A STUDY OF HIGH-RESOLUTION REMOTE SENSING IMAGE DATA FUSION BASED ON MULTI-LEVEL TECHNIQUES

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ABSTRACT:

Multi-source remote sensing image fusion was largely focused on in the recent years, especially in which high-resolution remote sensing image data fusion (HRRSIDF) was one of its important centers and is going into the main flow of the future remote sensing image data fusion. In the paper, the authors principally illustrated a concept model, constructed the RSIDF's (Remote Sensing Image Data Fusion) models on different levels and described their interactive progressive relationship, and then, using the formulized mathematic reasoning and formalized logic proving methodology, more deeply set forth the inter-independent and upgrading functionalities of RSIDF on different fusion levels in order to meet the different requirements of different persons. Subsequently, the high-resolution images of a test area were selected and experimented with the suitable methodologies; the results analyzed and estimated. Lastly, the conclusions and further prospect were presented about the HRRSIAF.

1. INTRODUCTION

With the development of remote sensing, a variety of satellite sensors acquire more and more multi-source remote sensing imageries (including multi-temporal, multi-spectral, and multi-geospatial-resolution derived from multi-platform and multi-sensor image data), but there exists one of main obstacles how to mechanically organize the large-scale and multi-source remote sensing data, fully and efficiently refine the various kinds of thematic information, and desirably meet the requirements of corresponding users. Thus, different data fusion techniques have been developed and become powerful tools to process tremendous remote sensing data for capability to combine useful information of multi-source or multi-temporal data, eliminate their redundancy, having been applied in remote sensing image processing extensively. Meanwhile, many remote sensing image data fusion (RSIDF) theories and methods have been proposed to produce multi-spectral images having the higher geo-spatial resolution available within the data set (Carper & et. al., 1990; Chavez & et. al., 1991; Kathleen & Philip, 1994; Jishuang Q. & et al., 2002). The military origin of image data fusion is mainly focused on specific object detection that can only be obtained with a certain image resolution, and that visual interpretation is preferred (Wald, 1999). However, in remote sensing applications inside more domains, the main aim is to characterize surface areas' and not special single objects (R. de Kok & et al., URL).

At present, while Very High-resolution remote sensing images running into the wider application domains: the mapping and chatting, the environment monitoring and appraisal, the urban dynamic monitoring and planning, the traffic control and dispatch, the commercial and agricultural management, the military application, etc., especially since the world first one-meter resolution commercial imaging satellite was successfully launched by Space Imaging Inc. in 1999 (which provided 1-meter panchromatic and 4 meter color imagery using a state of the art digital camera), and QuickBird satellite by Digital Global Company in 2001 (which was capable of gathering the first sub-meter resolution data over a very wide swath: 0.61-meter-resolution panchromatic imagery and 2.4-meter multispectral imagery), the discussion about exact definition of RSIDF is going into the direction of reconstructing a sensor simulation with all detectable wavelength, and making architecture of RSIDF standardized and reflecting the intelligent course of human being to understand realistic world, that is, RSIDF of a more utilizable and intelligentized phase.

In the paper, the authors principally illustrated a concept model, constructed the RSIDF's models on different levels and described their interactive progressive relationship, and then, using the formulized mathematic reasoning and formalized logic proving methodology, more deeply set forth the inter-independent and upgrading functionalities of RSIDF on different fusion levels in order to meet the different requirements of different persons. Subsequently, the high-resolution images of a test area were selected and experimented with the suitable methodologies; the results analyzed and estimated. Lastly, the conclusions and further prospect were presented about the HRRSIAF.

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2. RSIDF THEORIES AND TECHNIQUES

2.1 RSIDF Architecture

Data fusion is defined as a formal framework in which are expressed means and tools for the alliance of data originating from different sources. This aims at obtaining information of greater quality; definition of 'greater quality' will depend on the application (Wald, 1998, 1999, 2000). Practically, greater quality may an increase in accuracy of a geophysical parameter or of a classification; also be related to the production of more relevant information of increased utility, or to the robustness in operational procedures; mean a better coverage of the area of interest, or better use of financial or human resources allotted to a project; otherwise, in some case be replaced by better efficiency through which fusion process can also extract higher order spatial, temporal and behavior relationships between those entities.

