COMBINED ANALYSIS OF ERS-1 SAR AND VISIBLE/INFRARED REMOTE SENSING DATA FOR LAND COVER/LAND USE MAPPING IN A TROPICAL ZONE: A CASE STUDY IN GUINEA

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ABSTRACT

This paper presents the preliminary results of an assessment of the use of ERS-1 SAR (Synthetic Aperture Radar) data for land use mapping in a savannah zone of West Africa. Optical data (Landsat, Spot) were compared with microwave data (SIR-A, ERS-1). Landsat TM data were initially geocoded with a DTM and then registered to ERS-1 data. Standard and adaptive filters were applied to SAR data and the results compared. Two methods of optical/microwave data integration were tested. It appeared that land use classes identification was not satisfactory using single date ERS-1 data. Good results were obtained in the case of a multitemporal SAR approach and particularly when combining dry season optical data with rainy season SAR data.

Keywords: remote sensing, land use mapping, SAR imagery interpretation, crop mapping

1. INTRODUCTION

This paper presents the first results of a technical study to assess the usefulness of ERS-1 SAR images for land cover/land use mapping in West Africa. This study was undertaken as a joint project between FAO (Food and Agriculture Organization of the United Nations), ESA (European Space Agency) and MARA (Ministère de l'Agriculture et des Ressources Animales de Guinée, Direction Nationale des Forêts et des Chasses). The project also includes training activities in Guinea. Based on a study on the complementarity of microwave and optical remote sensing in Tunisia (EOQ, 1991), this project started soon after the launch of ERS-1, using early SAR data. The interest of FAO with respect to radar imagery in tropical and equatorial zones is related to the limitations of optical sensors in regions with a persistent cloud cover and results from the important contributions of airborne projects such as Radambrasil, NIRAD (Nigeria), Proradam(Colombia) to natural resources inventory and mapping.

2. OBJECTIVE

The principal objective of this study is to assess the usefulness of ERS-1 SAR images for land use/land cover mapping in Guinea. Specific objectives are:

- the assessment of the information content of spaceborne optical and microwave data, considered separately;
- the assessment of the information content of a co-registered set of optical and SAR data.

3. TEST AREA PRESENTATION

The test area (centre coordinates 10°32' Latitude North, 9°20' Longitude West) is a 30 km x 30 km square located north of Kankan (Guinea). It is crossed by the Milo River, a tributary of the Niger and includes the Bankalan watershed (182 km²), which is a site of an EEC agricultural development project. The relief is flat or slightly undulating, with a mean elevation of 391 meters, a minimum of 355 meters and a maximum of 460 meters. The climate is tropical of soudanian type, with the rainy season from April-May to October. The mean annual rainfall in Kankan during the 1973-1984 period was 1411mm of which 92% fell in a 6 month period, thus limiting agricultural production. The main soils are Ferralsols, Fluvisols and Hydromorphic soils (FAO-Unesco Classification). "Bowal" soils are also found here with the upper horizon substituted by a lateritic crust and generally being associated with grassland savannah. With respect to the 1:500 000 scale Forestry Map of Guinea (DNFC/BDPA/CTFT, 1989), the test area falls within the following categories:

- agricultural zone with intense clearings,
- tree savannah,
- mosaic of woodlands and tree savannah.

The region is characterised by environmental degradation due to bushfires and domestic fuelwood collection. Rice is the main agricultural crop and is cultivated in the wetlands, but productivity is low due to scarce rainfall at the end of the cycle and low fertility on the hill slopes. Rice is also grown in the Milo flood plain where fields are prepared in order to extend the flood period. Figure 1 shows the location of the test area.

Proceedings First ERS-1 Symposium - Space at the Service of our Environment, Cannes, France, 4 - 6 November 1992
ESA SP-359 (March 1993)

