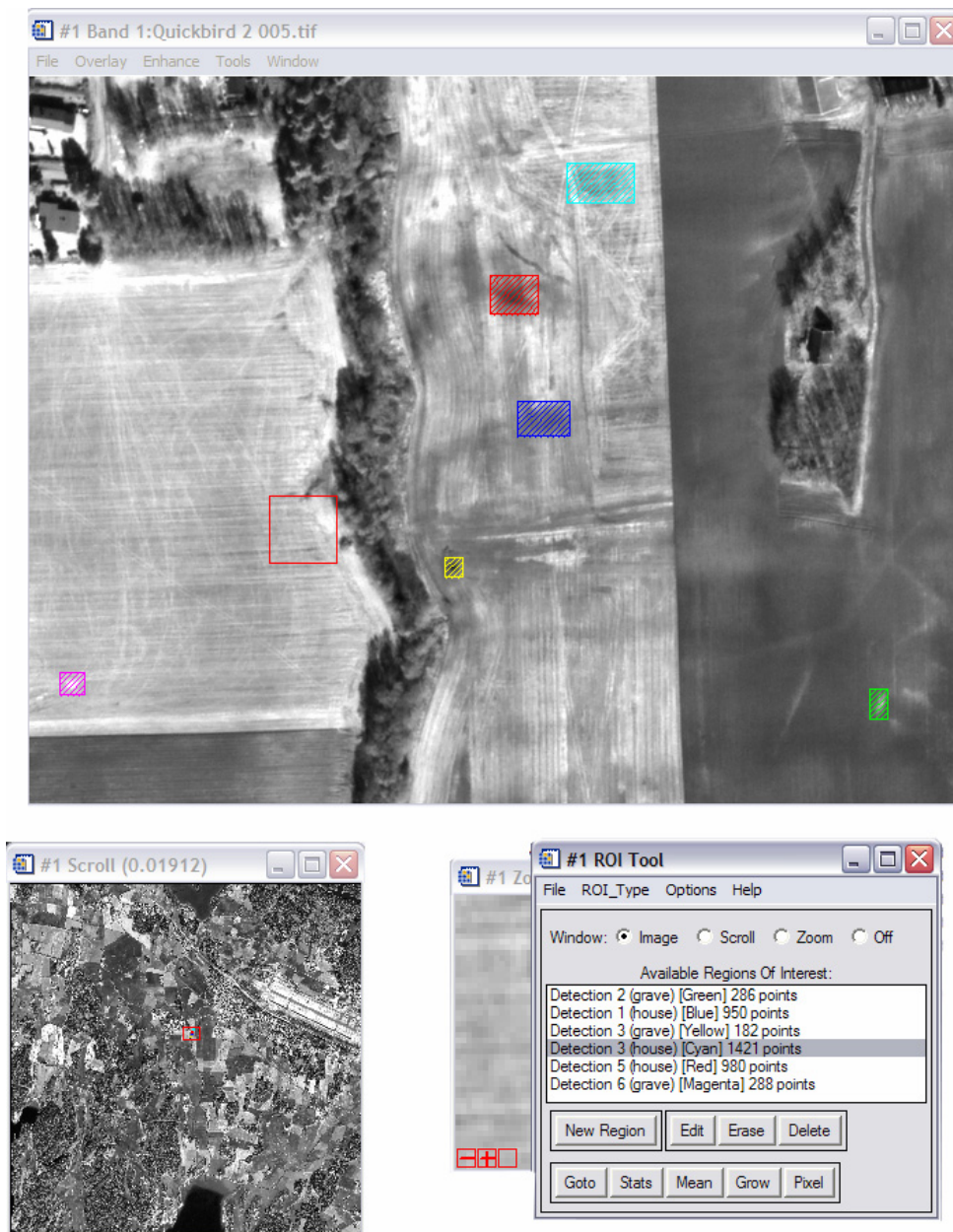


Figure 3: Conceptual display of detection result. Having run a cultural heritage site detection within the masks shown in the previous figure, these could be the detections returned. As before a navigation and zoom tool are available. The window listing the detection also show a (fictious) interpretation of each site. By clicking on a particular detection in this list (detection 3 in the example) this detection is centered in the 1:1 display window.