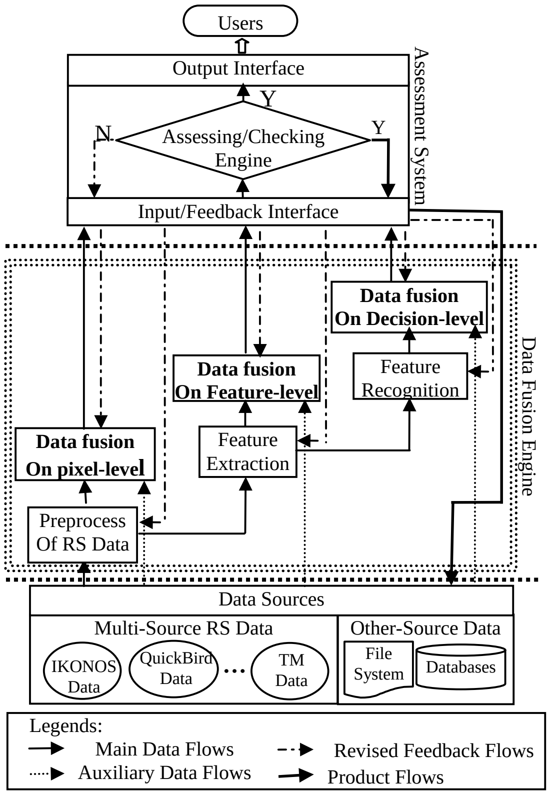

Figure 1. RSIDF Reference Model Based On Multiplate Levels

Therefore, the authors principally understand that multi-source and multi-temporal RSIDF may similarly be performed at different levels for instance, at measurement level (pixel-level), attribute level (feature-level), and rule level (decision-level). Figure 1 shows that there is a reference model of RSIDF formulated through the elements, rules, various kinds of data and their products flows on multiplate levels. Multi-source RS image data fusions, associated with other auxiliary information, are implemented with data fusion engine, and thus a assessment system with the core of assessing/checking engine deals with the results of fusing the above data, communicating with input/feedback interface: if rules is true, then corresponding results actively reach the users through output interface in order to meet a variety of applied requirements, or are adaptively stored into database management systems and file systems through input/feedback interface; otherwise return the corresponding levels of RSIDF so as to iterate the fusing procedures in data fusion engine (DFE).

2.2 Formulization and Formalization of RSIDF in DFE

2.2.1 Definition of Models: According to the above section, a data fusion engine comprises three levels of RSIDF and implements theirs corresponding functions and operations. Formally, it inner mechanism can be described by modeling data fusing procedures.

DEFINITION 1 Let a model $M=\langle D,O,R\rangle$ be *a closed abstract algebra space* with the original or derived dataset $D=\{d_i\}\neq\varnothing$, the operator set $O=\{o_j\}$ and any operator o_j with the corresponding *rank* $g\left(o_j\right)$, and the relation set $R=\{r_k\}$ and any relation r_k with the corresponding *rank* $g\left(r_k\right)$, where any map $o_j: D^{g(o_j)}\rightarrow D$, so o_j is called a operator, namely, *a field operator*, and $r_k\subseteq D^{g(r_k)}$ is called a *relation* in the field of M, namely *a field relation*, which is used to describe some relation between data of D.

DEFINITION 2 Let a set $D_M=\{M \mid M=\langle D,O,R\rangle\}$ represent all the D models, and a set $O_M=\{P_j\}$ describe all the *model operators*, where the map $P_j: D_M{}^{g(P_j)}\rightarrow D_M$ and P_j with the corresponding *rank* $g(P_j)$; and a set $R_M=\{S_k\}$ with $S_k\subseteq D_M{}^{g(S_k)}$ represent all the *model relation*, where $g(S_k)$ is the corresponding rank of S_k. So, let $MM=\langle D_M, O_M, R_M\rangle$ become a metamodel structure that is a model of simulatedly describing all the models, that is, it is a type including all the models and their structures.

2.2.2 Model Operator:

DEFINITION 3 Let a *model operator* $P=\langle P_D,P_O,P_R\rangle$ $\in O_M$ with *rank* g be a *map* $P: D_M^g\rightarrow D_M$, where P_D: $D_1\times D_2\times\cdots\times D_g\rightarrow D'$, $P_O: O_1\times O_2\times\cdots\times O_g\rightarrow O'$, and P_R: $R_1\times R_2\times\cdots\times R_g\rightarrow R'$, that is, $P(M_1,M_2,\cdots,M_g)=M'=\langle D', O', R'\rangle$

