10TH INTERNATIONAL COMMAND AND CONTROL RESEARCH AND TECHNOLOGY SYMPOSIUM
THE FUTURE OF C2

"HUMAN FACTORS ENGINEERING"

Realization and Evaluation of a User Support System for the Optical Classification of Naval Vessels

Oliver Mooshage & Dr. Jörg Schweingruber

FGAN - Research Institute for Communication, Information Processing and Ergonomics
Ergonomics and Information Systems Department
Neuenahrer Strasse 20, 53343 Wachtberg, Germany
Phone: +49-228-9435-461, Fax: +49-228-9435-508
E-Mail: Mooshage@FGAN.de, Schweingruber@FGAN.de

Abstract

The quick and accurate classification of unknown seagoing vessels is essential for the successful fulfillment of naval missions. Operators have limited time to analyze loads of imagery of the environment around their ship. To facilitate the use of all kinds of optical sensors, the support system UNbiS is being realized. The paper presents the steps during design, development, implementation, and evaluation of the system. The software is built around two reliable and accurate algorithms for the investigation of object contours as well as the relative locations of visible marks. The operator is guided through all steps to provide these algorithms with the data they need. In order to keep human decision makers in the loop, the main focus is on an efficient handling of the tasks to do. During development, subject matter experts were frequently asked to examine the system and give feedback, based on which it could be optimized and enhanced. Finally, experimental tests with experienced officers from the German Navy are conducted under realistic service conditions to evaluate the system. The acquired results will be used for further optimization.

1. Introduction

Reconnaissance is one of the most crucial tasks navies are facing. The quick classification and identification of unknown seagoing vessels is of the greatest importance, especially in the context of deployments like Operation Active Endeavor, where the mission is to conduct operations against suspected terrorist activities in the Mediterranean. Since the start of the operation in October 2001 until March 2004 about 41,000 contacts of interest (COIs) have been monitored (AFSOUTH, 2005). Modern combat direction systems (CDS) make use of several different stationary and mobile image generating sensors that constantly deliver raw image material to be evaluated in a ship's combat information center (CIC). As environment, sight and weather conditions vary, so does this material concerning its quality. Infrared (IR) sensors, for instance, deliver a significantly inferior signal-to-noise (S/N) ratio and are responsive to environmental conditions such as temperature and humidity. Hence the analysis of contained details and information can become exceedingly difficult and time consuming, if accomplished solely by human operators on their own. But given the busyness of merchant waterways nowadays, time is a very limited asset. Consequently, an advanced support system is needed to guarantee a quick and reliable classification and identification of observed COIs.

2. Human-centered approach

The major goals of the work are to design an ergonomic operating concept and to realize a user support system for those operators in the ship's CIC assigned to analyze the results of optical reconnaissance. With the design of the system, in order to keep operators in the loop during reconnaissance missions, the main focus is on an efficient handling of the tasks to do, an optimized graphical user interface, and clearly guided operating sequences (Schweingruber & Brütting, 2004). In order to become able to design adequate handling sequences, it is important to gather and structure ample information about the tasks to be supported (Mooshage & Distelmaier, 2001). Therefore, several discussions with experts as well as surveys of the procedures aboard took place.

The support system, carrying the working name UNbiS (support concept for the use of image generating sensors) according to the study within which it is developed, is based on an earlier concept that was designed to especially suit for an EO and an ISAR sensor aboard one particular naval unmanned aerial vehicle (UAV). With the new approach, imagery from all kinds of optical sensors on any platform shall be dealt with. The earlier concept had been evaluated using a demonstration and testing facility, too, and the lessons learned (Schweingruber, 2004; Schweingruber & Brütting, 2003) have been incorporated into the new concept.

The system is implemented in the modern and reliable programming language Java. A graphical development environment is used that allows quick testing of the semi-manufactured product. To assure that the final product will support all steps in-between the observation of the surroundings and finally reacting to what is observed, it is important to closely integrate designated users, who are experienced with nowadays missions, into the development process (Mooshage et al., 2003). According to the philosophy of rapid prototyping, subject matter experts were frequently asked to examine the system and give feedback, based on which it could be optimized and enhanced. This phase yielded a high quality ergonomically optimized system that is now ready to serve aboard.

