A HMI design method to address automation and information selection and presentation problems related to the use of data fusion techniques in the military domain of ISTAR

Hélène L'Heureux[1], Jean-Yves Fiset[2], Jean-Rémi Duquet[3], Jean-Marc Robert[4]

[1]École Polytechnique de Montréal
C.P. 6079, succ. Centre-ville Montreal (Qc)
Canada H3C 3A7
Helene.lheureux@polymtl.ca

[2]Systèmes Humains-Machines Inc.
C.P. 52014, Laval (Qc)
Canada H7P 5S1
jyfiset@shumac.qc.ca

[3]Lockheed Martin Canada
6111 Royalmount, Montreal (Qc)
Canada H4P 1K6
jean-remi.duquet@lmco.com

[4]École Polytechnique de Montréal
C.P. 6079, succ. Centre-ville, Montreal (Qc)
Canada H3C 3A7
Jean-marc.robert@polymtl.ca

Abstract

In this paper we address the challenges faced by the designers of human-machine interfaces (HMIs) and decision support systems (DSS) when dealing with data fusion (DF) processes in military domains, more specifically for the application known as Intelligence, Surveillance, Target Acquisition and Reconnaissance (ISTAR). Two main issues stand out: the selection of the appropriate level of intervention of the human operator within the fusion processes and the selection and presentation of the fused information in a HMI. To solve these problems, we turn to Tagci, a cognitive architecture that is used for the design of HMIs in the process control domain. After explaining why we believe Tagci can contribute to solve the problems mentioned above, we give details about how we are going to adapt it to the military domain of ISTAR and how we are going to make it more complete so it becomes an information presentation method as well as a HMI design method.

Introduction

In the military domain of Intelligence, Surveillance, Target Acquisition and Reconnaissance (ISTAR), the combination of high computing power, sophisticated sensors, multitask forces and networking results in the production of massive quantities of data. In fact, the amount of data available often exceeds the information processing capabilities of human beings. Data fusion (DF) is one of the techniques used to help reduce the burden of human operators by assisting them in their decision making process. However, DF creates new and challenging problems for the designers of decision support systems (DSSs) and human-machine interfaces (HMIs). Two issues confront those designers: selecting the appropriate mode of intervention of the human agent within the fusion process and presenting the fused information on a HMI. This paper is organized as follows: first, we explain the architecture supporting the data fusion processes and how it relates to the issues mentioned previously. Second, we briefly explain Tagci, a novel HMI design method based on a cognitive architecture, and why we expect that it has the potential to solve those issues. Third, we describe how we are going to adapt Tagci to the ISTAR domain and how we are going to make it more complete so it becomes an information presentation method as well as a design method.

Data fusion: processes and issues

Data fusion is "a process dealing with the association, correlation and combination of data and information from multiple sources to achieve refined position and identity estimation, and complete assessments of situation and threats, and their significance" (White, 1987). Data fusion techniques come from a diverse set of disciplines that include signal processing, statistical analysis, artificial intelligence, etc.

Figure 1 shows the logical flow among the different DF levels that are defined by Steinberg, Bowman and White,

(1998), in what is the most widely known and used DF architecture:

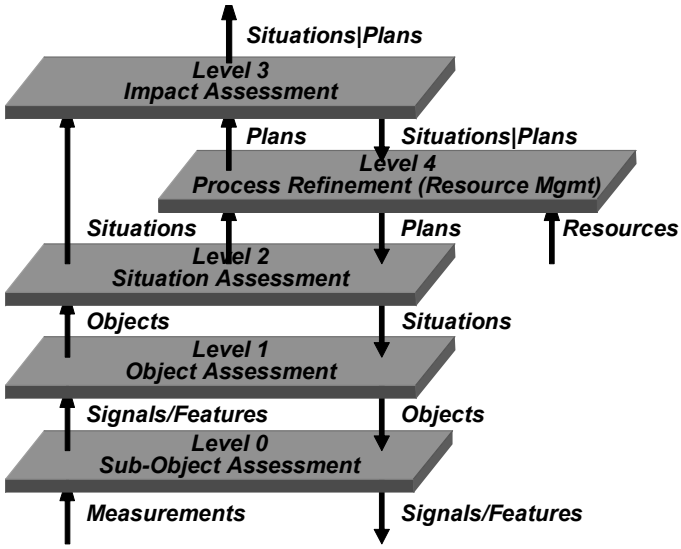

Figure 1: Logical flow among the "levels". Source: Steinberg, Bowman and White (1998).

