On Certain New Methodology for Reducing Sensor and Readout Electronics Circuitry Noise in Digital Domain

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Introduction
Sensors and Noise

- New sensors: near-infrared (NIR), wavelengths ~ 1 to 5 μm (Figure 1), “active” or “hot” pixel arrays capture image data
- Array is 2048 by 2048 pixels (2Kx2K>4×10^6 pixels, K=1024)
- Active pixel arrays are bounded by reference pixels, which measure noise (4 columns and 4 rows on the left-right and top-bottom sides of the array). Figure 1 depicts the **H**gCdTe **A**stronomy **W**ide **A**rea **I**nfrared Imager (HAWAII) with (**2**K-8)x(2K-8) hot pixel resolution, **R**eference pixels and **G**uide Mode (or **H2RG** sensor).
- Noise: readout error due to several sources, including background radiation and movement of electrons (thermal noise)

Introduction
Sensors and Noise
(Continue)

- Thermal noise effects are unavoidable in objects at temperatures above absolute zero (0 Kelvin)

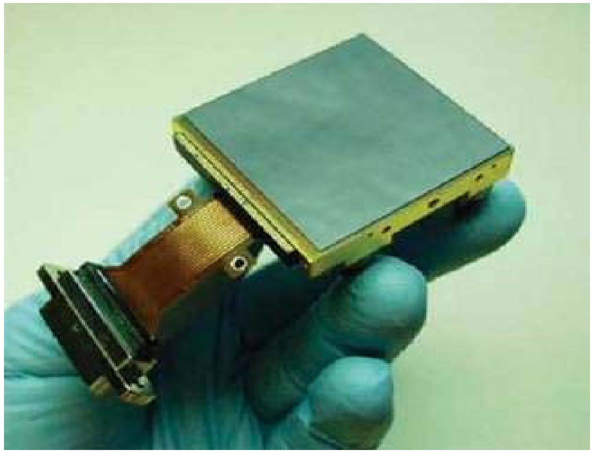
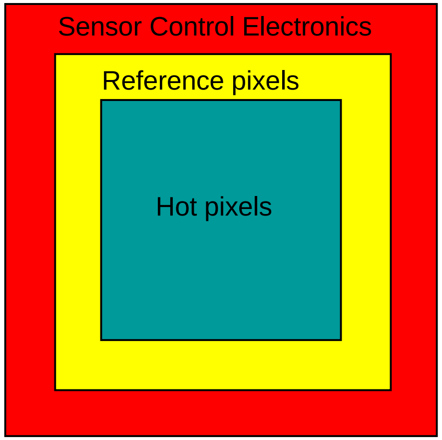


Figure 1. HAWAII-2RG NIR sensor.
Source: www.laserfocusworld.com



Heritage Noise Reduction Methods in Digital Domain

- Heritage Global Statistics Subtraction: Summarize reference (noise) pixels with a statistical parameter, such as the mean of all reference pixels, and subtract this single parameter from all active pixel data

- Heritage approach unintentionally ignores fast-varying noise components, which average out to zero.

Problem and Solution Hypothesis

Problem:

- Heritage noise reduction methods in digital domain do not give required measurement precision
- Certain key components of noise are unintentionally ignored by heritage approach for large detector arrays such as the H2RG

Solution Hypothesis:

- Heritage methods overlook fast-varying noise components in data
- Improved method: use HHT-DPS to identify and account for these components

Solution Tools

HHT-DPS:

- Hilbert-Huang Transform Data Processing System (HHT-DPS): software that breaks down any function into the data-derived basis functions that comprise it (Figure 2):

Intrinsic Mode Functions (IMFs)