3. Classification algorithms

The two algorithms (Günther et al., 1996) that are integral part of the support system were developed at the University of the Federal Armed Forces in Hamburg. One performs investigations of object contours (contour classifier), whereas the other investigates the relative locations of visible marks (marks classifier). Both deliver result lists containing the ship classes that have most in common with the analyzed data. The algorithms have been tested extensively at the Bundeswehr Technical Centre for Ships and Naval Weapons (WTD 71) in Eckernförde and both proved to be reliable and accurate (Schweingruber & Mooshage, 2004). These algorithms constitute the core of the support system.

3.1 Contour classifier

This classifier needs the outer contour of the object to be classified (OTBC) and the information whether it has its bow left or right on the image as input. The classifier compares the OTBC with reference silhouettes of all known ship classes in the database. These silhouettes are supplied binary and were derived from 3d models picturing representative role, pitch, and position angles. The bow and stern positions in the contour of the OTBC are fitted into the binary reference matrix so that the silhouette's length is standardized.

To assign the data at hand to the most probable reference objects, an average-free normalized cross-correlation function is used, whereupon movements in x and y directions are performed until a maximum correlation coefficient is found. Sections where lines are close-by but not exactly one upon the other are accounted for devalued. In the final step, the result list is sorted according to the correlation coefficients so that the ship with the most similar contour heads the result list.

3.2 Marks classifier

As input, this algorithm needs horizontal and vertical positions of visible marks on the image at hand as well as the rotation angle around the y axis. The system's database contains the same data for all known ship classes. The classifier compares the data of the OTBC with that in the database. This is achieved by accumulating scaled Euclidean distances between OTBC and presumably corresponding database mark positions. The visibility of the individual ship parts with different position angles is considered, so that erroneous assignments of hidden ship parts are impossible.

The operator's statement that a particular mark can be seen at a certain position is dealt with in a fault-tolerant way. Each pair of ship parts is allocated a confusion probability, from which a coefficient for the respective Euclidean distance is derived. The database ship classes are listed according to their total distance to the OTBC, so that the ship class with the most similar marks heads the result list.

4. Support System

The graphical user interface (GUI) of the support system is subdivided into four areas (Figure 1). The upper right area always contains imagery originating from the attached sensor. Depending on the process state currently performed, different manipulations can be made within this image. In the upper left, there is a database viewer in which all known ship classes can be browsed through. It is possible here to look at reference pictures, outline drawings, VRML models, as well as facts and data of all ship classes in the database. In the lower left, the overall controls can be found. This area consists of buttons to go to another process state, to load, save and store classification results, as well as to change the language used by the system, to change the colors between day-light and darkness mode, and to shut down the system. The lower right is reserved for controls belonging to certain tasks. The contents of this area change according to the process state that is selected.

Figure 1: Screen during process state Surveillance

4.1 Process state Surveillance

In this process state, the operator's task is to choose appropriate imagery from the available material. A time-bar allows to review what has been recorded within the past few minutes. Through buttons that are similar to fast backward, fast forward, single image back, single image ahead etc. on typical remote controls or simply by clicking at any position in the time-bar it is possible to navigate the available imagery easily. Images can be further optimized by zooming and manipulating brightness and contrast. Once the operator has decided which image to take, the next process state can be selected.

4.2 Process state Orientation

Both classifiers need information about the object's spatial orientation on the chosen image. This process state provides graphical support for the ascertainment of the rotation angles on all three axes (Figure 2). In the area at the lower right, a model ship can be rotated to the appropriate position. It is possible to choose among three different ship types, so that the model is somewhat similar to the OTBC seen above. However, it is not intended to have more ship types for choice, lest operators waste too much time for choosing.