8.4 Retained classifications

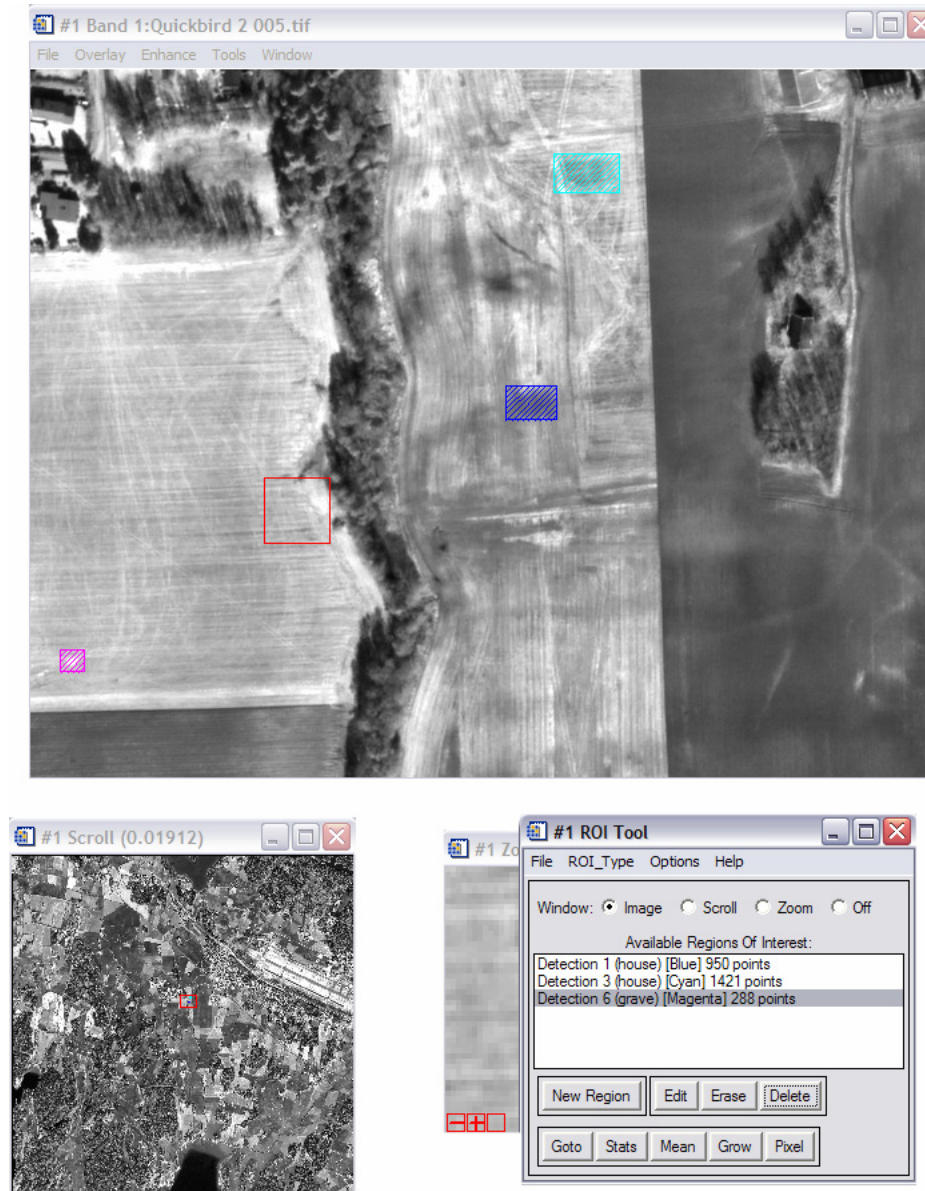


Figure 4: Conceptual display of edited detection result. Having run a cultural heritage site detection within the masks shown in figure 2, the user has deleted detection assumed to be of no interest. As before a navigation and zoom tool are available.

