



FEATURE

Open Source Remote Sensing: Increasing the Usability of Cutting-Edge Algorithms

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Abstract—One common problem when working with satellite images is the gap between cutting edge algorithms available in the literature and methods which are available in production software. Constraints on production are often strong and do not cope well with research algorithms. To help a faster transfer of the new algorithms to real production situations a strong and robust software architecture is required. One of the main objectives of the Orfeo Toolbox (OTB) is to provide such a framework to help the scalability of newly implemented algorithms and relieving (at least partially) the researcher from such concerns. OTB is valuable for all people working in the remote sensing imagery community. Releasing it under an open source license, CNES (French Space Agency) hopes to benefit from contributions of many specialists to help grow the practical use of satellite imagery. The first feedback has been very positive and open source development seems to be particularly suitable to increase the usability of cutting-edge algorithms.

I. INTRODUCTION

One common problem when working with satellite images is the gap between cutting edge algorithms available in the literature and methods which are used in production. Some of these new algorithms can require some fine tuning for which an in-depth understanding of the theory is necessary, some might not scale well when asked to process billions of pixel images, some would be too slow to enable interactivity, and some would try to guess (often wrongly) what the end user needs.

To bridge this gap, it is necessary to enable a shorter interaction between people creating improved algorithms and people using them. In other words, an easy access to these new algorithms must be given to end users in order to get feedback from them, so that the final result fits their needs.

Another problem is the complexity of the processes involved: it is not possible for a research team, not to mention a single individual, to be a specialist of all aspects of the satellite image preprocessing (calibration, localization, pan-sharpening) and information extraction (pattern recognition, image classification). Furthermore, all these steps of the processing chain may differ according to the type of data (optical, SAR data, Lidar).

In order to overcome these difficulties, CNES decided to develop an open source remote sensing image processing library, the Orfeo Toolbox [1], which capitalizes state of the art techniques as well as recent results published in the literature.

In the remainder of this paper we will address how OTB can be helpful for end-users and remote sensing scientists working

with them (section II). We will also introduce the features of the library as well as how it can be used for building innovative processing techniques (section III). Finally, the underlying software framework will be presented (section IV).

II. THE RIGHT ALGORITHM FOR THE END USER

Algorithms used for information extraction from remote sensing images in operational contexts are often not performing as well in terms of the resulting quality as the cutting-edge algorithms that are available in the labs. On the other hand, production software is often robust and does not need fine tuning of several parameters requiring an in depth knowledge of the underlying algorithms. It also performs fast enough to enable interaction with the expert.

To ensure compliance with operational requirements, it is important to bring the algorithms as early as possible to the end-user. Only the expert, whether it is in hydrology, forestry, oceanography, defense or disaster management can tell if the algorithm is doing what is required. On the opposite, only people with a deep experience in image processing can extract pertinent information with a good reliability using advanced methods.

In order to increase the interaction between end-users and researchers developing processing methods, OTB proposes some small applications. These applications make the use of these new algorithms easier and more user friendly. The feedback from users has been extremely positive.

Figure 1 shows a screen shot of an interactive object segmentation application which allows the non expert user to compare the performances of classical region growing approaches to recently developed algorithms.

Figure 2 shows a screen shot of an interactive classification application bringing Support Vector Machine methods to the end user.

Other applications are available for orthorectification, pan-sharpening, fine image registration, object counting, interactive change detection, for example.

III. THE BEST ALGORITHMS FOR THE RESEARCHER

Extracting information from remote sensing images relies on a complex process. The preprocessing required to generate the data is a heavy task that has a major impact on information extraction algorithms performance. Several steps such as orthorectification, radiometric corrections, etc. are necessary before providing an image with a physical meaning. Many

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Fig. 1. Segmentation application: cloud segmentation on a Quickbird image

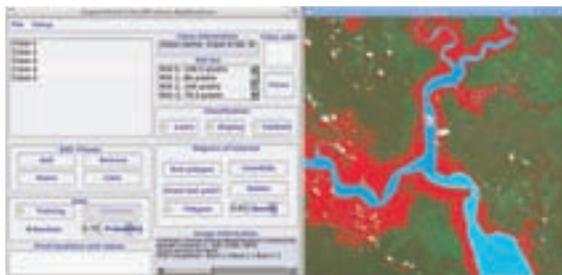


Fig. 2. Classification application: classification of mangroves on a SPOT 5 image

alternatives exist for each step of the processing. The optimal choice for each of these tasks is not necessarily the same depending on the final purpose. The idea of OTB is to provide the researcher with a wide range of choices for each of these tasks and give him control on the process as a whole. Of course, sometimes, it is not necessary to start from the lowest level of data.

