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User Report

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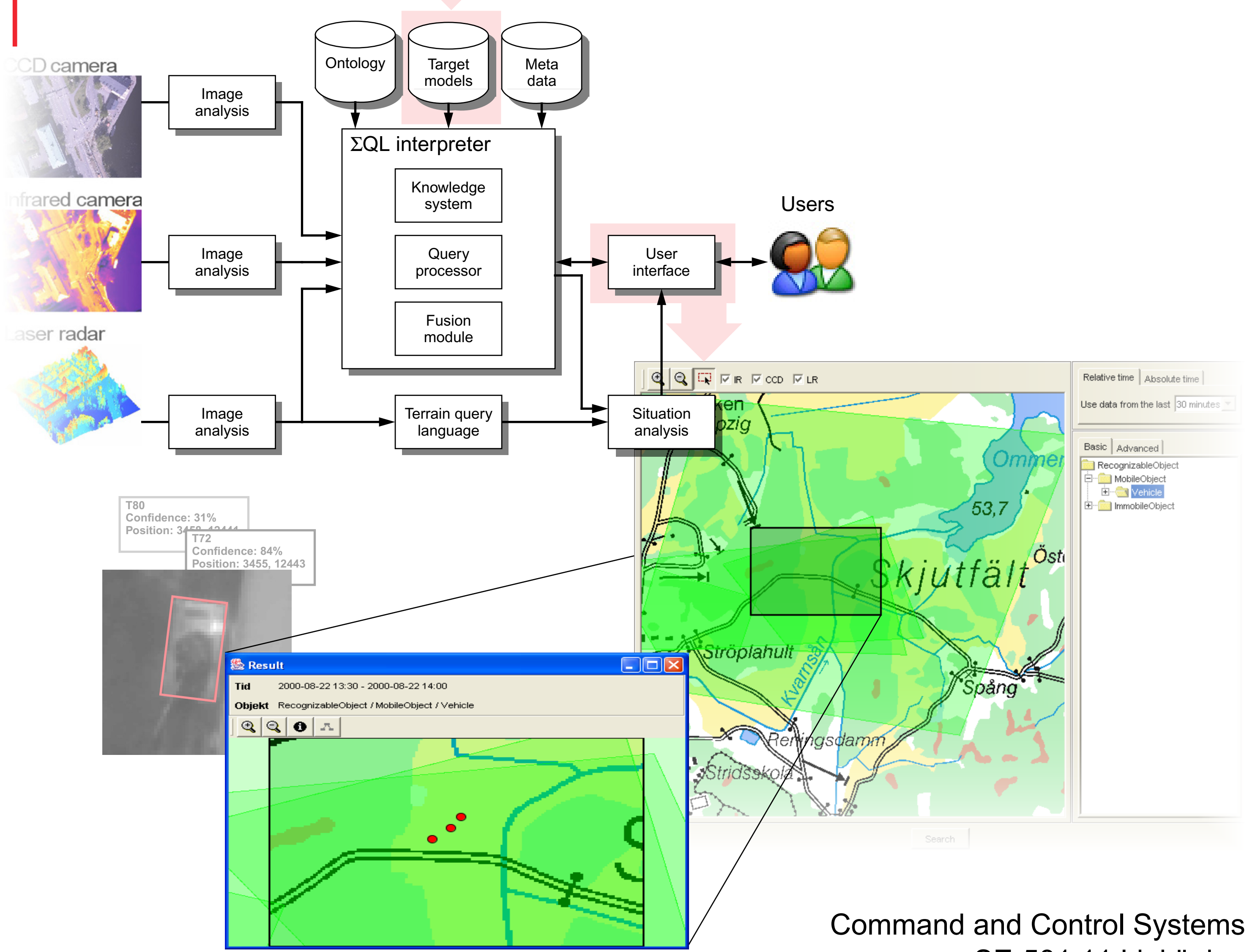
Erland Jungert & Christina Grönwall

From Sensors to Decision

Towards improved situation awareness in a network centric defence



Command and Control Systems
SE-581 11 Linköping

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Erland Jungert, Christina Grönwall (Eds.)

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Report title

From Sensor to Decision - Towards improved situation awareness in a network centric defence

Abstract (not more than 200 words)

The work described in this report concerns an information system for target recognition. The information system includes a query language for heterogeous sensor data sources. Currently the information system works on four sensor types, i.e. laser radar (scanning and gated viewing), IR-camera and CCD. Methods for analysis of data from these sensor types have been implemented as well. The query language, called ΣQL, includes means for sensor data fusion and sensor data independence. The latter aspect is supported by means of an ontology and its knowledge base. The information system is also equipped with a powerful visual user interface that allows the users to apply their queries in a simple way that is due to the sensor data independence concept. One of the main purposes with ΣQL is to support situation awareness and for this reason a subsystem including means for this is being developed. To improve the aspects of situation awareness the information system includes means for generation of a terrain model with a very high resolution. A further purpose of the terrain model is to allow determination of various terrain features that generally are difficult to identify in traditional terrain models. The data used for the determination of the terrain model comes from the laser radar system. This report concerns the research within the ISM project performed during 2001 through 2003.

Keywords

Query language, decision support, target recognition, multisensor data fusion, ontology, digital terrain model, laser radar, IR, CCD, Image processing, feature extraction, signal processing, situation awareness

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Från Sensorer till Beslutsfattande - mot en bättre situationsförståelse i NBF

Sammanfattning (högst 200 ord)
Det arbete som redovisas i denna rapport behandlar ett informationssystem för måligenkänning. Informationssystemet omfattar ett frågespråk för heterogena sensordatakällor. För närvarande arbetar informationssystemet mot fyra olika sensortyper, dvs laserradar (skannande och gated viewing), IR och CCD. Metoder för analys av sensordata från dessa tre sensorer har också implementerats i systemet. Frågespråket, som kallas ΣQL, innefattar stöd för sensordatafusion och kan arbeta mot sensordata på ett sensordataoberoende sätt. Den senare aspekten stöds av en ontologi och dess kunskapssystem. Informationssystemet är också försett med ett kraftfullt visuellt användargränssnitt som tillåter användaren att ställa frågor till systemet på enkelt sätt genom sensordataoberoendet. Ett av syftena med ΣQL är att ge stöd för situationsanalys och av detta skäl pågår också arbete med ett delsystem med sådan funktionalitet. För att ge ytterligare stöd till situationsanalysen pågår också utveckling av en metod för generering av en högupplösande terrängmodell med hjälp av laserradardata. Avsikten med denna terrängmodell, som har en symbolisk representation, är att effektivt kunna söka efter olika former av terrängstrukturer, t ex olika hinder, som kan vara svåra att hitta med traditionella metoder. Rapporten utgör slutdokument för projektet ISM avseende forskning genom förd 2001-2003.

Nyckelord
Frågespråk, beslutsstöd, måligenkänning, multisensordatafusion, ontologi, digital terängmodell, laserradar, IR, CCD, bildbehandling, särdragsextraktion, signalbehandling, situationsanalys

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Contents

1 Introduction

In this report a project called *information system for target recognition* (in Swedish Informationssystem för måligenkänning) is presented. This report describes an information system for recognition of ground targets, basically various types of vehicles. The main goal is to cover the complete process of target recognition, from the sensors to the decision support in a command and control system. The main applications will be concerned with surveillance and intelligence. The main goals of the project have been to:

- develop signal- and image processing methods for target recognition,

- demonstrate target recognition of ground targets, mainly military vehicles,

- demonstrate improved target recognition using data fusion,

- develop an information system for target recognition based on a query language, with a powerful visual user interface, for heterogeneous sensor data sources,elektrooelektrooptiskaptiskaelektrooptiska

- demonstrate how the decision support tool in the information system can support situation analysis.

The next generation decision support tools for situation and impact analyses [1] will generally require input from a large number of sensors located on different platforms. These decision support tools will also be integrated in a communication network to be able to carry out network centric warfare applications. Systems designed for this type of applications, i.e. basically command and control, will obviously become very complex. Hence, they will require users that are well trained in using complex technical information systems. Alternatively, efforts must be made into the design of *usable systems* [2]. The latter alternative is clearly preferable since most users will place a higher trust, or confidence, in the system at the same time as they will be able to focus their efforts on their primary tasks. Such a system requires capabilities to select sensors and algorithms for sensor data analysis without any user interference. This requires consideration of the actual weather and light conditions as well. Systems with this capacity are said to be *sensor data independent* [3], see also section 3.2. Sensor data independence can from a practical viewpoint be carried out by means of an ontology combined with an ontological knowledge-base [4], [5]. Another important aspect when designing systems for command and control applications, and where sensors are the primary input data sources, is that the users should be allowed to define relevant application oriented goals [6]. This should enable the system to acquire the information needed for the solutions to the problem associated with the given goal. Consequently, a system of this type must be *goal driven* or, as will be seen subsequently, *query driven*. Various means can be used to accomplish the user-defined goals. In this work a query language for sensor data, where the different occurring sensor data types are homogeneous with respect to the sensors, is introduced. The query language is called ΣQL. ΣQL uses a visual user interface [7] for application of the user defined queries and an ontology with an ontological knowledge base to achieve sensor data independence. A more thorough description of ΣQL can be found in [8], [9]. A discussion on the set of sensors and their sensor data analysis algorithms currently used in the information system is given in [10]. One of the primary objectives of the information system is to acquire information from the sensors and deliver input to a module for situation assessment [13]. To support the latter, a technique for generation of a symbolic digital terrain model in very high resolution (~ 0.5 m) has been developed. This includes a filtering method for determination of various terrain features [14].

The outline of this report is as follows. A motivation of the work is given in section 2. The different aspects of the complete information system are discussed in section 3. Section 4 contains a discussion of future work. Finally, section 5 discusses the experiences drawn from the project, and in particular the multi-disciplinary aspects.

1.1 Achievements

A simple prototype of the information system has been implemented and can be run. The prototype includes basically

- a ΣQL query processor,

- a query processor including an ontology and its knowledge-base; designed to allow sensor data independence from an end-user perspective,

- a data fusion module that fuses sensor data in two steps, i.e to support (1) attribute estimation (2) and target matching,

- a visual user interface that allows the application of queries in a sensor data independent way,

- means for visual presentation of query results,

- application, at this time, of sensor data from sensors of type IR, laser radar (scanning and gated viewing) and CCD-camera; the number and types of sensors are extendable,

- a number of algorithms for analysis and matching of sensor data generated by the applied sensors; an overview of these algorithms can be found in the table in Appendix A.

By means of the demonstrator queries can be applied and answered. Basically, these queries are concerned with recognition of targets of military type. The recognition algorithms allow recognition of partly occluded targets.

The activities in conjunction with the development of the high resolution digital terrain model show that

- various terrain features efficiently can be identified by means of the presented filter technique,

- the terrain model can be used for efficient visualization of the terrain in high resolution,

The activities to bring forward a system for situation awareness, finally, have not yet come to a break through although some fundamental results have been demonstrated; the reason for this is due to the fact that this part of the project has been going on at a low pace.

2 Motivation

In most command and control systems, the users are engaged in activities where problem solving is the main concern. That is, users are requesting information about the real world to get support for a solution of the problem at hand. Collecting the information needed for solving the actual problems requires not only means for sensor data selection, but also means for analysis of the sensor data as well. In modern information systems applied to command and control activities the data sources will most likely be sensors although human reports are possible. In this work, however, we are primarily concerned with sensor data sources. Sensors attached to information systems generate large quantities of heterogeneous data. In these data fact can be found that generally is redundant with respect to the problem to be solved. Furthermore, the data are often associated with various types of uncertainties due to limitations in the sensors and navigation systems. For this reason, a tool that can help separate the redundant information and fuse the relevant information is needed. However, such tools need to be general and efficient with respect to the variety of problems that may occur and that may require different combinations of information. For this reason we have chosen a solution based on a query language technique with built-in features for sensor data independence and sensor data fusion.