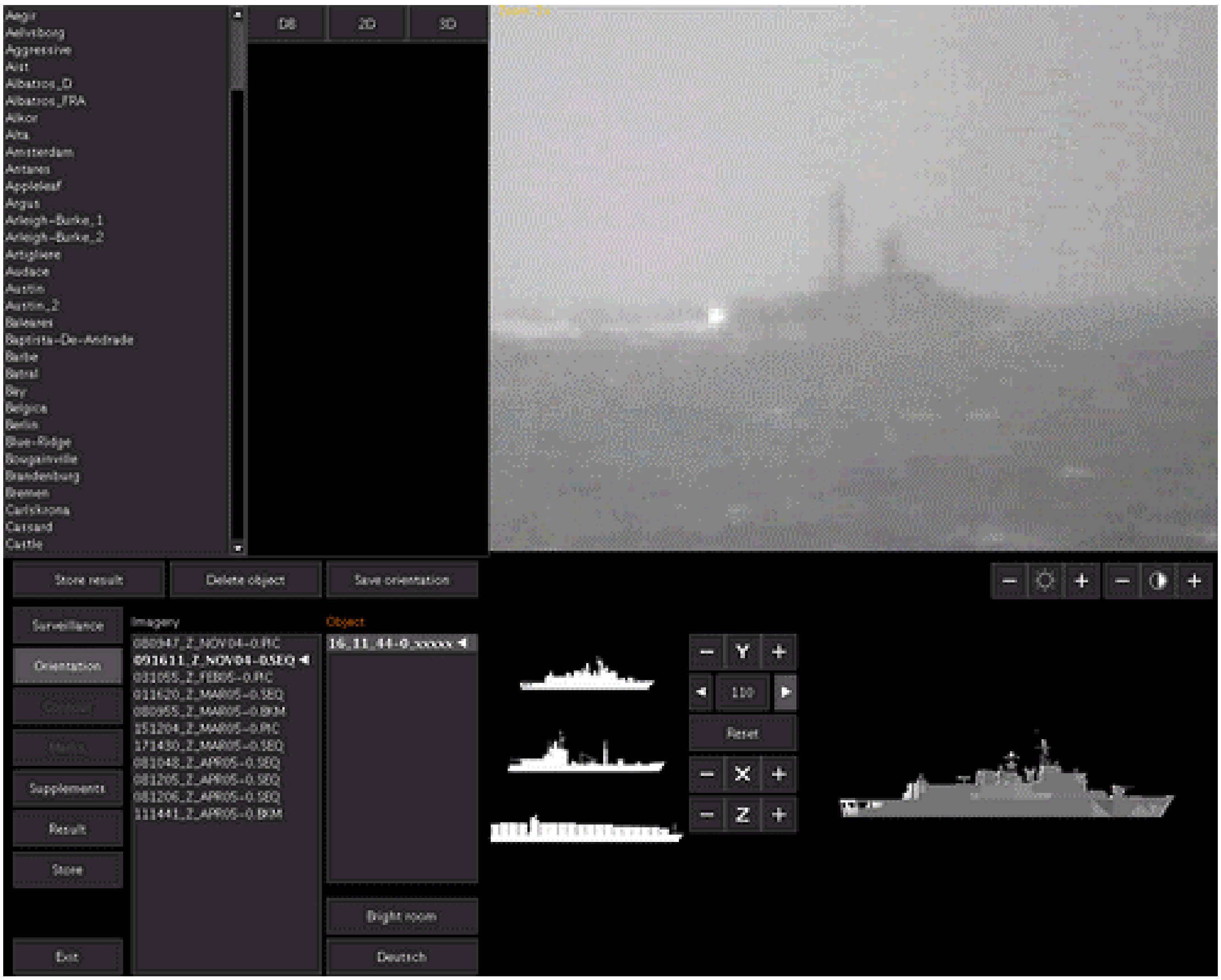

Figure 2: Screen during process state Orientation

4.3 Process state Contour

In this process state, the object's shape is supplied. The operator is asked to do that within the sensor image area at the upper right (Figure 3). It can be performed by inputting points that are connected by a polygon, by completely painting, or any combination of both. A preview line between the last clicked point and the current mouse position always indicates how it would look if clicked now. By clicking the right button of the input device, points can be removed. Painting can be removed by holding that button and moving the device, whereat the motion speed determines how fast painted sections are taken away. The area at the lower right provides undo and reset buttons as well as a button to close the polygon, so that it is not necessary to exactly hit the starting point again. This function is particularly valuable in combination with a high sea state.