Figure 2. Sample HHT-DPS IMF breakdown of a reference pixel column

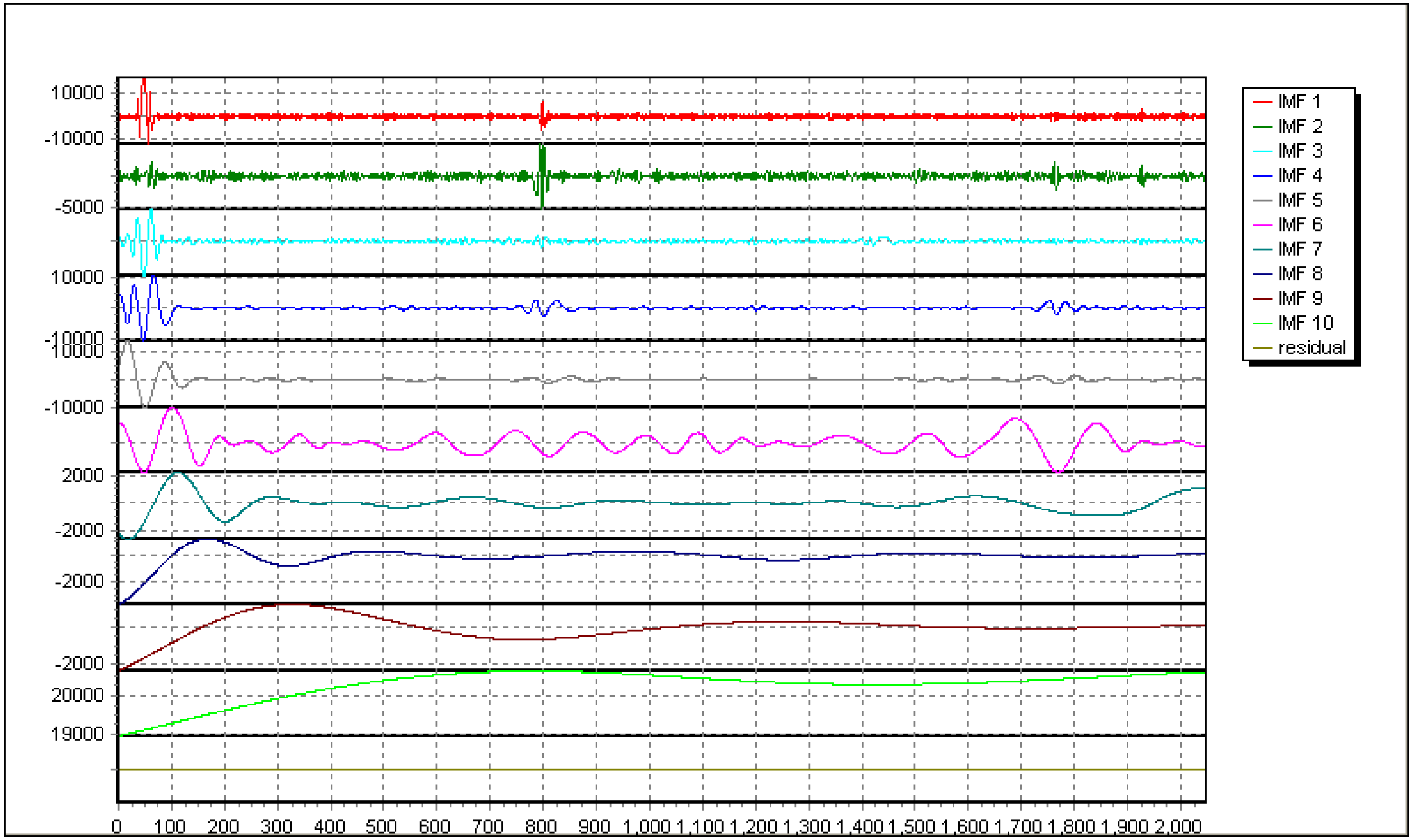


