

# **AUTOMATIC DETECTION AND CORRECTION OF RANDOM TELEGRAPH SIGNAL ARTIFACTS IN EARTH OBSERVATION IMAGES**

**DARTS**

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*Infrared Detection for Space Applications*

*7<sup>th</sup>- 9<sup>th</sup> June 2023*



## INTRODUCTION

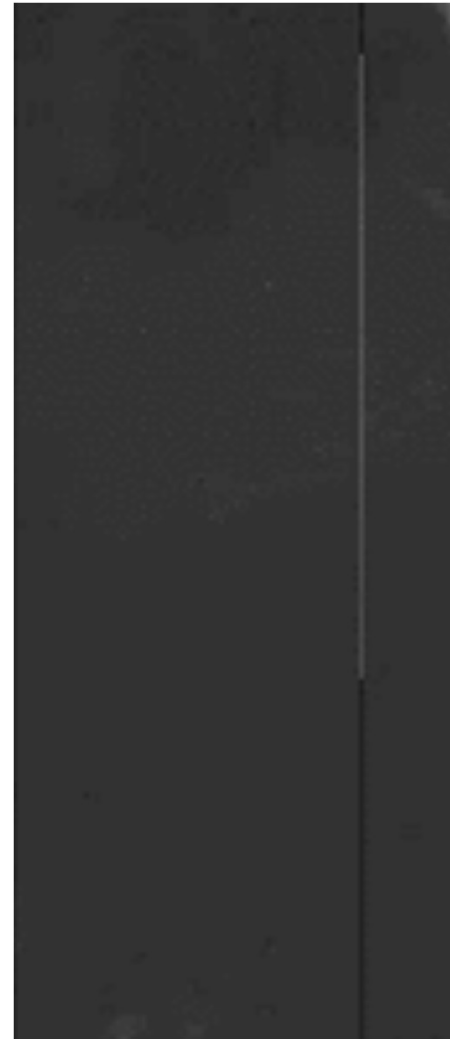
Work supported by CNES (the French Space Agency) R&T program 2020.

Contract with  

Random Telegraph Signal (RTS) : offset random fluctuation.

All semiconductors materials, in particular infrared detectors.  
Increased by space radiation environment.

Case of study : push-broom Earth Observation satellites.  
Single affected cell → “stripe artifact” in a column.



## SUMMARY



Image synthétique d'une contamination RTS  
issue d'une scène Pléiades.  
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- 1- Related work
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- 2 – RTS detection
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- 3 – RTS correction
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- 4 – Experimental results
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## RELATED WORK

- Dark current time series study. V. Goiffon et al. IEEE paper « Multi level RTS in proton irradiated CMOS image sensors manufactured in deep submicron technology »
- Frequency analysis

Without access to dark images during mission :

The aim is to detect the RTS superimposed to a column of EO image.

Similarities with destripping.

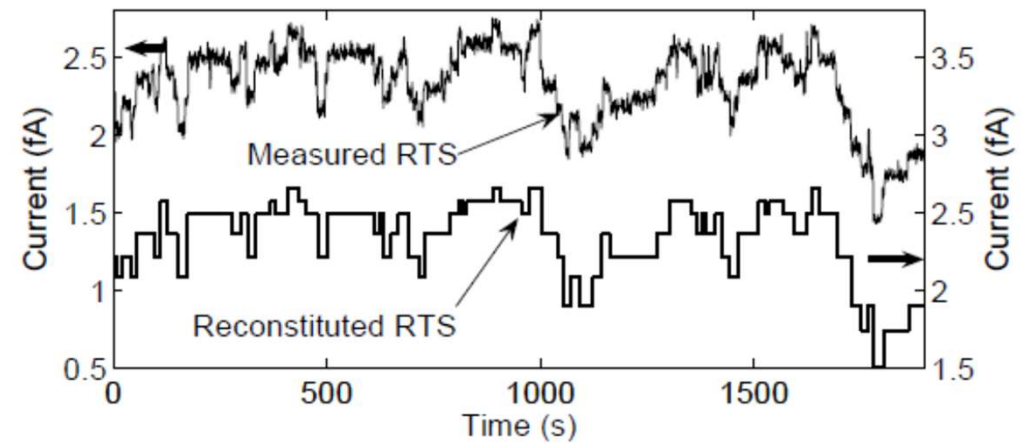


Fig. 3. Result of the proposed algorithm on a proton induced 10 level RTS signal. Both the analyzed pixel dark current and the signal reconstituted by the detection code are presented. All the levels are recognized and most of the transitions are detected.

