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# Information fusion in practice: A distributed cognition perspective on the active role of users

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ABSTRACT

Traditionally, the focus of most information fusion research has been on computational aspects, as illustrated by, for example, different versions of the JDL data fusion model. Consequently, the human user has mainly been conceived as a relatively passive recipient of fused information. However, the importance of understanding the active role of human information processing in information fusion is gaining increasing recognition, as also reflected in discussions of a "level 5" in the JDL model. This paper presents a case study of the interaction between human and machine information processing in a maritime surveillance control room. A detailed analysis of cognitive processes and information flows involved in identifying and tracking moving vessels illustrates how machines and human operators collaboratively perform fusion in a highly distributed fashion. The theoretical framework of distributed cognition provides an alternative or complementary way of analysing information fusion systems/processes that more clearly reveals the actual complexities of the interaction between human and machine information processing in practice.


## 1. Introduction: a passive or an active user?

Information fusion, or data fusion, aims to process multiple sets of data, gathered from multiple sources, in order to build a holistic view of the environment [1]. This representation of the environment should enable increased situation awareness and, ultimately, improved decision making. Based on an extensive review of models for information fusion and decision making, Hall et al. [1] conclude that (1) although it is recognised that decision making and situation awareness is both "components of a complete data fusion system" the ability to effectively represent such issues falls outside the traditional scope of the field, and (2) neither data fusion models nor decision making models cover the entire scope required by the situation assessment domain.

A first question arising from Hall et al.'s conclusions is whether or not it is desirable for the information fusion field to extend its traditional scope and include human situation awareness and decision making as objects of study. We agree with the observation of Hall et al. [1] that "decision making and situation awareness are components of a complete data fusion system" (p. 6). Without insight into the human situation awareness that is created and how it impacts decision making, it is impossible to define boundaries of the data fusion system in the design phase, and to monitor and manage its performance under operation. In terms of the JDL model there is a lack of necessary input for sensor management in terms of, e.g., mission objectives and mission constraints. Similarly, Blasch [2] argues that "[t]he user defines a fusion system, for without a user, there is no need to provide fusion of multi-sensory data" (p. 3). Situation awareness and decision making may not be the key issues in information fusion, but the relations between these concepts and core fusion processes need to be clarified. Thereby, information fusion systems designers and managers will be enabled to monitor validity issues (e.g., are we collecting and fusing relevant data and information?). Furthermore, incorporating the interdependencies with decision making and situation awareness in the models, answers the need to provide 'whole system solutions', where core fusion processes are embedded in and adapted to real-life situation awareness needs and decision making practices.

A deadlock in the ongoing discussion of how to link data fusion models and human decision making models to inform one and another, is how much of the information fusion community has conceived the human user and the interaction between humans and machines in fusion processes. Ever since Hall et al. [3] as well as Blasch and Plano [4] independently introduced human–computer interaction issues to be included in a so called level 5 extension of the JDL model, there has been an ongoing debate on whether or not, and how, user related issues need to be incorporated. Several authors [1,2,5] have stressed that this debate has not reached a final conclusion. A recurring issue in this debate is whether the user is a *passive* receiver of a situation picture, automatically generated by fusion technology (*Fusion Automation*), or whether the user is an *active* participant in the fusion process who, in collaboration with the fusion technology, generates and assesses a

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situation picture (*User-Fusion*) [2]. Consider the differences between the two examples in Fig. 1, they are drawn from the application area of target tracking and object identification in maritime surveillance, which will serve as an illustrative case in the empirical part of this article.

The first example illustrates the dominant traditional view in information fusion. The so called MSDF system generates tracks and identities which are used as input for a human decision making process. Human–computer interaction issues are framed as a problem of interface between the technology and the receiving user, involving issues like information presentation (menus, displays), transaction management (how do user and technology interact) and cognitive aids (tools to correct for human cognitive biases), as discussed by Hall et al. [3]. Based on the second example, we propose that, as we have argued in more detail elsewhere [7], in many cases, the information fusion process extends beyond the boundary of the actual technology itself (e.g., beyond mathematical computation of radar data to determine position) to include manual functions performed by humans. Throughout this article we will argue that existing models and methods commonly applied in information fusion do not acknowledge such an active contribution of users in the fusion process, or describe it in an abstract or mechanical way.

The theoretical framework of *distributed cognition* [8] is a relatively new approach in cognitive science and human–computer interaction that can be used to analyse the interaction between technology and human users from a different and broader perspective [9]. Distributed cognition can provide an alternative explanatory frame to the origin of interaction because it views cognitive processes as distributed and embedded in the environment. It can thus serve the information fusion community by a more profound insight in user needs and scenarios as well as a deeper understanding of how users actually utilise fusion technology. That in turn could eventually result in information fusion technology that is better integrated and utilised in fusion and decision making processes where machines and humans complement each other.

The study described in this article discusses human-technology interaction (i.e., User Fusion in Fig. 1) in the case of target tracking and vessel identification in maritime surveillance on an abstract as well as a very detailed level. The theoretical framework of distributed cognition [8] is used here to describe at an abstract level how human users and technology collaboratively perform fusion, and to describe in detail the propagation of information and its transformations through the system (thus, empirically verifying our previous theoretical arguments regarding the usefulness of a distributed cognition perspective in an information fusion context, see [7]). It is highlighted that sometimes machine processes mediate a transformation and that sometimes humans mediate a transformation. As such, the study empirically shows how the theoretical framework of distributed cognition can characterise the interaction between humans and technology, and thereby, provide the means to extend current information fusion design practices and theoretical models (cf. [7]).

The article is organised as follows: Section 2 provides a theoretical background by discussing in more detail how existing models and methods of information fusion portray the role of the user and what their limitations are. Then in Section 3, as an answer to the limitations of current methods, the theoretical framework of distributed cognition is introduced as an alternative or complementary means to model human–computer interaction. Section 4 presents the research design and Section 5 describes the case study results. Finally, the findings and their implications for information fusion research and practice are discussed and summarised in Sections 6 and 7.

## 2. The role of the user in current information fusion models and methods

The discussion of data or information fusion models presented here is not aimed to give an extensive overview of all aspects of all existing models and methods. Models and methods commonly used in the field of information fusion have been selected by

**FUSION-AUTOMATION: the user as passive receiver**

"The crew is bombarded with sensor and information from communication links that must be correlated, fused and interpreted in order to arrive at some understanding of the tactical situation. Automation of the data fusion process has emerged as a possible option to assist the operators in coping with the ever-increasing flow and complexity of information, in their task of compiling the tactical picture. A multi-source data fusion (MSDF) system processes the data reported by multiple sources to derive the best estimates of the kinematics properties for each perceived entity in the environment, and to infer the identity and key attributes of these entities" [6]

**USER-FUSION: the user as active participant**

In target tracking in the maritime surveillance fused information from different radars is utilised in order to identify objects positions to be tracked. In the studied setting, not only did the users (the operators) have to identify the radar readings as an object which initiates the target tracker, but also to associate the target tracker with the correct object when the target tracker lost the object to be followed. This is only one example of the way users work in cooperation with the technology in order to achieve their goals [this study].

**Fig. 1.** Illustrative examples contrasting the concepts of "Fusion-automation" and "User-Fusion". (see above-mentioned reference for further information.)