Figure 3

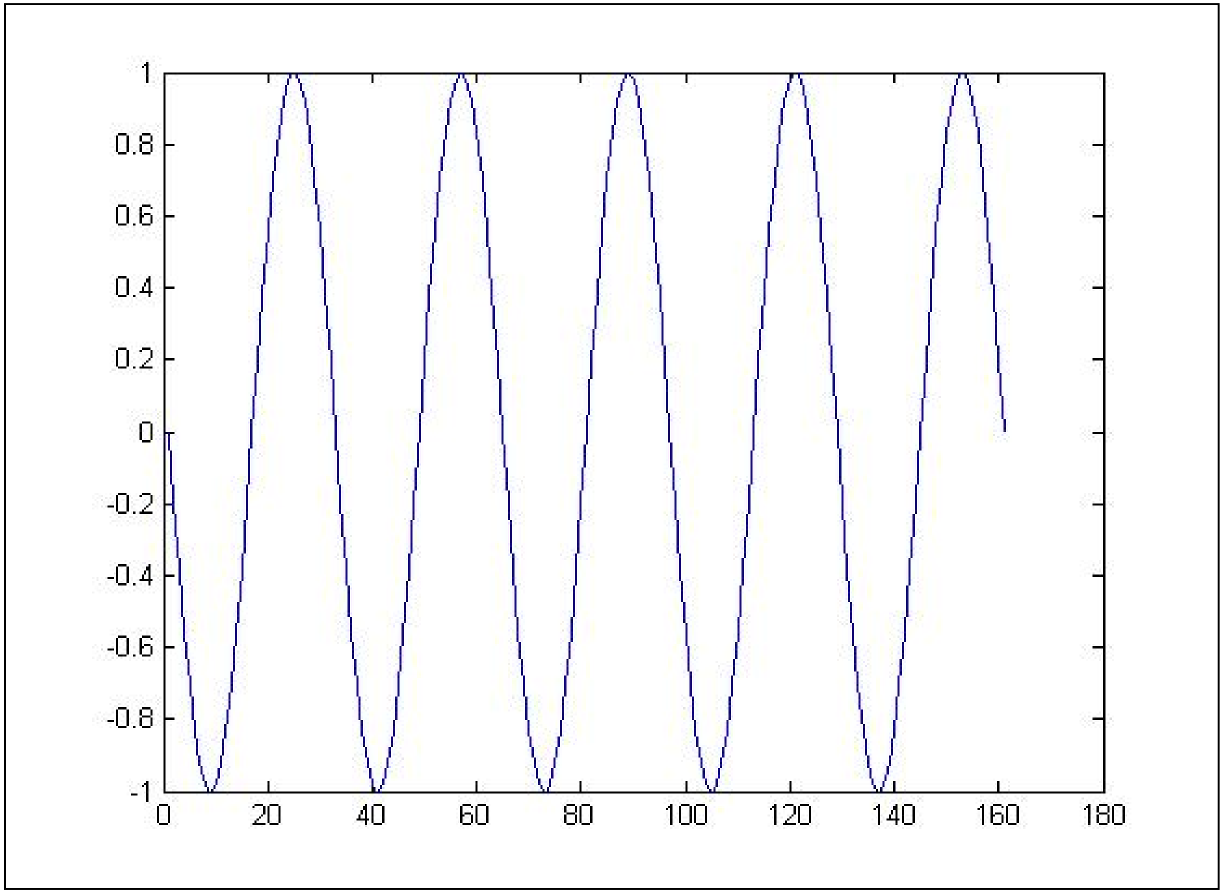
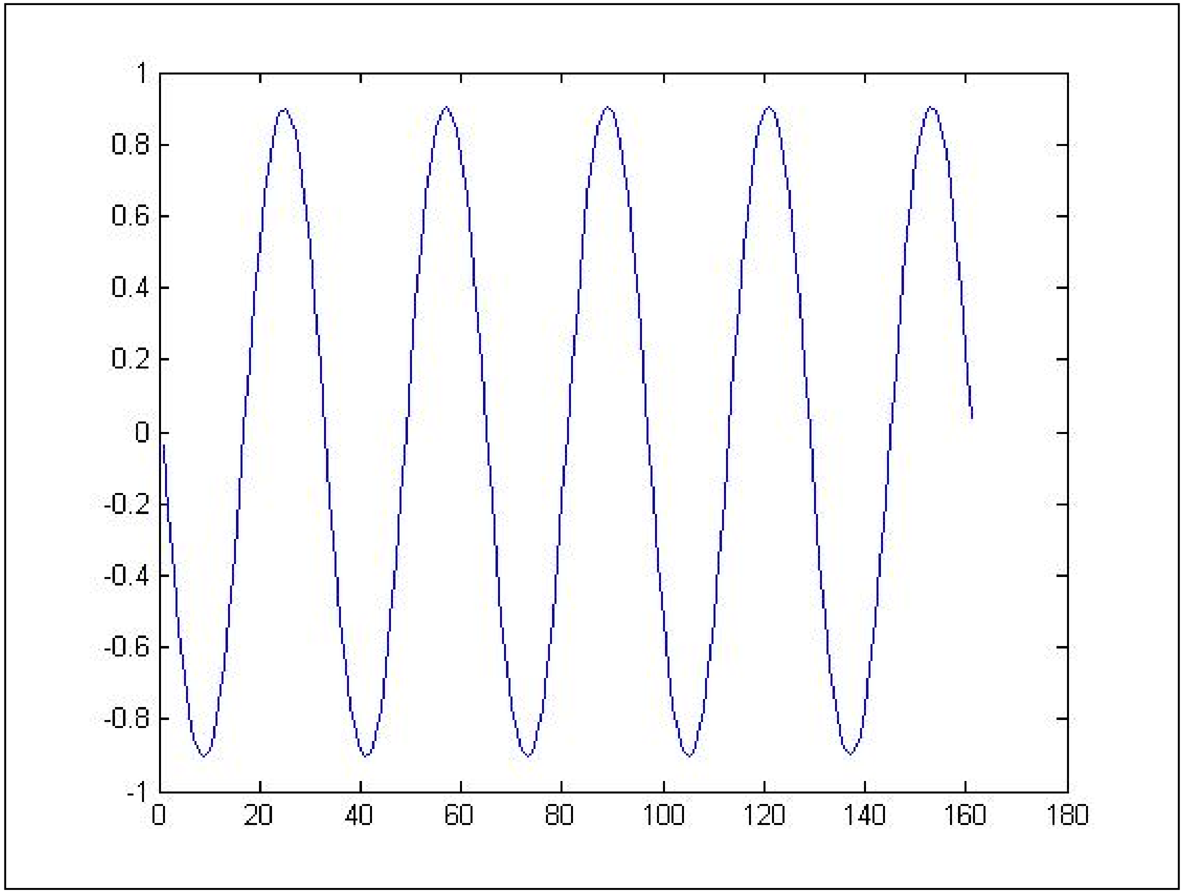