The problem of data access is also a major one when one first dives into remote sensing. Not two different sensors use the same data format with the same meaning for the different parameters. There is also an increasing amount of data on the Internet, not limited to images, and the access and formats are not uniform. It is necessary to free up the researchers from these tasks to help them focus on their work.

Moreover, the strong underlying software framework makes it easier to share the latest algorithms with a wide community as soon as they are published. This approach, known as reproducible research, is a good way to increase the impact of the publications and build on each other's work [2].

A. Many components available

About 3000 C++ classes are already available in the current version of OTB for most of the usual operations on remote sensing images. All of these operations can be combined to lead to fully functional applications. This modularity also enables replacing easily one method by another one in the processing chain to evaluate its impact on performance. Such modules include:

- image access: optimized read/write access for almost any of the existing remote sensing image formats, meta-data access, visualization;
- geometric modeling: sensor models for optical and SAR sensors, digital elevation models (DEM) access, cartographic projections, image registration, disparity map estimation;
- filtering: blurring, denoising, enhancement;
- feature extraction: interest points, alignments, lines;
- image segmentation: region growing, fast marching, watershed, level sets;
- object extraction: road network extraction, template-based detection;
- classification: K-means, SVM, Markov random fields;
- change detection.

As we can see, the functionalities cover the whole range of image processing, from access to image format to applications like change detection and the list is steadily growing. A few examples are detailed and illustrated below.

Segmentation is a basic task in image processing. On figure 3 an example is given for the fast marching algorithm starting from three different seeds directly on the luminance image.



Fig. 3. Segmentation example: from three different seeds. The fast marching algorithm generates three different areas.

It is increasingly common to have several data sets over the same area. Either to study temporal phenomena in multi-temporal image series or to jointly exploit information from multisensor datasets [3]. On figure 4, the registration between an optical and a radar image of the same area is illustrated. The deformation model is done by a centered affine transform which is able to introduce translation, rotation and scaling effects. The similarity metric cannot be a simple correlation due to the completely different acquisition processes between the two sensors: mutual information is used instead [4].

Often the registration is done by manually taking tie-points. This task can be automated using features like SIFT [5] or SURF [6]. Figure 5 illustrates the matching between tie points extracted from two images after a deformation.

Most current high resolution optical sensors (Spot 1 to 5, Quickbird, the coming Pleiades), have a high spatial resolution panchromatic band and a multispectral band with a lower resolution (typically by a factor of four). A pan-sharpening step is necessary to obtain an image with four spectral bands with the highest spatial resolution. Several pan-sharpening

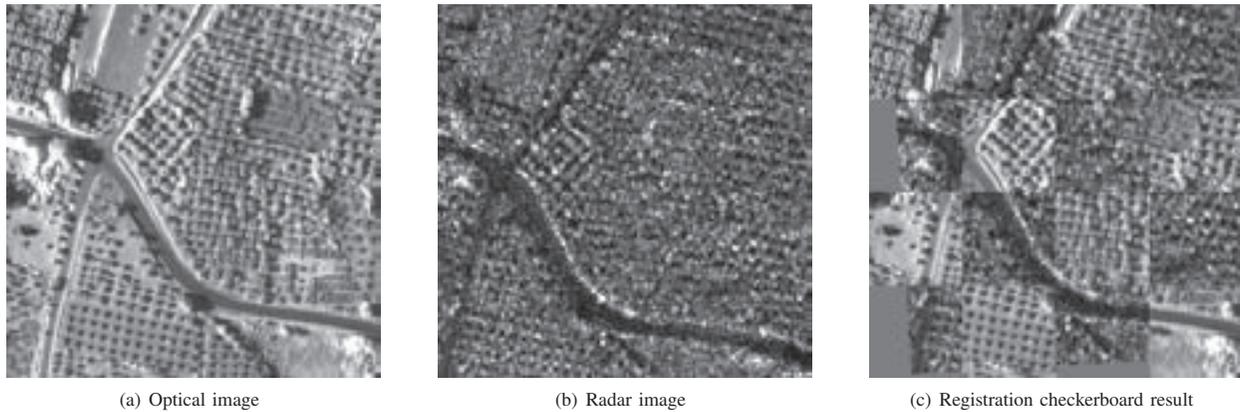


Fig. 4. Registration: the optical and the radar images represent the same area with a deformation. A six parameters transform is computed (translation, rotation, scaling) using the mutual information as a similarity measure.

