

This is a translation of an article in the periodical «Mikroskopet» of the Norwegian Defence Research Establishment published in February 2001. «Mikroskopet» appears 3-4 times a year and is basically for the employees but has an additional limited distribution in Norway.

The author gave a presentation with the same title in the forum “Study Group on Military Technology” at FFI (Norwegian Defence Research Establishment) in December 2000. The grand theme of the presentations that autumn was “Man and his role in our Defence”. Here are presented the same thoughts which also include critical views on Data Fusion. The author makes some predictions, and recommends continuous focus on sensor-oriented practical problems.

Data Fusion - for humans, computers or both ?

By Research Scientist Tore Smestad,
Division for Electronics



When FFI-projects in the seventies developed systems like MSI-70U¹, MSI80S², and NAVKIS³, and “fused” data from several sensors and information sources for target tracking, weapons control, and navigation, this was termed “sensor integration”. Methods and techniques within control theory and estimation theory were important at the time, especially Kalman filtering. During the more than twenty years having passed, military systems have solved more ambitious tasks and applied more types of sensors and information sources.

A beloved child with many names

“Sensor integration” has been

The definition of Data Fusion has developed over ten years

A process dealing with the association, correlation, and combination of data and information from single and multiple sources to achieve refined position and identity estimates, and complete and timely assessments of situations and threats, and their significance. The process is characterized by continuous refinements of its estimates and assessments, and the evaluation of the need for additional sources, or modification of the process itself, to achieve improved results.

(Data Fusion Lexicon, JDL Data Fusion Subgroup 1987)

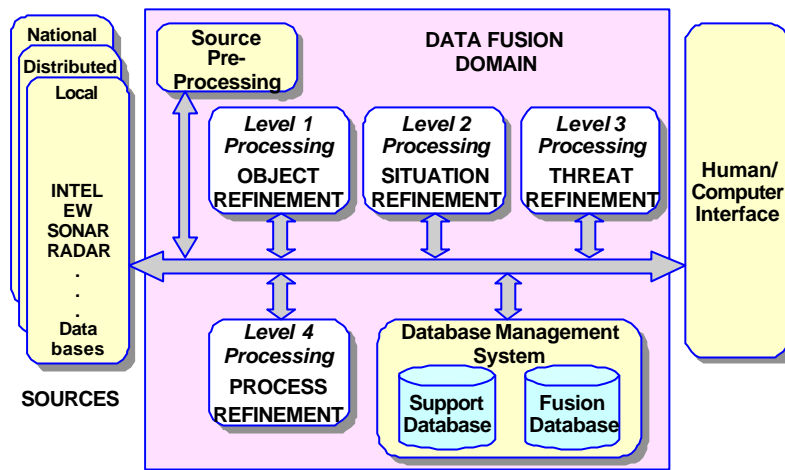
A process of combining data or information to estimate or predict entity states

(A N Steinberg, C L Bowman, F E White, 1998)

¹ Target tracking and torpedo guidance in the Kobben class submarines

² Target tracking, torpedo guidance, and Penguin control for the Hauk class missile torpedo vessels

³ Navigation-, command-, and weapons control system for the North Cape class coastguard vessels



(Fig. Alan Steinberg, 1999)

Figure 1 A dominating characterisation of functions in Data Fusion

The model was formulated by JDL in 1992. The levels 0 (source pre-processing) and 1 are now mature while the levels 2 and 3 will not be so for a long time. Level 4 pervade a system and involves feedback. Sensors and HCI are outside. The model is neither meant to tell about the system architecture, division of functions, where they are performed, the information flow between them, nor the sequence of actions. In principle everything is happening in parallel.

further developed and termed both “Sensor Fusion”, “Data Fusion”, and “Information Fusion” without a clear definition of the distinctions between them. I discuss Data Fusion according to the first definition on the “information sheet” and the characterisations made in Figure 1. Much as been added since the seventies: more general statistical methods, hypothesis testing, graph theory, data representation, resource management, artificial intelligence (AI), fuzzy logic, and neural networks, to mention examples from disciplines, methods, and techniques. Civil uses of methods in Data Fusion are found within robotics, medical diagnosis, earthquake prediction, satellite resource mapping, and traffic surveillance, which have influenced the definition, see the second one on the “information sheet”. The last

years have seen an enormous activity with several big international events per year. Experiences and further hopes that methods applied in one area may be used within an other, are important driving forces. Theories, methods, and techniques are otherwise so diverse that a unified field “Data Fusion” is hard to recognise. The “International Society of Information Fusion” (ISIF) arranged its first yearly conference in 1998, see more on www.inforfusion.org.