A general property of information systems concerns aspects such as the user's trust in the systems. Trust in an information system is an important issue to make the users feel that the system is reliable in a simple and understandable way. In ΣQL, means for trust will be carried out primarily through the ontological knowledge-base but also by means of the design of a powerful and useable visual user interface [7].

To avoid a situation, where the users need a deep understanding of the sensors and sensor analysis algorithms, their usage, and methods for sensor data analysis, ΣQL has been equipped with facilities for sensor data independence. Sensor data independence is basically similar to data independence in database design, where it was first introduced to allow modifications of the physical databases without affecting the application programs [17]. This was a powerful innovation in database design and generally in information technology. The main purpose was to simplify the use of the databases from an end-user's perspective while at the same time allowing a more flexible administration of the databases themselves [6]. A sensor-based information system with sensor data independence similar to the data independence in traditional databases is, for the same reasons, an advantage.

Another serious motivation for sensor data independence relies upon the extremely large data quantities, generally of heterogeneous type, generated by multi-sensor data systems. In the future, it may become more or less impossible to visualize these data individually with respect to their type. Thus users will not be able to extract all the relevant information by means of their queries. That is, the users will not be able to identify all objects of interest and even less so when multiple sources are used without fusion of the acquired information. Thus, support from fusion techniques is required for reliable results. This situation becomes even more obvious in cases where the users need timely response to their queries. Despite this, inexperienced users in many cases request raw data from single or multiple sensors without reflecting over whether this is realistic or whether they will be able to analyse these large data volumes in the first place. A very obvious consequence of the sensor data independence concept is that users must be able to trust the system and the result presented to them.

An important advantage of the system design described here is that new sensor types can be integrated by simply updating the ontological knowledge-base and, if required, including new sensor data analysis algorithms into the system. Thus integration of new sensor types can be made even without informing the end-user.

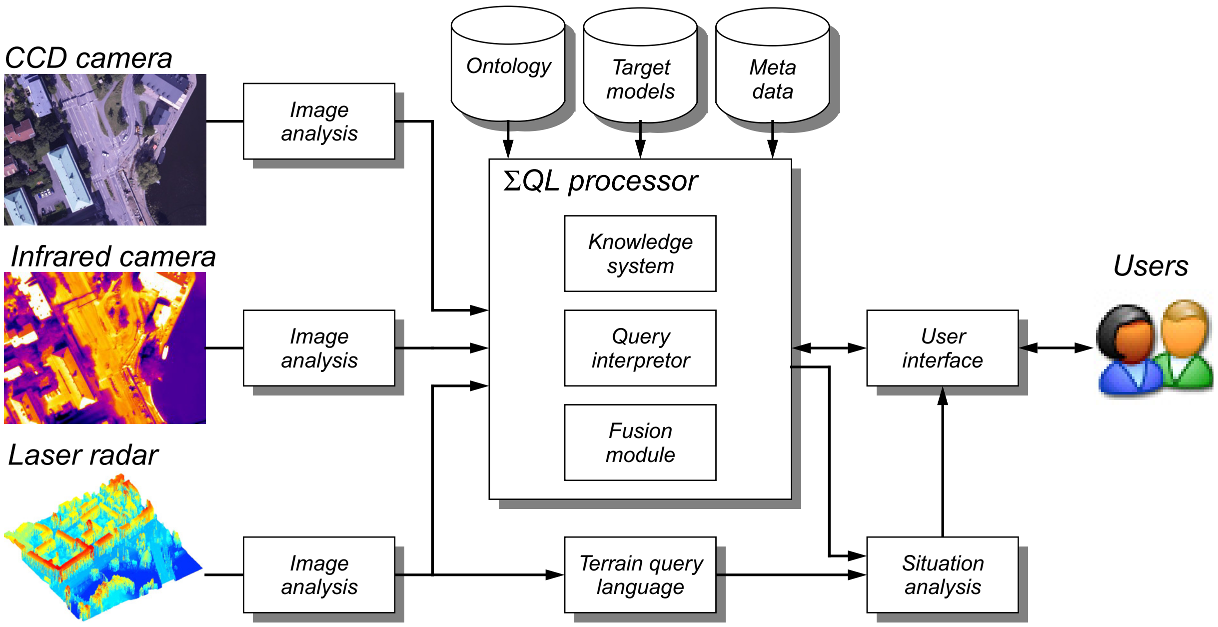

Figure 1. An overview of the information system.

3 System structure

In this chapter the structure of the system is described. An overview of the system can be found in figure 1. The system is, from right to left, divided into the visual user interface, the query processor and the sensor nodes to which the sensor data sources are attached. The query processor includes a knowledge system connected to the ontology. The sensor data fusion module is integrated in the query processor. There is also a situation analysis module attached to the system, which is more independently attached to the query processor. The sensor nodes include means for target recognition and terrain data analysis. One of the purposes with the query processor is to feed the situation analysis module with relevant information.

3.1 User interface

The basic idea of the information system is that the user should not need to have any knowledge about sensors or sensor data. The consequence is that the user interface should be based on concepts related to the users task. In this case those concepts are area, object, and time, in particular the *area of interest (AOI)*, the requested *objects* and the *time interval of interest (IOI).* The user interface for requesting a search of sensor data is split into three parts; one for area of interest, one for object selection, and one for specification of the actual time.

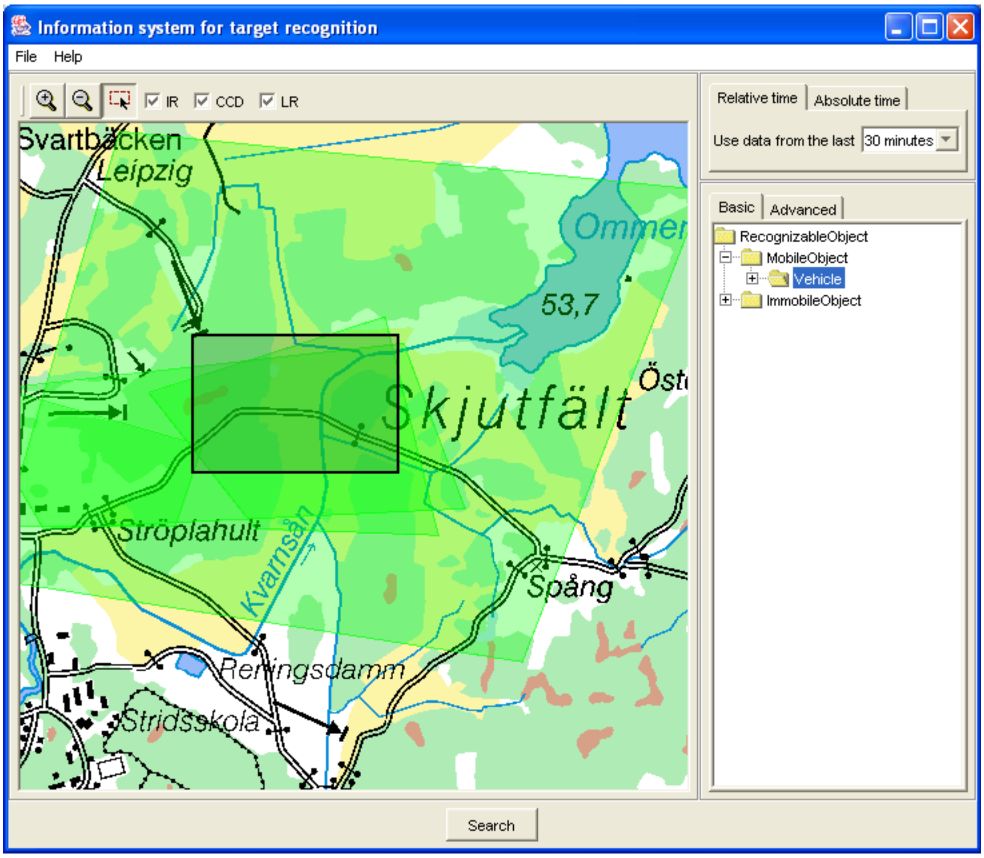

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Figure 2. The user-interface for creation of a query.

Generally, the user is not interested in data from all locations, so he/she must select the relevant area for the current query. To facilitate the AOI the user interface contains a map, see the left part of figure 2. It is possible to zoom and pan the map to find the desired area of interest. Once the user has determined the correct location he/she simply marks the actual area of interest. Although the user does not need to know anything about sensors, it is nevertheless undesirable to make a query where no data are available. Consequently, the map is also marked with those parts that contains available data for the selected time.

The user also has to specify which kind of objects that are currently of interest. This can be done by selecting the objects from a hierarchical list in the right part of the user interface, see figure 2. The user can use a more advanced tool for the object type selection, see figure 3. In the advanced user interface it is possible to specify object attributes, for example, length and velocity but also relations, both in space and time, between objects.

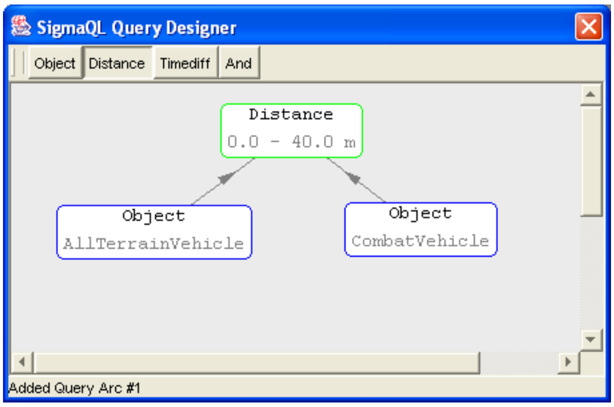

Figure 3. The user-interface for advanced object specification.

The third part of the user interface concerns the time-constraints on data for a particular search; that is basically the time span of the data. The user can either specify the absolute time for a query that should be repeated over time by giving start and end time, or he can specify the query in relation to *now*, for instance, by only using data collected during the last 30 minutes.

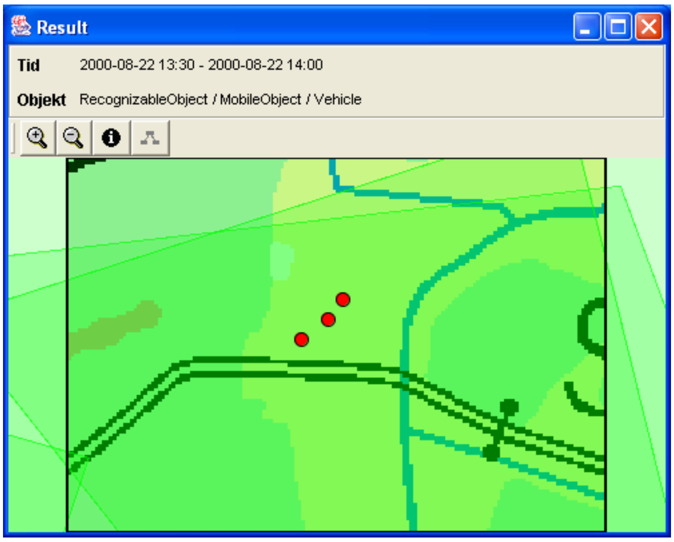

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Figure 4. The result of a query.

The result of the search is presented in a separate window showing the zoomed-in area of interest, see figure 4. All occurrences of relevant objects recognized in the area by the sensors are marked. At the user's request, additional information from sensor data about each of the objects can be shown.

