An end-user-oriented framework for RGB representation of multitemporal SAR images and visual data mining

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ABSTRACT

In this paper, we present a new framework for the generation of two new classes of RGB products derived from multitemporal SAR data. The aim of our processing chain is to provide products characterized by a high degree of interpretability (thanks to a consistent rendering of the underlying electromagnetic scattering mechanisms) and by the possibility to be exploited in combination with simple algorithms for information extraction. The physical rationale of the proposed RGB products is presented through examples highlighting their principal properties. Finally, the suitability of these products with applications is demonstrated through two examples dealing with feature extraction and classification activities.

Keywords: synthetic aperture radar, self-organizing maps, image enhancement, classification, multitemporal SAR, Level-1α products, Level-1β products

1. INTRODUCTION

Digital reconstruction of the world for data analysis, planning and monitoring is the most important aspect of sensing. Today, we can exploit a number of sensors acquiring data throughout the whole electromagnetic spectrum. However, when the acquisitions are made beyond the visible, the human-machine interface becomes fundamental for a correct interpretation of data, especially in multi-disciplinary contexts. Remote sensing is one of them, involving a large variety of professionals with different expertise and background. When a processing chain is designed, it is not conceivable to not take into account of the destination of data, which is often found in the end-user or decision maker community, in which one of the primary need is to interact with data even at visual level. Therefore, operating outside the visible spectrum, an effort is necessary to make data understandable to the "general public".

Dealing with synthetic aperture radar (SAR) data, one of the issues preventing their diffusion in applicative scenarios is the high technical expertise required to interpret and process images as they are usually delivered by space agencies and/or data provider. This paper presents a new framework for the generation of SAR RGB composites derived from multitemporal processing (see Reference 1 and 2 for further details). Its aim is the introduction of a user-friendly intermediate product level between the classic Level-1 and Level-2, which are those carrying an information directly linked to a physical property of the imaged surface.

The need to restore users' centrality in remote sensing data analysis has been suggested by several authors in the past literature (see as an example Refs. 3, 4, and 1). In fact, the use of "black box" algorithms (often characterized by a strong parametric nature) limited the use of remote sensing data in academic contexts, in which research needs are dominant. Industrial applications as well as large international projects for the production of continental/global maps, are carried out with strong human supervision (see as an example the Urban Atlas of the European Environmental Agency[5] or the CORINE land cover project[6]). Therefore, it is desirable the design of new products allowing for a better interaction with data and the exploitation of simple algorithms for information extraction, which are the most popular tools in the end-user community.[7]

The work is organized as follows. In Section 2, the framework for the generation of the RGB products is briefly recalled, and products main characteristics illustrated through examples. Some applications exploiting the new RGB products are addressed in Section 3. Conclusions are drawn at the end of the work.

2. FRAMEWORK AND PRODUCTS

The framework allowing the generation of the proposed RGB products have two objectives: i) to build a set of images geometrically and radiometrically comparable, and ii) to implement a fusion optimizing the interaction with data. In the following, two classes of products, having different characteristics, will be introduced: the Level-1α product class, and the Level-1β product class. Both of them aim at creating an intermediate product level between the classic Level-1 and Level-2 products, and at lowering the expertise required to handle data through an user-friendly rendering of the complex scattering mechanisms between the electromagnetic field and the Earth surface.

2.1 Level-1α products

Level-1α products are bi-temporal images. They are particularly oriented toward change-detection applications. In fact, they are composed by two intensity images and by the interferometric coherence (obviously computed exploiting complex data). One of the intensity images plays the role of the reference situation, i.e. the condition with respect changes are evaluated.

The rationale of these products will be clearer with the following example. We consider a semiarid environment in Burkina Faso (western Africa). In this area, the climate is characterized by a long dry season (at the end of which the landscape is almost completely dry), and by a short (but intense) wet season, which favors the growth of vegetation, as well as cultivations and water harvesting.[8]

The product depicted in Figure 1 has been obtained loading on the blue band the reference image, acquired in correspondence with the peak of the dry season (in this area it occurs at the end of April). On the green band, an image acquired during the wet season is placed (we will refer to it as test image). This composition leads to the following interpretation of the rendered colors:[1]