Fig.1: Test area location

4. DATA USED

This study was carried out using satellite data (microwave and optical), existing maps (topographic and thematic maps) and ancillary data. Table 1 summarizes the satellite data used. The ERS-1 SAR data used were Fast Delivery data (FDC) processed to 3-looks and with a 20 m x 16 m pixel size. The ERS-1 data were acquired during the commissioning phase by the Maspalomas receiving station and then processed at ESRIN, Frascati. The data were acquired during descending orbits. In the first part of this project, special emphasis was given to the analysis of FDC SAR products as in the past data delivery delay has been identified as a limiting factor for operational use of remote sensing in agriculture and land use change detection. Landsat TM, SPOT XS and SIR-A data were acquired in October-November at the beginning of the dry season, while ERS-1 SAR data were acquired in August-September during the rainy season. Optically processed SIR-A data were scanned from a 1:500 000 scale film at 50 μm intervals. The SPOT data had been preprocessed at level 1b which is adapted for thematic studies (500 meters RMS localization error in vertical viewing).
Ground truth data (field observations and photographs) were collected during a visit to the test area in April 1991, i.e. during the dry season, after the end of the rice harvesting period.

SENSOR	DATE	PIXEL SPACING
SIR-A	14 Nov.1981	40m x 40m
Landsat TM	12 Dec.1988	30m x 30m
SPOT HRV	14 Nov.1986	20m x 20m
ERS-1 SAR	19 Aug.1991 28 Aug.1991 24 Aug.1991	20m x 16m (FDC) 20m x 16m (FDC) 20m x 16m (FDC)

Tab.1: Satellite data used

The following maps were used:
- Vegetation Map, 1:5 000 000 scale (FAO-Unesco, 1981),
- Soil Map of the World, Africa Sheet, 1:5 000 000 (FAO-Unesco, 1973)
- Forestry Map, 1:500 000 scale (DNFC/BDPA/CTFT, 1989),
- UTM Topographic Maps, 1:50 000 scale (IGN, 1981).

The topographic maps had been recently updated using the JICA 1977-1979 aerial photo coverage at 1:100 000 scale. In addition, a 1:15 000 scale land use map of the Bankalan watershed was available. The latter had been produced (Kohl, 1992) from the interpretation of a non-controlled mosaic of false colour infra-red aerial photos acquired in October 1982.

5. DATA GEOCODING

5.1 DTM production

The production of a Digital Terrain Model (DTM) and the geocoding of the Landsat TM data were carried out by the Remote Sensing Laboratory of the Department of Geography of the University of Zurich (Bitter, 1991). The DTM covers a 30 km x 30 km zone with a 30 meter grid. It was produced by digitizing 20 meter contour lines from 1:50 000 scale UTM topographic maps of IGN (1981). Some of the contours were scanned but the rest, including spot heights, were digitized manually using ADS software (Arc Digitizing System). The DTM was produced using the ARC INFO TIN software (Triangulated Irregular Network).

5.2 ERS-1 SAR data registration

As reference for the ERS-1 image registration, the first date was chosen. Due to the apparent consistency of image geometry, only translation in X and Y directions were necessary to achieve a satisfactory fit. Since ERS-1 keeps a very stable orbit (often much less than 1000 meters latitudinal difference), images from repetitive orbits can be registered with few match points (e.g. strong scatterers such as single buildings) by a simple relative shift of the images.

5.3 Landsat geocoding

Difficulties were encountered during the Landsat TM data geocoding in identifying ground control points (GCP) in this savannah zone with very few villages or cross-roads. In addition the Milo Valley is periodically flooded. The Map/Image GCP selection was therefore difficult, inspite of the topographic maps having been recently updated using 1979 aerial photographs. Forty-one GCPs were initially selected. After elimination of GCPs with a high residue, 23 GCPs were finally used for the transformation coefficients calculation (least square method). The 23 GCPs give the following statistics:

mean residue (Column direction)	0.47 pixel
mean residue (Line direction)	0.31 pixel
RMS error	0.69 pixel

Image corrections were performed and resampling (1000 x 1000 pixels) was based on cubic convolution. The relative accuracy of the geocoding was verified by superimposing TM band 4 on the original maps.

5.4 Landsat/ERS-1 SAR data registration

In order to register the SAR data with the already geocoded Landsat TM data, 5 corresponding points were selected in both data sets. The affine coordinate transformation showed a RMS error of 1.89 pixel in the SAR image. This good result is due to the fact that the points were selected along the river (more or less the same height). A better result could not be achieved due to the fact that in the hilly region the SAR geocoding should be done with rigorous radargrammetric methods using a high-resolution DTM. The relief induced geometric distortion is 23.6 meter (more than 1 pixel) in range direction for every 10 meter height difference at mid-range of an ERS-1 scene. Therefore, terrain correction of ERS-1 SAR data is an essential pre-requisite for georeferenced data analysis (Relief distortion = delta Height difference * cot(incidence angle).

