High-Level Information Fusion Situational Developments

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High-level information fusion (HLIF) was coined in the 1990s following the original Joint Directors of Laboratories (JDL) working group model [1] and updated by the same working group in 2004 as the Data Fusion Information Group/JDL model [2]. One key discussion in the 1990s was the debate about awareness and assessment. *Awareness,* such as from Boyd's control loop [3] and popularized by Endsley et al. [4], is a humancentric concept. *Assessment* was the machine counterpart to awareness that includes the developments from sensing that afforded that ability to collect and analyze data. Figure 1 showcases the alignment of awareness and assessment between low-level information fusion (LLIF) and HLIF.

While the information fusion (IF) community focused on the LLIF of data preprocessing (level 0) and object filtering, estimation, and prediction (level 1), a sensor data fusion system product requires HLIF constructs of situation (level 2) and impact (level 3) assessment, along with sensor (level 4), user (level 5), and mission (level 6) refinement. Hence, systems compose the duality of fusion (machine assessment) and control (human refinement). It is noted here that the control of sensor and information in level 4 process refinement is designed by humans to control data processing.

HLIF CHALLENGES

HLIF has design challenges of (1) assessment, (2) design, and (3) cognition. Notions of situation and impact assessment are overlapping with "awareness". Awareness is rooted in human perceptions of the world; hence, the aggregation of LLIF information from a system is a *producer* that provides data to situation assessment for situation awareness. Similarly, level 3 threat or impact assessment is a function of the needs by a *consumer* of the sensor data fusion *design*.

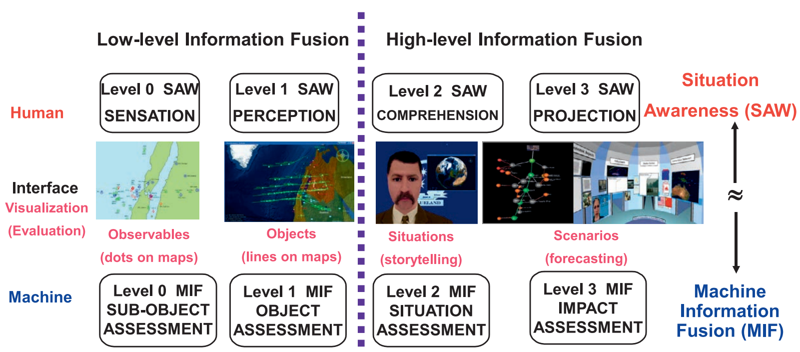

Figure 1
Awareness versus assessment.

The second area of HLIF is sensor, user, and mission (SUM) *refinement*. Since the IF system is a function of the product (e.g., architecture design, human user, and business operations), management of the information is conducted by refining the needs, such as sensor pointing, user satisfaction, and mission achievement. Essentially, HLIF allows stakeholders to tailor the system performance by exploiting the information they desire [5].

The term *cognition* is used often to seek elements of awareness that include reasoning, imagination, and understanding. Cognition is also a recent construct in machine intelligence (e.g., cognitive radar), from which the machine is aware of its own processes through self-assessment. Hence, data fusion system design requires physics-based and human-derived information fusion (PHIF) in translating machine sensor data results to human cognitive semantic meaning [6].

As from the HLIF taxonomy, issues of SUM management are more prescribed than those of situation and impact assessment. The assessment function can be that of the "situation", driven by context from data (assessment) and knowledge (awareness) [7].

HLIF DEVELOPMENTS

Over the last 25 years, even though it is well discussed in conceptual theory, there is no answer or solution to situation assessment. From the many papers referenced in published reviews [2], HLIF discussions emphasized the need for situation analysis, evaluation metrics, and realizable architectures [8]. One problem is that *scale* of the situation also depends on the SUM perspective on whether it is from the sensor (machines), user (organizations), or mission (purpose). As much as spatial, temporal, and spectrum scales, the same exists for HLIF. A PHIF system design as a user-defined operating picture (UDOP) is not the same as a mission common operating picture (COP). For example, the UDOP for the pilot must interface with the COP for an air traffic controller.

A key representation of the discussion through the 2000s was utilizing the advances in text analytics toward semantic meaning. Evaluations sought ways to measure a "situation". An example was that of hard (physics-based sensing) and soft (human-derived) *semantic constructs* [9] for UDOP surveillance systems, helping the user control sensing and supporting a narrative output.

The 2010s ushered in artificial intelligence (AI) as machine and deep learning (DL). The explosion of DL was applied to all forms of LLIF while discussions began toward using DL for situation, user, and mission analysis.

Since data-driven learning methods do not reason, there is still considerable need for HLIF research, especially for machine-supported situational assessment. With ever-increasing computing power to support HLIF, the current themes are in *multidomain operations*. Multidomain refers to data collection and application (space, air, ground, subsea, cyber, etc.). Currently, there are many multidomain paradigms for cloud, fog, and edge computing for IF. Hence, the recent decade focused on situation assessments such as from PHIF semantic cognition (reasoning), data utilization (context), and domain prediction (control).

APPLICATIONS

The design, development, and deployment of IF systems require many stakeholders coordinating the governance (policies), people (users), acquisition (buyers), and design (developers). Three examples include (1) surveillance, (2) logistic, and (3) infrastructure systems, all of which include various data, sensors, and IF. Most commonly discussed at the International Conference on Information Fusion are *surveillance systems* for ground-space management, such as underwater, battlefield, air, and space awareness.

HLIF for *logistics* includes the medical, aviation, and information communities. For example, the medical community includes patient care (diagnosis) and drug delivery (prognosis) from which LLIF data processing and analysis feed human–machine control of parts and supplies.

The *infrastructure* is critical for all systems, such as supporting the energy and supply grid. Utilizing LLIF signal processing, HLIF supports users of plant operations and maintenance engineers of components determined for failure and repair to enhance performance, safety, and security.

Operating pictures (Traffic management)—The development of a global positioning system (GPS) for ground systems (adopted in 1990), automatic identification system (AIS) for shipping (adopted in 2000), and automatic dependent surveillance–broadcast for aviation (adopted in 2020) have accelerated the constructs of HLIF SUM for traffic management, wit h future versions for space traffic management. Because the position, navigation, and timing data project the platform location, registration of many sensors affords the ability to sense (e.g., a camera on an unmanned aerial vehicle), use (e.g., displays), and task (e.g., route) systems for safety purposes. Hence, many COPs/UDOPs have been designed for space, air, ground (e.g., autonomous car displays), and maritime domain awareness through HLIF assessment.

Distributed human-machine teaming (Medical)—To acknowledge where HLIF added to decision speed for society improvement, the coronavirus disease 2019 pandemic provides a good use case. The many distributed researchers shared multimodal data, measurements, polices, and results.

LLIF data fusion (e.g., temperature and face detection) tools monitored the number of people complying with various polices to support government, commercial, and individual users through displays and apps. The detection and subsequent classification (who was wearing a mask) were correlated with the outbreak and spread. Diagnostic systems reported on the level of severity of individuals, with a widely available "heat map" of outbreaks to assess the "situation" and provide "awareness". At the same time, the introduction of vaccines required the distribution of these products to meet the mission need to get as many people vaccinated as possible. The medical community used these tools to aid the surge of where to place medical professionals, which policies to adopt, etc., which provided HLIF SUM refinements as to opportunistic placement of people, supplies, and polices to reduce the spread.

As a way forward, challenges of situation assessment for situation awareness still require IF researchers to characterize the "situation" uncertainty, determine the certification of systems, and support societal stakeholder needs [10].

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