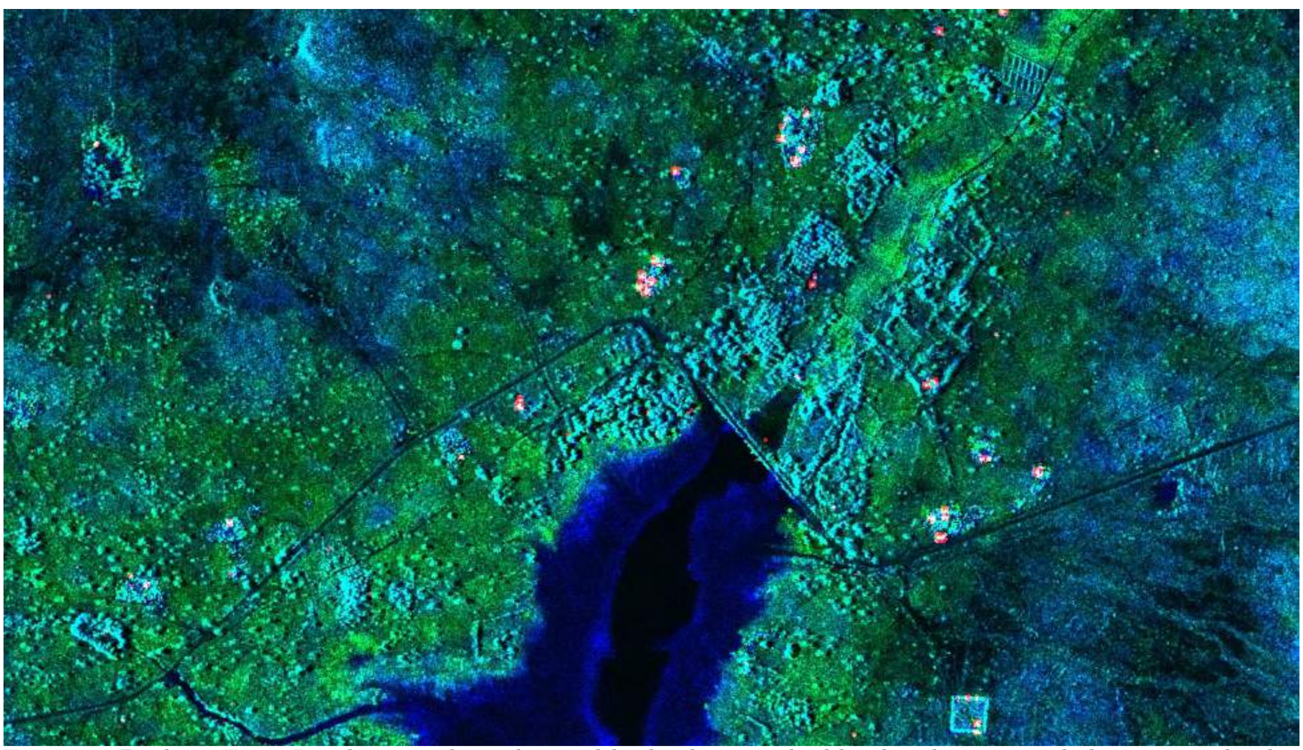


Figure 1: Burkina Faso: Level-1α product obtained by loading on the blue band an image belonging to the dry season and on the blue band an image belonging to the wet season. This combination allows for rendering in natural colors the most important features of the study area, i.e. water and vegetation. The red band is reserved to the interferometric coherence. It is useful to identify small human settlements.

- A balance of the blue and green channels (i.e. a balance of the backscattering of the reference and test acquisitions) indicates unchanged land cover. Bare soils are rendered in a cyan tonality (identifiable with the Prussian blue color). Permanent surface water is rendered in black;

- The green color identifies areas interested by vegetation growth due to volumetric enhancement of backscattering;[9]

- Pure blue color identifies areas covered by water during the acquisition of the test image (i.e. during the wet season). In fact, in this case, the terrain backscattering occurring during the dry season (when the basin is empty) is dominant;

- Bright targets identify small settlements due to the high contribution of all the bands involved in the composition.

This composition allows for rendering in natural colors the most important features of the study area, i.e. water and vegetation. As a general comment, an important property of Level-1α imagery is the stability of the chromatic response with respect to variation of the scene and/or of the climatic conditions.

To prove this claim, consider the scene reported in Figure 2a. It depicts the city of Castel Volturno (southern Italy), which has a temperate Mediterranean climate. The reader should note as the semantics carried by the colors of the composition is stable. In fact, green means growing vegetation; Prussian blue means bare soil; the built-up feature is rendered in white; the sea surface is rendered in black.