In most cases a query concerns the occurrences of objects of certain types including a number of attributes. Since the sensors and their platforms always are associated with various uncertainties there are always uncertainties associated with the query result. Clearly, there is no way of avoiding these uncertainties although the result can be improved, e.g. if the sensors are improved. For this reason, means to indicate the level of uncertainty of the queries must be available to allow the users to draw their conclusions regarding the result of their queries. Such means can, of course, be presented by the system in many ways. In this work we have chosen to represent the uncertainties by means of what are here called *belief values.* A belief value is a normalized value in the interval [0, 1]. The interpretation of such a value is that when it is close to 1 there is a high belief in the received objects and when close to zero a low.

3.2 Knowledge system

Two characteristics must be fulfilled to establish sensor data independence. First, the system must be able to select one or more sensors while considering e.g. the present weather and light conditions. Second, proper recognition algorithms must be chosen as well, i.e. algorithms that support an efficient recognition of the requested targets under the existing conditions. Finally, means to control the sensor data fusion process and to determine the interconnections between the controlling part and the fusion process must be established. A system designed to support all these characteristics will need a structure that on the basis of the requested targets is able to pick the most appropriate sensor(s) and recognition algorithm(s) and to access, analyse and eventually fuse the information gathered from the sensors. In this section an ontological knowledge-based system is described which has been developed to enforce sensor data independence and to control the sensor data fusion process. The ontological system is an integrated part of the query language ΣQL [8], [9]. The work on the ontological knowledge-based system was originally carried out as a master thesis [4].

3.2.1 The ontology

The knowledge represented in the ontological knowledge base is modelled in a hierarchical manner known as the ontology. All concepts in the universe of discourse, the interesting properties of the concepts and the important relations between the concepts are modelled. The hierarchy has the ultimately general concept called *Thing* at the top. All other concepts inherit directly or indirectly from *Thing*. The hierarchy is organized so that more specialized concepts appear further down the inheritance chain. The concepts of this ontology are divided into three major parts, i.e. *things*, *characteristics* and *conditions*. An overview of the ontology is presented in figure 5. Further details can be found in [4], [5].

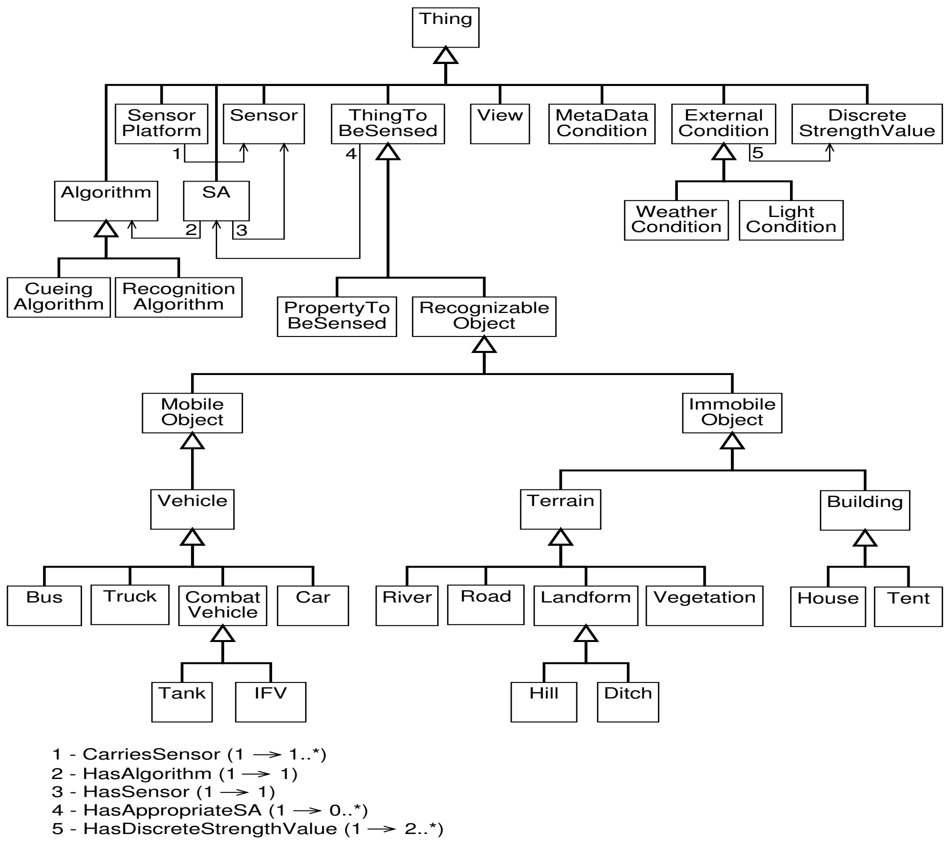

Figure 5. Ontology overview - The knowledge structure.

The *Things to be Sensed and Recognized* part of the ontology models everything that can be sensed by the sensors and everything that can be recognized by the recognition algorithms or cued by the cueing algorithms. It is represented in the ontology, see figure 5, by the *ThingTo-BeSensed* concept and subconcepts; examples are trucks and tanks.

The *Sensor and Algorithm Characteristics* part of the ontology models the characteristics of the sensors and the recognition and cueing algorithms. This part includes the concepts *Sensor platform, Sensor, Algorithm* (including subconcepts) and sensor-algorithm (*SA)*, i.e. the combination of a sensor and an algorithm.

The *Conditions* part of the ontology models the conditions that have an impact on the appropriateness of the sensors and the recognition/cueing algorithms. The conditions are state conditions describing the state of something, for example how rainy it is. The concepts that make up this part are *View, MetaDataCondition*, *ExternalCondition* (including subconcepts) and *DiscreteStrengthValue*.

Relations are used to model how the concepts in the ontology are related to each other. It is important to note that relations are inherited, meaning that if concept B inherits concept A and concept A has a relation to C, then concept B automatically has that relation to C as well. For example, the following relations can be found in the ontology:

- *Algorithm* to *sensor type*

- *SensorPlatform* to *sensor type*

- *ExternalCondition* to *DiscreteStrengthValue*

The relations are shown in the ontology overview in figure 5. Detailed relation descriptions can be found in [4].

3.2.2 The query execution process

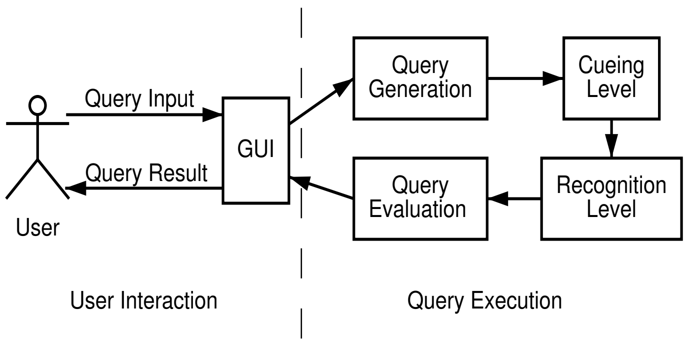

Figure 6. Overview of the query execution process.

The execution of a query, that is, everything performed between the reception of a query entered by the user and the presentation of the query result, is performed in a process controlled by the ontology; this includes the control of the data fusion process. An overview of the query execution process is presented in figure 6. More details can be found in [5]. The two basic levels in the data fusion control process are described below.

The first level is the *cueing level*, see figure 7, where the area of interest (AOI) can be large and the time interval of interest (IOI) can be long. Cueing in this sense means finding potential target objects (the ones searched for in the query) and indicating the positions of these potential targets. Note that the recognition algorithm can use other types of sensor data that can classify and/or identify the targets found in those positions.

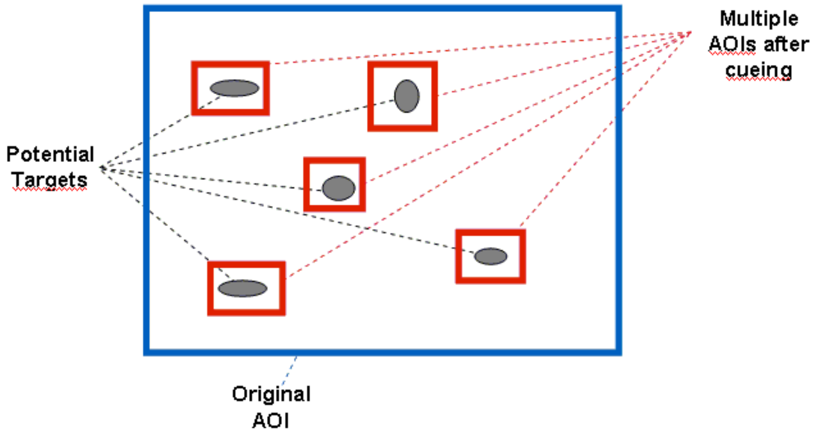

Figure 7. The Cueing level - Identifying potential targets.

The second level is the *recognition level* where the recognition process takes place. This is where recognition and possibly identification of the potential targets found in the cueing level is performed. The process includes two major steps. The first step involves estimation of the attributes of potential targets and the second matching of the potential targets against certain models selected from a library of models. Since the system allows for multiple algorithms to perform attribute estimation as well as model matching it is necessary to perform data fusion to get a better understanding of the target object attribute values as well as the target object classification/identification, see section 4.4. Therefore data fusion takes place both after attribute estimation and after model matching, see figure 8.

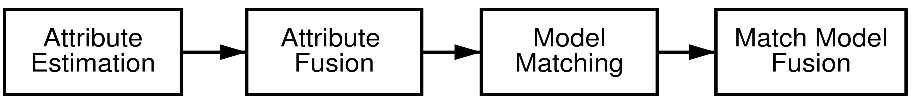

Figure 8. The recognition level - Classifying and possibly identifying potential targets.

When the recognition step has been carried out it is time to create an answer to the query. This is done by evaluating the logical expressions enforced in the query by the user. These expressions can constitute e.g. spatial and/or temporal constraints.

3.2.3 Selection of appropriate sensors and algorithms

The ontological knowledge base has been designed to help answer such questions as which sensor data to use under certain circumstances. Also of importance is which recognition and cueing algorithm(s) that should be applied. An algorithm that performs these selections using the ontological knowledge base is developed, that is, the knowledge in the ontological knowledge base is used in conjunction with the knowledge base rules (described below) to determine which sensors and recognition/cueing algorithms are the most appropriate under the given circumstances, i.e. the actual ΣQL query, the meta data conditions, the external conditions and the terrain background. This algorithm is called *Algorithm For Finding Appropriate Sensors and Algorithms (AFFAS)* and is described in detail in [4] and [5].

In the process of deciding upon appropriate sensors and algorithms it is necessary to have rules describing under which conditions certain sensors and algorithms are appropriate. The rules that are used to decide how the impact factors impact the sensors and recognition/cueing algorithms can be written in the following form:

"If an impact factor **x** has the discrete strength value **y** then the impact on the sensor/algorithm **z** is impact strength value **v**"

Example 1: "If the impact factor **Rain** has the discrete strength value **Gentle** then the impact on recognition algorithm **GeometricFeatureExtraction** is impact strength value **little**"

Example 2: "If the impact factor **View** has the discrete strength value **Local** then the impact on the sensor **Standard CCD Sensor** is impact strength value **None**"

A complete set of rules is needed for the system to function properly. Definitions of *impact factor*, *discrete strength value* and *impact strength value* are presented in [4]. The definitions are quite straight-forward.