The elements of the architecture are:

> Level 0 – Sub-Object Data Assessment: estimation and prediction of signal/object observable states on the basis of pixel/signal level data association and characterization;
>
> Level 1 – Object Assessment: estimation and prediction of entity states on the basis of observation-to-track association, continuous state estimation (e.g. kinematics) and discrete state estimation (e.g. target type and ID);
>
> Level 2 – Situation Assessment: estimation and prediction of relations among entities, to include force structure and cross force relations, communications and perceptual influences, physical context, etc.;
>
> Level 3 – Impact Assessment: estimation and prediction of effects on situations of planned or estimated/predicted actions by the participants; to include interactions between action plans of multiple players (e.g. assessing susceptibilities and vulnerabilities to estimated/predicted threat actions given one's own planned actions);
>
> Level 4 – Process Refinement (an element of Resource Management): adaptive data acquisition and processing to support mission objectives.

All of the different levels do not need to be present at all times and neither are they necessarily activated sequentially. Even though data fusion is a technology that is well established in specialized areas, cognitive challenges persist for the agents that use it, whether human or synthetic. More specifically, the results of the fusion processes are not always clear; they can be ambiguous and present themselves as a large tree of hypotheses with different levels of certainty, due to the fact that the inputs of the fusion process sometimes contain uncertain or contradictory elements of information. When such ambiguity is present, is it better to let the fusion process – which can be seen as the synthetic agent- act by itself in a completely automated fashion or should a human operator be involved? Even with seemingly simple algorithmic tasks like the gating and correlation of a positional fusion, there is a breaking point where the results can be ambiguous and where the operator might need to be involved. After studying human performance with expert systems that expressed probabilities associated with the correctness of various options, Selcon (1990) concluded that when those probabilities are close or ambiguous, it takes longer for the operator to make a decision as compared to situations in which people made the same decision without system advice.

There are many possible modes of interaction between the human operator and the fusion process. It can be fully automated, available on demand, incorporate "triggers" or decision points. Manual inputs can also be used. Depending on the situation, some options are more appropriate than others (e.g., for highly dynamic and time critical environments, manual correlations and combinations are not recommended). Also, it is possible to completely automate the fusion process at one level and let the operator take full or partial control of the other levels of data fusion. Therefore, the first of the two issues that concern us regards the selection of the appropriate level of intervention of the human operator within the fusion processes depending on the type of situation.

The second issue that we wish to address is the selection (and presentation) of the fused information in a HMI. Once again, among the potentially large tree of hypothesis and intermediate results generated by the fusion process,

it is often unclear what information should be presented to the human operator and how it should be shown on a HMI. For instance, a typical statement might be that at a given point in time, an observed ship could be either a frigate or a destroyer, with an associated belief of 55 %, or a commercial ship, with a likelihood of 30%, or none of those with a belief of 15%. The usefulness of each individual statement might depend on the specific elements it contains and their relevance to the operator's task, as well as the associated level of confidence (e.g., is it above a given threshold) and its stability. Relevant information then has to be presented in a meaningful, understandable, way to a human operator if he is to trust the DSS and to achieve his goals. It is our belief that an appropriate HMI design method based on a cognitive architecture would help to solve these problems.

Tagci : a cognitive architecture for the design of HMIs

Tagci, an acronym for "Tâches et architecture générique pour la conception d'interfaces" was developed by Fiset (2001) as a HMI design method for process control applications; this field shares several similarities with the military domain such as time dynamics, conflicting objectives, risk, as well as a large number of interconnected variables. Further, a human operator often has to deal with massive amount of data in process control applications and may rely on several mechanisms (e.g., correlations, predictions) to try and aggregate (or fuse, in DF parlance) this data. To help design better HMIs, Tagci models the operator's behaviour as a set of cognitive generic tasks and incorporates various, but rudimentary, HMI design rules. The generic tasks are: detection of a threat to a goal, diagnosis of the origin of a threat, transitioning a system between operating regions, compensating for a disruption in the nominal operation of a system, and optimizing the operation of a system. Those generic tasks are organised hierarchically; a specific type of knowledge is defined to support the human in carrying out each of the generic tasks. For example, procedural knowledge is specified to support transition tasks in known situations, causal and functional models help support transition tasks for novel situations, functional models are used to support the detection of threats to operating goals, etc. The linkage between these models and Tagci's generic tasks thus explicitly couples the domain and the operator's tasks (or equivalently, his goals). This coupling is the key to providing optimal, or near optimal, support to the operator. Figure 2 shows those components of Tagci for a typical process control application (the plant and operator are shown for the clarification of the context only).

