DATA FUSION, THE CORE TECHNOLOGY FOR FUTURE ON-BOARD DATA PROCESSING SYSTEM

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ABSTRACT:

Currently, more and more earth observation data have been acquired by many kinds of sensors on different platform, such as optic sensors, microwave sensors, infrared sensors, hyperspectral sensors, etc. Thanks to giant resource being required to store and transmit these tremendous data so that the cost is very large and the efficiency is low, investigators are compelled to process them on-board as possible as they can. So far, on-board data processing only settles on some simple preprocessing, such as correction, denoising, compensation, etc. Information extraction not only is the objective of earth observation, but can distill large amount data so that amount of data needing to be stored and transmitted is reduced greatly. Feature extraction, change detection, and object recognition executed on-board will provide us an efficient information extraction system for earth observation.

Data fusion technique has been widely used to process earth observation data on the ground, which can generate data with higher quality and extract better information from multisource or multitemporal data. Furthermore, data fusion can also be used to extract better information from these data on-board, simultaneously, the redundant data will be eliminated greatly so as to accelerate data processing and reduce data for storage and transmission. However, on-board data fusion processing will confront more difficulty, one of the most principal troubles is that on-board data processing system must be completely autonomous, which results in some procedures such as image registration, feature extraction, change detection, object recognition becoming more complicated, while they can be processed by help of manual operates despite being difficult on the ground. Of course, the tremendous advantage of data fusion for on-board data processing will promote investigators to remove the obstacles on the road to on-board data fusion-based information extraction.

1. CURRENT STATUS, TREND AND STRATEGIC DIRECTION OF ON-BOARD DATA PROCESSING

With the rapid development of information technology, the users' requirement to information is transform-ing from static state, un-real-time to dynamic state and real-time. The dynamic state and real-time information acquired by remote sensing technology has been used successfully in the area of urban planning, precision farming, vegetation coverage, ocean observation, disaster monitoring, etc. How to utilize the great amount data and the higher and higher resolution for the earth observation has been a focus to the users and investigators.

Currently, earth observation data are always processed after being transmitted to ground data processing center (GDPC), then, in GDPC, the data are de-noised, and corrected geometric and radiometric bias, and then accurate images can be acquired. After that, image classification, object category, target recognition, and decision generation are executed. Finally the processed result will be distributed to the entity units. For the sake of earth's curvature, sometimes the earth observation data and processed result are transmitted on the help of the ground delay station.

From foresaid procedure we can conclude that data processing and maintaining are very complicated because of the complex linking route, data type, and data format in the traditional earth observation data pro-cessing mode. Moreover, distribution of the processed data is also an intricate problem, sometimes the processed results need to be transmitted to the communicating satellite, and then distributed to the end users. Not only does the increase of number and depth of the linking route result in the increase of the complexity of data maintain-ing, but it reduces the reliability of the data processing system, and also increases the processing and transmit-ting time, going against real-time data processing and distribution. Furthermore, with rapid increase of the earth observation data quantity and image resolution, users are more and more eager to acquire information to detect objects' change, recognize target.

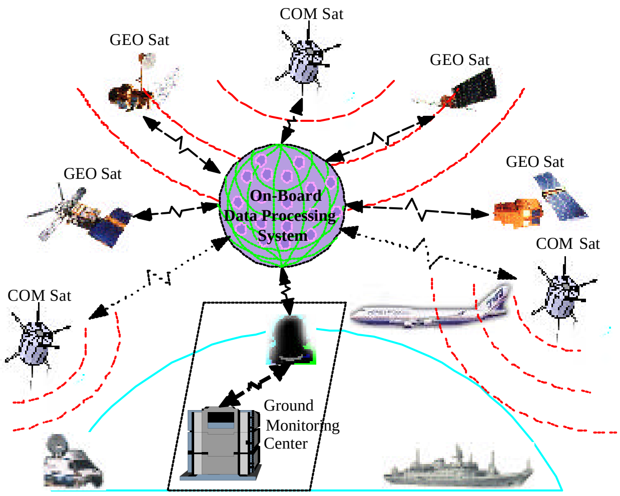

Figure 1 Future On-Board Data Processing-Distributing System of IEOS. Processed results by data processing system on each earth observation satellite are to be distributed to the end users (such as aircrafts, ships, vehicles, and so on) by communicating satellites. There is a bi-directional linking route between on-board data processing system and ground monitoring center.