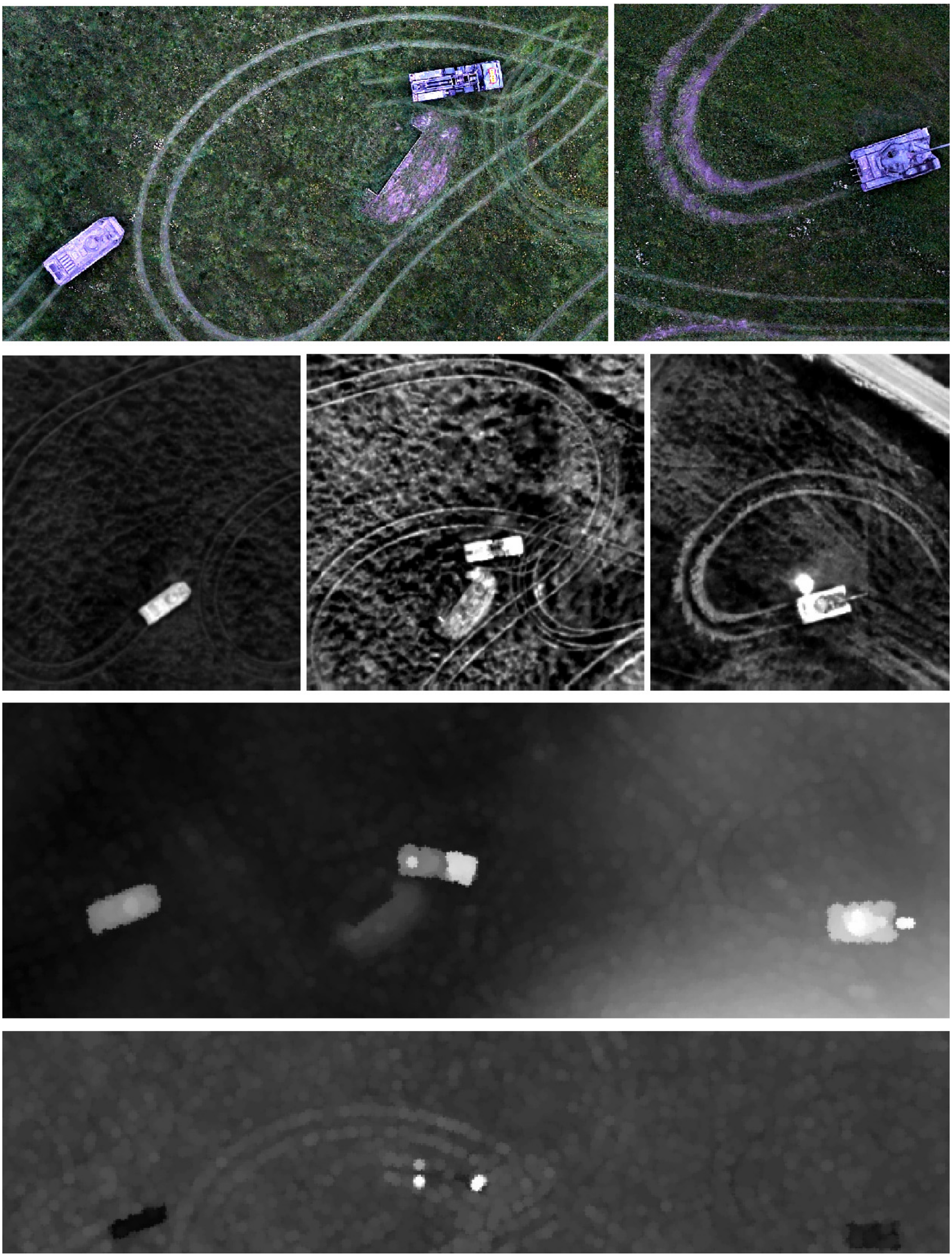

Figure 9. Registrations of an anti-tank gun vehicle BMP70 (left), truck TGB30 (middle) and a tank T72 (right). Top row: Visual senor data (CCD), second row: IR sensor data, third row: laser radar range data, bottom row: laser radar reflectance data.

3.3 Sensor data analysis

In this section we describe the target recognition process and the sensor data and algorithms used in that process. A recent overview is presented in [10]. There are several algorithms implemented in this project, they will be described briefly below and also in Appendix A. We will also show some of the information system's abilities to solve target recognition problems.

The target recognition task is performed by analysing sensor data that is simultaneously recorded by multiple sensors. Currently, data from IR, visual (CCD) and laser radar sensors are used and examples of data are shown in figures 9 and 10. Two types of laser radar data sets are included. The first set consists of 3D scatter and reflectance data from an airborne down-looking scanning sensor, seen in figure 9. The second set consists of gated reflectance 2D images from a forward-looking ground-based gated viewing system (GV), sequentially retrieved at different parts of the object as illustrated in figure 10. Such a data set provides for 3D reconstruction of the surface structure of a target, which is utilized in the analysis. The sensors are located on the same platform, with the exception of the GV sensor that is placed on a complementary platform. The sensor systems and the data collection in the visual, IR and 3D+reflectance scatter laser radar are described in [20]. In [20] the GV system and the data collection are described. The 3D laser radar data from the airborne down-looking platform is also used for terrain analysis. In this project we have developed a terrain analysis system that is adaptive and can operate in near real time, see section 3.3.5.

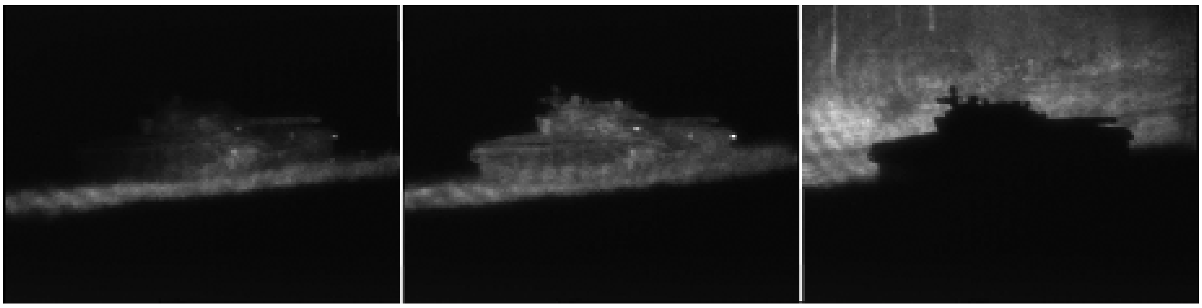

Figure 10. A sequence of gated 2D laser radar reflectance data recorded at varying distances. The target is a T72. Images are retrieved from in front of (left), on (middle) and behind (right) the target. From such sequence a 3D description of a target can be estimated.

3.3.1 The target recognition process

The target recognition process is performed in three steps; *attribute estimation, model matching* and *sensor data fusion* (decision). The two first steps are described below, while the third step is described in section 3.4. Here, several constraints are applied. For example, the number of possible targets is limited to a small set and it is assumed that detection and coarse localization of the target are handled separately.

Assuming a target is detected and approximately localized, the first step is to *estimate the target attributes* that *a)* should be used as input to the matching phase, and *b)* to reduce the number of possibilities in the matching process. In other words, the task is to estimate the most probable class or type of target to restrict the model library. If there are only a few models and few variations of each model, the total number of matches can be kept small. Examples of target attributes are position refinement, orientation, dimensions, temperature and colour. The estimated target attributes are returned to the knowledge system, see section 4.2, which based on the attributes determines the possible target types and the matching algorithms to invoke in the target model matching. The reliability of the attribute values are estimated by the algorithms themselves and can also, in the case when more than one algorithm has been invoked, be estimated by the knowledge system.

In the *target model matching* a common target model library is used, where each model is described by its 3D structure (facet/wireframe models), its appearance (visual or infrared textures), and, in some cases, algorithm/sensor specific attributes. Based on the operator's query and the estimated attributes, a set of target models are selected for the matching process. Depending on the situation and how reliable the attribute estimations are, one, a few or all of the available target models can be selected. For example, if the length of the target is estimated to eight metres, target models of small vehicles like cars can be excluded. However, if the length is an uncertain value, some of the smaller targets are included in the set of target models for the matching.

For each selected target model, one or more matching algorithms are invoked. The matching algorithm compares the target attributes with the corresponding target models and a likelihood is calculated. This likelihood is a value between 0 and 1, where 1 means a perfect match. The likelihood values from the different algorithms and target models constitute the output from the sensor data analysis module, and they are handed back to the sensor fusion module (described in section 3.4) for a final decision.

3.3.2 The algorithms

The data analysis methods need to be invariant to different sensing conditions, i.e. varying orientation and number of on-target samples. There is also a need to handle intra-class target variations, making the target differ from the pre-stored target model. The intra-variations are, for example, caused by variations in illumination, temperature and minor shape variations. Due to the different sensor characteristics, different algorithms are needed for analysing the images. Moreover, several technical approaches are implemented to analyse the sensor data. There are seven such algorithms implemented, with varying technical approaches and capabilities of handling occlusions, intra-variations and movements. Four of them operate on 2D visual- or IR data and tackle the two different kinds of 3D laser radar data. These algorithms are invoked by the knowledge system and can operate simultaneously or sequentially. Moreover, they can work on the same 2D or 3D data set or on different data sets depending on the situation at hand. The algorithms will be briefly described below, but a summary is included in Appendix A and several references are given. The algorithms for attribute estimation and matching used within this project are of different types. Some are less complex and thus less time consuming, while others are more sophisticated, and thus more time consuming in order to handle specific cases like occlusion. In the attribute estimation step, the main criterion for algorithm selection is fast computation, while in the matching step more complex algorithms are also used.

An interesting part of the attribute estimation and matching is to locate the main parts of an object. The main parts of a tank are typically the barrel, turret, and chassis, while a truck, for example, can be decomposed into driver's cab and platform. Recognition of such main parts can significantly support the knowledge system, such as selecting the models for the matching step. Further, we can fine tune the model to these articulations and deformations to obtain a more precise recognition and to derive a better understanding of its intentions.

In the *geometric feature extraction* algorithm [22], [23] we approximate a 3D point scatter (from laser radar) by one or several rectangles. We first study the target in top view and the main axis and orientation are calculated. This is done by fitting a rectangle as closely as possible (with minimum area) to the sensor data. The resulting rectangle gives an estimate of the main axis, orientation, length, width and height of the target. The rectangle calculation is then repeated along the main and secondary axis of the object. In this way we retrieve estimates of the orientation in 3D, length, width, and height of the target. The rectangle estimation method is also used to find the main parts of a target. In this step, still under development, the target is analysed once more, to find parts of the object that can be described by rectangles in top, side and back views.

Active shape models (ASMs) [28], [30] and [31] provide a technique for estimating contours around objects belonging to a specific class. Here, we use an ASM to find rectangular-shaped objects in IR images, 3D laser radar data, or laser reflectance data. To speed up the search, the ASM fitting is preceded by detecting corners and lines using standard detectors from the literature. To the possible corner–line combinations, ASMs are attached, and the one that achieves the best fit is assumed to describe the target. The output from the ASM is a quite precise estimate of the model parameters.

In the algorithm based on *active appearance modelling* [26], [27] and [29] we minimize the difference between a synthetic model image and an input image window (imaging the target) by changing the model parameters (position, size, shape, and texture). The image can be an IR or visual image. The model parameters are given by the attribute estimation step and the ontology. The final difference between model and image is used as the match for the recognition, and the final model parameters can be used as a refined attribute estimation.

The approach called *model fit with Gabor probes* [11], [12], currently under development, is based on multiscale Gabor filters in a sparse grid. These filters represent edges and lines in different orientations and scales, and together they give a representation of the image under the grid. The image can be an IR or visual image. Each of the models in the target model library has been analysed by the filter probes, and the outputs stored in an additional database. Comparing the filter outputs with the stored model outputs for the given target type, vectors instructing how to move each node can be calculated.