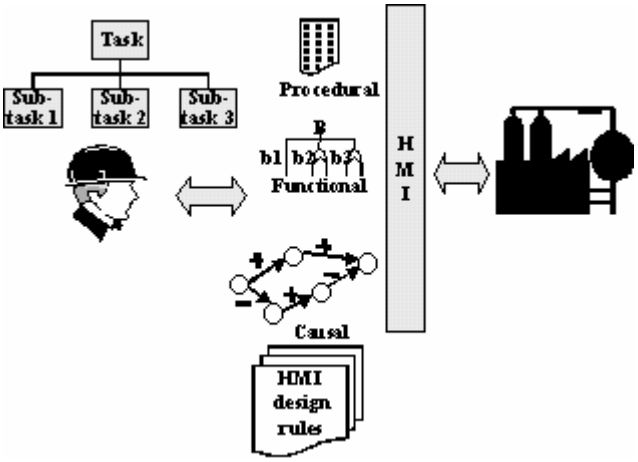

Figure 2: Elements of Tagci for a Process Control Application.

Applying Tagci to the design of a HMI thus consists in identifying the mission to be accomplished by the joint human-HMI system and to partition the information and functionalities in accordance with the structure provided by the method. If one stops for a moment on the Figure, it should be clear why we consider Tagci to constitute a cognitive architecture; it actually defines a series of reasoning mechanisms, embodied into the generic tasks, and a set of knowledge, embodied into the various models shown. The human operator (which we consider to be the agent in this system) thus carries out the reasoning using the various sources of knowledge made available to him. The concept of generic tasks used in Tagci strongly resembles the one introduced by Bylander and Chandrasekaran (1987). They see generic tasks as "basic combinations of knowledge structures and inferences strategies that are powerful for dealing with certain kinds of problems" and point out that "each generic task exploits domain knowledge differently; [therefore] it calls for knowledge in a specific form that can be applied in a specific way". Limited experimental validation of Tagci and the results that were obtained from an industrial application are quite encouraging; they have shown that Tagci can enhance the performance of operators using HMIs and provide a more traceable and defensible design basis (Fiset, 2001, 2004).

As a practical example of how Tagci could be used to specify the design of an HMI to help the human deal with the DF processes, let us consider the task of detecting a threat to an operating goal. As mentioned previously, Tagci supports this task through the used of a functional model called a Goal Tree Success Tree (GTST) that corresponds to the functions or goals (Modarres and Cadman, 1986). The different goals are organised hierarchically, with the goals being at the top of the GTST and success paths leading to the achievement of those

goals being located at the bottom. This functional model accommodates both top-down (goal-oriented) and bottom-up (data-driven) information processing. As a result, it is a very powerful tool for dealing with normal and abnormal situations, whether the latter has been foreseen or not. For data fusion applications, the GTST could be used help the operator determine at which level the DF processes intervene, how the results relate to the goals that are being pursued, which type and amount of uncertainties are tolerable and which effect the processes and associated uncertainties have on the goal(s) being pursued, thus enhancing the operator's situation awareness.

Adaptation of Tagci to the ISTAR domain

As we have previously mentioned, Tagci was first developed in the process control domain. We believe that it can be adapted to the design of HMIs and DSSs for military applications such as ISTAR. One of the adaptations required has to do with Tagci's generic tasks. Although some existing generic tasks can be relevant across domains, some of them may not be relevant in other domains. Further, additional generic tasks may need to be defined for the new domain. That is why we plan to carefully evaluate if the existing generic tasks are sufficient and relevant for this military application; where refinements will be warranted, adaptations, deletions or even additions will be made so as to obtain a set of generic tasks well suited to ISTAR.

