Combining Multi-Sensor Fusion and Information Fusion for Increased Situation Awareness: A Research Plan

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***Abstract*—In future military operations, the need for interaction between commanders and technical systems at different levels will probably increase due to the changing environment, threats and tactics involved. Since all data/information cannot flow freely in the network for practical and confidentiality reasons, new fusion methods that can handle this situation have to be developed. In this concept paper, we discuss some of the aspects that have to be considered in order to solve this problem.**

***Index Terms*—Combining high- and low-level fusion, Information system for commanders at different levels**

I. Introduction

Warfare is forever evolving. To meet the new demands set by the kind of operations that European forces are performing today, we need new technologies, new methods and new processes. The new types of missions and new surroundings where the missions are performed requires new, more advanced sensors and corresponding advances in the information systems that are used to control them.

Wireless sensor networks give us new possibilities to collect information. We can distribute large numbers of sensors that collaborate and give us access to vast amounts of information. The information collected by the networks can be combined with background intelligence reports and even with open source intelligence. One consequence of this is that the decision support systems will need to be able to handle larger amounts of information. It must also be possible for decision-makers and soldiers at lower levels of command than previously to access this information. Since they act on much smaller time-scales than, for example, analysts and commanders in a Brigade staff, the information systems used for decision support need to change in order to support them.

Since, e.g., platoon commanders, have much less time to spend looking at a computer, the decision support systems at this level need to be better at filtering the information displayed to fit the needs of the user. The threshold where information overflow occurs is lower at lower levels of commands. This needs to be taken account of in the information system. It is also more important to have real-time processing of information at lower levels than at higher. This requires a new architecture for information processing and also new methods for quickly finding relevant intelligence information and fusing it with the sensor information.

For example, information from a sensor network about an approaching vehicle could be combined with background knowledge that this type of vehicle is often used in suicide-bombings, leading to an alert to the platoon commander. If it was also possible to quickly fuse this with real-time open source information about the organisation that is behind the suicide-attack, the situation awareness of the platoon commander would be further increased. It has not yet been demonstrated that this type of fusion is really possible. While it is important to focus on lower levels of command, high levels cannot be ignored: the architecture and information system developed also needs to support their demands. Returning to the simple example, at higher levels it is necessary to fuse the information about the impending suicide-attack with both information from other sensor networks and information from e.g., political sources to get a situation picture. By mapping such user demands on decision support systems for wireless sensor networks and finding out what is technically possible to achieve, we can improve the sense-making capabilities of human decision-makers.

The sensor networks must manage sensors of heterogeneous types that at all times can be modified in operational mode (position, parameters, etc). A deployed sensor network should initially start working in an autonomous default mode. For example, the sensor network may be able to identify, recognize and track vehicles in the vicinity of the area to be protected. These areas can be of several types, e.g. hospitals, camps or dwellings of people that need protection. However, as the requirements change, the sensors should adapt to the new situation. This will be part of the decision support capabilities and thus determined by users/decision makers. The network must include components for resource sharing but also for information sharing and thus tasking of sensors will be made effective and efficient.

By integrating information from sensors with intelligence analyses and other background knowledge, it will be possible to provide low-level decision-makers with an improved situation picture. This will be particularly important in urban

settings, where it can be expected that sensor networks by themselves will give raise to a large number of false alarms. By fusing the information from the sensors with background knowledge or information gained from open sources, it will be possible to reduce the number of alarms that will need to be evaluated by humans.

II. Aspects for Low Level Fusion

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Combining sensor data with intelligence data can lead to significant increases in situation awareness also at low levels of command. For example, information from a sensor network about an approaching vehicle could be combined with background knowledge that this type of vehicle is often used in suicide-bombings, leading to an alert to the platoon commander. If it was also possible to quickly fuse this with real-time open source information about the organisation that is behind the suicide-attack, the situation awareness of the platoon commander would be further increased. It has not yet been demonstrated that this type of fusion is really possible. While it is important to focus on lower levels of command, high levels cannot be ignored: the architecture and information system developed also needs to support their demands. Returning to the simple example, at higher levels it is necessary to fuse the information about the impending suicide-attack with both information from other sensor networks and information from e.g., political sources to get a situation picture. By mapping such user demands on decision support systems for wireless sensor networks and finding out what is technically possible to achieve, we can improve the sense-making capabilities of human decision-makers.