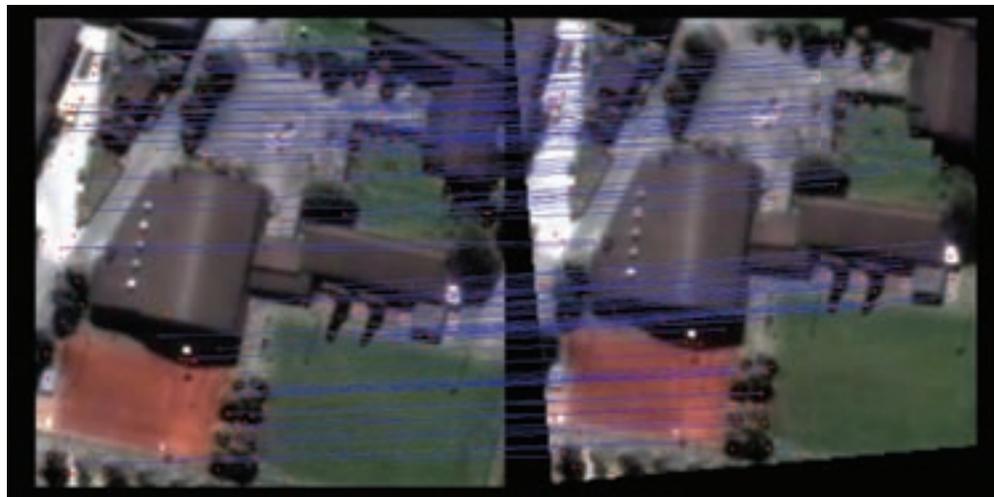


Fig. 5. Automatic tie-point extraction using SIFT: the red dots are the detected points; the blue lines link the pairs of points found by the matching algorithm.



Fig. 6. Pan-sharpening example: high resolution of the panchromatic image is introduced in the multispectral image to obtain a multispectral high resolution image.

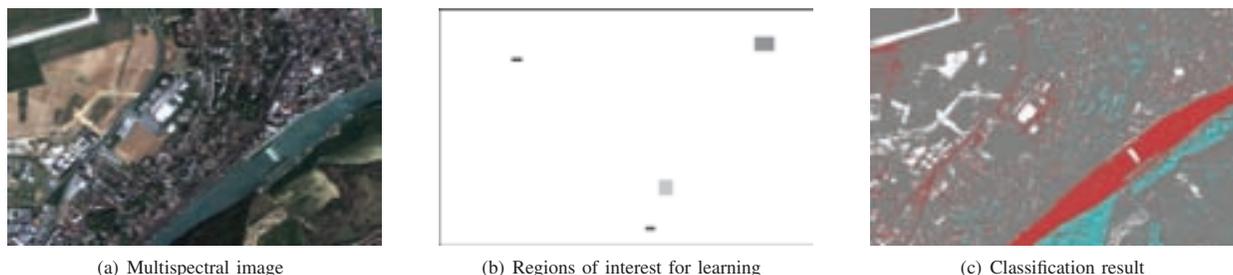


Fig. 7. Support Vector Machine example: on a multispectral image, four areas of interest are defined. These areas are the base for the SVM learning step. Then all pixels are classified.