Figure 4



Statistical Parameters' Equations and Table 1

Signal 1 (Reference Pixel Row): $s = \{s_1, s_2, \ldots, s_n\}$

Mean: $\mu_0 = (\Sigma\, s_i)/n,\ 1<=i<=n$

Signal 2 (IMF1): $r = \{r_1, r_2, \ldots, r_n\}$

Mean: $\mu_1 = (\Sigma\, r_i)/n,\ 1<=i<=n;\ \ \mu_{1ABS} = (\Sigma\, |r_i|)/n,\ 1<=i<=n$

Ref. Pixel Row 4		**% of Mu0**
Mu0 (Total Mean of Row)	10881	100
Mean of Abs. Value of Row	10881	100
Mu1 (Mean of IMF1)	2.7708	0.03
Mean of Abs. Value of IMF1	798.453	7.34

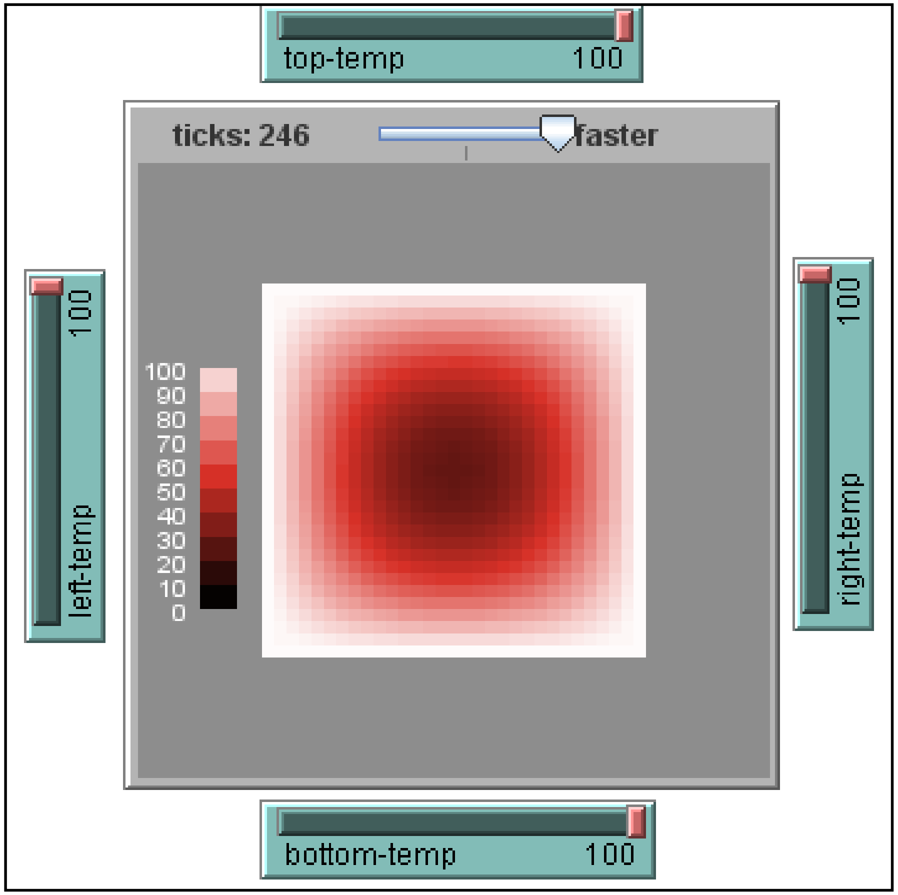
New Proposed Methodology

- Use both, the HHT-DPS/thermal model correction for noise fast varying components algorithm and the heritage statistical parameter subtraction method for low varying noise components
- Thermal model: take out fast-varying noise (HHT-DPS first IMF)
- Heritage method: statistically average the remaining IMFs and subtract average from all hot pixels.

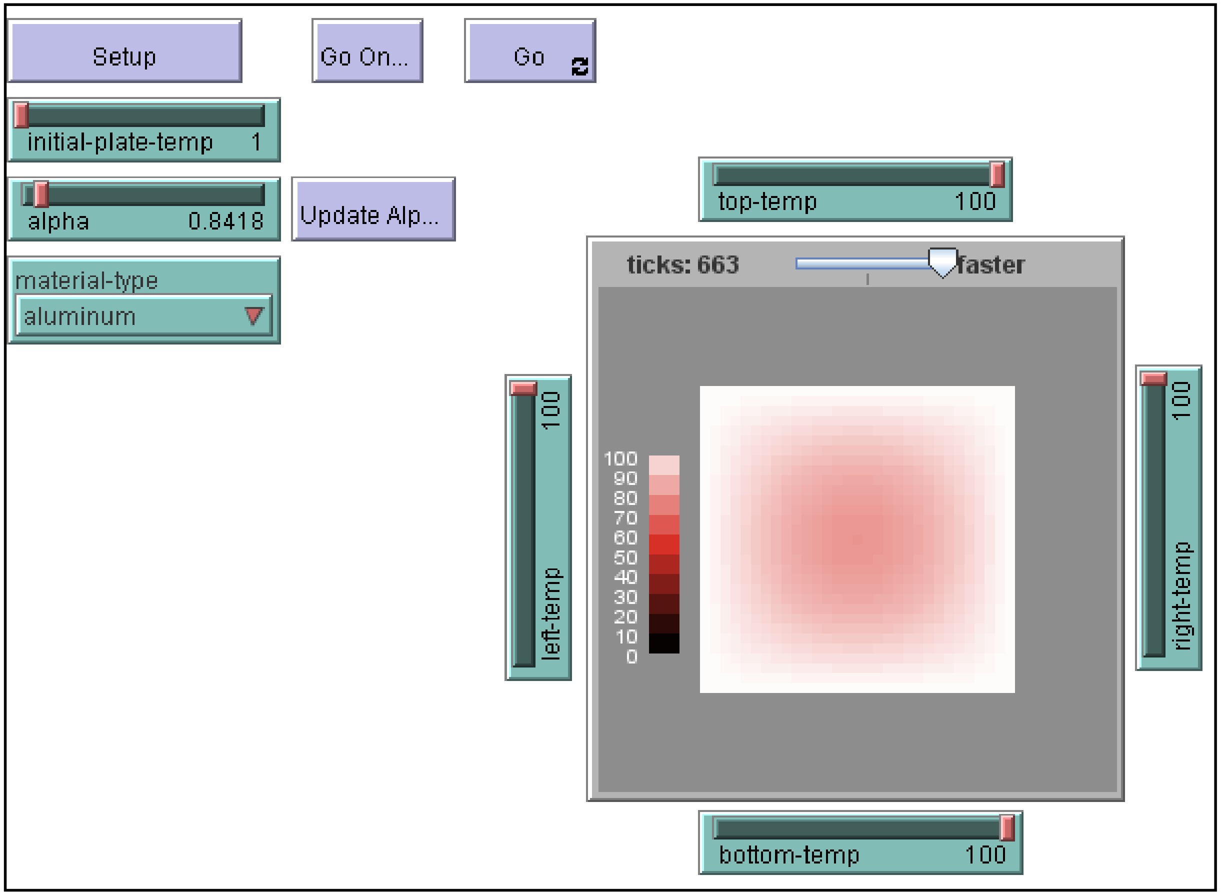
Thermal Model Analogy for Noise Propagation