Referring to the literature (Chen W. & et al., 2000), there is the following for the case of $g=1$: **1)** ***The stability of model operators*** If $P=\langle P_D,P_O,P_R\rangle: D_M\rightarrow D_M$ is a *model operator* that stabilize *all the field operators* of O, and P_D makes any $d\in D$ and $r\in R$ correspondingly defined necessarily, then P_D uniquely determine O' and P_O, and R' and P_R, respectively; **2)** ***The compatibility of model operators*** If *a model operator* $P=\langle P_D,P_O,P_R\rangle: D_M\rightarrow D_M$ can compatiblely map *all the field operators* and *field relations* of M into $M'=P(M)$, namely, *a compatible model operator* P is uniquely determined; **3)** ***The compound of model operators*** If *any two compatible model operators* P_1 and P_2 with *rank* 1, where P_1: if only if $M\in D_M$, and $P_1(M)\in P_M$; P_2: if only if any

$M \in D_M$, and any $P_1(M)$ such that $P^{'}(M) = P_2(P_1(M))$, then $P^{'}$ with *rank* 1 is called a *compound model operator* compounded by P_1 and P_2 with *rank* 1, marked by $P^{'} = P_1 \circ P_2$. Similarly, many single *model operators* can logically compound *a compound model operator* with the satisfied corresponding application conditions.

2.2.3 Fusion Operator: Now Let the case of $g = 1$ be expanded to this case of $g > 1$, and then *a compound model operator* is called *a fusion operator*, by describing the following:

Lemma *a model relation* for this model operator is often defined in field of models, that is, it is a subset of a relation set $D^{11} \times D^{12} \times \cdots \times D^{1g}$.

2.2.3.1 The compatibility of field relations of fusion operator of models

DEFINITION 4 Let *a model operator* $P = \langle P_D,\ P_O, P_R \rangle : D_M^g \to D_M$ of $M^{'} = P(M_1, M_2, \cdots, M_g)$ be call compatible if and only satisfying these tree conditions: P compatiblely maps, ① *all the field operators* of $M_i (i = 1, 2, \cdots, g)$ into *the field operators* of $M^{'}$; ② *all the field relations* of $M_i (i = 1, 2, \cdots, g)$ into *the field relations* of $M^{'}$; ③ *all the cross field relations* $r_k \in D^{11} \times D^{12} \times \cdots \times D^{1g}$ into *the field operators* of $M^{'}$.

2.2.3.2 The abstract characteristic of fusion operator

DEFINITION 5 Suppose that $M_1, M_{2,} \cdots, M_g \in D_M$ and if and only if $\Pi_i (M_1, M_{2,} \cdots, M_g) = M_i$, $i = 1, 2, \cdots, g$ (namely, there exists $\Pi_i :\ D_M^g \to D_M$ about *a model operator* with *rank* g) such that Π_i act as *the corresponding projection* of the i model, then Π_i is called *a pure abstract* of model.

2.2.3.3 The abstract characteristic of fusion operator

DEFINITION 6 Assume that $P_1, P_2, \cdots, P_i, \cdots, P_K : D_M^{g_l} \to D_M$, and if and only if corresponding P_i may be defined with any $(M_{i1}, M_{i2}, , M_{ig_i})$ while $M_i^{'} = P_i(M_{i1}, \cdots, M_{ig_i})$ and corresponding P_F may be defined with any $(M_1^{'}, \cdots, M_K^{'})$ while $M_D = P_F(P_i(M_{i1}, \cdots, M_{ig_i}, \cdots, M_{K1}, \cdots, M_{Kg_K}))$ such that *a model operator* $P_{g^{'}} : D_M^{g^{'}} \to D_M$ with *rank* $g^{'} = \sum g_i$, then $(P_1, P_2, \cdots, P_K)$ and P_F are compounded, denoted by $P^{'} = P_F \circ (P_1, P_2, \cdots, P_K)$.

Summing up the cases with $g = 1$ in the above (Section *B*) and with $g > 1$ this section (Section *C*), it can gain this conclusion.

THEOREM Suppose that $P_1, P_2, \cdots, P_K : D_M^{g_l} \to D_M$ and $P_F = D_M^K \to D_M$ such that $P^{'} = P_F \circ (P_1, P_2, \cdots; P_K)$, then $P^{'}$ become *a compound structure* (including *Transform* and *Abstraction structure*, referring to other pertinent literatures), and is called *a fusion operator*.