Then, it is an exigent requirement to build spatial information net with on-board data processing system as its core, and Figure

1 exhibits an on-board data processing-distributing system. After acquiring data by earth observation system, at first, on-board data processing system will preprocess these raw data as de-noising, geometric and radiometric correction, registration, etc. In order to increase efficiency of on-board data processing to satisfy the real-time processing, simultaneously, in order to satisfy change detection and target classification and recognition, further object detection (here we think that "object" is different from "target", the former is an abstract concept including targets, areas, and so on; however, the later is an embodying object) and object segmentation are held on the preprocessed images. At first, ROI (Region of Interest) and OOI (Object of Interest) detection are executed, and then the region or object is segmented away from background. It is Obvious that the data quantity is reduced greatly by this procedure. After that, Features are extracted from the ROI or OOI, and these Features are extended to a new feature space by combining the same region or object's feature of multiplatform and multisensor, then feature-level fusion is held on the help of some auxiliary information according to the user task's requirement. Furthermore, the fused features are applied on object change detection and target recognition, and decision-level fusion is taken combining the auxiliary knowledge and expert system, then decision information is extracted from raw data and auxiliary knowledge. Finally the decision information is distributed to the end users by communicating satellite. Simultaneously, there is a bi-directional linking route between on-board data processing system and GMC (Ground Monitoring Center), and necessary processed data on-board are to be transmitted to GMC by the down-linking route. GMC monitors the on-board data processing procedure, and corrects the processed result once bias of the on-board processed result being out of permitted bound, the correcting information is transmitted to on-board data processing system by the up-linking route.

However, storage, transmission, and real-time processing of the great amount data on-board have been tremendous challenges to on-board data processing technology. Not only can data fusion technology extract higher quality information by adequately utilizing complementariness among multisource data, but eliminate their redundancy, therefore valid information can be extracted from great amount data by it at very rapid speed, and greatly reduce data quantity for processing, storage, and transmission and processing time, so data fusion technology is very propitious to on-board data processing. Despite data fusion is different from object detection, change detection, target classification and recognition, however, there are also so many sameness among them that they intercross to great extent, for instance, feature-level and decision-level fusion are often used to increase accuracy of object detection, change detection, target classification and recognition, nay, methods used by data fusion such as statistics theory, neural network, fuzzy logic, expert system are also widely applied on them. All of those show that data fusion technology has combined with object detection, change detection, target classification and recognition, so much as, some investigators partition image classification and change detection into data fusion category.

In order to process these tremendous data observed by on-board sensors, at the same time of exploring and applying novel technology, more and more complicated, intelligent and powerful data processing systems (Marchisio, 1999, http://research.hq.nasa.gov/code_y), including software and hardware, are developed to execute specific tasks. Nevertheless, increase of system complexity results in very rapid development cost increase, and longer and longer development period, accordingly, larger and larger risk. Therefore, besides possessing powerful and rapid capability for data processing, future on-board data processing system will dedicate to following objectives:

- Reduce development risk, cost, period of space-based system for information acquiring, processing and distributing;
- Adequately and validly utilize earth science data;
- Possess capability to take up new earth observation data, information product, and data processing modules;
- Have adequate security mechanism;
- Try to reduce system's mass and save satellite's payload; and
- Possess robustness to resist execrable environment such as disturbance, radiometry.

OES of NASA has proposed a series of programs (http://research.hq.nasa.gov/code_y), such as AIST (Advanced Information Systems Technology), IIP (Instrument Incubator Program), NMP (New Millennium Program), and so on, in which on-board data processing is an important sub-system.