6. DATA ANALYSIS

Digital data were analysed on an Erdas System (7.5 Software version) and a Pericolor 2001. The objective of the digital processing was to produce enhanced optical data, SAR filtered data and optical/microwave combinations for visual interpretation. This approach was considered being better adapted to future operational mapping projects for the following reasons:

- FAO Remote Sensing Centre's experience and present activity in the field of thematic cartography using optical satellite data.
- limitations of digital classification of optical/SAR data already observed in a previous study carried out in Tunisia.

6.1 SAR filtering

The multiplicative noise (speckle) of a SAR image causes difficulties to visual perception and interpretation as well as in digital data analysis using established classification algorithms. Generally, a homogeneous region with fully developped speckle is statistically described by only one parameter, its mean value, which is directly proportional to the backscatter coefficient sigma. However the image variation is also directly proportionnal to the backscatter coefficient. This implies that a proper filtering process is needed in a way that intrinsic textures, boundaries, linear features and bright pixels (corner reflectors) are preserved. A measure for the homogeneity of an area (e.g. field) is the coefficient of variation (CV) defined as the ratio of standard deviation sigma per mean value μ. Table 2 lists some examples showing homogeneous areas with lower values. Conventional filters such as Mean, Median, Edge Enhancement Smoothing filters do not account for the scene heterogeneity while adaptive filters (Lee, Frost, MAP) do. Table 3 lists all the filters applied with the corresponding overall results in the statistics. It clearly shows that adaptive filters preserve high values (e.g. maximum value after Frost filtering) and augment the minimum values at the same time. From Table 3 the best conventional filter is the median filter which is confirmed by visual inspection. The more sophisticated and parameterized MAP filter (Nezry et al., 1991) was identified as a very promising filter not only for visual interpretation but also for further automatic image analysis and pattern recognition.

In order to test the processing procedure which might influence the radiometry, a further experiment for visual identification of land use classes was performed with 2 SAR data sets of 1024 x 1024 pixels by comparing:

- A) a subset first filtered then rectified,
- B) a subset first rectified then filtered.

In both cases, an EPS 5 x 5 filter and nearest neighbour method were used. A strong difference was noted between the two final images and the best interpretation results were obtained on A). The analysis of the histograms confirmed that the radiometry of B) had been overmodified in relation to the original image. As a consequence of this observation, filtering techniques should be available before geocoding in a user-oriented SAR processing sequence.

	Size (pixels)	CV = $\frac{\sigma}{\mu}$
Test area	1024 x 1024	0.37776
Wetland	588	0.37242
River	76	0.36285
Flooded rice, begin.of cycle	614	0.31408
Savannah	1750	0.31513
Pond	136	0.35593

Tab.2: Coefficient of Variation (CV) of selected samples, 1024 x 1024 pixels, ERS-1 FDC, 19 August 1991

	Minimum	Maximum	Mean	σ
Original data	0	32767	1943	734
Mean Filter 3 x 3	171	16760	1943	478
Mean Filter 5 x 5	171	7562	1943	361
Mean Filter 7 x 7	136	5577	1943	308
Median Filter 3 x 3	171	15637	1915	482
Median Filter 5 x 5	171	5952	1895	379
Median Filter 7 x 7	136	5577	1885	309
Lee sigma Filter	171	23056	1872	515
EPS Filter	157	17906	1870	536
Frost Filter	52	30778	1942	540
Li Adaptive Median Filter 5	171	5676	1942	359

Tab.3: Statistical parameters of original and filtered ERS-1 SAR FD image (1024 x 1024 pixels subset, 19 August 1991)

6.2 Visual interpretation of optical and microwave data

The visual interpretation of the satellite data was performed using 1:100 000 scale photographic enlargements from standard film. Complementary observations were done on digitally enhanced products. Landsat TM and SPOT data were acquired during the dry season. Using Landsat TM False Colour composite 4/3/2 and Spot XS 3/2/1 riverine forests can be delineated and therefore the drainage pattern of the zone; it is also possible to identify temporary ponds, roads, villages, burnt areas and agricultural zones. On SPOT XS data of 14 November, the difference between late rice in the Milo flooding plain and rainfed rice already harvested is evident due to the strong reflectance of soil and straw residues. Satisfactory results can also be obtained from the interpretation of Landsat TM 4/5/3, especially for the delineation of moist zones.

