# Direct Perception Displays for Military Radar-Based Air Surveillance

Oliver Witt, Morten Grandt, and Heinz Küttelwesch

FGAN-Research Institute for Communication,
Information Processing, and Ergonomics
Neuenahrer Str. 20, D-53343 Wachtberg, Germany
{witt,grandt,kuettelwesch}@fgan.de

**Abstract.** Air surveillance is among the time-critical and highly prioritized tasks of naval ships, in which the human operator will stay the decision maker in the future as well. User-oriented human-systems integration requires the provision of ergonomically optimized user interfaces. Based on functional system descriptions in the form of abstraction hierarchies, perceptive displays were developed for air surveillance that constitute an advancement with respect to so far principally alphanumerical displays supporting the operator with an improved situation awareness in his decision-making processes. It concerns, in detail, displays for the tactical situation picture, the explicit information about airborne contacts as well as the condition and the configuration of system state especially regarding the radar equipment.

**Keywords:** Abstraction hierarchy, user interface, polar diagram, military combat direction systems.

## 1 Introduction

Naval platforms that are earmarked for a versatile spectrum of military missions are characterized by combat direction systems that are technologically state-of-the art and equipped with high-capacity sensors and effectors. They shall guarantee that the crew is enabled to adequately master so-called “naturalistic situations” that may be characterized by insecurity, dynamic environments, varying and undefined users, competing aims, time pressure and a high risk of decision failures [1].

Air surveillance in particular is among the eminent time-critical and security-sensitive tasks for naval platforms because of the kinematic qualities of airborne contacts, e.g. aircrafts or missiles. Because of today’s primarily asymmetric threat, however, the combat direction systems that are operated with a high degree of automation do not guarantee a total reliability with regard to the identification and classification of such contacts. Therefore, the human operator will remain the final decision maker in the future. Also when using computer-based decision supports, the focus should consequently lie on the optimized human-systems integration when designing complex military human-machine-systems and the according human-machine interfaces. In order to avoid operator-out-of-the-loop problems, the operator should be included profoundly into the situation and the system (human-in-the-loop).

D. Harris (Ed.): Engin. Psychol. and Cog. Ergonomics, HCII 2009, LNAI 5639, pp. 606–615, 2009.

Looking at today's combat direction systems, however, one finds that information is predominantly offered to the operator on text-based (alphanumerical) and separated displays. For instance, crucial information about tracks, such as course, speed, altitude, position, etc., must be compared with given identification criteria by the operator and the individual results must then be mentally integrated in order to verify hypotheses concerning identities and intents. The operator has thus to complete multiple n-times-comparisons and integrations with respect to all aims observed by him as well as make multiple hypotheses tests. The actual system state, related, e.g., to the surrounding areas that are covered by radar, is not displayed. Instead, such information must be communicated verbally and henceforth be memorized in the working memory by the operator in order to include it in the decision-making process. It is obvious that a very high mental demand can hence result when complex decisions need to be made that may even entail deficits in performing and possibly fatal incorrect decisions in case of overload.

The design of user interfaces of complex systems with an mission spectrum characterized by unpredictability, is increasingly carried out based on abstraction hierarchies both in civil [2][3] as well as in military areas [4]. This contribution deals with perceptive displays for air surveillance using the example of class 124 frigates of the German Navy. The displays shall support the operator in his decision-making processes by improved situation awareness with regard to system state and the external tactical situation. In detail, it is about the design of the condition and the configuration of the applied radar equipment which affects the sensed tactical air picture and furthermore about the display design regarding decision relevant information about airborne contacts.

## 2 Knowledge Representation with Abstraction Hierarchies

Within greater military units like task groups or task forces the class 124 frigates of the German Navy primarily are responsible anti air warfare.

The radar SMART-L (Signaal Multibeam Acquisition Radar for Tracking, L band, today's D-band) is the main sensor for long-range detection, localization and tracking of airborne contacts. Therewith, objects with a high radar cross section such as air carriers or bombers can be captured up to a distance of approximately 400 km. Within the computer-aided information processing, the data provided by several sensors of the ownship and other (linked) platforms are fused in the process phase Sensor Data Fusion and subsequently undergo the process phases Identification and Classification.

