COMPILATION OF A REMOTE SENSING IMAGE FUSION ATLAS

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ABSTRACT: Remote sensing delivers multi-modal and -temporal data from the Earth's surface. In order to cope with these multi-dimensional data sources and to make the most out of them, image fusion is a valuable tool. It has developed over the past few decades into a usable image processing technique for extracting information of higher quality and reliability. As more sensors and advanced image fusion techniques have become available, researchers have conducted a vast amount of successful studies using image fusion. However, the definition of an appropriate workflow prior to processing the imagery requires knowledge in all related fields – i.e. remote sensing, image fusion and the desired image exploitation processing. From the results, it is can be seen that the choice of the appropriate technique, as well as the fine tuning of the individual parameters of this technique, is crucial. There is still a lack of strategic guidelines due to the complexity and variability of data selection, processing techniques and applications. This paper describes the results of a project that forms part of a larger initiative to streamline data selection, application requirements and the choice of a suitable image fusion technique. It aims at collecting successful image fusion cases that are relevant to other users and other areas of interest around the world. From these cases, common guidelines which are valuable contributions to further applications and developments have been derived. The availability of these guidelines will help to identify bottlenecks, further develop image fusion techniques, make best use of existing multimodal images and provide new insights into the Earth's processes. The outcome is a remote sensing image fusion atlas (book) in which successful image fusion cases are displayed and described, embedded in common findings and generally valid statements in the field of image fusion.

1 INTRODUCTION

Remote sensing is an important resource for information to understand crucial global processes. Climate change, environmental protection, natural resource management, urban planning, disaster mitigation and monitoring are applications that benefit from multisensor images acquired by multiple satellite sensors around the globe. Multisensor data provides a more complete view of the Earth's surface. It enables the operator to access timely information at an appropriate resolution since each sensor delivers different aspects in terms of radiometric content, incidence angle, time of acquisition, radiometric and spatial resolutions. In the context of multisensor image exploitation image fusion has become a recognized tool (Pohl and Van Genderen 1998, Zhang 2010, Palubinskas and Reinartz 2011, Berger, Voltersen et al. 2013). In particular the combination of high spatial resolution panchromatic with multispectral bands of lower spatial resolution known as pansharpening has drawn a lot of attention in the past twenty years (Ehlers 2004, Garzelli and Nencini 2005, Aiazzi, Alparone et al. 2006, Gonzalo-Martin and Lillo-Saavedra 2008, Ehlers, Klonus et al. 2010, Bo, Hankui et al. 2012, Choi, Yeom et al. 2013, Huang, Zhang et al. 2013). But also the integration of passive (optical) and active (microwave) remote sensing data benefits strongly from advances in remote sensing image fusion (Chibani 2006, Zhang, Yang et al. 2010, Amarsaikhan, Saandar et al. 2011, Abdikan, Balik Sanli et al. 2012, Byun, Choi et al. 2013). Recently the combination of remote sensing images with other types of data are introduced to the scientific activities, such as optical, hyperspectral or radar imagery with Laser Detection and Ranging (LiDAR) data (Millard and Richardson 2013, Bigdeli, Samadzadegan et al. 2014, Saeidi, Pradhan et al. 2014).

Image fusion is embedded in a much larger framework of data fusion (see figure 1). Depending on the processing stage three levels are distinguished in fusion (Pohl and Van Genderen 1998):

1. *Image level*, also mentioned as iconic or pixel level: The fusion process combines the images on pixel-by-pixel basis using a certain algorithm.
2. *Feature level*: In a pre-processing stage feature of interest are extracted from the images. Then these features, i.e. edges, segments, areas or similar are fused.
3. *Decision level*, also called information level: Here the fusion concerns the decision-making process where the information derived from the remote sensing data is combined to form a final decision.

It is self-understood that each level requires different approaches.