In the approach called *model-based recognition* [24], [25] a target is tracked and recognized simultaneously. The image can be an IR or visual image. By tracking a few critical points of the target, e.g. corners and turret, in a series of consecutive images, its movements and shape variations can be followed through the image sequence. Deformations from variations of the targets surface structure can, for example, be caused by opening of hatches or the appearance of fuel-tanks or bag-packs.

In the matching method *3D scatter matching* [25] a 3D laser radar point scatter describing the target is matched with a 3D CAD model of similar resolution. If articulation and deformation of the target are estimated in the attribute estimation, the CAD model is transformed to this pose. The squared distance between the points and the facets of the model is calculated and used to determine which target model to access from the object library.

In the *3D range template matching* algorithm [25] the surface and range boundary images of target and model, respectively, are matched. Based on the estimated attributes, a synthetic range image of the model is generated. From the model range image the surface and range boundaries are extracted. The difference of the surface and boundary images of the target, extracted from GV laser radar, and the model gives the matching score.

3.3.3 Examples of system abilities

We will describe some of the abilities of the information system with three examples. From the examples we show the potential of multisensor data and its fusion. The examples also emphasize the advantages of combining data analysis methods. The first example forms a “standard” situation and incorporates all data analysis methods**.** The second and third examples show non-trivial analysis problems where no general solution exists today. These examples show the possibilities and difficulties with recognition of ground targets.

Example 1: A target in an open field

This example is considered rather straight-forward and simple, as the target in this case is located on a flat, homogenous surface with no disturbing objects in the background. Moreover, the target is neither occluded nor camouflaged. The attribute estimation is performed on laser radar (3D and reflectance) and IR data using geometric feature extraction and active shape modelling, respectively. In the attribute estimation, the length and width of the target’s main part is estimated from using IR and laser radar reflectance data. From analysing the 3D laser radar data, set by the geometric feature extraction algorithm, the length, width, orientation and maximum height of the target, are estimated. In figure 11 attribute estimation of the data shown in figure 9 is illustrated. It is also possible to extract the main parts of an object from 3D laser radar data using geometric feature extraction, which will be described in the next example.

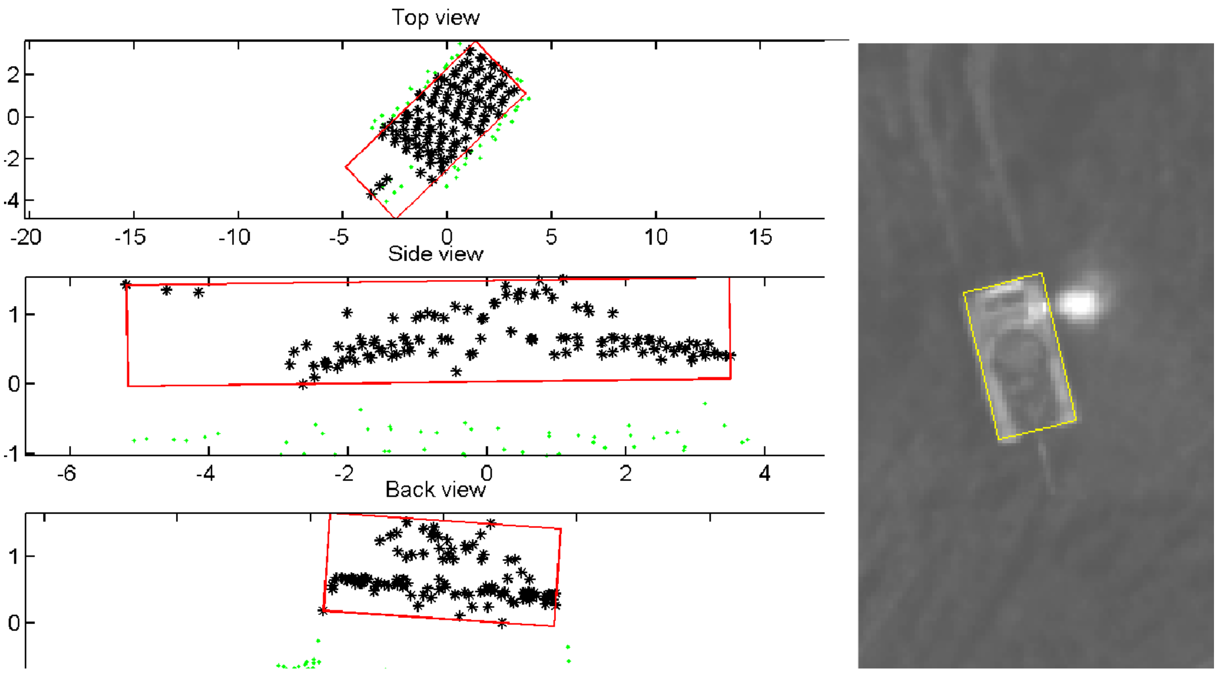

Figure 11. The attribute estimation methods. Estimations are performed on 3D laser radar and IR data of the T72 shown in figure 9. Left: Attribute estimation based on geometric feature extraction of 3D laser radar data. Each dot is a background sample and the stars are samples on the target. The rectangle shows the estimated length, width and 3D orientation. Axis in metres. Right: Attribute estimation based on active shape modelling, applied on IR data. The rectangle shows the estimated length, width and 2D orientation.

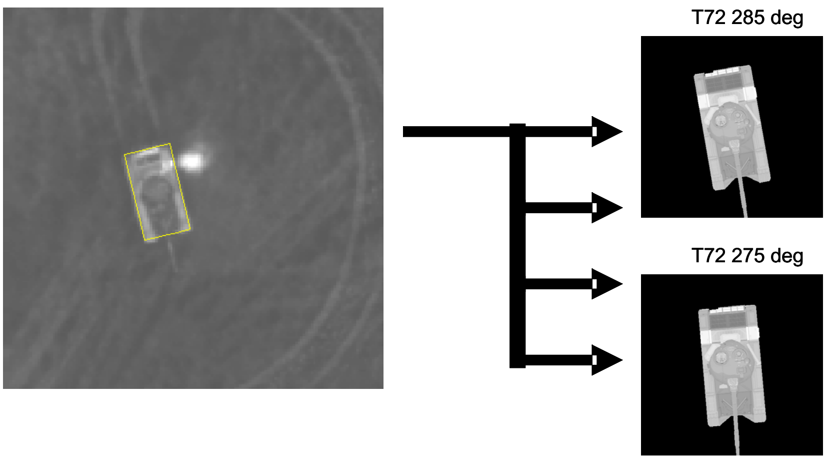

Figure 12. Matching using active appearance modelling, applied on the IR data of the T72 in figure 9.

In figures 12 and 13, results from the matching of the IR data in figure 9 are shown. In figure 12 we see the result of active appearance modelling and in figure 13 the result of model fitting with Gabor probes. Both methods work on single images, and the images of the target are matched with texture images generated using the target model library. By allowing limited deformations of both the model and the target a best matched is searched for. In figure 14, a result from the model-based reconstruction is shown, working on the IR data shown in figure 9. This method performs simultaneous matching and tracking in IR or visual image sequences. The method can handle both moving targets and sensor platforms, but in this project we have only been dealing with stationary targets and moving sensor platforms.

The two matching methods for 3D laser radar data are 3D scatter matching and 3D range template matching, see figure 16. The 3D laser radar data is either retrieved from 3D scatter or gated viewing. In the left picture in figure 16, it is illustrated how the 3D point cloud is fitted, using 3D scatter matching, to a low resolution CAD model. The squared distance between the points and the facets of the model is calculated and used to determine what target model in the object library is the closest fit. In the 3D range template matching, illustrated in the right picture in figure 16, both the 3D surface and boundary of the target is used for comparison with the model library.

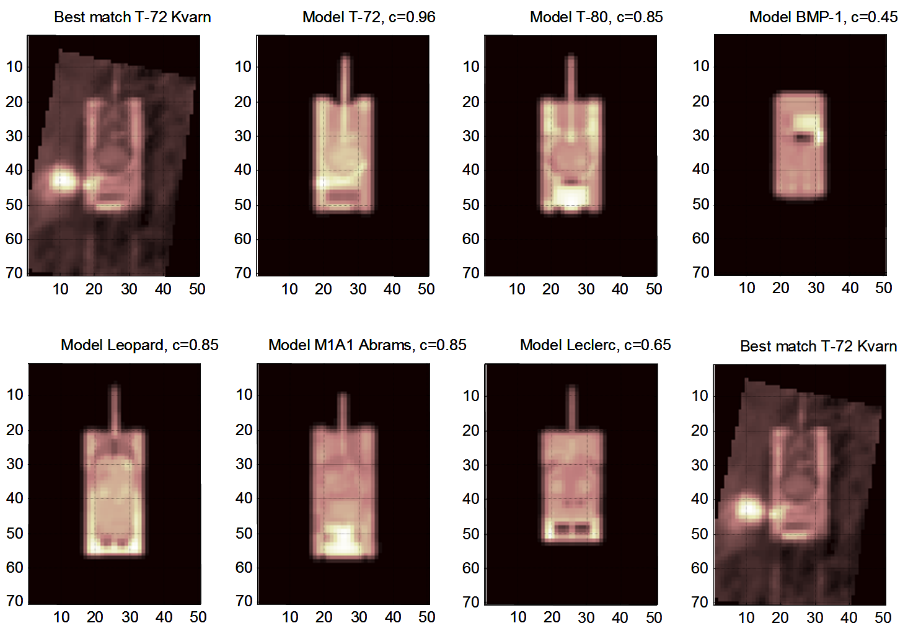

Figure 13. Matching with Gabor probe modelling for IR data in figure 9. 'The parameter 'c' indicates the belief value.

Example 2: Recognition of a deformed and articulated target

In figure 17, a preliminary result of an approach for articulation estimation by the geometric feature extraction algorithm is shown. For this approach, it is assumed that man-made objects can be approximated by one or several rectangles. If the estimation of deformation and articulation is used for a sequence of registrations, we can follow a target in detail over time. This is implemented in the method called model-based reconstruction, see figure 14.

In IR data it is possible to detect the engine exhaust plume and trails of a ground vehicle. These features are important indicators of target activity. Furthermore, the direction of the plume differs with target type and velocity. In figure 15, the exhaust plume and vehicle trails from a real IR-image of a T-72 is compared to the simulated version in the object model library.

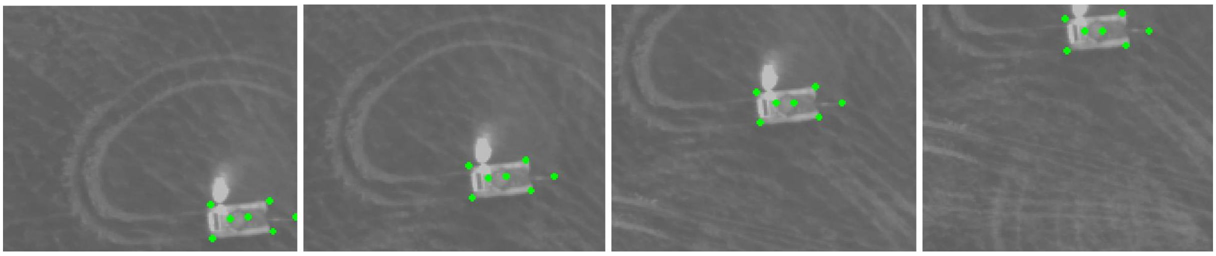

Figure 14. Matching and tracking using model-based reconstruction applied on IR data from figure 9. The marked points on the object are tracked. In this example the sensor platform is moving and the target is still.