ERS-1 SAR images were acquired during the rainy season (19 August, 28 August and 24 September) which is also the period of maximum cloud cover. The visual interpretation of non-filtered data gives very poor results due to the presence of speckle. On SAR filtered data (MAP, CESR), using single date acquisition, it is possible to identify agricultural zones but without separating flooded rice from rainfed rice or other crops. The drainage pattern can not be delineated as riverine forests do not appear. Results improve significantly in the case of a multitemporal approach with a colour combination of the three dates displayed in red, green, blue respectively. There is a very strong difference in the radar backscatter of flooded rice (Fig.2) between 19 August (high backscatter), 28 August (low backscatter) and 24 September (low backscatter). If on the first date crop/water interactions are present, on the following dates, due to the growth of the rice and to the limited radar penetration, only the backscatter component from the upper layer of the crop is observed. This observation is in accordance with the evolution of irrigated rice crop radar backscatter observed during the crop cycle using airborne radar data in the Camargue, France (Laur, 1989). Therefore it becomes easier to differentiate flooded rice from other crops; the agricultural field pattern can be extracted from dry season optical data and information on the development stage of the rice crop can be extracted from SAR images. On the multitemporal SAR image it is possible to estimate the extent of the flood of Milo River and the temporary ponds.

A visual comparison was done between ERS-1 SAR FD image and SIR-A 1:100 000 scale paper print. The time period of 10 years between the two radar image acquisitions is a limiting factor, although in this zone the land use does not vary much from year to year. The seasonal variations are more marked. SIR-A image was considered to have a poor information content due to optical processing and 40 meters spatial resolution. Nevertheless, riverine forests appear clearly on L band SIR-A data and can not be detected on C band ERS-1 data (Fig.3). This confirms the usefulness of L band for the separation of certain land use classes and stresses the usefulness of future combined ERS-1/JERS-1 SAR data evaluation.