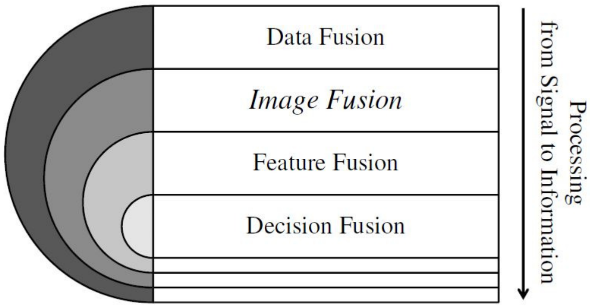

Figure 1 Image fusion in the context of data, feature and decision fusion.

Remote sensing image fusion is an advanced method to join two or more images into one fused image at pixel level. With the development in sensor technology, computer power and fusion techniques the possibility of combing different remote sensing images is manifold (Pohl and van Genderen 2013). The remote sensing community has succeed to establish standards in pixel level fusion in terms of terminology (Wald 1998), levels (Pohl and Van Genderen 1998), quality assessment (Zhou and Bovik 2002) and general frameworks (Palubinskas 2013), in particular in pansharpening as the most popular method. Of course there is more than pansharpening in image fusion. A special group forms the combination of optical and microwave images. Another large group reports on research results testing new algorithms or improving existing methods. The question that remains open is how to address the selection process: Which image pairs, using which method will lead to the best result for a certain application?

The research described in this paper focuses on identifying the communalities and conflicts arising from a global survey on scientific achievements in remote sensing image fusion. It is anticipated to draw general guidelines on data selection and optimized fusion techniques for different applications. The survey is expected to identify conflicts and open questions to provide directions for further research. The results will give another push to the advancement of this beneficial and capable technology.

2 BACKGROUND

A research project has been launched in December 2013 to address this problem. This initiative aims to derive commonalities from published scientific findings in the field of spaceborne remote sensing image fusion. Furthermore scientists from all over the world are invited to contribute successful image fusion cases and their findings through an online questionnaire. Putting research results in image fusion from the past 15 years into one context and drawing similarities and contradictions will provide a new view on the subject and help to design a tool. The idea is to support the selection of an appropriate fusion approach, using the knowledge compiled to feed a Fusion Approach Selection Tool (FAST). It is anticipated to build such a system as a continuation of the ongoing research effort which is scheduled to terminate end of November 2014.

3 METHODOLOGY

In the process of the research an extensive database of indexed international journal publications on remote sensing image fusion has been compiled. Within the database of about 850 papers reporting on data combinations, fusion techniques, applications of image fusion and quality assessment, various categories have been formed to interpret the commonalities and contradictions. A sub-group of about 300 journal papers was identified to be highly relevant to remote sensing applications. Out of this sub-group six categories of information have been built, as there are

1. *Journal* in which the research was published.
2. *Application* for which the data was fused.
3. *Sensors* that provided the images used in the case study.
4. *Technique(s)* which were used to fuse the images.
5. *Areas of achievement* to which the research contributed new knowledge.
6. *Ongoing Research* highlighting unresolved questions and current science.

In addition to the published literature a questionnaire was published to access international scientists working in the field. Based on the evaluated literature the questionnaire was designed to retrieve relevant information (Pohl 2013). It consists of two parts: Part A relates to the overall experiences obtained using remote sensing image fusion. Part B covers a particular case study that the scientist can provide to the fusion atlas.

Part A starts off with questions about the background of the scientist providing the information. Furthermore the information collected covers the sensors which acquired the data used in the fusion process, the application that the data was used for, the fusion techniques, information about quality assessment methods, the software used to process the images, the challenges encountered during the process, and questions about the individual conclusions, i.e. trends in image fusion, unresolved problems and key application areas.

The case study information in Part B compiles data on similar aspects but this time focused on a real world application to hook into practical experiences. These are very important for inexperienced users to obtain an understanding in the practical use of image fusion.

After completion of data and information collection the results will be published in a book. The contributors of the case studies are co-authors for individual chapters.

4 FIRST RESULTS

There are two steps to achieve the anticipated objectives of the reported research. The first step is the establishment of a remote sensing image fusion literature database. In parallel the experiences of other researchers are collected via the online questionnaire. Both information retrieval approaches will result in the fusion atlas to be published as a book.