The image depicted in Figure 2a has a strong blue component, which move the composition away from the natural color palette. However, this band disposition is particularly well-suited for a semiarid environment, where it allows for rendering in blue color temporary water bodies. In a temperate environment, where this phenomenon is less important, it could be desirable to retrieve a significant red component on terrains. This can be made by exchanging the role of the reference image and of the coherence bands. This way, the product depicted in Figure 2b is obtained, having a rendering closer to the natural color palette.

(a) (b)

Figure 2: Castel Volturno (Italy): (a) Level-1α product obtained using the same band disposition adopted for Figure 1, and (b) Level-1α product obtained by exchanging the role of the reference image and of the coherence bands. In a temperate environment, the last solution allows for obtaining a composition closer to the natural color palette.

Level-1α imagery is very well-suited for supervised classification,[7] change-detection,[10] and feature extraction applications.[11] An example concerning the built-up feature extraction will be provided in Section 3.1.

2.2 Level-1β products

Level-1β products are obtained by combining a set of images in an unique RGB frame.[2] These products are particularly oriented toward classification applications, being composed by temporal features which are useful to discriminate objects basing on their dynamics in the considered time span. As for Level-1α imagery, the objective is to provide a composition recalling the natural color palette, in which the association color-feature is stable, an suitable to be processed with simple algorithms.

In Figure 3, an example of such products is reported. It concerns a subset of the Castel Volturno scene previously discussed. The product is built loading on the red band the time series variance; on the green band the mean intensity; on the blue band a combination of the saturation index (i.e. the backscattered energy span computed pixel-wise) and of the interferometric coherence. In particular, the coherence is used when its value is above a user-defined threshold, and it is useful to separate the built-up feature from highly variable natural targets.

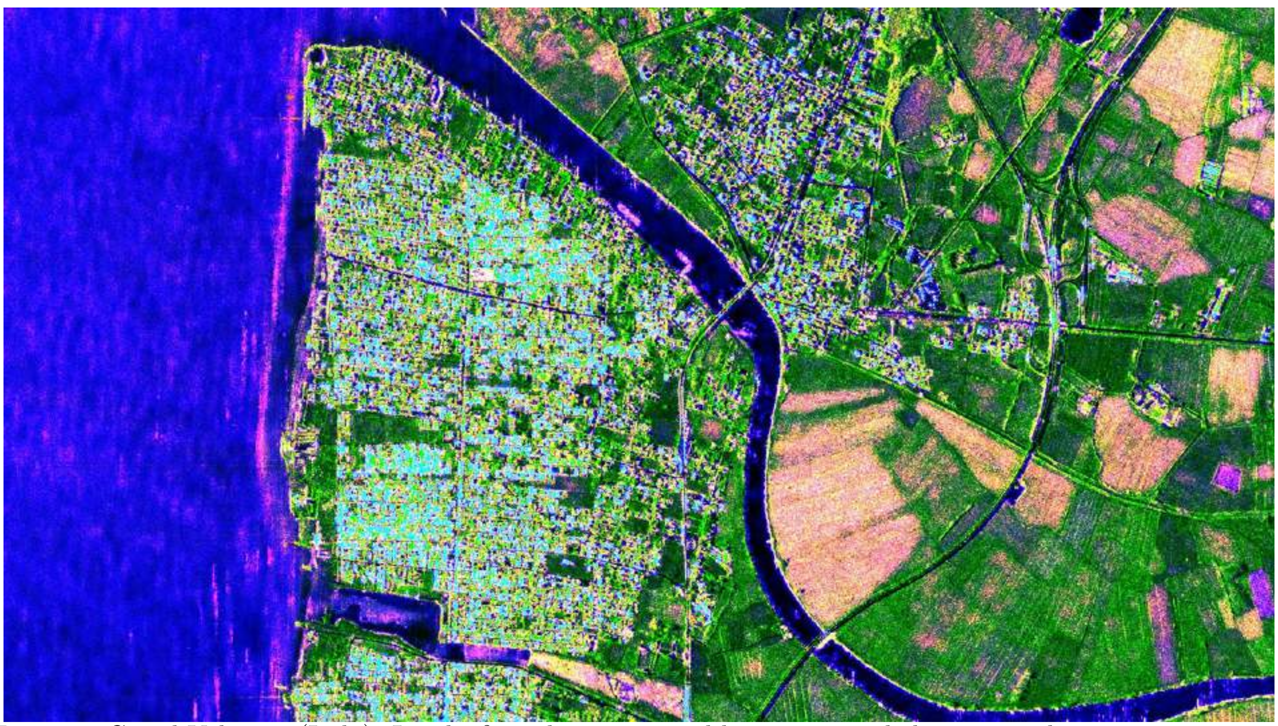


Figure 3: Castel Volturno (Italy): Level-1β product composed by six images belonging to the summer season of the year 2010.