SMART-L as well as the mentioned software processes possesses a multitude of settings (characteristics of the radar beam, degree of automation, etc.). The adjustments of these system parameters are made by a Doctrine Management Officer (DMO) in the combat information centers (CIC) of the frigates. The data provided by the sensor are used by several operators, e.g., the Anti Air Warfare Officer (AAWO), in air surveillance. Consequently, the system state configured by the DMO has a significant influence on the tactical situation picture offered to the AAWO dealing with tactical situation evaluation.

Depending on their roles, different information needs arise for diverse operators with regard to the system state and specific demands as to the interaction functionalities. These user requirements can be collected and structured by means of abstraction hierarchies which are about functional descriptions of the system to be conducted and the work domain respectively that is “independent of a particular worker, automation, event, task, goal or interface” (after [6]). Abstraction hierarchies were developed based on the analysis of system specification and manuals, interviews with operators of the German Navy and developers of radar equipment as well as the observation of team trainings [5,6].

The analysis resulted in the abstraction hierarchy pictured in abstracts in Fig. 1. The first of five levels (functional purpose, FP) describes the aim with which the work domain was developed. The second level (abstract function, AF) provides the underlying regularities and principles. The third level (generalized function, GF) covers the involved processes. The fourth level (physical function, PFu) defines the involved entities and their availability. The fifth level (physical form, PF) contains the physical appearance and local arrangement of entities.

Chen et al. [7] carried out this form of analysis for the interface design of sonobuoys. The difference between the deployment of sonobuoys and of radar equipment such as SMART-L lies, e.g., in the medium (water versus air), the time factor (critical versus uncritical), the kind of radiation (acoustic waves versus electromagnetic waves), the type of detectable contact (submarines versus aircrafts, missiles), the contact details (direction, distance, depth, acoustic data versus position, speed, IFF, ESM) and the location of the sensors (mobile versus ship-based).

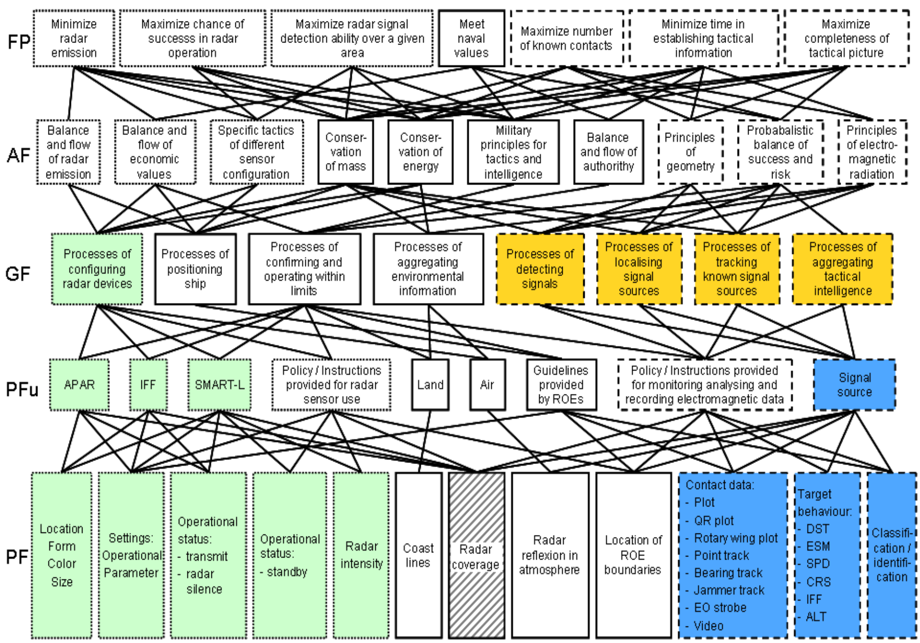


**Fig. 1.** Abstraction hierarchy for military radar-based air surveillance (excerpt)

Chen et al. [7] distinguish between sensor management and tactical situation awareness. In Fig. 1, elements for radar system management are dashed, dotted for Tactical Situation Awareness and solid framed for commonality.

The functional aim is the fast supply of a complete and accurate list of track attributes of airborne contacts under minimization of radar emission. This track attributes list covers distance, azimuth angle, elevation angle, speed, etc. The so-called jammers, that try to constrain or inhibit with active blockage the use of the D-band, belong to the objects as well. The illustration of radar echoes, the so-called radar video, in addition, serves for the observation of contacts.