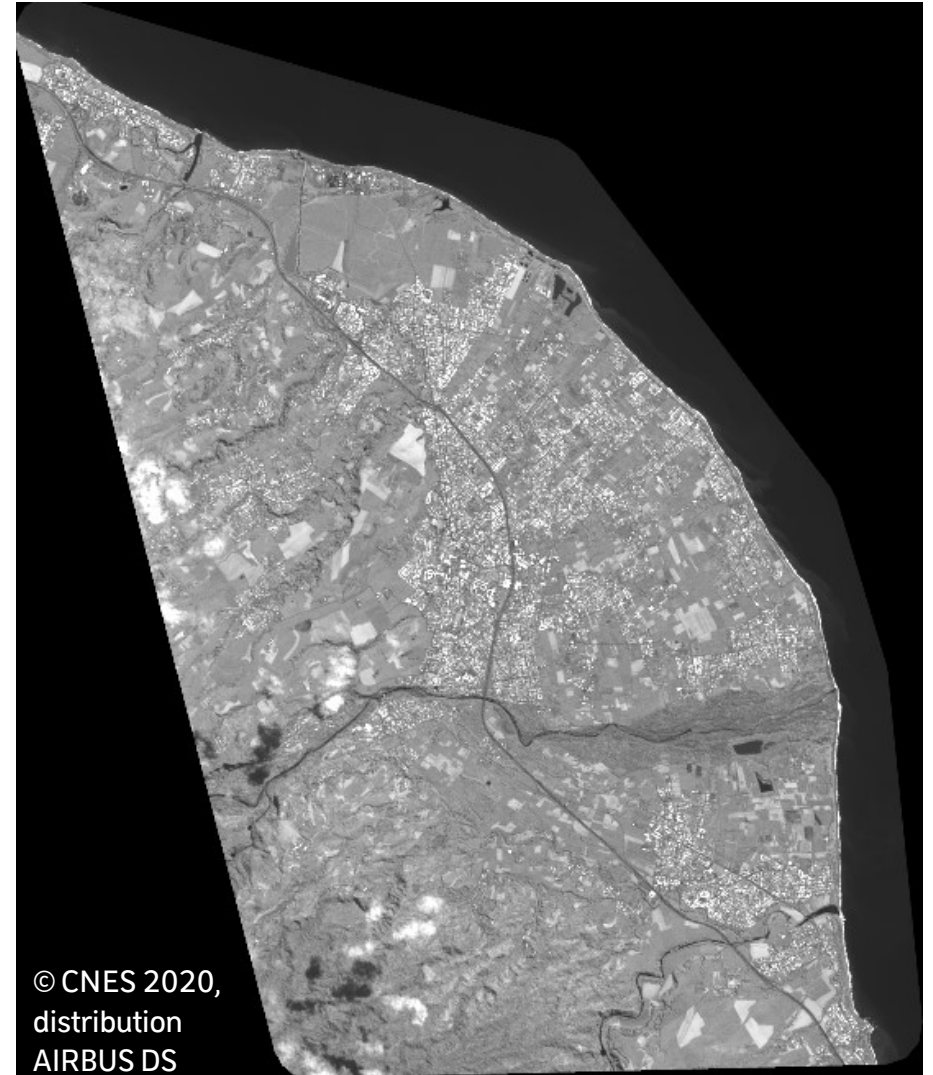
## RTS DETECTION

Means : simulated images based on models :

- RTS levels : random between 2 and 5
- Maximum level : between 0.4 and 30 % of the saturation
- Duration on a level : random
- Additional white noise in 2 cases

Source images : provided by  (Dinamis – Dispositif Institutionnel National d'Accès Mutualisé en Imagerie Satellitaire ([data-terra.org](https://data-terra.org))).

3 sites on La Réunion isle. 3 sets of contaminated images (Low, medium, high). > 1200 RTS columns



## RTS DETECTION

Detection method :

- pre-processing : 3X3 median filter
- Considering  $F_1(x)$  and  $F_2(x)$  as the empirical distribution functions of the residuals of two adjacent columns, we compute the Kolmogorov-Smirnov statistic:

$$D = \max_x |F_1(x) - F_2(x)|. \quad (1)$$

- The null hypothesis  $H_0$  is true if both samples have a similar distribution. This hypothesis is rejected at level  $\alpha$  if:

$$D_N > \sqrt{-\log\left(\frac{\alpha}{2}\right) \frac{1}{N}}, \quad (2)$$

where  $N$  denotes the number of samples, i.e. the number of rows of the image. A given column is then considered as containing a RTS if the test is positive for its both neighbors.