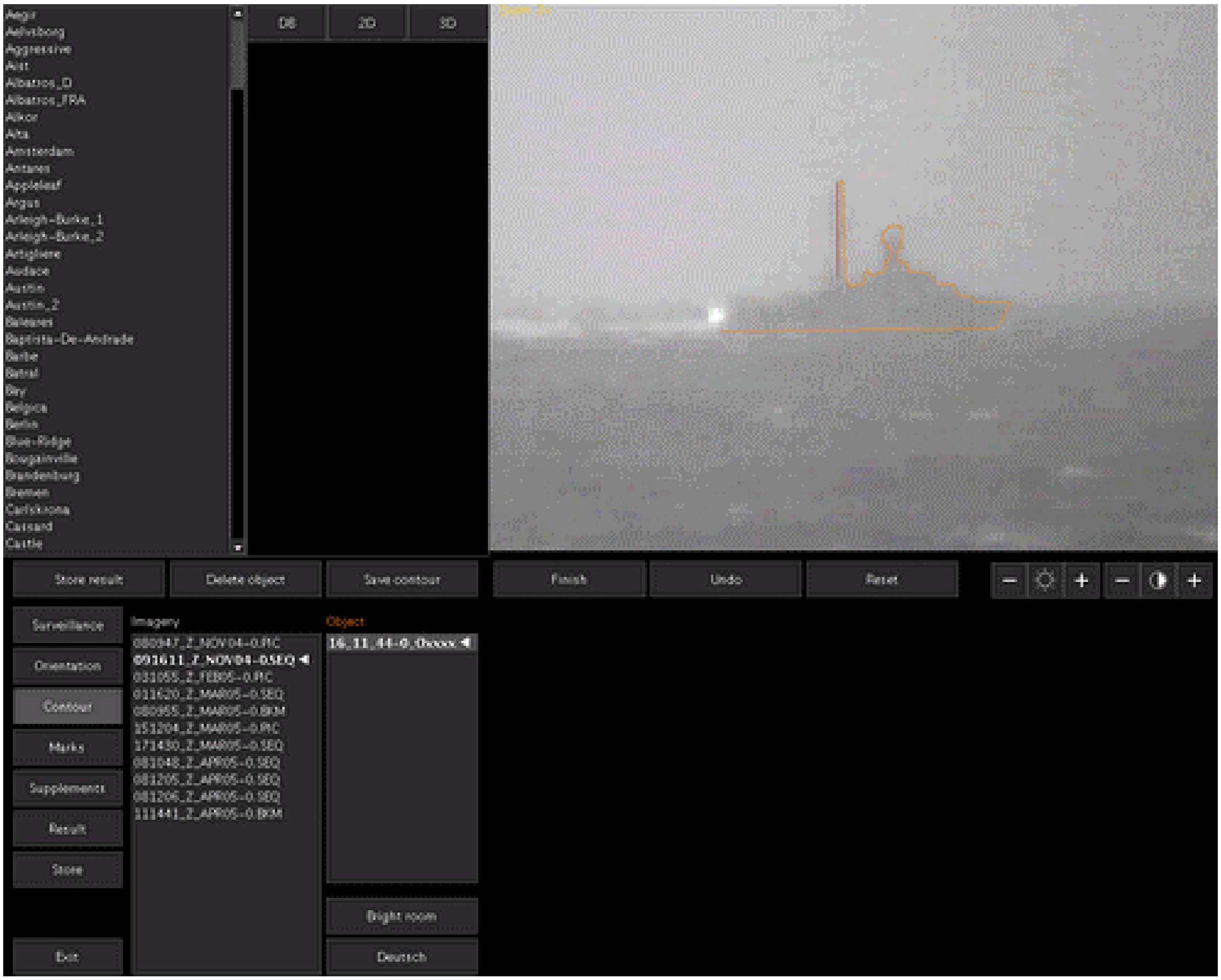

Figure 3: Screen during process state Contour

4.4 Process state Marks

The operator is asked to input the identifiable marks within this process state. If process state Contour has not been completed before, it is necessary to highlight the frame of the OTBC first, otherwise it is derived form the silhouette. In the area at the lower right, a list of all position dependant marks such as bridge, turrets, masts etc. can be found (Figure 4). After a mark has been chosen, its position must be clicked at on the image at the upper right. An erroneously entered mark can be removed by placing the cursor nearby and clicking the right button. Therefore the temporarily nearest mark is always highlighted by a hook circle.

Furthermore, an undo button allows to remove the mark entered last, a remove button to remove all of a kind and a reset button to forget about all of them. It is not necessary to always move the cursor to the menu below the image to change to another kind of mark. By clicking the left or right button outside the frame, the next or previous line of the marks list is selected. The marks are sorted as they typically appear from bow to stern. In addition to the position dependant marks, there are more marks whose positions are not relevant, such as helicopter-deck, because they are too huge to be assigned to a particular position. These marks can be found in a list of their own alongside the position dependant marks. For each of these marks it can be denoted whether or not it is visible via check box.