2. REQUIREMENTS FOR ON-BOARD DATA PROCESSING

It will take tremendous time and system resource to directly process earth observation images pixel by pixel, which is obviously not advantageous to real-time processing on-board. In fact, users' task requirements generally focus on object detection, change detection, object classification, and target recognition, etc. However, there are many environment background data in observational data, so eliminating these data before further processing will save much time and resource so as to improve performance of on-board data processing system greatly, which is an important step to real-time processing. Figure 2 gives users' requirements and application execution flows.

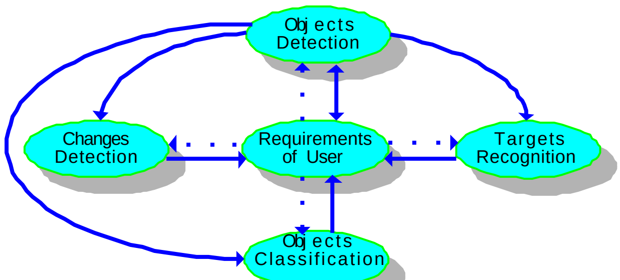

Figure 2 Users' requirements for earth observation. The dashed lines represent users' requirements flow, and the real lines exhibit execution flow.

This eliminating procedure is implemented by object detection, including ROI and OOI (In fact, this paper regards ROI as part of OOI). While detecting OOI, scale-space method will be very useful to accelerate the processing. For example, on the help of auxiliary information system can compute the top bound of scale not to filter object, and then executing OOI detection at this scale will be more efficient than at scale of original detailed image. After detecting OOI in images, they will be segmented and taken further processing.

With more and more requirement for change monitoring of climate, environment, ecosystem, precise agriculture, etc, space based multisensor data processing system for earth observation and change detection is widely used for the reason of their expansive coverage and some sensors all-weather capacity (Lunetta, 1999).

Currently two detection modes have been used to implement change detection, which are post- classification approach and pre-classification approach. The former mode classifies multitempotal images by thematic features at first, and then compare the classification result to acquire change results. This mode has been considered a reliable approach for change detection, so it is regarded as a normal technique to quantity evaluation for image difference. But, computation resulting in consumption of system resource, consistency, and false propagating are all constraints to it.

Pre-classification approach compares the change of multitemporal images at first, afterwards, the change features are to be classified, which includes composite analysis method using standard pattern recognition and spectral classification techniques, image differencing method comparing spectral value of multitemporal images directly and judge the change by threshold, principal components analysis method reducing redundancy so as to reduce features dimensions, change vector analysis method using the temporal trend of mean vectors to categorize object change, and spectral mixture analysis method decomposing and analyzing spectrums of multispectral images, etc.

Object classification is one principal objective of on-board data processing (Solaiman, 1999), which is used to classify objects in images by thematic rules, such as urban area, vegetation area, agriculture area, etc. Furthermore, with more and more on-board earth observation data being acquired, higher and higher image resolution, for example, ground resolution of either optical or SAR sensor for commerce having been in the range of 10m~1m, which provides the possibility to recognize embodying target, then target such as road, ship, harbor, aerodrome recognition, has been widely investigated and advanced to some extent.

Methods for object classification are generally classified supervised classification methods and unsupervised classification. The former define all kinds of objects in images as different numerical descriptors, which is implemented by analyzing specific training examples, and the later directly categorize objects into different clusters by object features. From which it can be concluded that the execution flow is contrary between these two kinds of methods, the former define class information at first, and then categorize objects into these classes; on the contrary, the later categorize objects into different clusters, afterwards, use other information to merge or delete these clusters, until no further action can be taken.

Conventional statistic based supervised classification methods always assume that spectral features of different objects can be described by probability distribution function in spectral feature space, as normal, normal or gaussian distribution. These methods include maximum likeness method, minimum distance method, parallelepiped method, context classification method, etc.