As for Level-1α imagery, the colors restituted by the composition have a precise physical explanation. As an example (see Reference 2 for further details):

- The sea surface is rendered in blue due to the Bragg scattering causing a significant contribution of the saturation index;
- Unchanged land cover/grasslands are rendered in green due to the dominance of the mean intensity;
- The built-up feature is rendered in cyan due to the combined contribution of the interferometric coherence and of the mean intensity;

- Growing crops are rendered in yellow or pink due to a significant contribution of the variance and/or of the saturation index, depending on the kind of cultivation and on the harvesting time.

An example of application exploiting these product is provided in Section 3.2.

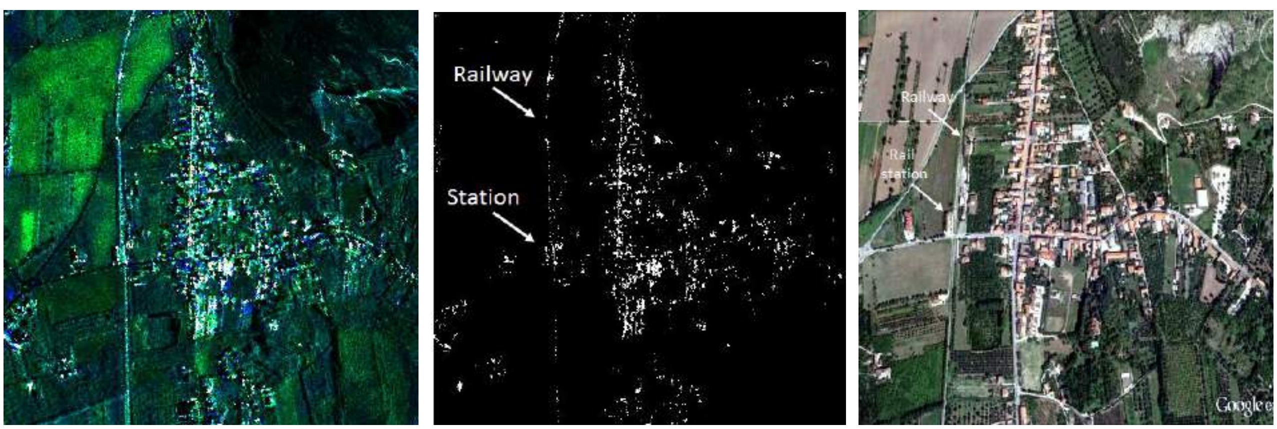
3. APPLICATIONS

In this Section, some applications exploiting the products introduced in Section 2 are addressed. In particular, built-up feature extraction using Level-1α products is faced in Section 3.1. A land cover mapping application using Level-1β products is carried out in Section 3.2.

3.1 Built-up feature extraction

Level-1α products can be effectively exploited for the extraction of the built-up feature.[11] In fact, this feature, thanks to double bounce scattering phenomena,[12] has a very clear response (and very well separated from all the other scene objects) in the RGB composition. In fact, in Level-1α images, buildings are represented in white, due to the contribution of both intensity and coherence channels.

As suggested in Reference 13, in Level-1α imagery, the built-up feature can be simply identified through thresholding of the Building Index map, which is a band product involving the intensity and coherence channels. This procedure is detailed in Figure 4. In particular, in Figure 4a, the input Level-1α product is shown (the algorithm for the enhancement of the built-up area suggested in Reference 11 has been applied). In Figure 4b, the building mask after the thresholding of the building index map is reported. Finally, a Google Earth view of the study area is reported for a qualitative comparison in Figure 4c.