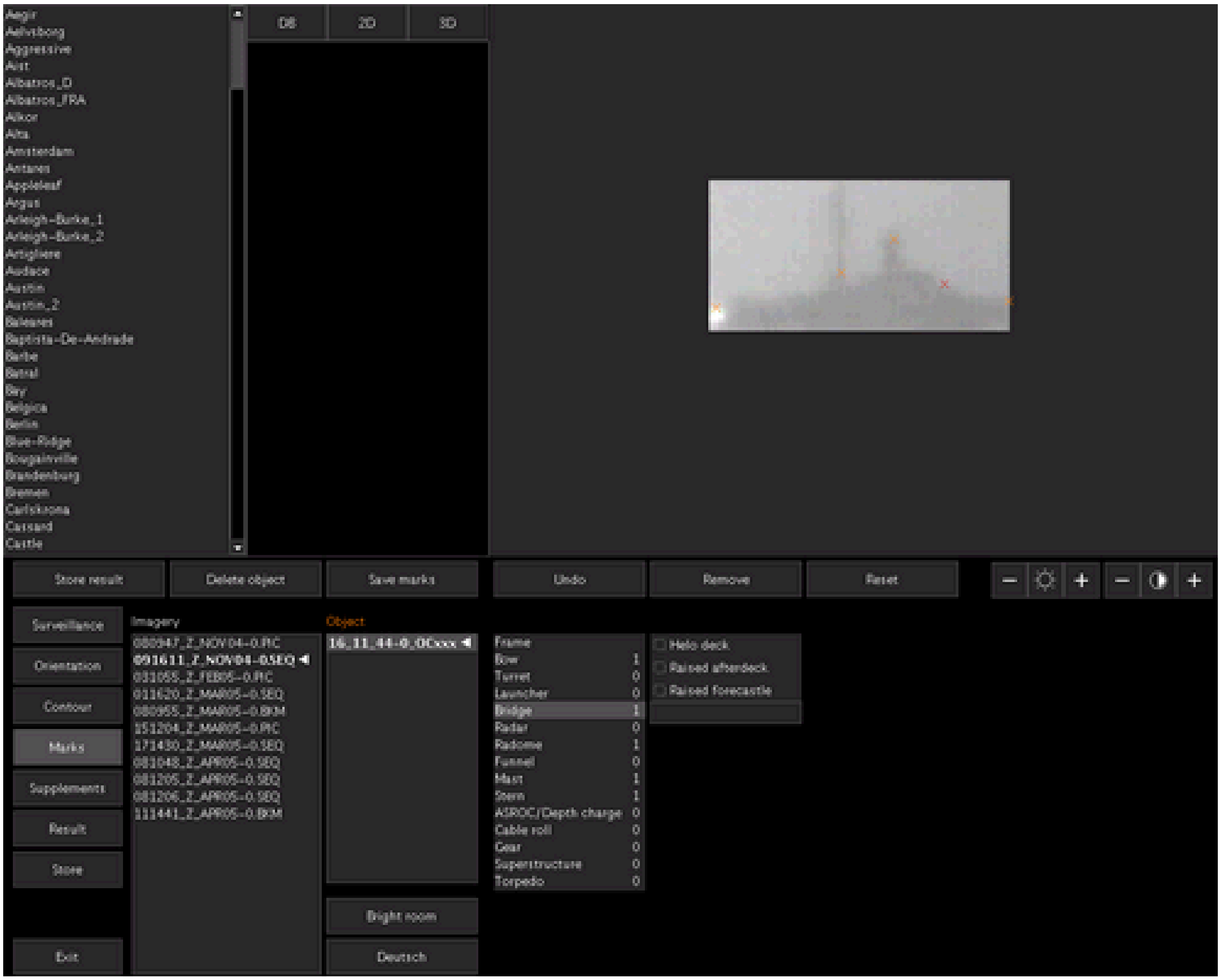

Figure 4: Screen during process state Marks

4.5 Process state Supplements

The supplements can be used to incorporate any almost definite information into the classification process. If, for instance, the length of the OTBC can be estimated quite exactly, ships that are significantly shorter or longer can be neglected. The supplements function is similar to a filter, but not as rigorous. It does not exclude anything, but rather substantially reduces the score of any ship class that does not match the given criteria. The magnitude of the reduction depends on how many facts diverge. This approach guarantees that candidates figured out by one or both of the algorithms are not ultimately removed from the result set due to wrongly assumed supplements. However, unlike with the classifier algorithms that are highly fault-tolerant, in result lists ship classes degraded by this means will be found well below those that fit all criteria. It is a powerful tool to get rid of unwanted candidates at the top of the result list, but is to be used carefully.