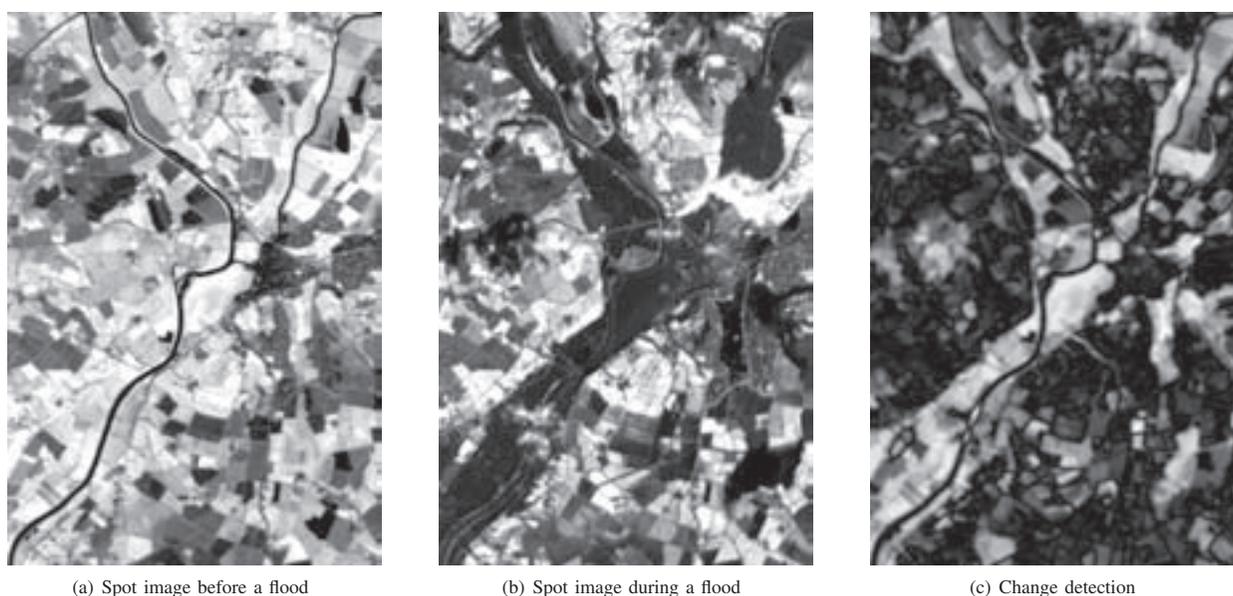


Fig. 8. Change detection example on two SPOT images (before and during a flood) in the South of England with a mean difference change detector.

methods are available in OTB. One example is illustrated in figure 6.

Image classification from examples is a very useful task. Support Vector Machines (SVM) can produce good classification models from a few examples [7]. On figure 7, an example of classification by SVM is illustrated. On the multispectral image, a few regions of interest are selected to train the SVM. Then the entire image is classified.

One common application of satellite images is the change detection between two images, either to detect the effects of natural disasters or to update vector databases [8]. Figure 8 presents the application on floods on the South of England using SPOT images. Many other change detectors have been implemented in the toolbox using statistical similarity measures, as for instance the one presented in [9].

Finally, direct objects or network extraction can also be developed. Figure 9 presents a real-time road extraction algorithm [10].

B. Using the best established libraries

When developing a complex library, thorough validation of the algorithms is always a very delicate part. To be able to provide well tested algorithms, OTB is based on numerous, carefully chosen, open-source libraries. For each domain, we select the library which has a broad base of users (the library is well tested) and which is compatible in terms of license requirements (open source). Access to these libraries is then integrated in the framework of OTB, giving a homogeneous interface for the OTB user: there is no need to learn the interface of each underlying library.

The core of the OTB system is coming from ITK [11] which has proven its efficiency for medical image processing. Most of the algorithms for segmentation and registration have been well tested in this context. For the Support Vector Machine (SVM), OTB includes the libSVM [12] library. The graph representation is done using the Boost library [13].

Sensor models, map projections and DEM handling capabilities are provided by OSSIM [14]. The sensor models are integrated as a special type of ITK transforms which enable



(a) Multispectral image



(b) Road network extraction

Fig. 9. Road extraction example combining radiometric and geometric features.

| Libraries | Functions |
|-------------|--|
| ITK | Architecture, Segmentation Registration |
| libSVM | Support Vector Machines |
| Boost | Graph representation |
| OSSIM | Sensor models, DEM handling |
| 6S | Radiometric corrections |
| Gdal | Image formats |
| dxflib | DXF format |
| OpenJPEG | JPEG 2000 format |
| libLAS | LIDAR data access |
| libSiftFast | SIFT implementation |
| Edison | Mean Shift clustering |

TABLE I

OPEN SOURCE LIBRARIES USED IN OTB AND THEIR FUNCTIONS

an elegant structure for the orthorectification. Radiometric correction capabilities are provided by 6S [15]. 6S is originally a Fortran code that has been automatically translated in C to enable integration into OTB.

Most image formats are read through GDAL [16], enabling OTB to read and write numerous image formats. DXF files are handled by the dxflib library [17]. For the case of JPEG 2000, as options required by satellite images were not available in any JPEG 2000 implementation with compatible license, CNES participated in the development of OpenJPEG [18] to add these capabilities.

The implementation of the SIFT detector is complex and difficult to validate. The LibSiftFast [19] made the integration of SIFT in OTB straightforward. The Mean Shift filtering and clustering is a recently introduced technique which allows image pre-processing and segmentation yielding very interesting results [20]. The code implemented by the authors of the algorithm, called Edison [21] is available in OTB.

As we can see, many algorithms are available and well-tested in the open-source community. Therefore, they can be integrated into an existing project at marginal cost. When only a few options are missing in projects integrated in OTB, the project team usually welcomes contributions to add them.

IV. ALGORITHMS READY FOR PRODUCTION

Without using established methods for software development, it is hard to combine efficiently the work of several people. Sharing software is not easy: each computer, due to its hardware and software configurations, is more or less unique. Without proper planning, it can take a few days to migrate a program from one computer to another one.