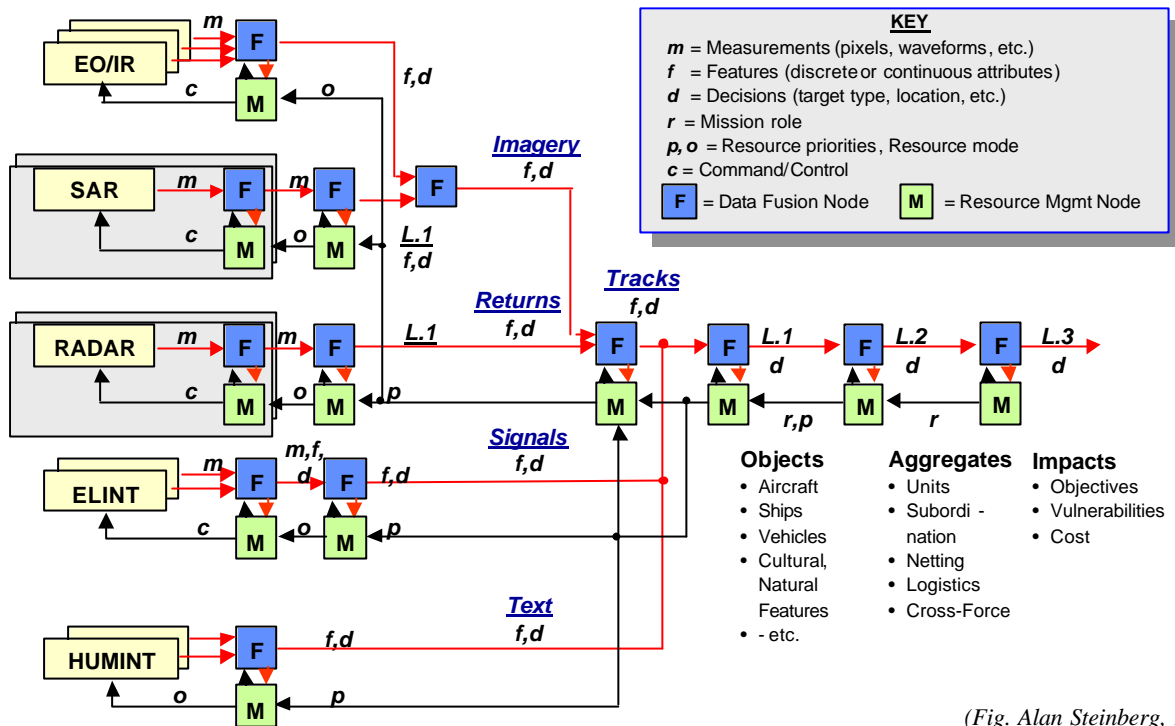
Data Fusion - an old “invention”

The term is only used in connection with computers, and is thus restricted to them. However, humans, and living organisms in general, have performed Data Fusion since the Dawn of Day. The five senses of

humans accept input in different physical formats and by an incredible process in these organs and the brain transform the inputs to a sensation of being in reality and having a much more complete picture of it than immediately available through the senses. Additionally, humans do planning and actions. Human activities like detective work, market analysis, military intelligence, and journalism may be characterised as advanced Data Fusion. Representatives from these areas have met with researchers in Data Fusion in the US for mutual inspiration. A participant from the latter reported a number of surprising similarities in approaches and ways of thinking.

Overwhelming diversity and complexity

Figure 2 shows an appropriate information flow structure when different types of information sources are to produce a situation picture in a military setting. Even if the different types of information sources here first fuse their own information, the structure is centralised since the tracks are established at one location. This is theoretically correct, but practical reasons may often favour local tracks for each sensor group or even at each sensor. Methods and algorithms in the different fusion nodes obviously become quite different and numerous. However, the applicable methods and techniques to use within each type of fusion node also turn out numerous. In the node for fusing the radars (Multi Radar Tracking) one could expect established and accepted solutions due to the well-known nature of this problem. So is not the case,



(Fig. Alan Steinberg, 1999)

Figure 2 Communication structure of an imagined Data Fusion system in a military setting

The labels L1, L2, and L3 mean the levels in the JDL model, see Figure 1. Nodes with “M” represent level 4 in the model. Note that data from similar sensors are first internally fused before fusion with other sensors. Restrictions on the communication bandwidth might give other solutions. Note the various data formats, and that text is involved.

approximately ten methods might still be appropriate, most of which include a Kalman Filter formulation. The choice depends on properties like sensor density, measurement accuracy, measurement rate, and on conditions like the amount of false detections, the target density, target manoeuvres, and on the available computing power and required time response. The choice of methods are more difficult in nodes where the problem is less understood. In new applications the choice might be quite open. A three days course in Data Fusion only allows a shallow treatment of the numerous methods, theories, and techniques that might be useful. Probability arguments appear quite central in most of these.