3. CHALLENGES OF ON-BOARD DATA PROCESSING

Two principal performance indexes, accuracy and false alert, are generally used to evaluate on-board data processing. Unfortunately, while detecting objects, detecting changes, classifying objects, or recognizing targets using single image by a specific method, accuracy and false alert are mutually exclusive, and either of them being improved will result in another being worse. Speed of data processing is also a great challenge for on-board data processing with Users requirement for real-time processing data. Figure 3 exhibits the challenges during on-board data processing, and data fusion technology can provide valid solutions.

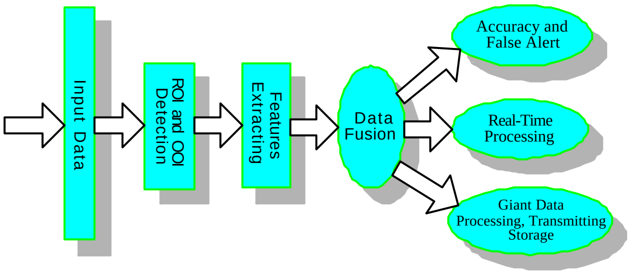

Figure 3 Challenges during on-board intelligent data processing, for which data fusion can provide valid solutions.

But then, multisource or multitemporal data fusion can solve these troubles commendably (Benediktsson, 1999; Gatepaille, 2000). Different sensors such as visible, infrared, microwave radar, multispectral, hyperspectral can capture different features of object (Myler, 2000), and extracting features from raw data can reduce processing data greatly, by which it is very advantageous to accelerate data processing and transmit data between satellites (Petrou, 1999). However, there must be any information lost during this procedure, which will descend the effect, so these features can be fused to improve both accuracy and false alert.

Principal objects of change detection are those in Multitemporal images. In fact, multitemporal data processing is also an important part of data fusion, which decides whether data fusion can highly integrate with change detection or not. In fact, in post-classification mode, data fusion technology can improve classification accuracy, which is obviously helpful to later change detection. Furthermore, while detecting changes, fusing features of changed object and enhancing feature information will make change detection more accurate, and can reduce false alert markedly. Moreover, in pre-classification method, using Raw Data-Level fusion to enhance images can provide higher quality information, and in later change classification, extracting changed objects' features and fusing them can also improve classification accuracy.

On higher and higher requirement for accuracy and intelligence of object classification and target recognition by users, knowledge based methods such as neural network and fuzzy logic methods are more and more used to classify objects and recognize targets for reason of many data not able to be accurately depicted by model or statistic theory.

Generally, traditional supervised classification and unsupervised classification methods are always used to process single image, so while image quality is high, execution procedure such as OOI extraction, segmentation, and feature extraction will be successful, (McConnell, 1999). However, while earth observation is executed all-weather, there will be many data whose quality is reduced, which will results in reducing accuracy and increasing false alert for object classification and target recognition, severely, classification and recognition can not be successful. Data fusion provide more ideal classification and recognition methods, that is, take raw data level fusion to multisensor or multitemporal images at first so as to enhance object features in images, and then extract OOI features form fused images, afterwards, execute feature level fusion to intensify object features and decision level fusion (Gee, 2000) combining external knowledge database and expert system, finally, these fused results are to be used to classify objects and recognize targets. Upon that, data fusion based classification and recognition methods are formed, which can improve effect of classification and recognition.

Currently, data fusion based classification and recognition methods are statistic methods, neural network methods, fuzzy logic methods, and so on. In fact, these methods are always combined to compensate defects each other. For example, neural network methods combining statistic methods can be applied on classifying objects or recognizing targets in data whose statistic information is completely known, from which we can acquire more accurate results than by single method, and in which neural network methods need to spend less training time for using part of statistic information.

