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DEFINITIONS AND TERMS OF REFERENCE IN DATA FUSION

L. Wald
Groupe Télédétection & Modélisation, Ecole des Mines de Paris, BP 207, 06904 Sophia Antipolis cedex, France,
lucien.wald@cenerg.cma.fr

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ABSTRACT

The concept of data fusion is easy to understand. However its exact meaning varies from one scientist to another. A working group, set up by the European Association of Remote Sensing Laboratories (EARSeL) and the French Society for Electricity and Electronics (SEE, French affiliate of the IEEE), devoted most of its efforts to establish a lexicon or terms of reference, which is presented in this communication. A new definition of the data fusion is proposed which better fits the remote sensing domain. Data fusion should be seen as a framework, not merely as a collection of tools and means. This definition emphasizes the concepts and the fundamentals in remote sensing. The establishment of a lexicon or terms of reference allows the scientific community to express the same ideas using the same words, and also to disseminate their knowledge towards the industry and 'customers' communities. Moreover it is a *sine qua non* condition to set up clearly the concept of data fusion and the associated formal framework. Such a framework is mandatory for a better understanding of data fusion fundamentals and of its properties. It allows a better description and formalization of the potentials of synergy between the remote sensing data, and accordingly, a better exploitation of these data. Finally the introduction of the concept of data fusion into the remote sensing domain should raise the awareness of our colleagues on the whole chain ranging from the sensor to the decision, including the management, assessment and control of the quality of the information. The problem of alignment of the information to be fused is very difficult to tackle. It is a pre-requisite to any fusion process and should be considered with great care.

1. THE NEED FOR CONCEPT AND TERMS OF REFERENCE

The concept of data fusion is easy to understand. However its exact meaning varies from one scientist to another. Several words have appeared, such as merging, combination, synergy, integration, ... All of them appeal more or less to the same concept but are however felt differently. Several times, the word « fusion » is used while « classification » would be more appropriate, given the contents of the publication. There is a need for terms of reference in the remote sensing community, which has been strongly expressed in several meetings. A working group, set up by the European Association of Remote Sensing Laboratories (EARSeL) and the French Society for Electricity and Electronics (SEE, French affiliate of the IEEE), devoted most of its efforts to establish a lexicon or terms of reference, which is presented in this article.

This is not the only attempt to set up definitions in data fusion. The remote sensing community should not establish terms which are also used elsewhere with different meanings. Therefore, whenever possible, definitions were adopted which are already widely used in the broad scientific community, especially that dealing with information. Examples of such terms are image, features, symbols, etc.

Several lexicons have been already set up which have been established in the framework of the Defence domain (e.g., US Department of Defence, 1991, DSTO, 1994). It was found that it is not easy to translate military terms in meaningful words for the scientific community dealing with Earth observation: this would imply a refinement of the military terms to expand their meaning, with a reference to the time-space scales. It was concluded that using an existing lexicon is not straightforward, and that a new one is required to tackle the specific needs of our community. However we should benefit from these previous works as much as possible, and, whenever possible, we should use the terms already adopted.

2. A DEFINITION OF DATA FUSION

Data fusion means a very wide domain and it is very difficult to provide a precise definition. This large domain cannot be simply defined by restricting it, for example, to specific wavelengths, or specific acquisition means, or specific applications. A fusion process may call upon so many different mathematical tools that it is also impossible to define fusion by these tools.

Several definitions can be found in the literature: Hall, Llinas (1997), Klein (1993), Li *et al.* (1993), Mangolini (1994), Pohl, Van Genderen (1998), US Department of Defence (1991). They have been discussed by Wald (1998c, 1999). It was felt that most of these definitions were focusing too much on methods though paying some attention to quality. As a whole, there is no reference to concept in these definitions while the need for a conceptual framework was clearly expressed by the scientists as well as practitioners.

It is often written that fusion takes place at three levels in data fusion: pixel, attribute and decision (Brandstätter and Sharov, 1998; Csathó and Schenk, 1998; Mangolini, 1994; Pohl and van Genderen, 1998). It presents two drawbacks. The word "pixel" is inappropriate here ; the pixel is only a support of information and has no more semantic significance than voxel or *n*-dimension cell. Measurements or observations or signal would be more appropriate. But even if “pixel” is corrected and though the authors understand very well data fusion, my own experience in teaching shows that such a categorization, also proposed by Klein (1993) or Hall, Llinas (1997) may be misleading and should be avoided. It may falsely imply that fusion processes do not deal simultaneously with these different levels. Usually, fusion of measurements results into attributes, and fusion of attributes into decisions, but it may be different. In Earth observation domain, one may use some features (attribute level) held in a geographical information system to help in classifying multispectral images (measurement level) provided by several sensors. In this particular case, some data are measurements of energy, and others may be symbols. Inputs of a fusion process can be any of the levels above-mentioned, in a mixed way, and outputs can be any of these levels. Consider the case of the ARSIS concept which increases the spatial resolution of a multispectral image given another image of a better resolution not necessarily acquired in the same spectral bands (Ranchin *et al.*, 1996, Ranchin, Wald, 1998). It intends to simulate what would be observed by a multispectral sensor having a better spatial resolution. Accordingly, it simulates measurements through a fusion process and inference models. The formalism of Houzelle, Giraudon (1994) is preferable. It allows all semantic levels (measurements, attributes, decisions) to be simultaneous inputs of a fusion process. Wald (1998a) presented several examples of this formalism applied to remote sensing.