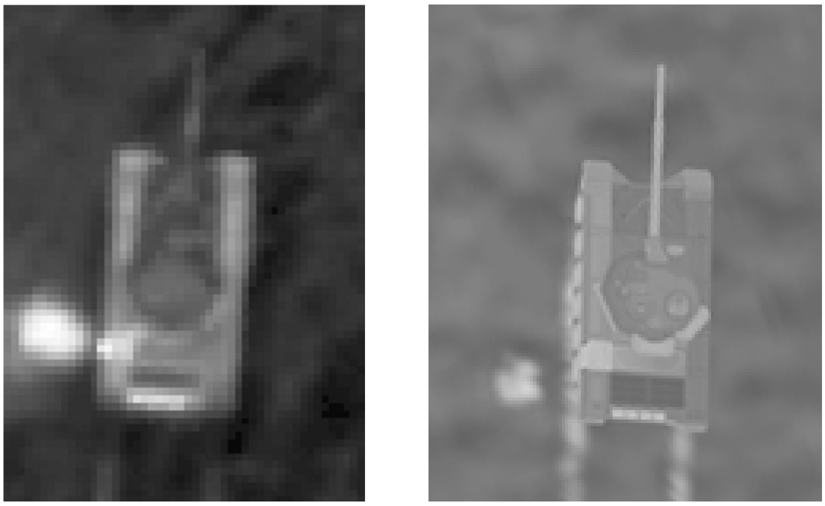

Figure 15.Models for exhaust plume and vehicle tracks are included in the IR-model library. Left: IR-image of a T-72. Right: IR-model of the T-72 with activated models for exhaust plume and vehicle trails.

Example 3: Recognition of a partly occluded target

The problem described in this last example is more complex. Consequently, only a small subset of the many problems associated with this example is addressed here. In this example we will discuss some ideas of tackling the problem, but there is not enough research conducted yet to draw any conclusions. However, for a ground target recognition system it is necessary to be able to handle (partly) occluded and/or camouflaged targets and this is a novel attempt to obtain better understanding. To solve the problem high demands are placed on both the sensors and the analysis methods. The analysis method must be capable to perform its task even if part(s) of the target is not registered. Here, the ability to penetrate sparse objects, such as some categories of vegetation and camouflage, is a key issue to overcome the problem. For example, laser radar has been shown to have this capability.

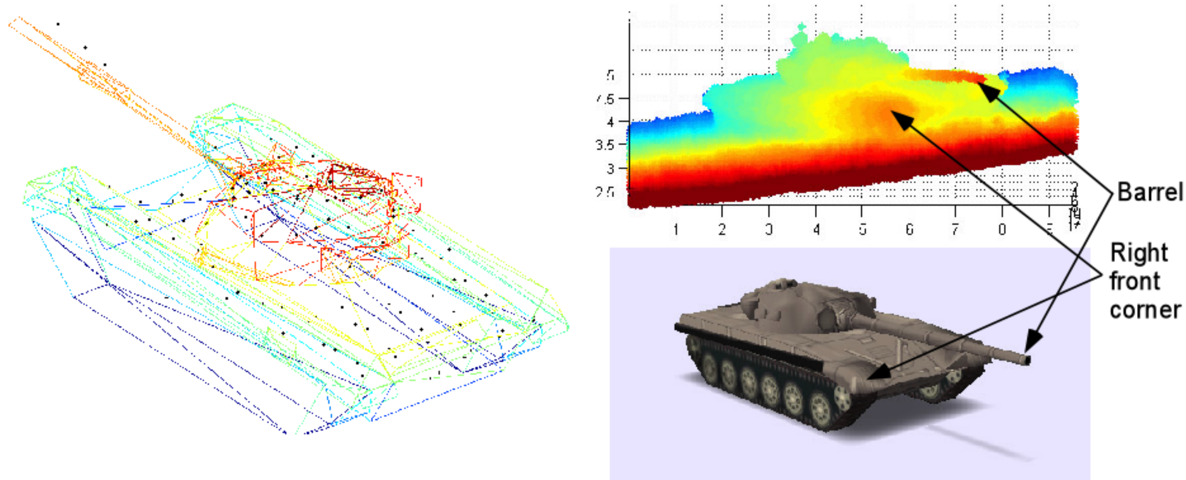

Figure 16. Matching using the target's 3D structure (extracted from laser radar range data). Left: matching using the 3D scatter matching method. The samples on the target and the facets of the model are shown. The matching is performed on laser radar range data of the T72 shown in figure 9. Middle and right: matching using the 3D range template matching method. Middle: processed sensor data, right: the model transformed to the same articulation. Matching is performed on data of the T72 of the same type as shown in figure 10.

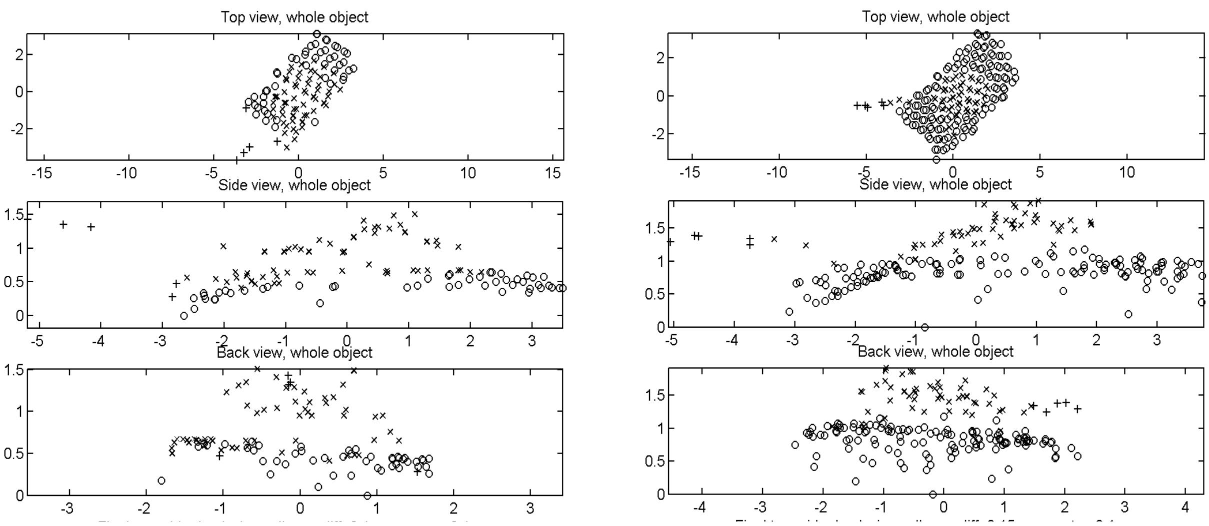

Figure 17. Estimation of barrel articulation and turret extraction of a T72 using the geometric feature extraction algorithm. Note the different positions of the barrel. The circles, x-marks and plus-signs indicate different parts of the object, approximately the barrel, turret and chassis. Axis in metres.

The technical approach used in this work is to fuse IR and laser radar data. The laser radar data analysis supports the IR data analysis, by penetrating the vegetation and separating objects at different heights, for example a tree and a vehicle. The IR data analysis supports the laser radar data analysis by detecting areas with similar 2D shape and texture. In a first attempt, shown in figure 18, we use the attribute estimation from the laser radar data analysis to cue the IR data analysis. The two analysis methods, model-fitting with Gabor probes and active appearance models, respectively, can weight the IR image and focus the analysis on the image regions that have been classified as belonging to a target from the geometric feature extraction analysis.

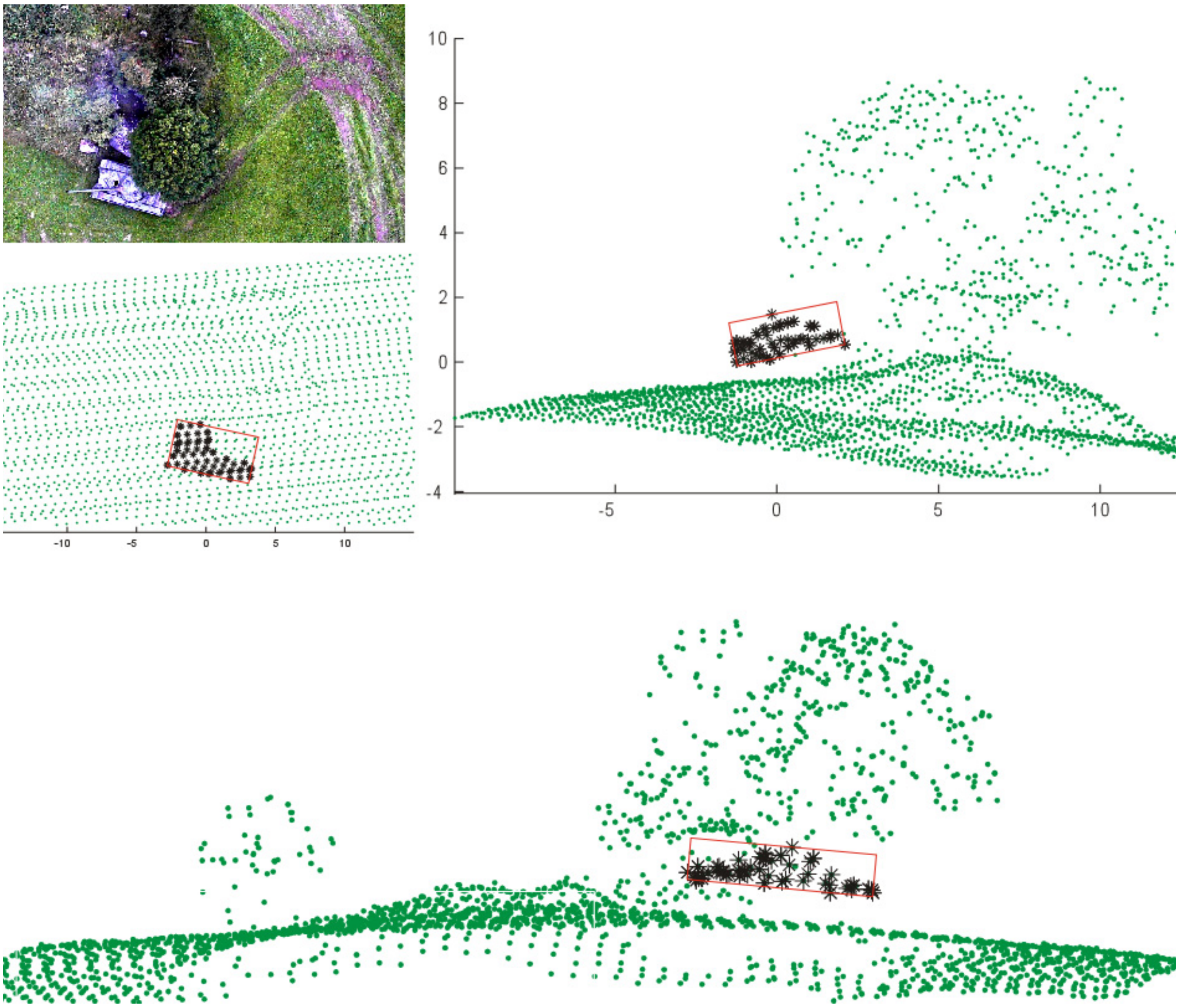

Figure 18. Attribute estimation using geometric feature extraction of a T72 partly occluded by a tree, 3D laser radar data. Top left: top view, visual image and 3D laser radar data of the target. Top right: back view of the target. Bottom: side view of the target. The rectangles show the estimated size and orientation of the target. Each dot is a background sample and the stars are samples on the target.