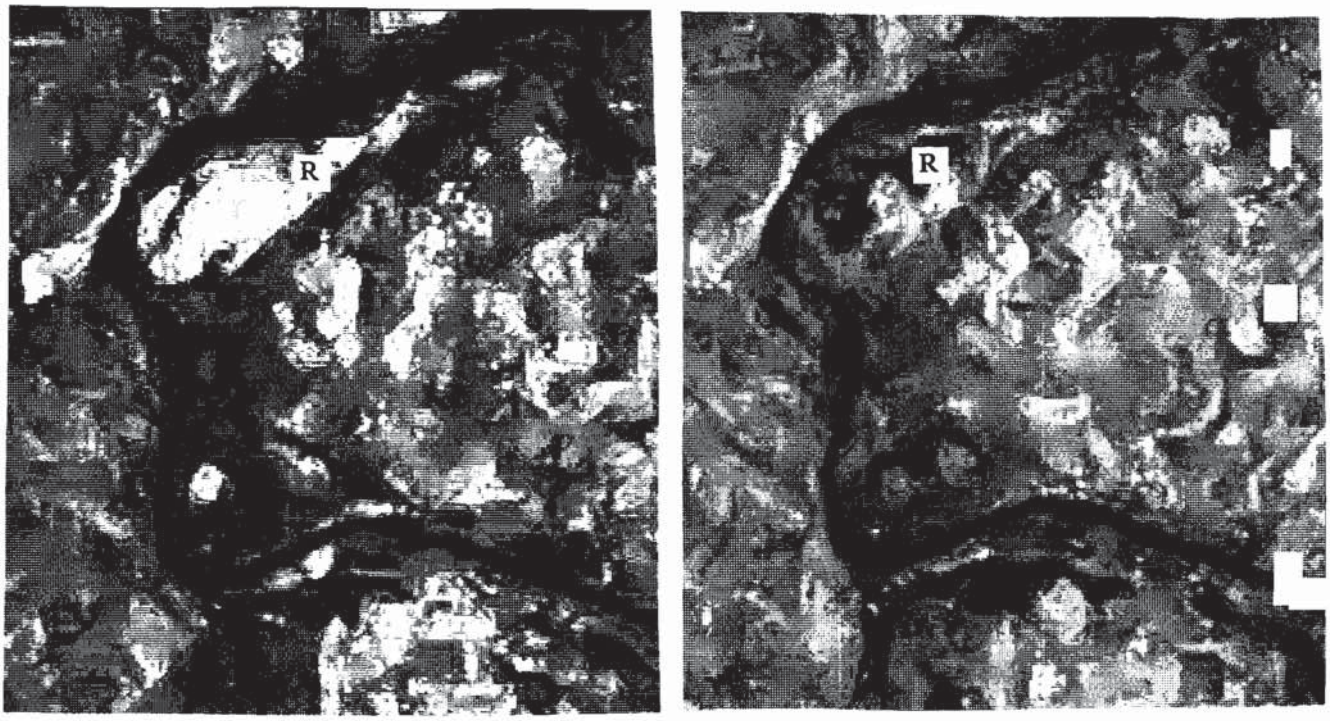

Fig.2: Backscatter variation of Flooded rice fields (R)
(ERS-1 SAR FD images, 256 x 256 pixels at full resolution)
Left: 19 August 1991, high response
Right: 28 August 1991, low response

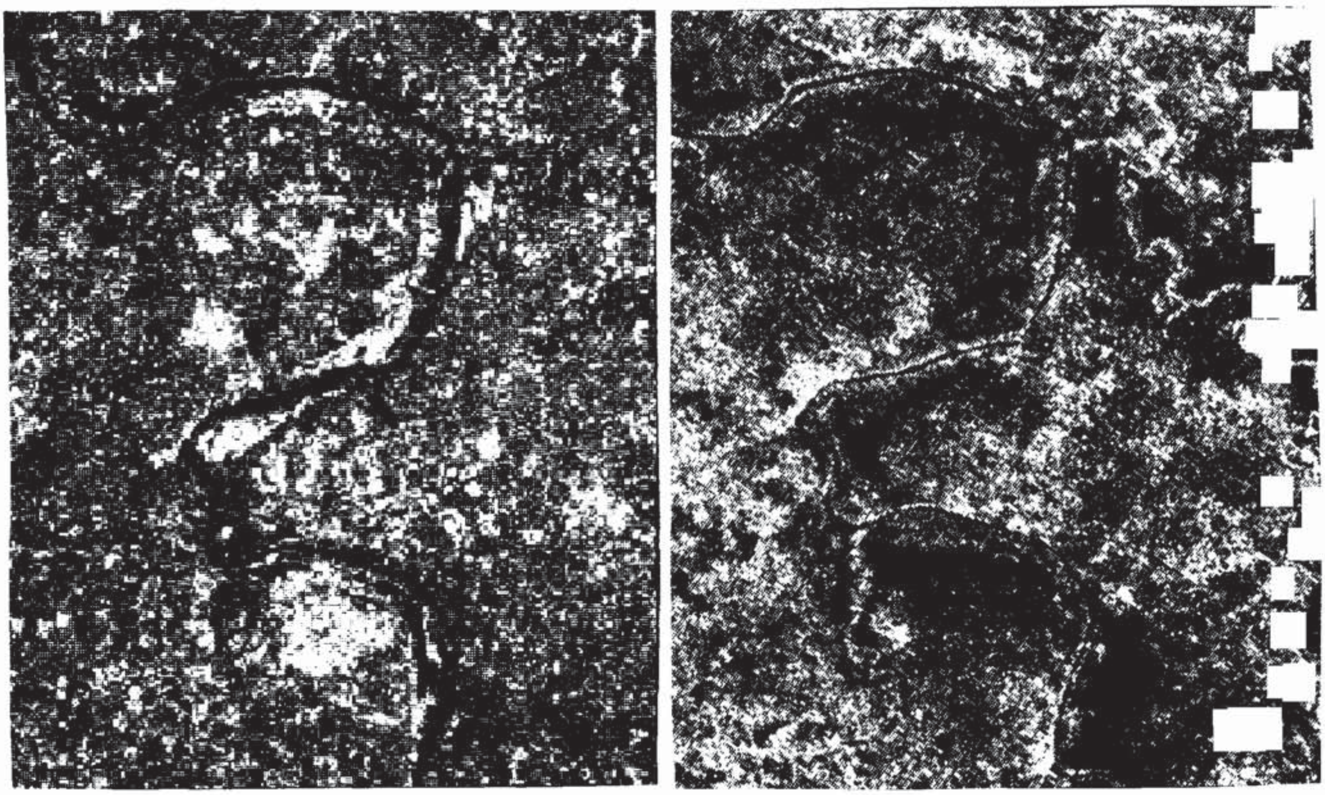

Fig.3: Riverine forest on ERS-1 (left) and SIR-A data (right)