In situations with a high degree of sensor working load, the completeness and accuracy of data is not simultaneously guaranteed for all contacts because of physical or operational restrictions depicted on the level „abstract function". Therefore there must be a balancing depending on priority. The required resource management and energy input depends on physical regularities such as the law of conversation of energy. Operational restrictions, like the so-called Rules of Engagement, determine the operational options, e.g. they may restrict the usage of radar systems in order to avoid radar emissions in certain parts of the operational area.

Located on the level Generalized Function are the processes for the configuration of a radar equipment that are necessary for the transmission of signals as well as the reception of echoes, e.g., signal generation, amplification, transmission, reception and processing. For the tactical situation awareness the processes for the detection of signals, the localization of signal sources and the tracking of contacts are given.

The level Physical Function contains radar equipment such as APAR, SMART-L und IFF on the one hand and the signal sources on the other hand.

On the level Physical Form, the elements of the level Physical Function as well as the applied radar equipment are described by their location, form, dimension, material, etc. The attributes of the airborne contacts and their kinematic data stand on this level as well.

The different layers of hierarchy are connected by means-end-relationships (symbolized by lines in Fig. 1), i.e., one layer respectively provides the means in order to reach the aims of the overlying layer, whereupon each layer in its particular form contains a complete system description.

A central aspect of visualization is, as mentioned above, the adjustment of radar coverage (hatched in Fig. 1) normally carried out by the DMO, as it plays a decisive role in the interpretation of the tactical situational picture and the enclosed contacts.

## 3 Design of the User Interface

The abstraction hierarchy provided contents for the human-machine interfaces to be designed by dissipating the information demands necessary for the operator from the individual cells of the abstraction hierarchy. The radar coverage, e.g., informs whether the functional purpose of the provision of contact data is achieved by SMART-L in a defined section. Conclusions concerning completeness, accuracy and actuality of the data are indeed desirable, but are presently not provided by SMART-L.

For information needs emanating from the (highlighted in grey) elements of the abstraction hierarchy (Fig. 1) displays were designed that will be explained individually in the following paragraphs. This concerns the visualization of the control parameters of the radar equipment and the master screen of the state of SMART-L (light grey), visualization of the tactical air picture (medium grey) as well as detailed contact details (dark grey).

In contrast to the DMO who has to configure the combat direction system, as explained above, in relation to the qualities of the radar sensors and who needs a detailed display of the system state for this purpose, the AAWO has the task to carry out an analysis of threat based on the air picture shown on a tactical situation display and to initiate necessary activities, if applicable. The available radar equipment is the primary source for the design of the air picture. These can be configured by the DMO in a way that they cover the entire airspace or only certain sectors with certain degrees of intensity.

The AAWO essentially needs displays for his task that inform him about the position and the qualities of the contacts picked up via the sensors. Nevertheless, it is also relevant for him which areas in the surroundings of the ownship are covered by which sensors. In this way, he can, on the one hand, detect in which sectors airborne contacts may actually be detected and, on the other hand, in which sectors the ship can be reconnoitered by other target objects due to the emitted radar radiation. Thus, both the DMO and the AAWO need information about the system state, even though on different levels of aggregation.

### 3.1 Visualization of Control Parameters

For the visualization of control quantities and its influence on the system functionality a form following designs of civil process control systems was chosen. Fig. 2 shows the interrelation of radar system components while sending, i.e., the hardware structure (PFu) is shown according to the information flow (GF) from signal generation (Fig. 2, left) to signal transmission (Fig. 2, right) for the transmitter of the SMART-L radar system. The different components contain aggregated displays of the availability of the subsystems and the according operational condition, at which green symbolizes the availability, yellow the partial availability and red the unavailability of the respective component.

The displays of the Frequency Control Unit (FCU) which generates the radar radiation, cover, amongst others, the current operational state (online operational) as well as the FCU's availability. SMART-L possesses 8 frequency sub-bands in the RF-area. Each frequency sub-band can separately be approved for use. If none of these sub-bands has been selected, the aggregated display of the module additionally shows a warning symbol that the creation of transmitting energy is impossible at present.

The signals generated in the FCU are amplified in the Amplifier Unit (AU). Amongst others, the lower part of the display points up the coherence between the adjusted scan range and the number (4, 8 or 32) of needed amplifiers. Highlighted in dark are currently not built-in slide-in modules.