3.3.4 Terrain analysis

Most research in 3D terrain modelling is focused on obtaining maximum accuracy and fidelity of the model, while not being constrained with particularly difficult time requirements. In the military domain the purpose often is to perform mission training or to simulate sensors with a very high level of accuracy. In contrast to that, the terrain analysis considered in this project should be viewed as a part of a decision support system (DSS). Such a system must be able to answer queries from the users about the terrain properties, relevant to their goals, with a speed and accuracy that is required by the situation and the mission. Consequently, the designed terrain analysis system must be adaptive and able to respond to queries in close to real time. The system should also automatically permit translation of the queries into an appropriate format. Another important demand is that the system must be able to support multi-step processing, where initial detection and coarse description of the feature of interest is done first and where refined, special purpose methods can be used afterwards to obtain the needed accuracy. To support this demand, methods that reduce the data volumes have been developed. Reduction of the data volumes is also necessary to reduce the search times and to make further processing more efficient. The approach in this work has been to use a symbolic method, as no quantitative algorithm can answer the queries quickly enough. The main result is concerned with detection of important terrain features and can be used for e.g. construction of drivability maps. A recent overview of this part of the work can be found in [14].

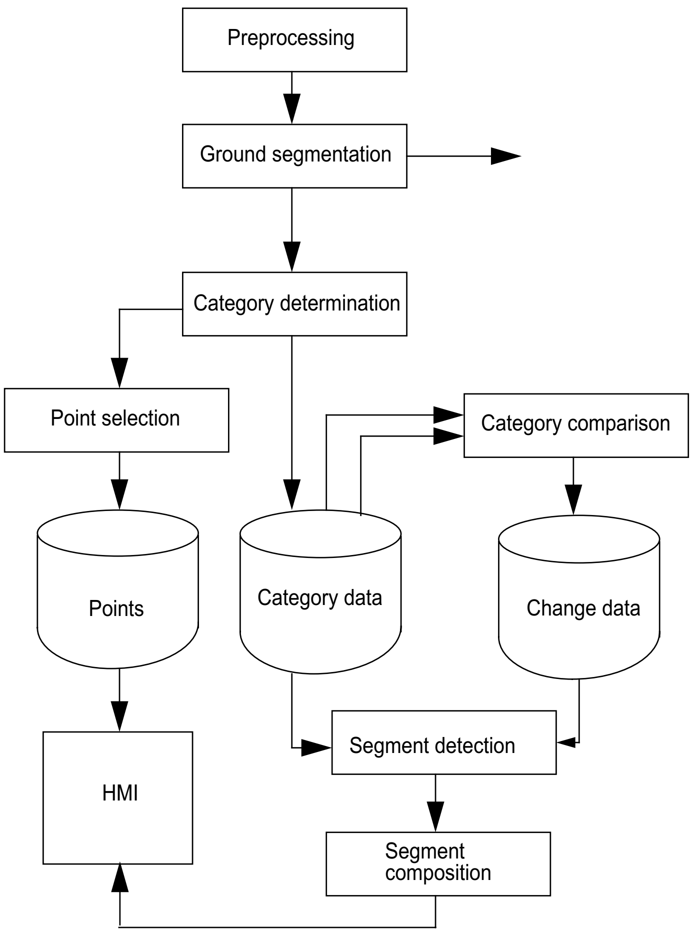

Figure 19. An overview of the most important processing steps and data sets in the terrain analysis system.

During the last year, most effort has been put into designing and implementing algorithms for detecting changes in the terrain surface, derived from laser radar data collected at different times. Change detection is an important component in a terrain analysis system for two reasons. Firstly, the ground surface changes very slowly over time and to store and access large unchanged quantities of data is clearly detrimental to the system functionality. Considering only the changed parts from a newly acquired data set can speed up processing considerably, which is a necessity in a DSS. Secondly, the changes that have occurred are potentially very important as they may be a sign of conscious alteration of terrain. An overview of the terrain processing system can be found in figure 19.

3.4 Fusion methods

There are two fusion processes in the query system. The first one considers the attribute set estimations (*ASE*). The second one considers the matching output from the recognition algorithms, i.e. the match results (*MR*), which each consist of a refined object *state* estimation and a *belief value* (BV). The object's state is described by those attributes in the ASE that are sent to the recognition algorithms (RA)[1]. A target's state easily changes over time; examples are *orientation* and *speed*.

The first step of the ASE fusion consists of identifying sets of similar ASEs. Each set, or cluster, is then replaced with one single, representative ASE, i.e. the fusion result. The aim is to provide the matching process with a condensed number of distinct ASEs. These can then be kept apart in the matching process, so that the second fusion process can make comparisons between BVs regarding objects in the same state[2]. Since a typical ASE is likely to be incomplete, the problem is similar to a general set of problems called *clustering of incomplete data*. Such problems have been addressed for example in [16]. Here, an euclidean distance between ASEs has been used as a basis for clustering. Roughly, it states that if the error volumes of a set of ASEs are pairwise non-disjunct, the set forms a cluster.

Figure 20 visualises the first step of the first attribute fusion process. Note that the ASEs here are represented by dots (with estimated error circles), which corresponds to *complete* ASEs. Generally, however, the ASEs are *incomplete*. The idealisation has been done here since both

1. The other attributes of the ASE refer to the object's *properties*. Those values are never sent to the RAs. Instead, the RAs are supplied with models consistent with the estimated properties.
2. It is assumed that two matching algorithms using similar state estimates, refine these to essentially the same state estimate. This is why clusters are identified in the attribute estimation fusion.

the state and the properties really are multidimensional, which complicates the drawing of an incomplete ASE.

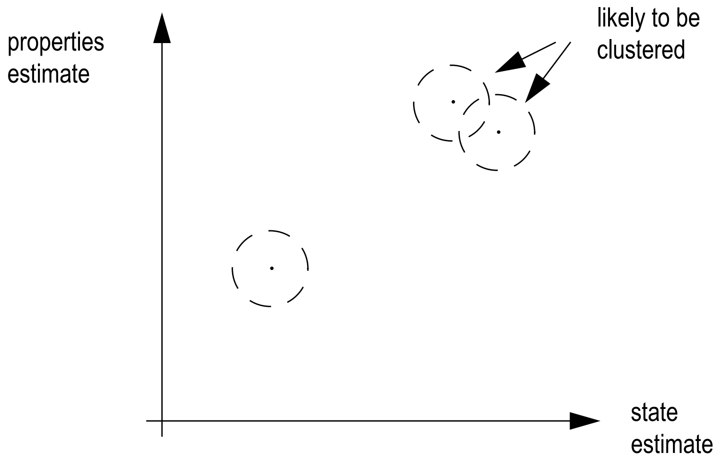

Figure 20.Clustering of similar ASEs. In this example the ASEs are complete and thus represented by dots (with estimated error bounds). In general, ASEs are incomplete and represented by objects of higher dimension. Also, both axes are in reality multidimensional.

Selection of a representative ASE for each cluster is the second step of the first fusion process. Here, the ASE is chosen and should be as complete as possible. The state, especially, needs to be well-defined. Otherwise, the match result fusion cannot make the comparisons mentioned above. Two main approaches to obtain a well-defined state estimate have been identified. Which approach will be followed is not yet decided but work to solve this problem is currently continuing. However, the two approaches are:

1. *Fusing* state estimations, i.e. combining values from incomplete estimations in order to form a complete one. This is not trivial, since the resulting state might be unattainable from different aspects.

2. Supplying the RAs with incomplete estimates, using *them* as input to the attribute estimation algorithms and then rerun the processes. The states from the RAs should be well-defined. The confidence values produced in the preliminary run can be fused with a “safe” fusion method. Its result can be taken as a preliminary result from the system.

The second fusion step deals with the results from the different matching algorithms. Here the belief value is in focus. Several simple approaches have been implemented. They correspond to different strategies, respectively. For example, one could argue that a hypothesis (model + state) should be heavily supported by *all* RAs to be considered heavily supported. Also, one could argue that high enough support from *one* RA is enough. Figure 21 exemplifies such a situation. Other, desired properties of the fused result, call for other strategies as well.

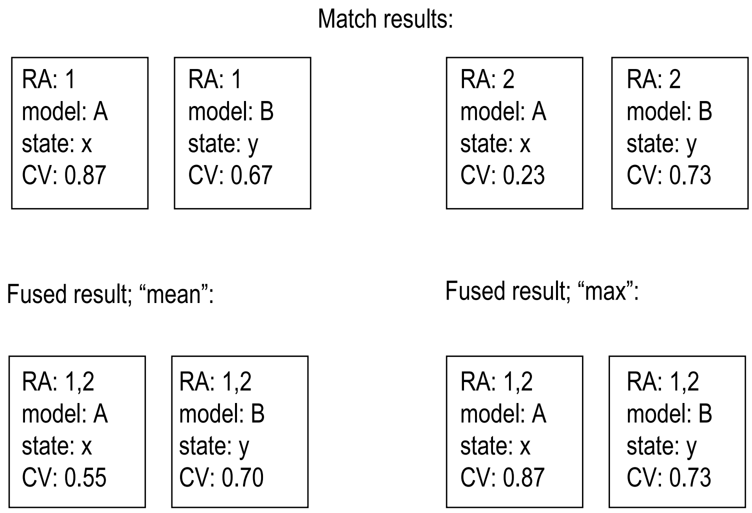

Figure 21. Illustration of the second fusion step, in this case with only two hypotheses and two RAs. Considering mean and maximum confidence values for the two hypotheses, respectively, leads to radically different results.

3.5. Situation awareness

The work in this area has been oriented towards framework design and identification of required algorithmic support. A suggestion for a basic framework for situation analysis (SA) support has been presented in [13]. Although a very general framework, it is based on some assumptions of what the characteristic problems are when looking at sensor observations spread over time and space in a dynamic tactical land-based context. The basic underlying assumption is that of observation *fragmentation* in time and space. This makes association between observations a fundamental and difficult problem, one which cannot be solved by physical laws and statistics alone. To deal with such situations we have to make use of a priori knowledge of typical organization and behaviour of military vehicles and units. Straightforward use of such knowledge in a computer optimization model, to find the most likely interpretation of a given data set, does however raise several questions. Two main concerns are those of a priori knowledge reliability and context dependency. If we ignore these issues, the result will most probably be an unreliable system with a high degree of user distrust.

The conclusion we draw from the reasoning above is that the user must be involved in the interpretation process. The SA system then becomes a tool for user guided exploration of possible/likely interpretations. An optimization model is still at the core of the SA system, but it is now required to be able to find *alternative solutions.* The concept of alternative solutions can be defined as a set of solutions which are sufficiently likely and sufficiently dissimilar from each other to be of interest. The estimation of solution likelihood should be built into the optimization model, but the concept of solution similarity is context dependent and can only be defined by the user. The overall goal is to give the user an overview of interpretation possibilities by presenting a manageable number of solutions where the differences are relevant. This should be done in an iterative way, where the user can become more precise as to what information he is interested in as the optimization process proceeds. This can be viewed as a learning process.

To meet the requirements of a flexible optimization process capable of generating multiple solutions, the paradigm of evolutionary computation (EC) has been investigated [15]. This paradigm has some inherent properties that suit the demands of our SA framework. It has for example been extensively used in the area of Multi-Objective Optimization, where multiple solutions are searched for in parallel. In order to develop an EC-based optimization kernel of our framework for SA, there are two major methodological/algorithmic issues that have been addressed.

The first issue is a *selection of a representation and of operators* for EC for the combinatorial problem of set partitioning. There are some interesting suggestions in the literature. A common property of all these pure EC variants, however, is low computational efficiency. This is primarily due to the strategy in pure EC based systems of blind randomization with feedback, which is very general and flexible but often inferior to heuristic based systems. To remedy this we have adopted the common strategy of hybridization, where heuristic components are integrated into the EC machinery to guide the search process. In this case we use the local object-to-object association values for search guidance. With this approach we can quickly find a good solution in most situations and then continue searching for better or different solutions as time permits. However, the machinery developed still needs to be tested in realistic and dynamic scenarios.