4.1 Journal publications 1999-2014

Looking at the literature database that was formed the information groups are very important to derive conclusions.

Journals: The group of journals contains fourteen major indexed journals that publish research in the field of remote sensing. Only two of this list specifically have their aims and scope on fusion: International Journal of Information Fusion (Elsevier) and International Journal of Image and Data Fusion (Taylor & Francis); the latter being most appropriate regarding the topic discussed. Interesting enough most of the published remote sensing image fusion work appears in the International Journal of Remote Sensing (Taylor & Francis).

Applications: Remote sensing applications are manifold. In the context of image fusion authors are concerned with urbanization, change detection, geology, forestry, vegetation, agriculture, hazards and land cover mapping in general. Due to the fact that the literature search for this project focused on advances in fusion techniques the coverage of existing literature in the application group is not complete. Often the fusion algorithm plays a sub-ordinated role and cannot be identified from title or abstract of the publication.

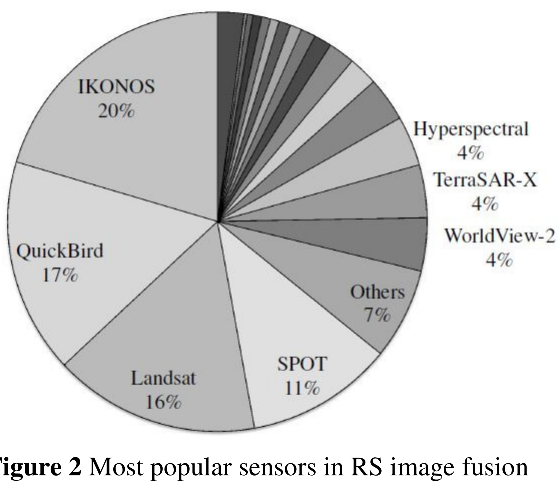

Figure 2 Most popular sensors in RS image fusion

Sensors: The past decade has resulted in an increase of available satellite data on an operational basis. Increased spatial and radiometric resolutions result in very diverse information (Pohl and van Genderen 2013). Most popular platforms in the use of remote sensing images for fusion are IKONOS followed by Quickbird and Landsat as depicted in figure 2. Also the SPOT satellite data receives a lot of attention. The sensors onboard of these satellites are so popular because they enable single-platform pansharpening. The high resolution panchromatic band is acquired at the same time as the lower resolution multispectral bands so that there are no problems related changes on the ground over time.

Techniques: It has to be stated that most of the publications in remote sensing image fusion are technique driven. More than half of the identified publications report on findings in algorithm testing, development and modification. It becomes clear that the largest number of published work relates to component substitution (CS) methods, such as Intensity Hue Saturation (IHS) (Choi, Yu et al. 2011), Principal Component Analysis (PCA) (Ling, Ehlers et al. 2007), derivatives from these methods as well as connected hybrid approaches (Chibani and Houacine 2002, Gonzalez-Audicana, Saleta et al. 2004). The reason for the lasting popularity of IHS and its modified version, including the Ehlers method (Ehlers 2004) is its straightforwardness and simplicity. These are followed by multiresolution approaches (MRA) using wavelets (Wald and Ranchin 2003), curvelets (Nencini, Garzelli et al. 2007) or others. These methods are much more complex and require more computation time. However, this investment is worth it because they mostly lead to better results.

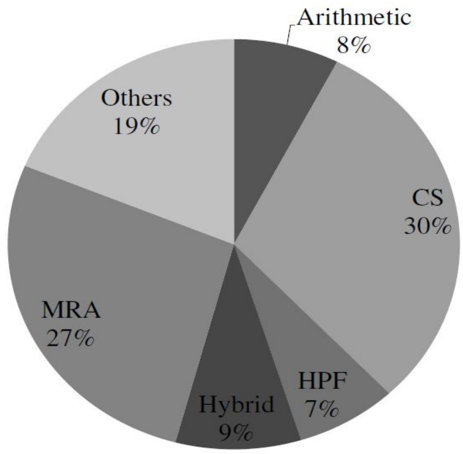

Figure 3 Occurrence of image fusion techniques presented in six categories

Also high pass filtering (HPF) and Brovey transform as part of the arithmetic group still receives attention till today even though it has limited applications like for example urban area mapping (Dahiya, Garg et al. 2013). An upcoming approach is the sparse representation based on learning dictionaries (Bo and Huihui 2012, Zhu, Grohnfeldt et al. 2013, Wang and Du 2014).