*Main limit : RTS columns must be scarce*



## RTS DETECTION

### Experimental results

TABLE I  
PARAMETERS FOR RTS SIMULATIONS

Parameter	Value or distribution
RTS columns per image	50
Number of levels	$\mathcal{U}\{2, 5\}$
Minimum amplitude $a_{\min}$	0.1% of saturation
Maximum amplitude $a_{\max}$	30% ( <i>large</i> ), 2% ( <i>medium</i> ) or 0.4% ( <i>low</i> )
Values of levels	$\mathcal{U}[-1, 1] * \mathcal{U}\{a_{\min}, a_{\max}\}$
Time constant $\tau$	$\mathcal{U}\{2, \frac{N}{2}\}$
Step duration	$\text{Exp}(\tau)$

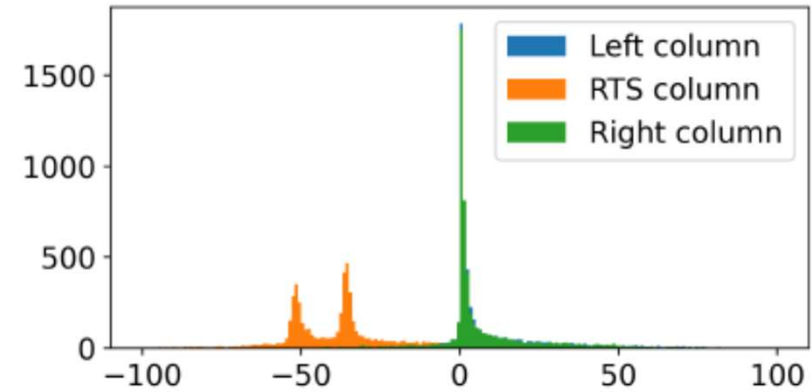


Fig. 1. Histogram of the residue of a 3x3 median filter for a RTS contaminated column and its two neighbours from *medium* dataset.

TABLE II  
DETECTION PERFORMANCE FOR THE THREE CONTAMINATION LEVELS.

Contamination level	Large	Medium	Low
TPR	100%	100%	100%
FPR	0.1%	0.1%	2.7%
F <sub>1</sub> score	98.8%	97.4%	76.9%

## **RTS CORRECTION :**

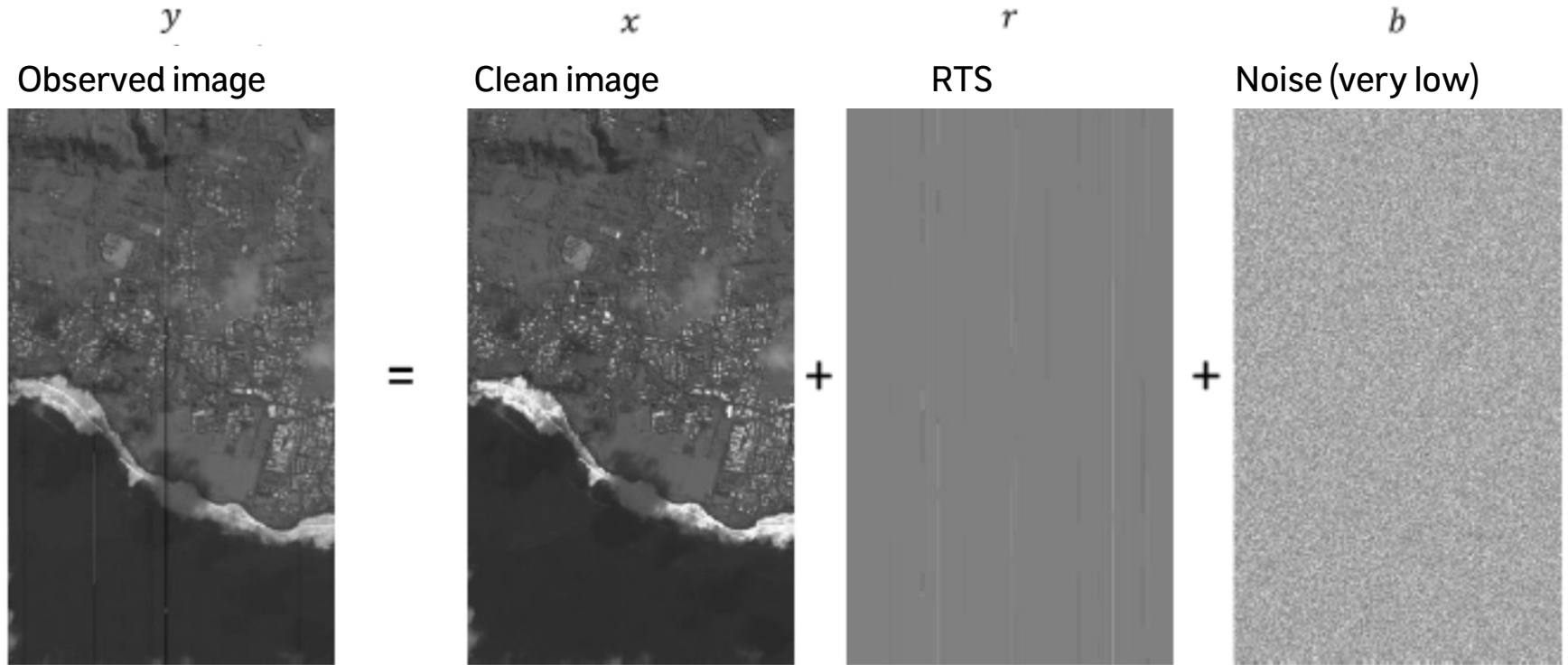
### **a – signal processing approach based on RTS characterization**