The second major issue is that of *generating multiple solutions* which are “dissimilar”. There are quite simple ways to achieve this but the principal problem is that of low computational efficiency. Some efforts in this area are reported in the literature, but none of which have the generality needed in our framework. This is a crucial part of our suggested SA framework which needs further research.

4 Executive summary

4.1 Project summary

This project concerns the development of an information system for recognition of ground targets, basically various types of vehicles. The main goal is to cover the complete process from sensor data analysis to the decision support in a command and control system. Applications of concern are surveillance and intelligence.The information system includes a query language for heterogeneous sensor data sources. Currently the information system works on four sensor types; laser radar (scanning and gated viewing), IR- and CCD-camera. Methods for analysis of data from these sensor types have been developed. The query language, called ΣQL, includes means for sensor data and information fusion. A fundamental aspect of the system is sensor data independence, which is carried out by an ontology and its knowledge base. The information system is also equipped with a powerful visual user interface that allows the users to apply their queries in a simple and straight-forward way. One of the purposes of the information system is to support situation awareness. For this reason, a subsystems for situation analysis is under development; this subsystem uses input from ΣQL and a symbolic digital terrain model.

In this report we have discussed a project concerning the development of an information system for target recognition and its decision support tools that includes a query language called ΣQL of which an overview is given in the beginning of section 3. The user interface of the query language is discussed in section 3.1. Other aspects of the query processor can be found in section 3.2 where the knowledge system is discussed. A discussion of the sensor data analysis is presented in section 3.3. The data fusion methods that are used in the information system for fusion of the sensor data are discussed in section 3.4. Section 3.4 contains a discussion of the situation awareness aspects of this work.

4.2 Results

A simple prototype of the information system, and its query language, has been implemented and can be run. The prototype includes basically

- a ΣQL query processor,

- the query processor includes an ontology and its knowledge-base; designed to allow sensor data independence from an end-user perspective,

- a data fusion module that fuses sensor data in two steps, i.e to support (1) attribute extraction (2) and target matching,

- a visual user interface that allows the application of queries in a sensor data independent way,

- means for visual presentation of query results,

- application of sensor data from sensors of type IR, laser radar (scanning and gated viewing) and CCD-camera; the number and types of sensors are extendable,

- a number of algorithms for analysis sensor data; an overview of these algorithms can be found in the table in Appendix A.

By means of the demonstrator queries can be applied and answered. Basically, these queries are concerned with recognition of targets of military type. The recognition algorithms allow, although not completely, recognition of partly occluded targets.

The activities in conjunction with the development of the high resolution digital terrain model show that

- various terrain features efficiently can be identified by means of the filter technique,

- the terrain model can be used for efficient visualization of the terrain in high resolution,

The activities to bring forward a system for situation awareness, finally, have not yet come to a break-through although some fundamental results have been demonstrated; the reason for this is due to the fact that this part of the project has been going on at a low pace.

4.3 Conclusions

The main conclusion drawn from this work is that we have been able to demonstrate the feasibility of a query language that can be applied to various types of multiple sensors for target recognition. The query language is characterized by its sensor data independence capability. This makes it possible even for users that lack technical sensor and sensor data experiences to use the system. To support the users even further the system includes means for sensor data fusion and it can deliver answers to the queries so that the uncertainties introduced by the sensors are taken into account by the resulting belief values. Thus we believe that ΣQL is a powerful tool that can be used as a decision support tool in a network centric command and control system. We also believe that even inexperienced users can feel confidence in the system.

There are two aspects of importance that must be considered when looking into the further developments of the work discussed in this report. The first one concerns the *service concept* that is subject to intense discussions within Swedish defence organizations. The concern in this discussion is to regard the sources of information, which on demand can deliver user requested information, as different types of services. Mirrored from this perspective ΣQL is in itself a service that can be integrated in a command and control system.This is because the query language can give the users information about specified targets, their objects and their relations, for example, the target is a tank, the speed is 90 km/h etc. Consequently, ΣQL is a service in the same sense as, for instance, a geographic information system. The second aspect of importance to the information system is that in a longer perspective it is necessary to integrate it with a *network centric command and control system*. To make this possible, a new and more powerful system architecture must be developed. This architecture, that is network oriented, must be connected to the query language. In this way it should be possible to apply queries to sensor data from sensors distributed among the nodes on the network. This is possible to do but must be subject to further research.

4.4 Discussions

In this section aspects of the information system that must be subject to further research will be discussed.

An important objective in the development of ΣQL has been the property of sensor data independence. The primary motivation for this has been to develop a system in which practically any sensor type can be attached to and used by the query system. Since both detection and recognition of targets must be possible to achieve, two main sensor classes can identified. So far, only sensor setups and algorithms for target recognition have been integrated to the system. In the next step sensors/sensor setups and algorithms for the detection phase will be included. Plans for the use of an unattended ground sensor network (UGS) and a synthetic aperture radar (SAR) are currently developed. Such sensor systems and sensors support cueing which eventually can improve both the efficiency and effectiveness of the information system since the search time to detect potential targets can be substantially decreased.

A problem, associated with target recognition, is that the targets may be moving. A consequence of this is, as has already been indicated, that the information system must be able to not only handle tracking but also many other types of dynamic situations that will be going on over time. In particular, it is not a simple thing to demonstrate the full dynamic potential of the information system since that can, because of practical and economical reasons, only be made in a simulated environment. However, a simulated environment that can be used for this purpose is developed at FOI. This environment is called MOSART [18].

The problem of recognition of a partly occluded target is very complex. However, for a ground target recognition system it is necessary to be able to handle (partly) occluded and/or camouflaged targets. To solve this problem makes high demands on both the sensors and the analysis methods. Thus, the analysis methods must be capable of performing its task even if part(s) of the target are not registered. Here, the ability to penetrate sparse objects, such as some categories of vegetation and camouflage, is a key issue to overcome the problem. To handle the problem a local scene analysis must be performed, where objects beside and close to the target are analysed and recognized as well.

The information system, where the query language ΣQL is an essential part, is primarily designed to support target recognition and to some degree also to function as a tool for generation of input information to a system for situation analysis. However, the work on situation analysis, as described in [13] demonstrates that there is a logical gap between the situation analysis module and the information system. The reason for this logical gap is that the query output from ΣQL to some extent is too limited. For instance, ΣQL cannot, as is, carry out all required special operations like tracking and aggregation of sets of targets into groups. This is due to the fact that these operations normally may require output from a number of queries performed over time and normally it is difficult to handle such result since a query system operates on a query at a time basis. Nevertheless, the result of some preliminary work demonstrates that it is possible to fill the gap by the introduction of iterative and extendable query types.

The information system will eventually be attached to a sensor network that will be part of the network based defence in Sweden (in Swedish nätverksbaserat försvar (NBF)). A query system where input data are coming from multiple sensors working across a large network will with necessity become very, if not extremely, complex. For this reason, traditional approaches to the program design of such a system will lead to a large monolith that evidently will cause severe maintenance and implementation problems. The solution to this problem has to be based on some novel type of programme design. Here we suggest a design based on systems of autonomous intelligent agents [19]. A study of this problem will be initiated during 2004. A further problem somewhat related to this is that since the sensors are distributed across the network, selection of single sensors in each query must be distributed as well to achieve sensor data independence in a simpler and more efficient way. Distribution of the selection of the sensors can be carried out through the distribution of the ontology and its knowledge base or parts thereof. Exactly how this should be done is, however, still an unsolved problem that must be addressed not just to improve query efficiency but also to support sensor and platform management with respect to control of the equipment in focus.

4.4 Recommendations for further research

As a conclusion of the discussion in the previous section the following topics are recommended for further research.

- Integration of further sensors to the information system so that cueing can be applied for target detection, e.g. by means of UGS and SAR.

- Adaptation of the query language to dynamic activities by attachment to the MOSART simulator environment.

- Improvement of the technique for recognition of partly occluded targets.

- Extension of the visual user interface to support the relevant parts of the service concept as suggested by the LedsystT project.

- Design and development of a network based architecture to which ΣQL can be attached.

- Extension of the query language to include means for querying the high resolution terrain data model. Among other things, to improve the support of the situation awareness module.

- Development of techniques and methods for determination of drivability from the high resolution terrain data model.

- More complicated issues such as off-road movement and military hierarchical organizational aspects should be addressed in the situation awareness part.

- Development of methods for data mining to improve the support to the situation awareness module and in a longer perspective also to impact analysis, that is to the higher levels of information fusion but also, in particular, to support the maintenance of a consistent operation picture.

4.6 Closing words

The project discussed here has been of multi-disciplinary type and has involved specialists from both the sensor and the command and control divisions at FOI. This constellation has been very fruitful and both groups have learnt from each other despite the fact that they come from different disciplines and have a different focus in their research. Furthermore, the two groups have also come to a mutual understanding of how projects of multi-disciplinary type can be managed. The main reason for this is that the project involved a set of well defined goals that everybody agreed upon. All members of the project group also had opportunities to focus on their own specific research issues which eventually was beneficial to the project as a whole. A general conclusion that can be drawn from the work in this project is that there are strong potentials for cross division projects that cover several different disciplines and that this is a unique resource at FOI. This can be beneficial to the whole organization when used in all kinds of research projects since there is generally a large added value in research of multi-disciplinary type.

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Appendix A: Target recognition algorithms

In the table below all sensor data analysis algorithms that are implemented in this project are listed and briefly described. Let us describe the cell headings further; in the first columns the name of the algorithm is written, in the second what type of sensor data that the algorithm is capable of processing. In the third column, "# Frames", we show if the algorithm works on single frames only (1) or on a sequence of images (>1). Algorithms with a "Y" in column four, "Extracts Features", are capable of analysing the unknown object and extracting features like length, width, temperature etc. These algorithms are used in the first step in the target recognition process. Algorithms with a "Y" in column five, "Perform matching", are used in the second step in the target recognition process, the matching with library models. In column six, "Tracks", we mark algorithms that can perform tracking of moving objects with a "Y". In column seven, "Level of detail", we describe what level of detail of the target that the algorithm is capable to analyse. Algorithms that cannot extract the details of the target are denoted "main part", algorithms that can detect and track the large details on a target, i.e, barrel and turret of a tank, are denoted "Barrel etc.". Some of the algorithms can perform their tasks even if parts of the target are not registered, which can be the case if the target is partly occluded or camouflaged. These algorithms are denoted by "Occlusion" in column seven. In column eight references to technical details and to figures in this document are given.

Algorithm	Sensor data	# Frames	Estimates attributes	Performs matching	Tracks	Level of detail	References
Geometric feature extraction	3D laser radar	1	Y	N	N	Barrel etc.	[22], [23], [25] see Figures 11,16,17,18
Active shape modeling	IR, 3D laser radar, laser radar reflectance	1	Y	N	N	Main part	[28], [30], [31] see Figure 11
Active appearance modeling	IR, visual	1	N	Y	N	Main part, occlusion	[26], [27], [29] see Figure12
Model fit with Gabor probes	IR, visual	1	N	Y	N	Main part, occlusion	[12] see Figure 13
Model-based reconstruction	IR, visual	>1	N	Y	Y	Barrel etc.	[24], [25] see Figure 14
3D scatter matching	3D laser radar	1	N	Y	N	Barrel etc.	[25], see Figure 16
3D range template matching	3D laser radar (GV)	>1	N	Y	N	Barrel etc.	[25]x, see Figure16

Appendix B: Project publications, January 2000 - December 2003

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Chang, S.-K., Costagliola, G., Jungert, E. and Orciuoli, F., *Querying Distributed Multimedia Databases and Data Sources for Sensor Data Fusion*, accepted for publication in the journal of IEEE transaction on Multimedia, 2003.

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