4.6 Process state Result

Finally, this state presents a list containing the most probable ship classes as figured out by algorithms and supplements function and offers several opportunities to compare the material at hand with reference imagery, outline drawings, 3d models, and data records. The database viewer at the upper left changes its appearance, so that 3d model, outline drawing and the reference image with the most similar rotation angle of an entry selected in the result list can be seen in maximum size directly alongside the chosen original sensor image (Figure 5).

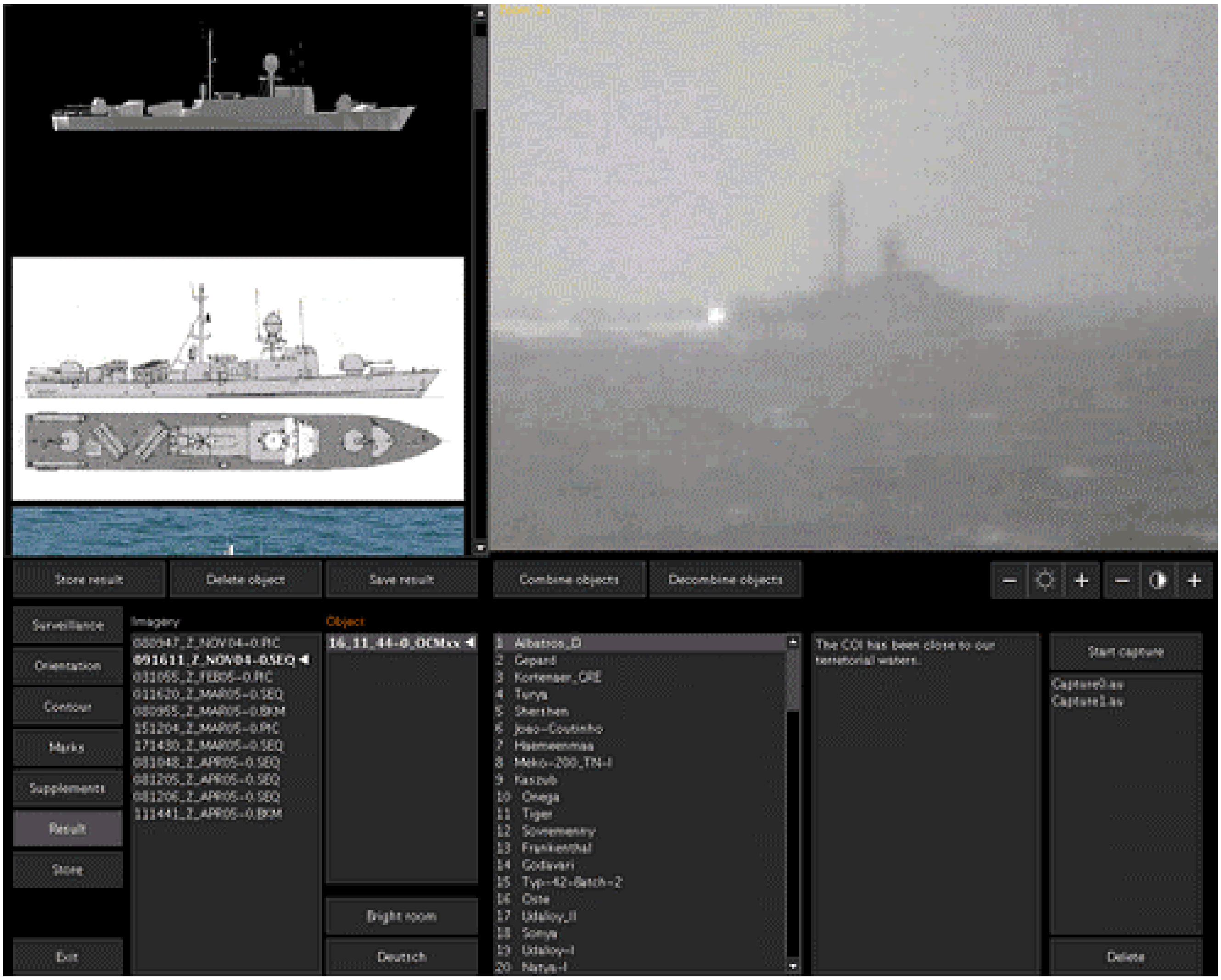

Figure 5: Screen during process state Result

It is important that the operator performs a visual comparison, because the scope covered by the algorithms is limited and humans have different skills as to pattern recognition. Once the operator has found the entry within the result list that seems to equate the OTBC, the decision can be saved. It is possible to add comments in written and spoken form, so that another operator investigating the material can be told the circumstances of the classification, e.g. why there was a particular interest in that special object.