4. DATA FUSION FRAMEWORK

As the core technology of future on-board data processing, data fusion is widely relative to many research areas. Basing on theories as digital signal processing, control theory, artificial intelligence, pattern recognition, and combining spectral analysis and reliability theory, simultaneously, utilizing many mathematic and statistic tools, data fusion is technology combining statistics analysis, wavelet analysis, neural network, fuzzy logic, expert system with many applications such as image processing, object detection, change detection and target recognition (Mahler, 2000).

After fusing many remote sensing data and analyzing the experimental result, L. Wald (Wald, 1999) gave the following definition to data fusion: data fusion is a formal framework that expresses the means and tools for the alliance of data originating from different sources; It aims at obtaining information of greater quality; the extract definition of “greater quality” will depend upon the application.

Above definition exhibits two main purposes of data fusion:

- Combine data information with higher quality;
- Refine data and eliminate redundancy.

Data fusion technology formed with the development of multisensor data processing methods, and applied widely on remote sensing image processing, robotic vision, industry procedure monitoring, medical image processing, etc (Jousselme, 2000). Specially, data fusion has been successfully applied on processing remote sensed data of Landsat series, SPOT series, ADEOS, SIR-C/L, ERS-1 and 2, JERS-1, Radarsat-1.

Generally, application analysis and design for data fusion are held at different levels, therefore, data fusion is divided into three levels, that is, raw data level fusion, feature level fusion, and decision level fusion. Data from multisensor always include any noise and distortion, which will take disadvantage to later processing, so preprocessing such as denoising, geometric correction, radiometric correction have to be executed. During procedure of every level data fusion, in order to increase accuracy, external knowledge is always utilized as auxiliary information, and extracted information during processing procedure can also be saved to the external knowledge database. Figure 4 gives a framework of data fusion.

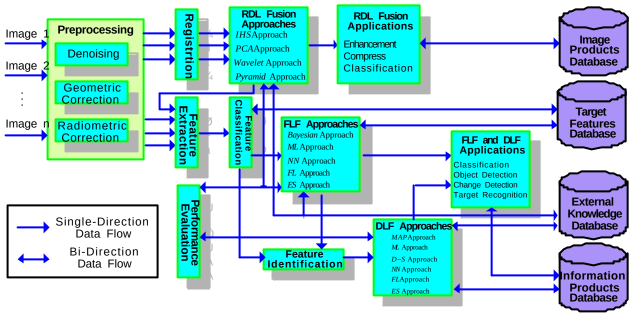

Figure 4 Framework design for three-level data fusion structure.

While images are input into the framework, they are preprocessed firstly, including denoising, geometric correction, radiometric correction, and so on. Then, raw data level fusion can be executed after multisource images being coregistered. Raw data level fusion is the most mature among the three levels fusion, and has formed rich and valid fusion methods, which are generally concluded following three types:

- Color transformation method, taking advantage of possibility of presenting data in different color channels, typical one of them is IHS method;
- Statistical and numerical method, utilizing arithmetic operators and others to combine images in different bands, such as PCA, PCS method; and
- Multiresolution analysis method, taking advantage of different scale to decompose, fuse, and restore multisource images.

Applications of raw data based level fusion are generally image enhancement, image classification and image compress, which can be advantageous to manually understand images, or provide better input images for feature level fusion. Processed result by these will form images product, and on-board data processing system will put them into images product database.

After extracting features from raw data, data fusion system will save them to object feature database, on the other hand, the features from multiplatform and multisensor will be fused to acquire higher quality attributes, whose quantity is also much less than before.

Feature extraction (Haralick, 1973; Pigeon, 2000) means that extract all kinds of characters of data and transfer them to another attributes which is advantageous to processing. These features form a feature space, then, investigators can fuse, identify, classify them to serve for object detection and target recognition. In general, features of earth observation data include:

- Geometric features, such as line, curve, edge, ridge, corner, etc;
- Structural features, for example, area, relative orientation;
- Statistic features, including number of object’s surfaces, perimeter of plane, and texture character; and
- Spectral features, such as color, spectral signature.