A search for a more suitable definition was launched with the following principles. The definition for data fusion should not be restricted to data output from sensors (signal). It should neither be based on the semantic levels of the information. It should not be restricted to methods and techniques or architectures of systems, since we aim at setting up a conceptual framework for data fusion. Based upon the works of Buchroithner (1998) and Wald (1998b), the following definition was adopted in January 1998: « data fusion is a formal framework in which are expressed means and tools for the alliance of data originating from different sources. It aims at obtaining information of greater quality; the exact definition of ‘greater quality’ will depend upon the application ». (in French: la fusion de données constitue un cadre formel dans lequel s’expriment les moyens et techniques permettant l’alliance des données provenant de sources diverses. Elle vise à l’obtention d’information de plus grande qualité ; la définition exacte de « plus grande qualité » dépendra de l’application.)

This definition is clearly putting an emphasis on the framework and on the fundamentals in remote sensing underlying data fusion instead of on the tools and means themselves, as is done usually. The latter have obviously strong importance but they are only means not principles. A review of methods and tools can be found in Pohl, Van Genderen (1998), US Department of Defence (1991).

Secondly it is also putting an emphasis on the quality. This is certainly the aspect missing in most of the literature about data fusion, but one of the most delicate. Here quality has not a very specific meaning. It is a generic word denoting that the resulting information is more satisfactory for the « customer » when performing the fusion process than without it. For example, a better quality may be an increase in accuracy of a geophysical parameter or of a classification. It may also be related to the production of a more relevant information of increased utility, or to the robustness in operational procedures. Greater quality may also mean a better coverage of the area of interest, or a better use of financial or human resources allotted to a project.

In this definition, spectral channels of a same sensor are to be considered as different sources, as well as images taken at different instants. Hence, any processing of images acquired by the same sensor is relevant to the data fusion domain, such as classification of multispectral imagery, or computation of the NDVI (normalized difference vegetation index), or atmospheric correction of spectral bands using other bands of the same sensor. Any processing of time-series of data acquired by the same sensor or different sensors, is a fusion process.

3. OTHER DEFINITIONS

It then has been suggested to use the terms merging, combination in a much broader sense than fusion, with combination being even broader than merging. These two terms define any process that implies a mathematical operation performed on at least two sets of information. These definitions are intentionally loose and offer space for various interpretations. Merging or combination are not defined with an opposition to fusion. They are simply more general, also because we often need such terms to describe processes and methods in a general way, without entering details. Integration may play a similar role though it implicitly refers more to concatenation (*i.e.* increasing the state vector) than to the extraction of relevant information.

Another domain pertains to data fusion: data assimilation or optimal control. Data assimilation deals with the inclusion of measured data into numerical models for the forecasting or analysis of the behavior of a system. A well-known example of a mathematical technique used in data assimilation is the Kalman filtering. Data assimilation is daily used for weather forecasting.

Terms like measurements, attributes, rules or decisions, are often used in data fusion. These terms as well as others related to information are defined in the following. These definitions are those used in information science and have been found in several publications (Bijaoui, 1981, Kanal, Rosenfeld, 1981, Lillesand, Kiefer, 1994, Tou, Gonzalez, 1974).

Measurements are primarily the outputs of a sensor. It is also called signal, or image in the 2-D case. The elementary support of the measurement is a pixel in the case of an image, and is called a sample in the general case. By extension, measurement denotes the raw information. For example, a verbal report is a piece of raw information, and may be considered as a signal. In remote sensing, in the visible range, the measurements are digital numbers that can be converted into radiances once the calibration operations performed. If corrections for the sun angle are applied, one may get reflectances which are still considered as signal.

An object is defined by its properties, e.g., its color, its materials, its shapes, its neighborhood, etc. It can be a field, a building, the edge of a road, a cloud, an oceanic eddy, etc. For example, if a classification has been performed onto a multispectral image, the pixels belonging to the same class can be spatially aggregated. This results into a map of objects having a spatial extension of several pixels. By extension, the support of a signal (e.g., a pixel) may be considered as an object.