4.7 Process state Store

The amount of stored classifications is likely to increase quickly when vessels are, for instance, deployed to sea area monitoring operations. To ease the handling of such material, this process state provides a concise table that is sortable according to many different criteria. The store can be burned on CD or DVD to enable the crew to send it to naval command for further analyses.

5. Evaluation

Testing under realistic conditions is of course a part and parcel of the human-centered development process. Therefore the nearly finished system is being tested on several different seagoing vessels. Initial tests have taken place onboard the German fast patrol boat S71 Gepard (P 6121) in the Baltic Sea in November 2004 as well as onboard the German frigate Lübeck (F 214) on the passage from Reykjavik/Iceland to Wilhelmshaven/Germany in December 2004. More tests are taking place as this paper is being written. In the experiments, navy personnel got a standardized personal introduction to the system and its functionality. Then the operators observed an exemplary classification process run by the investigator, before they had to work on realistic scenarios on their own. Besides performance, reliability and stability of the system, acceptance and utilization by the navy personnel is of paramount importance. The experiments under realistic conditions are particularly valuable to find out about the two last mentioned.

Clues on how to design dialogue systems can be found in the international standard DIN EN ISO 9241 (DIN EN ISO 9142-10, 1996), the German norm DIN 66234 (DIN 66234, 1988), as well as in comments on these standards (DATech, 2001). Although these criteria are analysis oriented, predominantly consist of negative wording, and do not contain any advice on how to deal with design conflicts, they provide an accredited assessment framework for finished (resp. nearly finished) systems. Based on the ergonomic criteria suitability for the task, self-descriptiveness, controllability, conformity with user expectations, and error tolerance, a questionnaire following a specific test procedure is being used for evaluation purposes. Test persons rate the named qualities by means of the 2-level rating scale (Figure 6) called ZEIS (Pitrella, 1989). In addition, they have to answer questions on what in particular displeases them and what appeals to them. The ratings on the first level of the 2-level rating scales were made as follows:

<u>Fast patrol boat</u>

Suitability for the task:	low	0	adequate	3	high	1
Self-descriptiveness:	low	0	adequate	1	high	3
Controllability:	low	0	adequate	1	high	3
Conformity with user expectations:	low	1	adequate	2	high	1
Error tolerance:	low	1	adequate	3	high	0

<u>Frigate</u>

Suitability for the task:	low	0	adequate	8	high	10
Self-descriptiveness:	low	0	adequate	9	high	9
Controllability:	low	0	adequate	7	high	11
Conformity with user expectations:	low	0	adequate	5	high	13
Error tolerance:	low	2	adequate	9	high	7

The achieved ratings must be seen in context with the very short introduction to the system of approximately only half an hour, as compared to courses of introduction for comparable workstations that typically last about one week, which is a clear hint to the easy appliance of the ergonomically designed system and graphical user interface.

The definite process structure with its process states and operating sequences in combination with the supporting functionality of the system and the clearly arranged graphical user interface obviously result in a high acceptance of the system. Many subjects mentioned potential details to augment and enhance the user support system in their questionnaires as well as in personal discussions with the investigator. The thorough analysis of these inputs and the implementation of all reasonable ones resulted in the realization of a suitable user support system with ergonomically optimized user interfaces and handling sequences enabling the operator to carry out quick and confident classifications of COIs on sensor imagery.