Feature level fusion methods include assumption and statistics based methods, and knowledge based methods. The former include Bayesian theory statistic method, D-S evidence method, correlation clustering correlation method, and so on; and the later comprises of neural network learning method (Zhang, 2000), fuzzy logic de-uncertainty method (Solaiman, 2000), expert knowledge intelligence method, etc.

Following further processing will be executed utilizing fused features:

- Save to objects' characters database;
- As the input information for feature identity;
- Apply on image classification, change detection, target detection and recognition.

Decision level fusion is the highest level among all levels data fusion, which is validated by that the fused result can be used to provide decision for mankind.

Decision level fusion methods are generally divided into identity based and knowledge based methods. The former takes advantage of assumption and probability to classify object, including MAP method, ML method, BC method, D-S method, and so on; the later utilizes logic template, syntax rule, and context to fuse data, comprising of expert knowledge method, Neural network method, fuzzy logic method, etc. The inherent principal of these methods is almost same as that of Feature-Level fusion methods', except for following difference:

- Object fused are not the same, that is, the object of Feature-Level fusion is characters space, while the decision fusion's is decision action space; and
- Extent of depending on supporting knowledge is different, that means Decision-Level fusion depends on external knowledge absolutely, which depends much more inference and decision inferring from external knowledge than Feature-Level fusion.

Results fused by decision fusion can also be used to classify images, detect changes, detect and recognize targets, at the same time, they are saved to information product database, and then these product can be distributed to end users by on-board distributing system.

Figure 5 shows an integrated highly global logic architecture of on-board data processing system. The base kernel, space from the global origin to real curve, comprises some elementary data processing procedure and methods, such as denoising, geometric and radiometric correction, image co-registration, etc. Outer of the base kernel, space between real curve and the dashed curve, is data fusion processing. As the core of whole system, it will provide powerful tools and functions to all kinds of applications, such as enhancing images, improving images' resolution, extracting objects' features in image, and executing feature level and decision level fusion, and so on, so as to provide support of inference and decision for outer applications. Then outer of data fusion level, that is, space between the two dotted curves, there are some basic applications framework such as object classification, object change detection, target recognition. There are some space overlapped among these applications, as the same as overlapping with the inner data fusion level, which denote that there are many methods and applications shared by them. On the surface of the global architecture, space from dashed curve to surface, there are many embodied applications processing, such as land cover classification, urban change detection, road recognition, and so on.

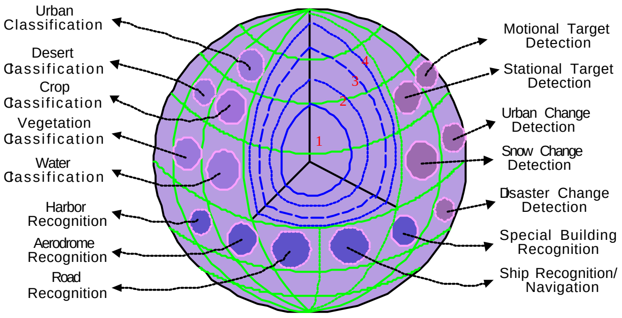

Figure 5 The global logical structure of data fusion integrating with Applications, and it's a procedure from abstract processing to idiographic applications along every core-to-surface direction. 1. (Space from the global origin to real curve) The framework's base kernel, including preprocessing such as denoising, correction, co-registration, etc. 2. (Space between real curve and the dashed curve) Data fusion Processing. 3. (Space between the two dotted curves) Basic applications framework as classification, object detection, change detection, and target recognition. Due to using many similar methods with data fusion, it has any overlapped space with data fusion space. 4. (Space from dashed curve to surface) Idiographic applications, including image classification (urban classification, etc), object detection (motional target detection, etc), change detection (urban change detection, etc), and target recognition (harbor recognition, etc), they are also overlapping with the basic applications framework.