A second issue is coming from the size of the data to process. When designing an algorithm, it is unpractical to run it on the full size image. However, after the algorithm has been proven to be working well on the small test data, one has to ensure that it will still perform properly with full-size data.

Finally, with the growing popularity of multi-core processors it becomes easy to double or quadruple the speed of a program, provided it was coded in the right way to enjoy this benefit. This is a very technical issue which involves much more than remote sensing expertise.

Here are some of the strengths of OTB which provide a rigorous framework to alleviate the hassle of such considerations.

A. Multiplatform

The library is multiplatform and works under different operating systems (Linux, Unix, Windows, or MacOS X) and different architectures (32 or 64 bits) to get rid of hardware constraints. The multiplatform aspect is also very important because it imposes to follow strict design and coding rules thus leading to a robust system less sensitive to particular platform specificities.

B. Large data processing

One frequent problem when going from the research algorithms to the real application is the difference in the data



size. A satellite image can reach billions of pixels often in several spectral bands. In this situation, it is unreasonable to load the whole image in the computer memory to process it. This is even truer for high resolution imagery based mapping applications, where, in order to cover the area of interest several satellite scenes are usually used.

Streaming techniques enable one to read, process and write the result progressively without having to load the entire image into memory. Most image processing operations work locally and are compatible with streaming. Streaming capabilities are included in OTB transparently for the user, thus enabling easy processing of huge images.

C. Efficient data processing

Since images are divided into separate streams and since most current processors have two, four, or even more, cores, it is tempting to use these capabilities to process data in parallel and to reduce computing time. This property is called multithreading. Once again, OTB automatically enables multithreading when it is possible. This is especially valuable for work on computer clusters where the combination of several processors helps to greatly reduce the total processing time. These operations and the balancing on the different computing units is transparent for the OTB user, thus removing most of the burden of multithreaded programming.

D. Validation

OTB is a complex system and needs to be validated both at a computer engineering level and at a functional level. Automation is the key factor for an efficient validation. Every atomic function has several tests to check the non regression and the validity of the results. All these tests are executed every night on 15 different platforms with different compilation options. Impact of modifications on one small part of the code is clearly visible on the whole library for the different compilers and compilation options.

A more difficult part, but critical for the OTB user is the validation of the proposed functions from an application point of view: not only make sure that a given function is doing something but make sure that it is doing it well. Basically, it is not because a program returns a good looking result that the program is correct. For this validation, in-depth knowledge of remote sensing is compulsory. That is why it is particularly important to start with existing and validated developments or to rely on experts for each domain. For example, an image processing specialist can't qualify a classification algorithm for forest types without relying on a forest specialist. This validation is done through the availability of user friendly applications.

V. PERSPECTIVES

For information extraction from remote sensing images the concepts used are often difficult to handle and many users rely on commercial products. However, to truly master the process, a hands on approach is unavoidable.

In this context, OTB allows the user to practice and experiment with real data and real tools and can be used in several situations:

- for end-users:
 - easy access to a wide range of well tested algorithms;
- for engineers:
 - efficient development of new remote sensing applications;
 - quick evaluation of the performance of a particular algorithm on a specific type of data;
- for researchers:
 - fast prototyping of new algorithms;
 - library of existing algorithms to compare the results with a new one;
 - easier to share a new algorithm to increase the impact of a publication;
- for professors: teaching of image processing;
- for students: benefit from many heavily-tested algorithms popular in the literature.

This is an ambitious goal and it can't be attained without a wide participation. The Orfeo Toolbox (OTB) tries to federate several initiatives borrowing a lot from existing projects and with the contributions of many researchers. The ORFEO Toolbox is valuable for all people working in the remote sensing imagery community. Releasing it as an open source software, CNES hopes to benefit from the contribution of many specialists to help grow the practical use of satellite imagery. The first feedback has been very positive and open source development seems to be particularly suitable to increase the usability of cutting-edge algorithms.

A special session will be held on *Open Source Initiatives for Remote Sensing* at IGARSS 2009 and will be particularly focussed on OTB. Join us in Cape Town to meet OTB users and contributors.

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2006 at Rensselaer Polytechnic Institute, Troy, NY, USA. From 2006 to 2008, he was a research engineer at CNES, the French Space Agency, focusing on information extraction for high resolution optical images. Since that time, he is also deeply involved in the development of the open-source Orfeo Toolbox. In October 2008, he moved to Singapore at CRISP, National University of Singapore, where he now is tackling new challenges for remote sensing in

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