Therefore, in applications of data fusion the data models of information are operated with *fusion operator* $P^{'}$ that is compounded by *transformation* or *abstraction* of $P_1, P_2, \cdots, P_K$ respectively corresponding to *the fusion principles*, that is, the data of information is functioned in corresponding data models; meanwhile, the principles of processing information is designed in corresponding *operators* (Chen W. & et al., 2000).

2.2.4 Formalization of RSIDF:

PROPOSITION Let *a quaternion group* of a formal system be $G = \langle V_N, T_N, C, B \rangle$, where V_N is *a non-terminal symbol set*, T_N a terminal symbol set, C a generator set, and B *a original symbol set*, then let M be a multi-source remote sensing image data set (MSRSID), M_1 a result set of preprocessing MSRSID, $M_1^{'}$ a result set of MSRSID fusion on pixel-level, M_2 a result set of extracting or classifying features of MSRSID, $M_2^{'}$ a result set of MSRSID fusion on feature-level, M_3 a result set of recognizing features of MSRSID, and $M_3^{'}$ a result set of MSRSID fusion on decision-making level.

According to the above contents (Section 2.2.1, 2.2.2, and 2.2.3), the following can be gained:

$$V_N = \{M, M_1, M_2, M_3\} ;$$
$$T_N = \{M_1^{'}, M_2^{'}, M_3^{'}\} ;$$
$$C = \{M \xrightarrow{P_1} M_1 \xrightarrow{P_1^{'}} M_1^{'},$$
$$M_1 \xrightarrow{P_2} M_2 \xrightarrow{P_2^{'}} M_2^{'},$$
$$M_2 \xrightarrow{P_3} M_3 \xrightarrow{P_3^{'}} M_3^{'}\} ;$$
$$B = \{M\}$$

where P_1 is a operator set of pre-processing MSRSID, $P_1^{'}$ a operator set of MSRSID fusion on pixel-level, P_2 a operator set of extracting or classifying features of MSRSID, $P_2^{'}$ a operator set of MSRSID fusion on feature-level, P_3 a operator set of recognizing features of MSRSID, $P_3^{'}$ a operator set of MSRSID fusion on decision-making level.

Additionally, in order more distinctly to describe the above formalized transmission relation of RSIDF on a few different levels, let $C = \{M \xrightarrow{P_1} M_1,\ M_1 \xrightarrow{P_2} M_2,\ M_2 \xrightarrow{P_3} M_3\}$, then there constructs a formalized grammar structure and running mechanism of a generalized system of RSIDF; meanwhile, it can also be established into a corresponding grammar tree structure logically showing direction of flow of fusing information.

3. EXPERIMENT AND DISCUSSION ABOUT HRRSIDF

According to the above mentioned principles, models and methodologies, now a series of tests are designed, using the original dataset: a panchromatic QuickBird (QB) image of 0.61-m resolution and a multi-spectral QuickBird (QB) image of 2.44-m resolution (size in 600 by 600 pixels, acquired in July 2002), and a multispectral Ikonos image of 4-m resolution (size in 600 by 600 pixels, acquired in September 2003), all in the same suburban areas of Beijing.

To begin with, the HRRSIDF was implemented on pixel-level with the QB panchromatic and multispectral images, using the software of Erdas Imagine 8.7, while comparing the quality effects of fusion (see Figure 2), whereafter the authors selected the better fused result (QB fused image) with the approach of WA-PAC method as the data source of next classification methodology.

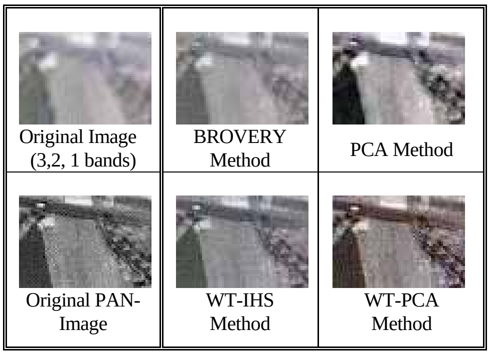

Figure 2. Fusions of QB Pan and Multispectral Images

Secondly, the QB fused image and the multi-spectral Ikonos image mentioned above were classified respectively with the RSICA of IMBPNN (Faguan W. & et al, 1991; Yonghong J, 2005), and subsequently, their results of classification was fused on decision-making level with the pre-designed principles and algorithm of classification fusion

As is shown in APPENDIX A: TABLE, the correct ratio of classifying the QB fused image is higher than that of classifying the Ikonos multispectral image, using the approach of RSICA of IMBPNN, and consistent with that of the result of fusing the above two classification results by employing the classification fusion algorithm of IMBPNN. So, it presents the classification effect of separately classifying the Ikonos multispectral Image lower and the quality effect of the classification fusion of images better because of the integrated classes including the more information and more objectively representing the real world.