5. DATA FUSION INTEGRATION IN ON-BOARD DATA PROCESSING SYSTEM

Figure 6 exhibits a framework of on-board data processing system with data fusion technology as the core, which is driven by users' requirement, and provided data by autonomous sub-system for earth observation. At first, end users (such as vehicles, ships, aircrafts, etc.) send a task requirement to on-board data processing system, then task decomposing sub-system will decompose the task and perceive user's requirement, and analyze required resource, data type, data resolution, data quantity, etc for implementing the task. Afterwards, it will drive earth observation execution system (including autonomous satellite controlling sub-system, autonomous sensor controlling sub-system, and earth observation sub-system) to acquire data needed. After acquiring data needed and preprocessing, ROI and OOI detection will be executed.

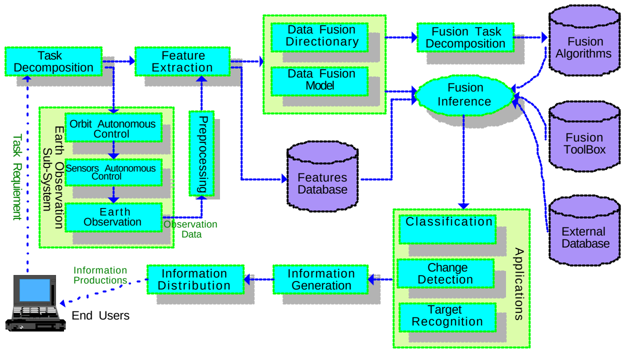

Figure 6 Structure of on-board data processing system with the core of data fusion engine.

Then features of these ROI and OOI will be extracted, on the one hand, which are to be saved to features database; on the other hand, which are to be input into data fusion description module, and then interpreted by data fusion lexicon or produced description model by data fusion model. Furthermore, the description model will be fused by fusion inference engine, including multiplatform and multisensor data fusion, so as to enhance object's characters. Simultaneously, how to fuse the description model will be decomposed and optimal algorithm will be scheduled to execute so as to satisfy requirement of task as fast as possible, which will be advantageous to ensuring real-time execution of task by the system to the most extent, while more complicated algorithms will provide more accurate result but be apparently too costly for real-time processing. In addition, images' features database and external information database will be used during fusion inference procedure, and fusion tools will also be used.

Results of fusion inference will be enhanced features and decision information, and then these results can be used to detect object's change, classify and recognize targets. Afterwards, the detection and recognition results will be produced information required by users, and finally these products will be distributed to the end users.

6. CONCLUSION

Currently, more and more data acquired by various kinds of sensors on-board, how to extract information from these data intelligently, with a real-time processing and distributing to all kinds of users. There is no doubt that it's more convenient processing data on-board and distributing information from satellite to end users directly than from ground processing and distributing, because the later needs many ground station to transmit, process data and distribute information, or distributing by a returning linking from ground station to communicating satellite. Therefore, data processing and information distributing on-board have been the future development trends of earth observation data utilizing.

In fact, users' application requirements for earth observation focus on object detection, change detection, image classification, target recognition, etc. Therefore, how to provide solutions to these applications will be a crucial technology for on-board intelligent processing system. Nay, Data processing on-board will confront more challenge such as autonomous processing, real-time processing, accuracy and false alert, safety, and so on.

Data fusion is a valid technology having been mature stage by stage and used widely on earth observation data processing, which has provided powerful tools for users of earth observation. Divided into three levels, each of them can provide solutions to some applications. That is, raw data level fusion can fight for image enhancement, image classification, image code and compress, change detection, however, by utilizing features of image, feature level fusion can strike object detection, change detection, target classification and recognition. The decision level fusion will provide further solutions to applications in feature level fusion, so that more accurate and lower false alert information can be generated. There have been many methods for data fusion, which are stepping to intelligence more and more, such as neural network methods with ability to learning, fuzzy logic methods providing depiction to uncertainty, and experts system, combining many human's knowledge.

As an integrated highly system for information processing, including preprocessing, data fusion, abstract applications, and idiographic applications, data fusion system can be integrated into whole on-board data processing system, provide powerful and valid tools for earth observation.

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