Something characterised - everything is not optional

The communication structure is essential both for the system properties and for the choice of fusion methods and algorithms. Rigid theory mainly exists for extraction of information upwards in a hierarchy. With today’s paradigm of Network Centric Warfare, one has to be aware that the information might flow uncontrolled if not guarded, possibly in loops (like the spread of rumours). When apparently new and independent information has the same origin, fusion results become skewed or wrong. In many cases the sensors and even more the communication structure are decided beforehand when a system with Data Fusion is constructed. There will be no

established knowledge and documentation of how the numerous possible composition of available methods in Data Fusion fit the specific characteristics of each case. An attempt for such a documentation was the “Data Fusion Engineering Guidelines” developed by the US Joint Directors of Laboratories (JDL). FFI researchers have asked for this material without success, even though the material is said to be unclassified.

A frame of reference for cost reduction

The vision of component based software and reuse was important when JDL started its work to make a common frame of reference in Data Fusion in the

middle of the eighties. In the seventies and eighties the US and other nations had developed a number of military systems applying Data Fusion. These became quite expensive, especially in terms of maintenance and updates. Cost reduction by reuse of components turned out impracticable as existing systems were not able to interact and were constructed from different functional architecture, different methods and use of concepts. Underlying construction principles and solutions were poorly documented. A result within this effort was the JDL Data Fusion Model, as shown in Figure 1. This “model” has been the dominating one in this area for almost a decennium. It should be regarded mainly as a characterisation of functions. Target tracking based on several sensors belongs to the levels 0 and 1, and is, despite ongoing research, an established area compared to level 2 and 3 (situation assessment and threat assessment). Methods from AI may have a role to play here. Data Fusion for military use should be seen in relation to command and control where the OODA-loop (Observe, Orient, Decide, Act) is involved. The JDL-model is criticised for several reasons. Attempts to harmonise the model with the OODA-loop are made.

Still a critical technology for the US?

In the nineties Data Fusion was regarded in the US as one among approximately 30 technologies that the country ought to keep fairly closed. The yearly “DoD

National Symposium on Sensor & Data Fusion” has been arranged for nearly a decennium. The first international conference arranged by the US in this area was held in 1997. The US seems less restrictive now, and there is a broad US participation in ISIF. In 1999 FFI got two informal visits of central persons from the early work in Sensor Fusion in the US; Jim Llinas visited in the spring and Alan Steinberg in the autumn (Figure 1 and 2 are based on material from Steinberg). Both visited FFI in their effort to create a broader international co-operation. The latter has recently worked for the establishment of a FUSIAC (“Fusion IAC”, IAC: Information Analysis Centre). If successful, this becomes the 15th IAC supporting the US military with top expertise in selected areas. FUSIAC might be open for international researchers also. See IAC-information on www.iac.dtic.mil.

Data Fusion only as good as the sources allow!

For ten years ago or so there was an overoptimism of what might be achieved by Data Fusion, somewhat similar to the overoptimism in AI ten years earlier. Several benefits were advertised like increased geographical coverage, increased temporal coverage (POI - Probability of Intercept), improved detection, improved dimension/spectral coverage, reduced ambiguity, improved accuracy, improved confidence, improved robustness, improved reliability, and reduced operator workload. However, a closer look reveals that most of the benefits might as well be assigned to the

availability of more sensors and complementary information, rather than to Data Fusion itself. Data Fusion cannot supply information that is not already there, but has a hard time extracting what is present theoretically. Target data from more than one sensor should be exploited, for example to obtain the position by intersecting bearings or by time difference of arrival of signals. In case of a lot of signals from the same area, the correct pairing of the signals might be quite difficult. Data Fusion is especially useful when complementary types of sensors detect the same object, especially for identification. This depends on a correct association of data, which is generally a hard problem. The control and management of sensors to get the proper information are also quite important, as indicated by Figure 2. One can not expect all measurements to be correctly sorted and treated to give their contribution to the result. One overheard comment at MIT in 1979 concerning the so called “force multiplier” in command and control is also valid for Data Fusion also: “Remember, the value of the force multiplier is always less than one”!

Advanced Data Fusion only a niche product?

Good algorithms in Data Fusion cannot compensate for lacking and poor data. Accurate and proper data makes Data Fusion in principle needless. In NAVKIS a number of navigation aids were used. These had complementary properties in terms of type of information, accuracy, availability in time, long and



Figure 3 Data Fusion should better support the human

Further development is necessary before Data Fusion can produce a clear situation picture, including threat assessment for the military. The co-operation between humans and computers also has to improve. Good HCI and visualisation are here important.

short term stability, and robustness. The system was prepared for GPS¹ that became operational nearly ten years later, possessing almost all the beneficial properties itself. If GPS had been available from the start, the need for the programmed advanced fusion of the navigation sensors had not been there. Put to the point, one may claim that advanced Data Fusion lives in a relatively small niche between too poor and too good information sources. An investment in more and better sensors might turn out beneficial compared to more advanced fusion of the data.