- In-time progression of diffusion of heat across a small, thin square plate (Figure 5)
  Source: NetLogo Models Library website
- Variable temperature settings along edges analogous to reference pixel values
- Simulates propagation of thermal noise in NIR sensor

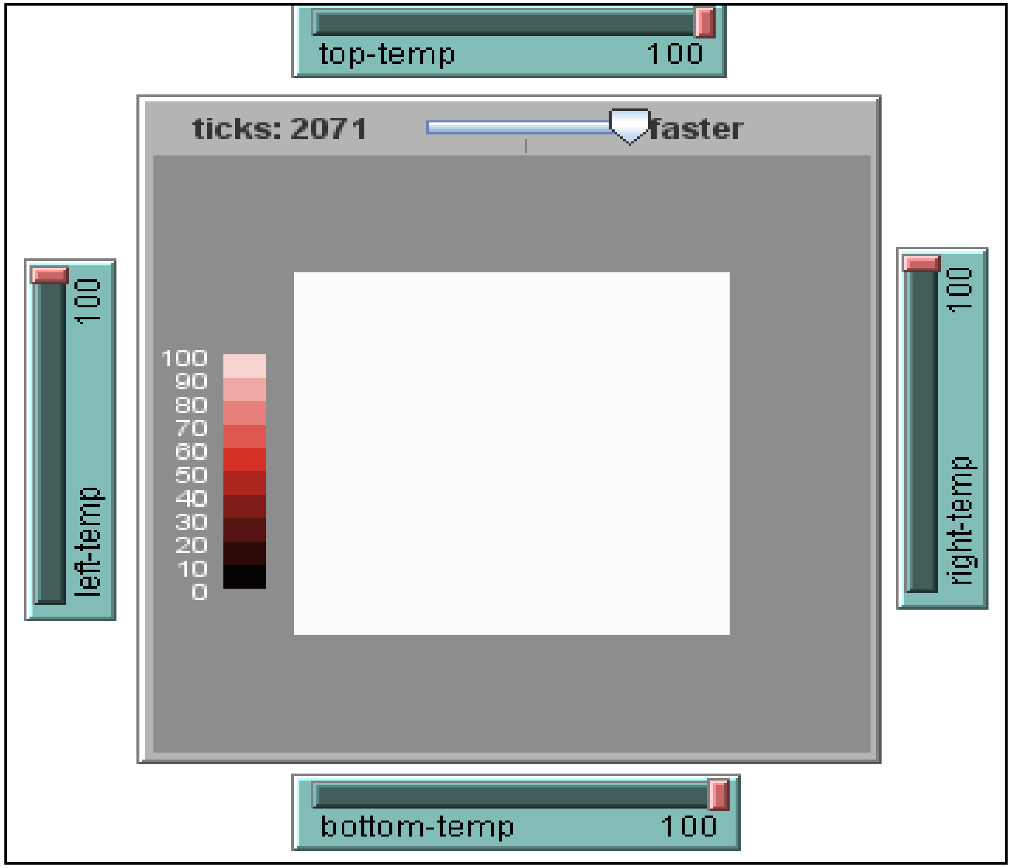
Beginning Thermal Configuration



Middle Thermal State



End Thermal State



Algorithm Outline

- Use sample binary data file in FITS format from an H2RG HgCdTe NIR sensor; read file into MATLAB (Trademark Of MathWorks Inc.) array
- Use HHT-DPS to decompose innermost reference pixel rows/columns into IMFs
- Find noise matrix due to first IMFs using thermal model :