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Current sensor networks are not adequately able to autonomously (re) configure themselves, nor are they able to analyse and deliver reliable decision support from data of varying quality. They must also allow for the (current) lack of a common time-base and deliver decision support of known reliability. Furthermore, sensor networks are often designed for a many to one data flow where all the data from the sensor network is transmitted to a single sink from where it is forwarded to a data store from where the clients can access the data. In the context described above such an approach will not work since the clients will access data directly from the network. This means that novel approaches must be developed in order to meet the different users' information demand:

- Data acquisition and signal processing:
    - The signal processing has to be performed locally to a great extent, and methods for autonomous optimisation of where and how the processing should be done have to be developed
    - In some cases, data will have to be interpolated or extrapolated in order to compensate for data loss due to sensor or network malfunctioning
- Distributed and/or decentralised data fusion
    - Autonomous data fusion methods (e.g.

classification and tracking) that utilise the fact that the sensors are distributed must be developed. In order to do this, autonomous methods for data association must be developed, and distributed consensus and decision strategies must be considered (for example, reviewing average consensus, belief propagation and self-synchronisation techniques). Different architectures can be used, e.g. distributed, hierarchical, or combinations thereof

- Communication networking protocols
    - Wireless Sensor Network (WSN) networking protocols suitable for use in the planned application must be developed (aspects like self-discovery and self-configuration are of particular relevance)
- Distributed data storage
    - Distributed data storage methods (data bases) suitable for the target application must be developed. The methods must support both the real-time demands (fast access) of the user in the field, and the data mining methods required by the user in the command centre

III. ASPECTS FOR HIGH LEVEL FUSION

Current decision support and situation awareness systems do not perform well in fusing pre-known intelligence or context data with sensor data. Some specialist information systems exist that are focused on intelligence and the semantic relationships between the different components of an intelligence picture, e.g. in order to tackle organised crime. These systems could possibly be extended to incorporate the data from the sensor networks and thus advance the current capabilities for integrating sensor and context data.

A key element in presenting an accurate situational picture is to perform all of the information processing in real-time, presenting information with minimum latencies and providing operators with a representation of the warfare environment as it is occurring. Related to this, time horizons are very important for decision making. A piece of fused data presented to the operator will only be relevant to a situational picture for a certain time horizon, beyond which it becomes irrelevant. To achieve both of these elements, novel approaches to both manipulating (through algorithms and a well designed System Architecture) and representing the time factor (through the latest visualisation techniques) have to be developed.

Today there exist a wide variety of different data mining algorithms that can be used to detect interesting patterns and deviations from normalcy (anomalies) in data. Of particular interest are matrix-based methods and stream-processing methods. Both of these areas will need to be further developed. An interesting data mining technique today is to use latent semantic analysis (originally from natural language processing) and topic models (latent Dirichlet allocation) to find explanations of observations and connections between observations. One challenge is to extend these methods to handle heterogeneous data from a variety of sources, including both sensor and text-based information.

Current use of data mining on sensor network data is mostly done off-line and at a low level of decision-making. Data mining of other kinds of data is often used at higher-levels of decision-making. To solve the applications above, we must bridge the gap between these two uses of data mining. Visualisation of the data mining results will also need to be addressed. Different levels of command will require different visualisations.

Current research on intelligent user interfaces provides methods to tailor the information presentation to the momentary context-of-use. In a similar way, methods are being developed to attune the allocation of tasks, the provision of cognitive support and the presentation of information to the momentary operator capacities. Integrated user interfaces can help to overcome the cognitive limitations of operators (e.g., cognitive biases) that are partly caused by dynamic situational conditions. Another very important issue is the display and manipulation of uncertain information. There are a number of different methodologies for managing uncertainty, and more research is needed on how to construct computer systems that enables humans to understand and interact with these uncertainty structures.

Research on Computer-Supported Cooperative Work has provided diverse solutions for “collaboration at a distance”, among other things to construct and maintain shared situation awareness. Questions remain on (1) how to adequately deal with different abstraction levels in the decision-making processes, and (2) how to support the maintenance of an adequate trust level in these processes, both for the technological and colleagues’ information processing capacities. User interfaces must be developed to provide solutions for these two questions by supplying information access at different abstraction levels and supporting the assessment of information on aspects of ambiguity, topicality, noise and reliability. Mixed-initiative dialogue information can be added, annotated and consulted to improve the shared situation awareness.