Data Fusion victim of deceptions in war?

Fusion algorithms are often based on assumptions normally being true, but not easily verified. A target tracking algorithm may assume periods of targets non-maneuvring, the presence of a large force might be implied by the presence of a special radar

system, and an attack might be implied by the pattern of activities of deployed units. Especially in situation assessment and threat assessment (level 2 and 3) such deductions are used and are based on the doctrine of the adversary. However, deception is an important activity in war. This might influence the outcome of Data Fusion; one should be prepared for Data Fusion being outsmarted by creative adversaries. To make the Data Fusion helpful and trustworthy for a decision maker in his OODA-loop, the co-operation has to be good. The computer has to quickly analyse the often enormous data flow while the decision maker has to critically judge data, assumptions, and the reasoning of the system. Explicit representation of the computer knowledge and reasoning might allow for such a human re-examination, which is impossible for some solutions, neural networks being one of them.

Early prototypes and demonstrators gave mixed impressions

As far as I know, no operational system is available today having all the levels of Figure 1, but several countries have developed prototypes and demonstrators. Some examples I have heard of were not particularly successful, but the information is too uncertain to be referred. One well known example is the demonstrator that seven NATO countries agreed to develop in 1992; Norway did not participate. The demonstrator was meant to automatically put together an intelligence situation picture based on different sources in a land-scenario of the cold war (level 2). In October 1997 a trial was held in Italy to evaluate the demonstrator after miscellaneous delays and reduced ambitions. I have seen conclusions formulated in six points, five of which are relevant here. The two first claimed that the “automatic display” and the message classification had been quite useful and saved a lot of manual work, and that HCI (Human Computer Interaction) was the most important aspect of the system. Further, AI turned out to be an important tool for this application, but lacked sufficient operational insight. The flexibility for other scenarios was lacking, and the essential conclusions could not be expected drawn from a computer in this application. These conclusions underline the need for a better co-operation between the humans and computers here, see Figure 3.

¹ Global Position System - gives currently position and altitude better than 10 m and speed better than 1/4 m/s.

Here is appropriate to mention that FFI participated in the development of a demonstrator for decision support and planning for a maritime application under international co-operation (EUCLID) in the GRACE project in the years 1993 to 1998. Situation assessment and threat assessment (level 2 and 3) were involved, but were not viewed within the framework of Data Fusion. Methods and techniques from AI were used extensively, HCI was also important. The project was successful, see more on public.logica.com/~grace.

“Fusion” between Data Fusion and visualisation?

Visualisation is a means for improved HCI, also when massive geographically related data are involved, as often is the case in Data Fusion. Both areas use similar phrasing of the problem with today’s mixed and massive data flows (“information overload”). This and the points of the previous sections make me believe that a promising area of interplay might be found between the two, maybe a sort of “fusion”. NATO research groups on

visualisation have existed for approximately ten years. The current group is termed IST-021/RTG-007, “Multimedia Visualisation of Massive Military Datasets”. Visualisation here means something that happens in the mind of the viewer; software termed “engines” are meant to combine and present the available data by means of efficient screen presentations for this purpose. The boundary to Data Fusion seems somewhat unclear, but might be well-defined within a few years time, see more on www.vistg.net.

Data Fusion at FFI - let the past inspire the future!

FFI has been engaged in problem areas associated with Data Fusion far beyond the examples mentioned in the introduction. During the latter years FFI has sent researchers to international courses and conferences for learning from presentations. FFI made a first such contribution at the third international conference of ISIF in Paris in 2000. The presentation was titled “Fusion of Radar Tracks, Reports and Plans”. The authors Ole Martin Mevassvik and Arne Løkka

showed examples of identification and tracking of ship traffic along the Norwegian coast based on real data. They used a tool applying “constrained programming” previously used in the GRACE project.

The “information age” and the scarce personnel resources of the Norwegian Defence, make FFI’s involvement in Data Fusion a natural choice. FFI has put this topic on the long term activity list, and is prepared to support activities with own budget resources. The lack of knowledge of how to solve specific Data Fusion problems and the continuous and quick development of sensor technology and processing power, offer opportunities for smart solutions in specific areas for a long time to come. Previous successful FFI-projects applying new and advanced theory seem highly based on deep and practical insight in the data sources and the needs of the users. This looks as important factors to succeed in Data Fusion also. I therefore recommend that we continue to base theoretic effort on sensor-oriented and practical problems.