*Calculate mean of first-IMF for each decomposed reference pixel row/column: this is the value for the corresponding boundary row/column of noise array

*Divide maximum of these means by number of values in the total array (2042) = initial value of all noise

Algorithm Outline (Continue)

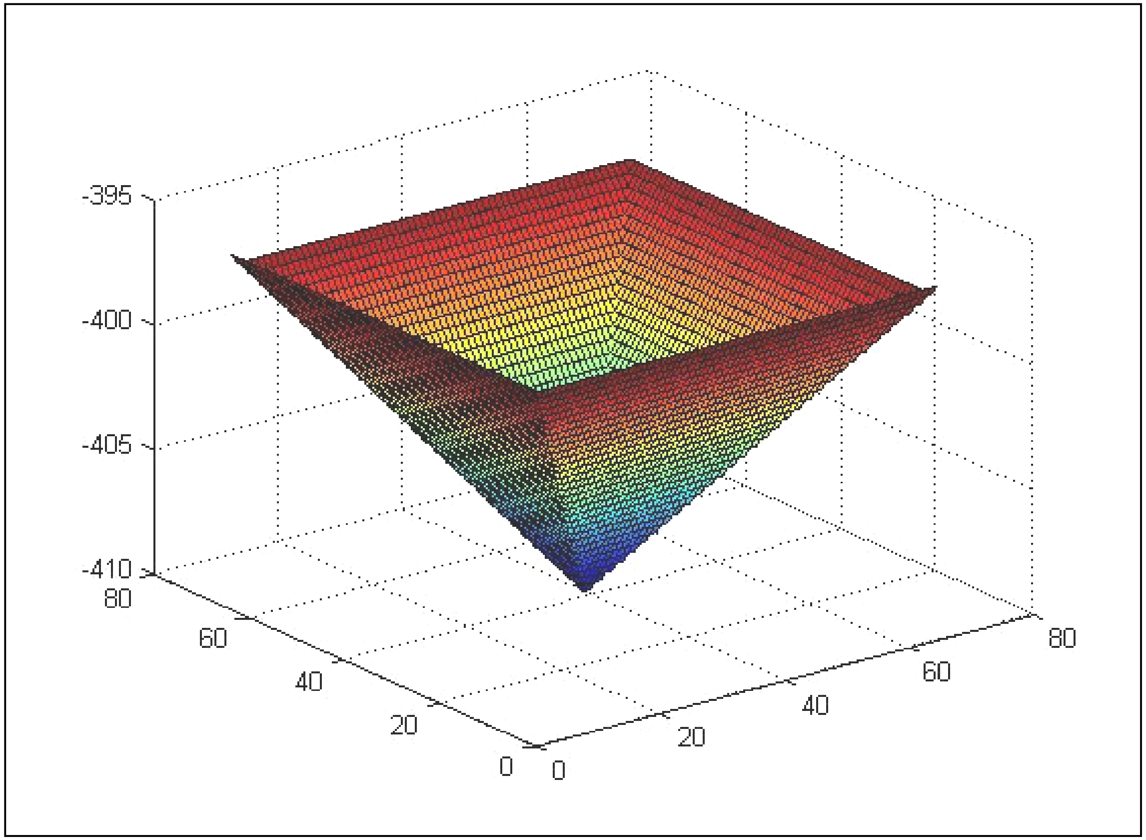
*Propagate first-IMF noise using embedded squares:

starting with boundaries, calculate matrix values by moving inward, forming ever-smaller squares (Figure 6)

- Subtract resulting first-IMF noise matrix from active pixels
- Average remaining IMFs for each innermost reference pixel row/column, then average all these means=global mean
- Subtract this global average from active pixels that are already corrected for first-IMF error

- Subtract resulting first-IMF noise matrix from active pixels

Figure 6. Result of Thermal Model Analogue for Noise Propagation



Conclusions and Acknowledgements

Conclusions:

- Method appears effective
- Further testing and refinement of methodology is needed

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