- Level detection : Kernel Density Estimation (KDE).
  - **Empirical histogram peak detection → number of RTS levels and values**
- Jump detection : Gaussian Derivative.
  - **Post-processing : segments too small are merged**



## RTS CORRECTION : b – variational image restoration approach

- Hypothesis :



- Aim : solving  $\hat{r} = \arg \min_r \phi(y - r) + \lambda \psi(r)$

**RTS CORRECTION :****b – variational image restoration approach**

- RTS is a piece-wise constant signal : 1D Total Variation  $\psi(r) = \sum_i |r_i - r_{i-1}|$

- Image regularization : 2D total variation similar to Huber-Markov

$$\phi(x) = \sum_{i,j} \sqrt{|x_{i+1,j} - x_{i,j}|^2 + |x_{i,j+1} - x_{i,j}|^2 + \varepsilon^2}$$

- Using the 1D finite difference operator  $D$  and posing  $u = Dr$ , equation to solve is :

$$\hat{u} = \arg \min_u \phi(y - D^{-1}u) + \lambda \|u\|_1$$

- Problem solved with the proximal gradient algorithm (forward-backward or ISTA)
- $\lambda$  is tuned with the regularization computed on the two neighboring columns.

## RTS CORRECTION : experimental results

- 4 indicators between clean images and contaminated-restored images

- SSIM : Strutural Similarity Index (target 1)

- PSNR : Peak Signal to Noise Ratio

- NRMSE : Normalized Root Mean Square Error

- NMAE : Normalized Mean Absolute Error

TABLE III

RESTORATION PERFORMANCE IN TERMS OF SSIM, PSNR, AVERAGED NRMSE AND NMAE ON 150 RTSs OVER 10500 COLUMNS. THE BEST SCORE BETWEEN THE SIGNAL AND IMAGE METHODS IS HIGHLIGHTED IN BOLD.

Method	Error	Large	Medium	Low
Input	SSIM	0.96423	0.99877	0.99993
	PSNR	47.26 dB	57.67 dB	70.43 dB
Signal	SSIM	0.99971	0.99981	<b>0.99997</b>
	PSNR	56.76 dB	65.17 dB	<b>73.56 dB</b>
	NRMSE	0.218	0.432	<b>0.719</b>
	NMAE	0.087	0.310	<b>0.586</b>
Image	SSIM	<b>0.99977</b>	<b>0.99985</b>	0.99996
	PSNR	<b>58.17 dB</b>	<b>65.74 dB</b>	71.77 dB
	NRMSE	<b>0.126</b>	<b>0.419</b>	1.267
	NMAE	<b>0.067</b>	<b>0.260</b>	0.735

## EXPERIMENTAL RESULTS



Input image



Restored (signal method)



Restored (image method)

Fig. 2. Illustration of RTS correction, with a *large* RTS contamination. Pléiades © CNES 2020, Distribution AIRBUS DS, all rights reserved.

Limits : over- corrections & non-corrections

Limits : computation time 180x higher than signal method

## CONCLUSION AND WAY FORWARD

- Good results in detection method,
- Signal method & image method : perfectible but concept proved.
- Work in progress to replace pre-processing, image regularization, etc.
- Publication : *IEEE Geoscience and Remote Sensing Letters*, vol. 19, pp. 1-5, 2022, Art no. 6015905, doi: 10.1109/LGRS.2022.3224520.

**THANK YOU FOR YOUR ATTENTION**