A precondition for an undisturbed operation of the transmitting antenna is its coaction with the B-Drive and the climate system. The B-drive state shows whether

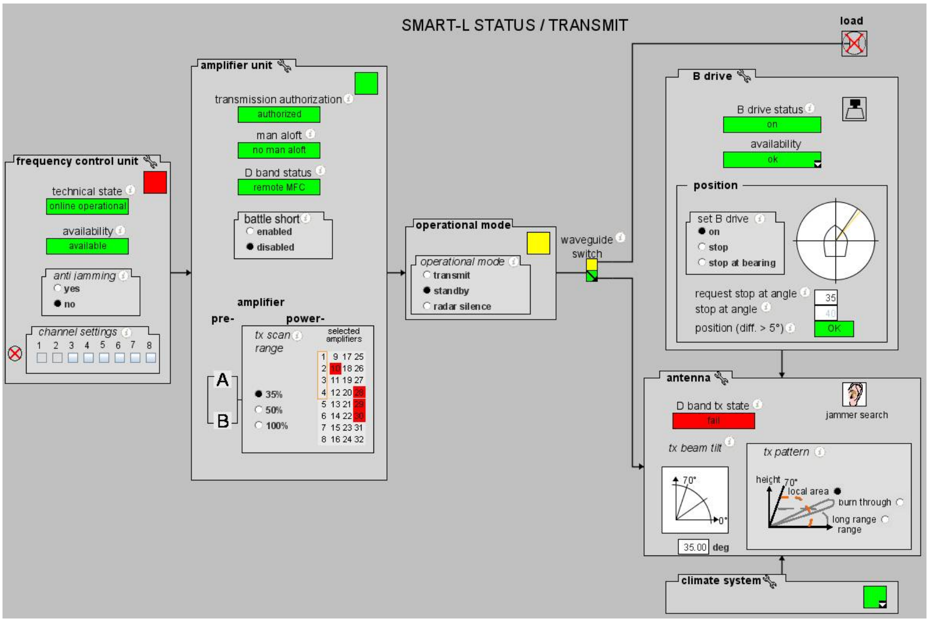


**Fig. 2.** Visualization of control parameters

the SMART-L rotates. The availability of the antenna's rotating part is aggregately displayed as a link. In case of a blockage the selection of this link delivers the cause in a separate overlay-window. The positioning indicator of the B-Drive contains a display showing the momentary position of the antenna (grey marking) and a display as well as a graphic input option for the position that the antenna shall take up after the halt (black marking). Because of the multitude of state displays, the animated iconized design of a revolving or not revolving B-Drive clarifies the two basic settings of the mechanical part of SMART-L, shown at the top right angle of the module.

### 3.2 Master Display of the Condition of SMART-L

The monitoring display in Fig. 3 provides, on the one hand, relevant information primarily attuned to the functional aim, and allows, on the other hand, a fast access to detailed information of the underlying levels.

Three iconized state indicators show whether SMART-L radiates (radiation), the transmitting energy is loaded into the artificial antenna (load) and whether the antenna rotates (B-Drive). In addition to the basic states „radiate“ and „not radiate“, the radiation symbol additionally displays the state „listen“ (ear symbol) that allows for, e.g., detection of jammer tracks if the antenna rotates without active radiation. If the DMO defined a azimuthally limited radar coverage "radar sectors" is displayed as "selected" and the radar coverage angles are displayed in the Tactical Situation Display (see Fig. 4).

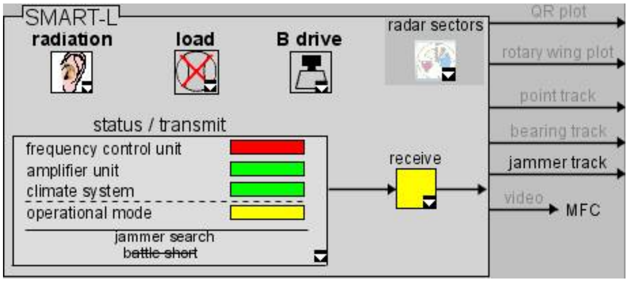


**Fig. 3.** SMART-L master display

The lower part of the master display is based on a distinction between the transmitter and the receiver part. In the area "status / transmit" the different functional components of „SMART-L Status / Transmit" shown in Fig. 2 are aggregately represented. For instance, the Frequency Control Unit is not ready for use at present. The detailed state display can be navigated from the aggregated master display. At the same time, Fig. 3 shows on the right hand which kind of track information SMART-L provides for the following process phase "Sensor Data Fusion" based on the current system configuration, in this case it is exclusively about Jammer Tracks.