6.3 Integration of Optical and SAR data

Two methods of merging these complementary data sets were tested in this study.

- In the first case, a colour composite Red/Green/Blue as TM4/TM3/ERS-1 SAR was produced, i.e. a false colour composite in which the TM2 band (green component of the electromagnetic spectrum) was substituted by the respective radar image data. The visual interpretation of the various colours enables a correlation between properties of the surface and its response on microwave/optical data, e.g. yellowish colours correspond to surface elements with intermediate reflection in NIR and red, and also low SAR backscatter: scarse vegetation and smooth surface. Such areas were identified as sand-banks and some agricultural zones along the Milo river.

- In the second case, the method for merging multisensor image data using a Intensity-Hue-Saturation (IHS) transformation was applied. The infrared false colour composite was transformed from RGB colour space into the IHS colour space, where the intensity component was substituted by the SAR image data. This new image was transformed back to the colour space for display. The advantage of this method is that it combines radar backscatter values with spectral information of 3 optical bands. Classical image interpretation can be applied, i.e.: bright reddish colours correspond to high backscatter (rough surface) with dense vegetation, dark ones to low SAR backscatter (smooth surface), respectively.

In order to check and validate the observations, the existing 1:15 000 scale land use map was used. This land use map was produced from the interpretation of 1: 15 000 scale Infrared aerial photographs (Kohl, 1992).

7. CONCLUSIONS

ERS-1 Fast Delivery SAR data were found useful for land use/land cover mapping purposes in the Bankalan test area which is a savannah zone with rather flat topography and agricultural activity. Multitemporal ERS-1 FD SAR data were considered as satisfactory due to:

- data delivery delay,
- information content especially concerning flood extent quantitative assessment, rice crop identification and monitoring, water saturated zones and temporary ponds identification.

For land use/land cover mapping, interpretation of the C band monospectral ERS-1 FDC data did not provide satisfactory results in the case of a single date interpretation. Problems were encountered for riverine forests identification on ERS-1 data but not on L band SIR-A images. For thematic purposes in this rather flat zone (105 meters height difference in a 30 km x 30 km square), it was possible to register ERS-1 SAR FDC image to a Landsat image taken as reference without SAR terrain correction. Good results were obtained by registration of 3 ERS-1 SAR images in a multitemporal data set. In the case of combined analysis of ERS-1 SAR data with Landsat or SPOT optical data, ERS-1 data allow the interpreter to improve visual interpretation keys, especially using dry season optical data and wet season radar data. In all cases, (SAR monotemporal, SAR multitemporal, SAR and optical data) ERS-1 SAR data had first to be filtered with an adaptive filter in order to reduce image speckle.

8. RECOMMENDATIONS

Based on the preliminary observations of this land use/land cover mapping study, the following is recommended:

- the possibility to have ERS-1 SAR image data filtered on request using adaptive SAR filters at the Processing and Archiving Facilities, prior to image geocoding.

- the presentation on tape of ERS-1 SAR FD image data with pixel (1,1) associated to the North-west corner of the scene, as in the case of Landsat and Spot, independantly of ERS-1 SAR acquisition in an ascending or descending orbit. Since one single ERS-1 SAR FDC image corresponds to 60 Megabytes and as there is a growing use of PCs with limited memory capacity for image processing, this would eliminate the need for the image reflection by the user and would make data integration more straightforward.

- the possibility to require ERS-1 SAR image quick-looks, in analog or digital format (block averaging).

- software: dissemination of product reading programs and filtering/texture analysis software.

- experiments: development of controlled data bases in selected zones including Digital Terrain Model, optical data (SPOT and Landsat) and SAR data (C band ERS-1, L band JERS-1, S band ALMAZ) for environmental thematic studies.

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