An attribute is a property of an object. Feature is equivalent to attribute. For example, the classification of a multispectral image allocates a class to each pixel; this class is an attribute of the pixel. The equivalent terms label, category or taxon are also used in classification. Another well-known example is the spatial context of a pixel, computed by local variance, or structure function or any spatial operator. This operation can be extended to time context in the case of time-series of measurements. Equivalent terms are local variability, local fluctuations, spatial or time texture, or pattern. By extension, any information extracted from an image (or mono-dimensional signal) is an attribute for the pixel or the object. The aggregation of measurements made for each of the elements of the object (for example, the pixels or samples constituting the object), such as the mean value, is an attribute. Some authors call mathematical attribute such attribute deriving from statistical operations on measurements.

The properties of an object constitute the state vector of this object. This state vector describes the object, preferably in an unique way. The state vector is also called feature vector, or attribute vector. The common property of the elements of the state vector is that they all describe the same object. If the object is a pixel (or a sample), the state vector may contain the measurements as well as the attributes extracted from the processing of the measurements.

Rules, like the syntax rules in language, define relationships between objects and their state vectors, and also between attributes of a same state vector. Rules may be state equations, or mathematical operations, or methods (that is a suite of operations, *i.e.* of elementary rules). They may be expressed in elaborated language. Known examples of such rules are those used in artificial intelligence and expert-systems. Decisions result from the application of rules on a set of rules, objects and state vectors.

4. THE PROPERTY OF ALIGNMENT

Several problems are to be solved prior to any process of fusion (see e.g., Castagnas 1995, Pau 1988). The information entering a fusion process should present several properties. They deal with either the selection of the representation space and the level of fusion, or with the processing to be applied onto the data.

A common co-ordinate system (e.g., geographical space and time) should be found in which the sources data can be represented. This is called alignment, or conditioning, or positional data fusion. For example, geocoding the images is part of the alignment problem. Then the images are superimposable and mathematical operations can be performed at each pixel.

The alignment problem is difficult and according to some authors (see e.g., Thomopoulos 1991; DSTO 1994), it differentiates data fusion from data concatenation. Data concatenation is accomplished easily and straightforward by juxtaposing all the data into the state vector, hence augmenting it. These data should be homogeneous. An example is given by a time-series of images from the geostationary satellite Meteosat. The raw data are processed by Eumetsat, and are spatially superimposable once delivered to the customer. In that case, at each pixel, one can define a state vector by the concatenation of all the observations made at this pixel in the period under concern.

Data fusion requires conversion of the data into a common co-ordinate frame before concatenation. Alignment should provide a general frame of referencing that can apply to homogeneous (commensurate) as well as heterogeneous (non-commensurate) data. This is a difficult problem, and there is no general theory. Even in the simple case of measurements of radiances, which are comensurate, it may still be not straightforward. Though having the same space reference, two sources may not refer to the same object (landscape). In the Meteosat case, the water vapour channel does not provide any information on the ground, while the visible and infrared channels do. Another example in oceanography is the fusion of observations of sea surface temperature, which are relevant to the very surface of the ocean, and of ocean colour, which are depth-integrated. Data to be fused need to be relevant to the objectives of fusion process. Then these data can be associated or concatenated into the state vector of the studied object (landscape).

This concept of alignment is extended to a wider reference space (representation space) which also includes standardisation of units, calibration of sensors and atmospheric corrections, etc., if necessary. The alignment problem calls upon physics, and is certainly the problem in data fusion which is the most relevant to the concerns of the remote sensing community.

5. CONCLUSION

A new definition of the data fusion has been proposed which better fits the remote sensing domain. Data fusion should be seen as a framework, not merely as a collection of tools and means. This definition emphasizes the concepts and the fundamentals in remote sensing. Several other terms are also proposed which for most of them are already widely used in the scientific community, especially that dealing with information.

The establishment of a lexicon or terms of reference allows the scientific community to express the same ideas using the same words, and also to disseminate their knowledge towards the industry and 'customers' communities. Moreover it is a *sine qua non* condition to set up clearly the concept of data fusion and the associated formal framework. Such a framework is mandatory for a better understanding of data fusion fundamentals and of its properties. It allows a better description, using similar terms clearly understood by everybody, of the potentials of synergy between the remote sensing data, and accordingly, a better exploitation of these data.

The problem of alignment of the information to be fused is very difficult to tackle. It is a pre-requisite to any fusion process and should be considered with great care. The remote sensing community may play a role in that domain since it has a great experience in both the physics involved, including sensors, and the mathematical operations of sampling.

Finally the introduction of the concept of data fusion into the remote sensing domain should raise the awareness of our colleagues on the whole chain ranging from the sensor to the decision, including the management, assessment and control of the quality of the information.

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