### 3.3 Visualization of the Tactical Air Picture

For tactical situation analysis and threat evaluation the Tactical Situation Display (TSD) realized here as an overview display displays all geo-referenced airborne, surface and subsurface contacts detected by the ownship's sensor systems or by other platforms linked to the combat direction system in bird's view perspective (Fig. 4). A vertical section allows for the direct allocation of the contacts to altitude bands. Thus, potentially threatening contacts flying at low altitude can be recognized faster.

On the other hand, the display shows which sectors are covered by SMART-L. Consequently, it is directly apparent for the AAWO why the areas not covered by radar do not capture contacts or only electro-magnetic bearings.

In order to allow for a fast survey over the track attributes, so-called polar displays were integrated in direct vicinity of the Tactical Situation Display (see Fig. 4) as an addition to the detail displays for track evaluation that can not be examined more closely here for lack of space. The advantages of polar displays for the support of supervisory control tasks were pointed out using the example of nuclear power plants [8]. In this military application they constitute in integrated form the track attributes that are crucial for identification, such as distance to the ownship (DST), altitude (ALT), speed (SPD), course (CRS), IFF-information (IFF) and ESM-emissions (ESM). The activation of the individual polar displays occurs threat-triggered in the upper area and event-triggered in the lower area.

For a single track attribute the polar display generates display proximity between the current attribute value and – taking into account predefined identification criteria – an un-critical attribute value on the attribute's parameter beam. The symmetric figure in the background, the so-called normal range, represents the a priori defined scenario knowledge. For instance, it is known in advance which friendly, neutral

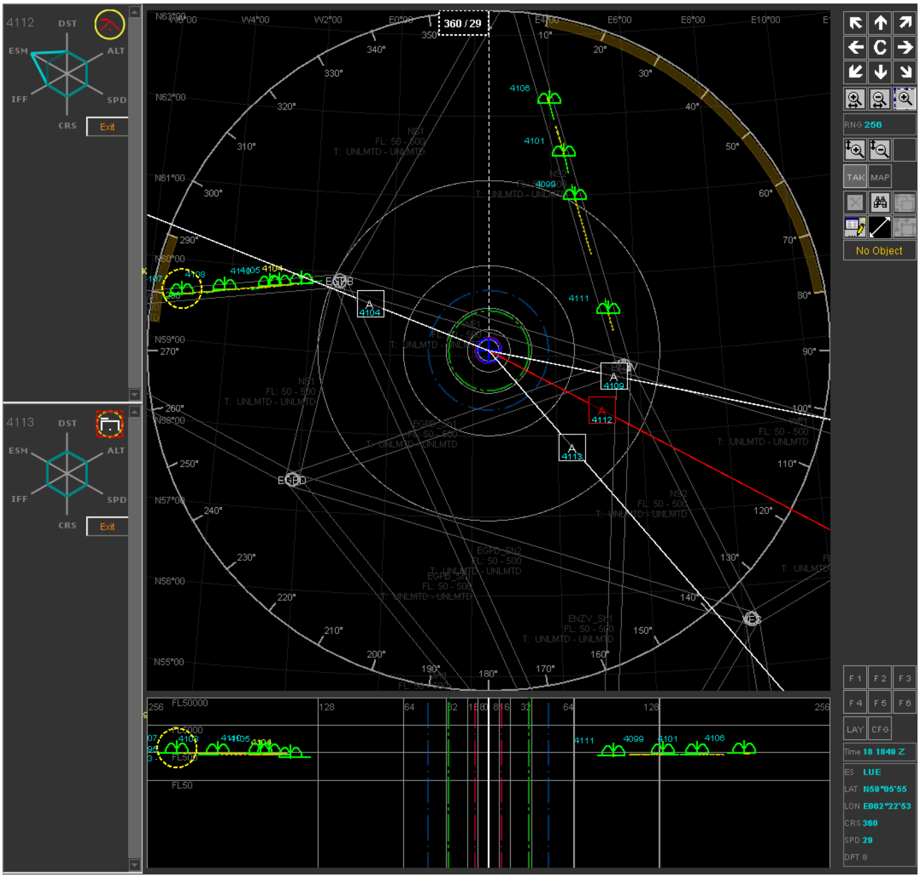


**Fig. 4.** Tactical Situation Display with a display of radar coverage configured by DMO (accentuation of active areas 10°-80° and 275°-290° at the compass rose) and polar displays in the left range of the figure. In area 100°-140° three electro-magnetic bearings are displayed, among them a hostile emission (118°).