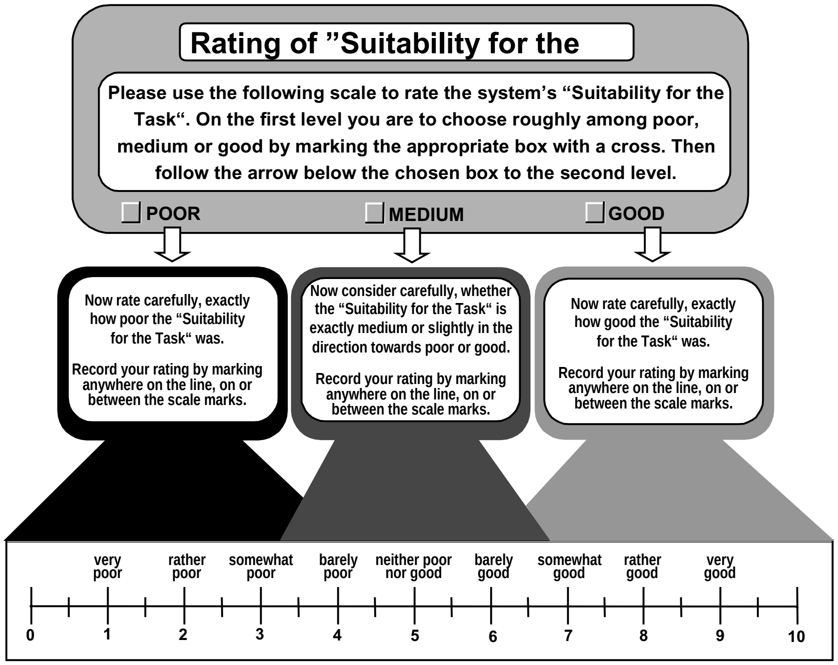

Figure 6: ZEIS rating scale for quality of suitability for the task

6. Conclusion

With the design of the user support system, in order to keep operators in the loop during reconnaissance missions, the main focus was on an efficient handling of the tasks to do, an optimized graphical user interface, and clearly guided operating sequences. The evaluation phase with the trials at sea has reconfirmed that the system provides substantial support for image analysis as well as object classification and identification.

7. References

AFSOUTH - NATO Regional Headquarters Allied Forces Southern Europe: "Operation Active Endeavour" [WWW document], URL: www.afsouth.nato.int/operations/Endeavour/Endeavour.htm, March 2005.

DATech: "Prüfhandbuch Gebrauchstauglichkeit - Leitfaden für die software-ergonomische Evaluierung von Software auf Grundlage von DIN EN ISO 9241, Teil 10 und Teil 11", Version 3.0, DATech Deutsche Akkreditierungsstelle Technik e.V., Frankfurt a. M., 2001.

DIN 66234: "Teil 8 - Bildschirmarbeitsplätze, Grundsätze ergonomischer Dialoggestaltung", Deutsches Institut für Normung e.V., Berlin, 1988.

DIN EN ISO 9142-10: "Ergonomic requirements for office work with visual display terminals (VDT´s) – Part 10: Dialogue principles", International Organization for Standardization, Geneva, 1996.

Günther, J.; Haese, K.; Meier, W. & vom Stein, H.D.: "Computer-aided recognition of ship signatures", Proc. of 2nd NATO/IRIS Joint Symposium, London, June 1996.

Mooshage, O. & Distelmaier, H.: ”Ein modellgetriebener Ansatz zur Unterstützung von Entscheidungsprozessen bei der Lagebewertung”, In: Gärtner, K.-P. & Grandt, M.: ”Human Factors bei der Entwicklung von Fahrzeugen”, pp. 165-182, DGLR, Bonn, 2001.

Mooshage, O.; Distelmaier, H. & Grandt, M.: ”A Knowledge-Based Approach to Provide Adaptive Support for Anti-Air Warfare Decision Makers on Naval Vessels”, Proceedings of the Systems Concepts & Integration Panel Symposium on ”Critical Design Issues For The Human-Machine Interface” (SCI-129/SY-012), paper #13, Prague, May 2003.

Pitrella, F.D.: ”A Cognitive Model of the Internal Rating Process”, FAT-Bericht Nr. 82, Forschungsinstitut für Anthropotechnik, Wachtberg, 1989.

Schweingruber, J. & Brütting, M.: ”Ergonomisches Bedienkonzept für die Objektidentifizierung mit bildgebenden Sensoren”, FKIE-Bericht Nr. 58, Forschungsgesellschaft für Angewandte Naturwissenschaften e.V. (FGAN), FKIE, EFS, Wachtberg, 2003.

Schweingruber, J. & Brütting, M.: ”User Support System for Naval Reconnaissance - Design and Evaluation”, Proc. of The Technical Cooperation Program (TTCP), Human Resources and Performance Group (HUM)-TP9, Human Systems Integration (HIS) Workshop, Ottawa, May 2004.

Schweingruber, J.: ”User Support System for Image Analysis and Object Identification”, Proc. of 9th International Command and Control Research and Technology Symposium, Coalition Transformation: An Evolution of People, Processes, and Technology to Enhance Interoperability, Copenhagen, September 2004.

Schweingruber, J. & Mooshage, O.: ”Unterstützung Nutzung bildgebende Sensoren”, Zwischenbericht II, Forschungsgesellschaft für Angewandte Naturwissenschaften e.V. (FGAN), FKIE, EFS, Wachtberg, September 2004.