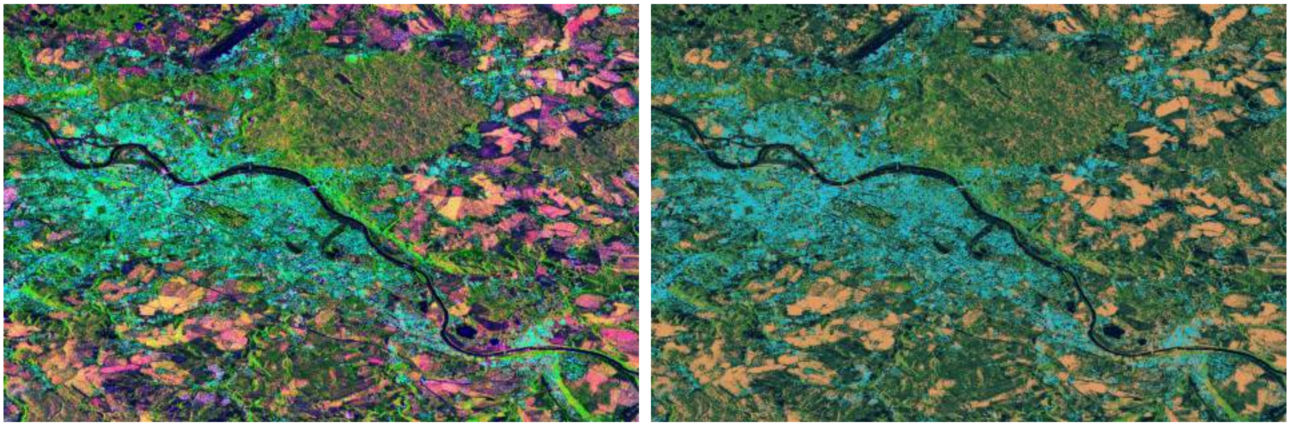
(a) (b) (c)

Figure 4: Built-up feature extraction from Level-1α images. (a) Input RGB product, (b) built-up mask obtained through thresholding of a suitable band product involving intensity and coherence channels, and (c) correspondent Google Earth view for qualitative comparison. The study area concerns the town of Sant'Angelo in Formis (Italy).

3.2 Land cover mapping

As stated in Section 2.2, Level-1β products can be effectively exploited for supervised/unsupervised classification. Here we want to highlight the suitability of this class of products with neural net classification, with particular reference to Kohonen's self-organizing maps (SOMs).[14]

In Figure 5a, we show the Level-1β product we used as input for the classification. It concerns the city of Dresden, and has been obtained by fusion of six images acquired by the Sentinel-1A satellite between October and December 2014. The product resolution is about 15 meters.



(a) (b)

Figure 5: Dresden (Germany): (a) Level-1β product obtained by fusion of six images acquire between October and December 2014 from the Sentinel-1A satellite, and (b) its 5-class land cover map generated through SOM clustering. The use of a SOM allows for obtaining a clustered product which looks quite similar to the input image. This way, an immediate semantic transferring between the two images is possible. In this case, the color-feature association in the cluster map is the following: cyan-urban area, orange-growing vegetation, dark green-woods, light green-grassland, black-water/weak scatterers.

In Figure 5b, a 5-class land cover map obtained through SOM clustering is shown. The class-object association is the following: cyan-urban area, orange-growing vegetation, dark green-woods, light green-grassland, black-water/weak scatterers.

The reader should appreciate as the clustered product looks quite similar to the input RGB product. This is due to the training mechanism of the Kohonen net, in which the training sets to be presented to the network are randomly selected within the input dataset, which, in this case, is a RGB image. This way, as detailed in Reference 2, an immediate semantic transferring between the two products is possible.

4. CONCLUSIONS

In this paper, we presented a new framework for RGB composition of multitemporal SAR data. The aim of our processing chain is to provide products whose principal characteristics are the interpretability and the possibility to be exploited in combination with standard algorithms for information extraction.

The physical foundations of the proposed Level-1α and Level-1β products have been demonstrated through examples showing that the rendering is guided by electromagnetic scattering mechanisms. In some cases, it is consistent with the expectation of the operator, being very close to the natural color palette. For other objects, in which the natural color display is not guaranteed, the association color-object, being physical-based, is stable for variation of sensor, scene, and climatic condition.

The suitability of our RGB products with applications has been demonstrated through two examples dealing with built-up feature extraction and classification. In both cases, the information was reached through the exploitation of simple, end-user oriented techniques.

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