Thus, The model and methodologies described above are testified with the multi-source and multi-temporal dataset of HRRSIDF (Yongsheng Z. & et al., 2005).

4. CONCLUSIONS

In this study, the authors principally illustrated a concept model, constructed the RSIDF's models on different levels and described their interactive progressive relationship, and then, using the formulized mathematic reasoning and formalized logic proving methodology, more deeply set forth the inter-independent and upgrading functionalities of RSIDF on different fusion levels in order to meet the different requirements of different persons. Subsequently, the high-resolution images of a test area were selected and experimented with the corresponding methodologies; the results analyzed and estimated.

Otherwise, this topic along with the mechanism of feeding back and reasoning with by using the expertise knowledge database and the like for the HRRSIDF on different levels is our effort of study on the ongoing way.

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REFERENCES

Carper W.J., Lilesand T.W. & Kie.er R.W., 1990. The use of Intensity-Hue-Saturation transformation for merging SPOT panchromatic and multispectral image data. *PE&RS*, 56(4), pp. 459–467.

Chavez P.S., Sides S.C. & Anderson J.A., 1991. Comparison of three different methods to merge multiresolution and multispectral data: Landsat TM and SPOT panchromatic. *PE&RS*, 57(3), pp. 295-303.

Chen W., Xinfeng L. & et. al., 2000. Study on the Modelization and Formalization of Data Fusion Systems. *Journal of East China Shipbuilding Institute*, 14(3), pp.13-19.

Faguan W., Jian L. & et al, 1991. *Digital Process Technology of Remote Sensing Image.* Central China Technical University Press.

Jishuang Q., Chao W. & Zhengzhi W, 2002. Data Fusion Based Technology for Remote Sensing Image Processing. *Journal of Image and Graphics*, 7(10), pp.985-993.

Kathleen E. & Philip A.D., 1994. The use of intensity-hue saturation transform for producing color shaded relief images. *PE&RS*, 60(11), pp. 1369-1374.

R. de Kok, Schneider T., Baatz M. and Ammer U., Object based image analysis of high resolution data in the alpine forest area. URL:http://www.pcigeomatics.com/services/ support_center/ tech_papers(accessed 28 Nov. 2005).

Wald L., 1998. A European Proposal for Terms of Reference in Data Fusion. *In International Archives of Photogrammetry and Remote Sensing*, 32(7), pp. 651-654.

Wald L., 1999. Some terms of reference in data fusion. *IEEE Transactions on Geosciences and Remote Sensing*, 37(3), pp.1190-1193.

Wald L., June 2000. The present achievements of the EARSeL - SIG "Data Fusion", In: *Proceedings of the EARSeL Symposium*, Dresden, Germany.

Yonghong J, 2005. *Multi-source Remote Sensing Image Fusion Technology*, Mapping and Surveying Press, pp.25-58,77-140.

Yongsheng Z., Yunbin Z. and Chenguang D., 2005. *Outer Space Multi-Source Remote Sensing Image Fusion----Theory, Algorithm and Application System*, Science Press, pp.112-145,197-207.

APPENDIX A: TABLE

Classification and Image Fusion on Decision-making level, and Quality Effect

Methods	Operated Objects	Confusion Matrix of the Classification						Correct Ratio of average classification (%)
		Water Area	Agricultural Lands		Wood land	Public Land		
			Dry Land	Bare Land		Traffic Land	Construc-tion Land	
The RSICA of IMBPNN	The QB Fused image	88	1	7	2	1	1	89.0
		0	89	6	3	1	1	
		3	4	90	0	1	2	
		1	1	6	88	2	2	
		0	2	3	3	91	1	
		1	1	7	2	1	88	
	Ikonos Image (3,2,1)	80	1	11	2	3	3	83.3
		1	79	10	3	1	6	
		7	8	82	1	1	1	
		2	6	9	79	1	3	
		1	5	4	2	84	4	
		1	4	11	3	2	79	
	Fused Image of Classifi-cation	89	1	6	2	1	1	88.5
		0	88	6	3	1	2	
		1	5	89	1	1	3	
		1	1	6	87	3	2	
		1	1	3	3	91	1	
		0	1	8	1	3	87	