Finally, tools are needed to support operators and commanders in collaborative decision making. Distributed collaboration yields challenges not present in co-located teams, i.e., less frequent communication, non-verbal communication is not possible; communication often takes place in a formal setting, while informal communication has proven to be important for sharing and synchronizing ideas and developing common ground. We therefore have to involve aspects such as:

- Information management. Prevent information overload problems, filter irrelevant details
- Team situational awareness. Team member must

have a common understanding of the environment

- Team awareness and shared intent. Know each other's tasks, capabilities and workload. Synchronise each other's goals and give guidance to decisions that must be made

IV. Combination of Different Levels

In Fig. 1, fusion processes at different levels are described. The levels are introduced here only to make a distinction between the different needs and methods of different people and different sub-systems, they have no direct connection to levels used in other contexts such as command- or JDL levels. In reality there may be more levels involved, but the figure shows the principle rather than an exact architecture.

The first level shows a field operator, who has the task to perform reconnaissance in an urban environment. The operator often looks for indicators such as slogans written as graffiti on the walls, politicians visiting religious leaders, etc. If we assume that a sensor network is placed in the vicinity, the operator can tag certain objects such as a person or a car and give the task to the sensor network to track the object and gather as much information as possible. Accordingly, the sensor network may discover interesting objects and ask the operator for refinement of the information (e.g. improved classification) or alert the user when a possible indicator has been discovered. The network may thus learn also from these events. One big challenge at this level is the association problem, ie, how to be sure that the sensor network and the human refer to the same object.

The second level shows how information from several field operators, sensor networks etc. are combined to form a situational picture for the national level. As indicated above several intermediate levels may exist. The situational picture is combined with intelligence information and is processed by intelligence analysts. One of the many difficulties that arise when including sensor data in this level is that the tagging of information sources may be impractical when several fusion steps have been performed. This means that the same data may be re-used many times, and thus given too much importance (also known as data incest).

The third level in the picture shows how the national situational picture is fused with that of different coalition partners. From a fusion point of view, it would be advantageous to fuse data/information at all levels, but this is still not feasible for political reasons. In this process, data incest is even more of a problem since the data probably is exchanged at a rather high level.

V. Conclusion

In the future, the need for including data/information from other sources than what has traditionally been used will be increased. This means that technical systems supporting commanders at low levels, e.g. sensor networks, will benefit from using information from traditional high level information sources, such as intelligence reports regarding the threat level in the area. There will also a be bigger need for information exchange regarding the operation picture between different coalition partners, something that for political reasons is made at a rather high information level causing problems such as data incest.

There exist some methods to handle some of these problems, but this is also a field very much open for new research. We would like to challenge the participants into finding relevant research issues within this field, since we believe that there will be a large demand for this type of knowledge in the future.

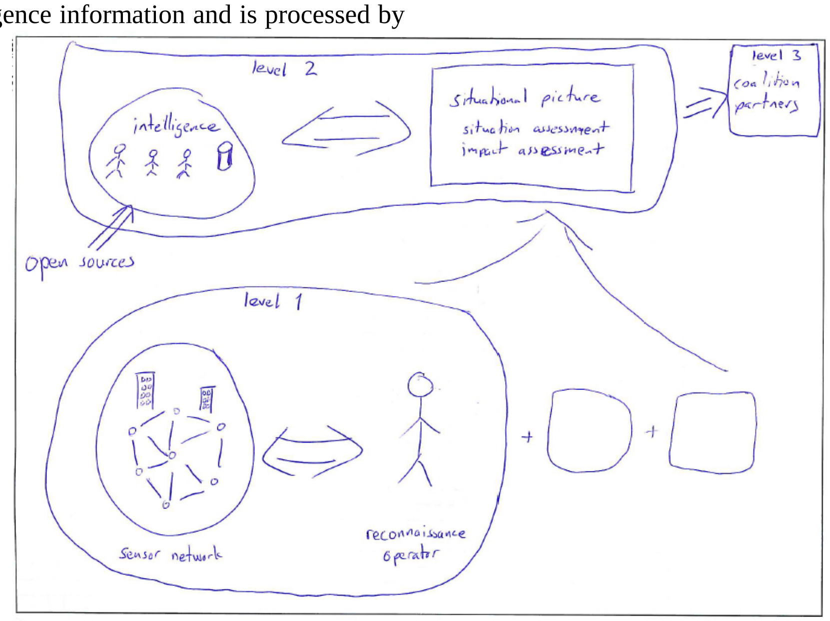

Fig. 1. Different levels of information that need to be combined to obtain a common operational picture in the field.