Areas of Achievement: This group forms a very important part in the research because it reports on findings and results pointing out the various benefits, surrounding issues and quality assessment of remote sensing image fusion. The list of aspects looked at comprises

- Benefits,
- Categorization of techniques,
- Generalized fusion frameworks,
- Geometrical issues,
- Scale and ratio of image pairs,
- Optimum index factor use,
- Quality indices,
- Resampling, and
- Publications on optical and radar fusion.

Furthermore the group distinguishes technique-driven from application-driven research, pansharpening publications from others and lists all reviews that have been published so far.

Ongoing Research: Currently the image fusion research in remote sensing is centered around four major blocks:

1. Further refinement of performance and quality of pansharpening algorithms,
2. Retrieving 'the best algorithm',
3. Fusing images with other data, and
4. Hybrid methods.

Only in 2014 to date there are more than 30 new papers in pansharpening published in the major remote sensing journals, each claiming to have found an improvement of existing approaches. Reducing computational cost of high performance algorithms using parallel computing is another upcoming topic. Computational costs have been and are still an issue even though computer power has increased. But likewise the amount of data to be processed has grown, too (Gonzalez-Audicana, Otazu et al. 2006, Yuhendra and Kuze 2011, Wieland and Pittore 2014, Yang, Zhang et al. 2014).

It is obvious that questions number two will not be answered because there is no such thing as 'the best algorithm'. The results depend so much on the application, the selection of the types of input images, quality of the data, and the parameter fine-tuning of the advanced techniques.

With the development of new data acquisition types, such as hyperspectral images (An and Shi 2014) and Light Detection and Ranging (LiDAR) (Basuki, Skidmore et al. 2013, Berger, Voltersen et al. 2013, Gulbe and Mednieks 2014, Saeidi, Pradhan et al. 2014) researchers explore the benefit of combining these with remote sensing images.

A very fascinating trend is the use of different image fusion algorithms in a hybrid approach. Very successful has been the improvement of IHS and Brovey Transform (Su, Lee et al. 2013), IHS using wavelets (Amolins, Zhang et al. 2007), PCA with contourlets (Shah, Younan et al. 2008, Metwalli, Nasr et al. 2014). There is still a lot of potential in the development of hybrid image fusion in remote sensing.

4.2 Questionnaire evaluation

The questionnaire evaluation is still ongoing. The data collected is manifold and the information retrieval is performed on the background of the findings from the literature exploitation. The questionnaire will be kept online to continue information acquisition in this interesting research field. So far 11 case studies have been collected in the field of underground coal fire monitoring, detection and mapping of landmines, surface urban heat islands and thermal patterns, land cover mapping, agriculture, and forest mapping including tropical forest (Simone, Farina et al. 2002, Paganelli, Janssen et al. 2008, Fadaei, Sakai et al. 2010, Amarsaikhan, Saandar et al. 2011, Abdikan, Balik Sanli et al. 2012, Zheng, Blasch et al. 2012, Berger, Voltersen et al. 2013, Jawak and Luis 2013, Palubinskas 2013, Pohl and van Genderen 2013, Huang, Song et al. 2014).

5 CONCLUSIONS & OUTLOOK

Image fusion has developed into a mature and recognized valuable tool in remote sensing. Pixel-based methods are implemented in commercial software and part of processing chains of satellite image providers. It is obvious from the increasing number of publications that this field is an active research field. New developments explore the yet unexploited possibilities of hybrid approaches. The exchange between different disciplines could advance both disciplines, e.g. remote sensing and medical image fusion contributes to the advancement of the technology itself. The fusion atlas is

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