8.5 Zoom and contrast enhancement of detection

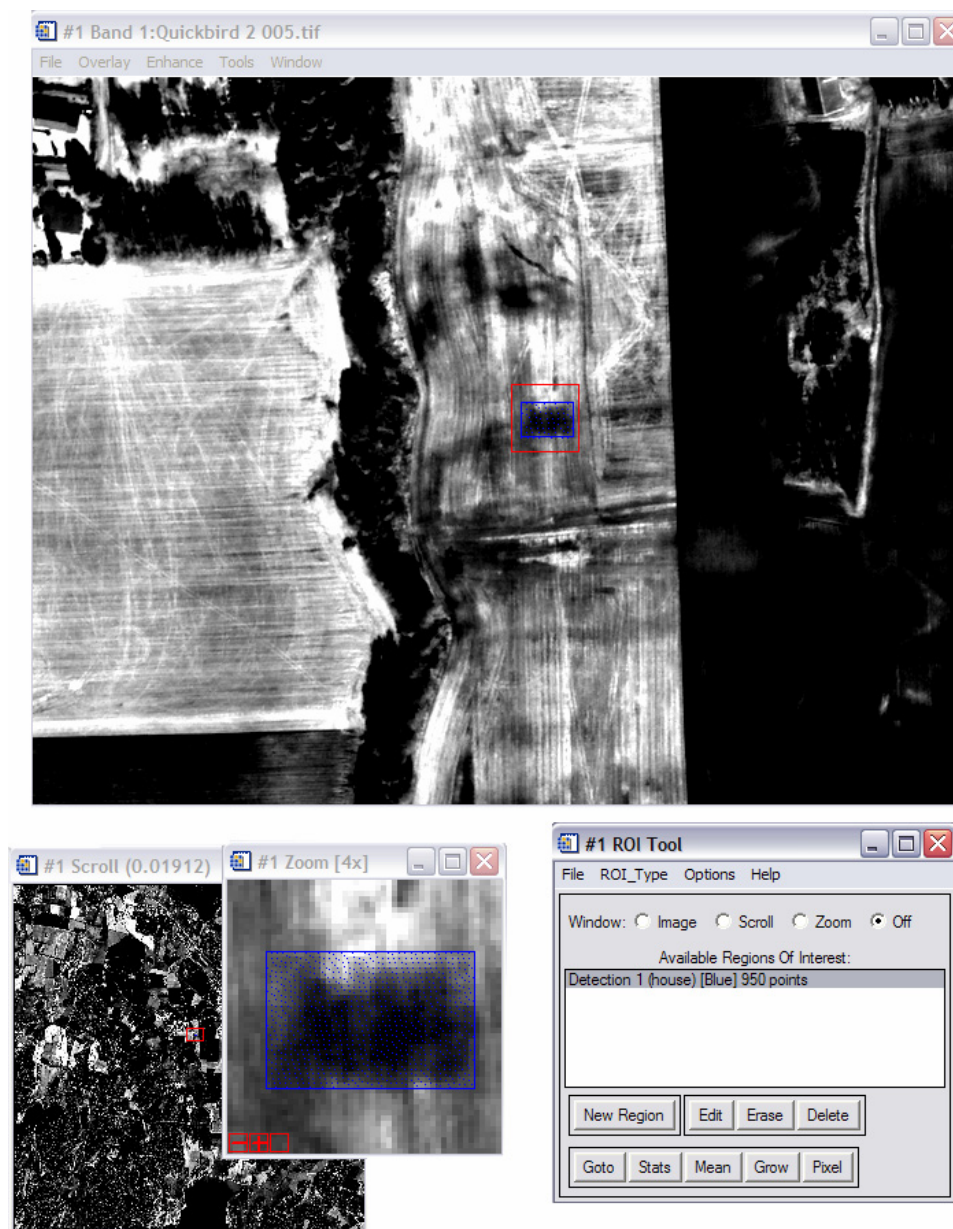


Figure 5: Conceptual display of detection result after modification of the brightness/contrast of the display.