ISTAR can be considered a part of the larger domain of military command and control (C2). "The role of ISTAR is to integrate the intelligence function with surveillance, target acquisition, reconnaissance and other information-generating assets in order to improve a commander's [situational awareness] SA, streamline decision-making processes and cue manoeuvre, strike and/or other ISTAR assets" (National Defence of Canada, 2001). The All-Source Cell (ASC) is the fusion center of ISTAR and it forms the nucleus of operations with the ISTAR Coordination Center within a brigade headquarters. Therefore, the set of generic cognitive tasks that we will identify and define for the adaptation of Tagci to the ISTAR domain, are the tasks that ASC operators need to perform in order to achieve their goals.

Since generic tasks possess logical and temporal constraints (Fiset, 2004), they will be organised hierarchically in a generic architecture similar to the one found in the original version of Tagci (Fiset, 2001). Plans such as the ones found in hierarchical task analysis (HTA) will be used to specify the organisation of the tasks (for more details on HTA see Shepherd, 2001). As in the initial development of Tagci, the required coupling between the operator's tasks and the domain will be achieved by identifying the information needed to support him and domain models that can provide this information. If existing Tagci's models prove suitable, they will be kept, otherwise, new types of models will be specified and integrated into the framework. Again, rules will be used to specify when to make these groups of information available.

As we have argued, Tagci is a powerful HMI design method. As all the other HMI design methods such as EID (Vicente and Rasmussen, 1992) or IMAC (Thurman, 1997), it does not provide detailed guidance for the selection of graphical object, mainly because this last step is very domain dependant. However, we believe that since the framework is already in place, Tagci could easily become an information presentation method as well as a design method for military applications such as ISTAR. In order for that to happen, we will do a pairing between the groups of information previously identified and HMI components. Once again that pairing will be based on rules that will allow HMI components that possess predetermined features (e.g. colors, fonts, etc.) often imposed by the military domain, to be assembled.

Conclusion

The information revolution that is actually taking place in the military domain results in the production of such important quantities of data, that human agents quickly become confronted to an information overload. Data fusion techniques are used to assist them in their decision making processes, but they also generate some problems in the field of DSS and HMI design. In this article we have explained two of these problems that particularly concern us: the appropriate level of intervention of the human operator within the fusion process and the selection and presentation of fused information in a HMI. Our solution to these problems rests on Tagci, a cognitive architecture for the design of HMIs. Tagci was developed in the process control domain (Fiset, 2001), but we aim at adapting it to the military domain of ISTAR. We also pursue the goal of making Tagci more complete so it becomes an information presentation method as well as a design method specific to the military domain of C2.

References

Bylander T. and Chandrasekaran B. 1987. *Generic tasks for knowlege-based reasoning : the « righ » level of abstraction for knowledge acquisition*. International Journal of Man-Machine Studies. (26), 231-243.

Fiset, J-Y. 2001. *Conception d'interfaces humains-machines pour la conduite de systèmes complexes.* Ph.D. Thesis, École Polytechnique de Montréal.

Fiset, J-Y. 2004. *Tagci: A Cognitive Architecture For Designing Interactive Human-Machine Systems*. Unpublished.

Modarres, M. and Cadman, T. 1986. A Method for Alarm system Analysis for Process Plants. Computers & Chemical Engineering, 10 (6), 557-565.

National Defence of Canada. 2001. Intelligence, Surveillance, Target Acquisition and Reconnaissance (ISTAR). B-Gl-352-001/FP-001.

Selcon, S.J. 1990. Decision support in the cockpit: Probably a good thing? Proceedings *of the Human Factors Society 34th Annual Meeting,* Santa Monica, CA: Human Factors Society, 46-50.

Shepherd, A. 2001. Hierarchical Task Analysis, London: Taylor & Francis.

Steinberg, A.N., Bowman, C.L. and White, F.E.. 1998. *Revisions to the JDL Data Fusion Model*, Proc. Third NATO/IRIS Conference, Québec City, Canada.

Thurman, 1997. The Interactive Monitoring and Control (IMaC) Design Methodology: Applications and empirical results. *Proceedings of the 1997 Annual meeting of the Human Factors and Ergonomics Society*, 289-293.

Vicente, K.J. et Raamussen, J. 1992. Ecological interface design : Theoretical foundations. *IEEE Transactions on Systems, Man and Cybernectics*, 22, 4, July/August, pp. 589-606.

White, F.E. Jr., 1987. *DF Lexicon*, Joint directors of Laboratories, Technical Panel for C3, DF Subpanel, Naval Ocean Systems Center, San Diego.