(civil) and hostile radar emissions (ESM emissions) are to be expected. Similar friendly and neutral IFF (identification friend foe) codes are defined a priori. If potentially threatening attribute values are detected the respective value indicator deflects. The normal range of kinematic attributes like speed or altitude is defined in advance as a tolerance area. For instance, high velocities can be reached only by (hostile or friendly) military fighter aircrafts. Additionally, the variation of kinematic attributes, e.g., a sudden significant change of speed or altitude, is untypical for non-military aircrafts and causes therefore a deflection of the respective value indicator.

By connecting the current indicator values of single attributes a figure is generated which integrates the single pieces of information on a higher level of abstraction. This figure by means of symmetry or a-symmetry forms a so-called emergent feature which helps to transfer the interpretation of information content to the perception phase of human information processing, i.e. direct perception: A symmetric figure (Fig. 4, lower polar display #4113) indicates an un-critical airborne contact. In contrast, the easy to perceive a-symmetry of the resulting figure in polar display #4112 (shown in the upper left part of Fig. 4) states the reason that this contact is critical regarding its ESM activity.

Emergent Features, e.g., symmetry, alignment, parallelism, emerge from the relative constellation of multiple displays to each other. As the most relevant advantage of polar displays, in spite of the graphical aggregation of individual attributes they assure that the single pieces of information are better noticeable and perceivable. Thus, in contrast to classical alarm displays polar displays are alarming and diagnostic at the same time, because the possibly symptomatic characteristic of a single parameter value can be noticed easily. Furthermore, under different parameter constellations the figure-forming aggregation of single attributes allows for the direct derivation of higher-level task-related manifestations. In contrast, the notification about several pieces of information on separated displays as mentioned above requires multiple mental transformations and comparisons.

## 4 Conclusion and Outlook

Based on functional system analyses by means of abstraction hierarchies visual displays for system configuration and tactical situation analysis in the context of air surveillance have been developed which support the human operator in decision-making providing enhanced situation awareness. For instance, interrelations between system configuration and the sensed tactical situation have been analytically determined and modeled and were integrated within the Tactical Situation Display.

In several evaluation phases these visualizations have found to be a significant improvement regarding effectiveness, efficiency in comparison to displays known from current German naval platforms. They were rated to have a better usability, too. Thus, the benefits applying abstraction hierarchies and a model-based visualization of complex information have been shown.

In the next step a further integration of displays and an optimized user guidance shall be realized which should take into requirements arising from both the users and the tasks. Doing so, combat direction systems shall be improved in order to ensure safe and efficient decision-making of human operators which is crucial facing the current and anticipated scenarios and operational conditions.

## References

1. Orasanu, J., Connolly, T.: The reinvention of decision making. In: Klein, G.A., Orasanu, J., Calderwood, R., Zsambok, C.E. (eds.) Decision Making in Action: Models and Methods, pp. 3–21. Ablex Publishing Corporation, NJ (1993)
2. Jamieson, G.A., Vicente, K.J.: Ecological interface design for petrochemical applications: supporting operator adaptation, continuous learning, and distributed, collaborative work. Computers and Chemical Engineering 25, 1055–1074 (1999)

3. Yamaguchi, Y., Tanabe, F.: Creation and Evaluation of an Ecological Interface System for Operation Nuclear Reactor System. In: Proceedings of the XIVth Triennial Congress of the International Ergonomics Association and 44th Annual Meeting of the Human Factors and Ergonomics Society, vol. 3(2000), pp. 571–574 (2002)
4. Burns, C.M., Bryant, D.J., Chalmers, B.A.: Boundary, Purpose, and Values in Work-Domain Models: Models of Naval Command and Control. IEEE Systems, Man, and Cybernetics Part A: Systems and Humans 35(5), 603–616 (2005)
5. Rasmussen, J., Pejtersen, A.M., Goodstein, L.P.: Cognitive Systems Engineering. Wiley, NY (1994)
6. Vicente, K.J.: Cognitive Work Analysis: Toward Safe, Productive, and Healthy Computer Based Work. Erlbaum, Mahwah (1999)
7. Chen, H.Y.W., Burns, C.M., Lamoureux, T.: Work Domain Analysis for the Interface Design of a Sonobuoy System. In: 51th Annual General Meeting Human Factors and Ergonomics Society, Baltimore, MA (2007)
8. Wickens, C.D.: Engineering Psychology and Human Performance. Harper Collins, New York (1992)