Mathematical formulation of the HYPR algorithms

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1 Introduction

This report is a summary of the *HI*ghly constrained Back *PR*ojection (*HYPR*) team work performed so far relating to the HYPR research project. We will describe the work done and results found.

The goals set for the HYPR project included formulating the HYPR algorithm and some of its variations (such as Wright-Huang HYPR (WH-HYPR), I-HYPR and HYPR-LR) in a mathematical framework which would allow the study and analyze of these algorithms in relation to other well known non-linear methods such as maximum a-posteriori (MAP) estimation and Maximum Likelihood Expectation Maximization (MLEM). These algorithms, like HYPR, use prior information on the object being reconstructed and they are extensively used in nuclear medicine where the data is intrinsically under sampled.

The initial period of this project, which this report reflects on, was spent becoming familiar with the HYPR algorithm and its connection to MLEM. Towards this goal, the HYPR algorithm was formulated mathematically and schematic diagrams created which helped in its implementation. MATLAB simulation software was developed to enable more understanding of the algorithm and its behavior by running it on a number of test cases. Initial comparison between the original HYPR and the WH-HYPR made on a number of different test configuration which are described in detail in the simulation section below. The MLEM algorithm was implemented and compared the HYPR algorithm.

In addition, A mathematical connection between HYPR and Expectation Maximization (EM) is described and formulated.

2 Mathematical formulation of the HYPR algorithms

2.1 Original HYPR

2.1.1 Mathematical formulation

Please see the appendix for a complete description of the notation used in this section and throrught the rest of the report.

The mathematics of this algorithm will be presented by using the radon transform R notation and not the matrix projection matrix H notation.

The projection s_t is obtained by applying radon transform R on the image I_t at some angle ϕ_t

$$s_t = R_{\phi_t}[I_t]$$

When the original object image does not change with time one can drop the subscript t from I_t and just write $s_t = R_{\phi_t}[I]$

Next, the composite image C is found from the filtered back projection applied to all the s_t as follows

$$C = \sum_{i=1}^{N} R^f_{\phi_{t_i}}[s_{t_i}]$$

Notice that the sum above is taken over N and not over N_p. Next, a projection s_c is taken from C at angle ϕ as follows

$$s_{c_t} = R_{\phi_t}[C]$$

Then the unfiltered back projection 2-D image P_t is generated

$$P_t = R^u_{\phi_t}[s_t]$$

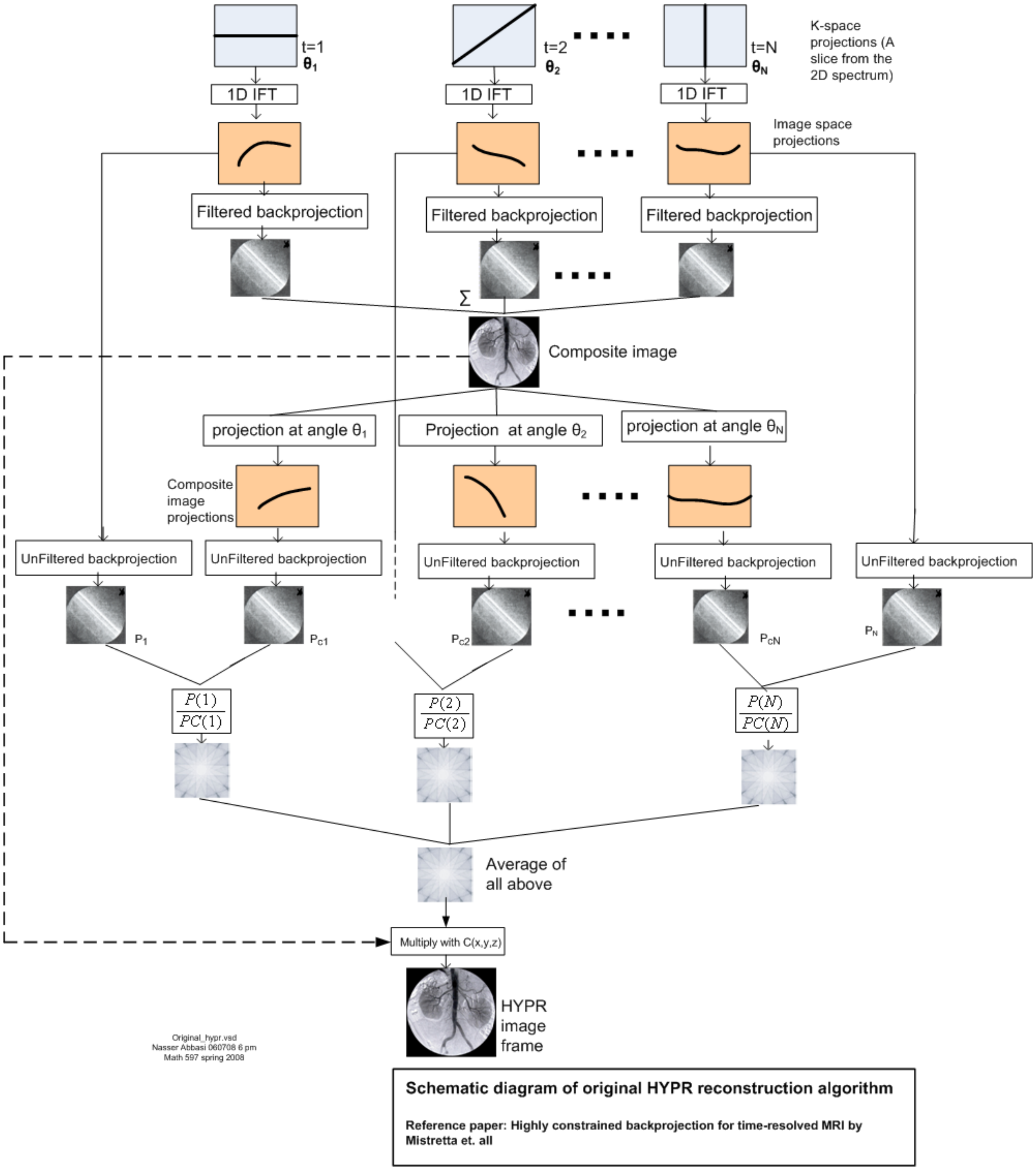
And the unfiltered back projection 2-D image P_{c_t} is generated

$$P_{c_t} = R^u_{\phi_t}[s_{c_t}]$$

Then the ratio of $\frac{P_t}{P_{c_t}}$ is summed and averaged over the time frame and the result multiplied by C to generate a HYPR frame J for the time frame.Hence for the k^{th} time frame we obtain

$$\begin{aligned} J_k &= C\ \left(\frac{1}{N_p}\sum_{i=1}^{N_p}\frac{P_{t_i}}{P_{c_{t_i}}}\right) \\ &= \frac{1}{N_p}C\ \sum_{i=1}^{N_p}\frac{R^u_{\phi_{t_i}}\left[s_{t_i}\right]}{R^u_{\phi_{t_i}}\left[s_{c_{t_i}}\right]} \\ &= \frac{1}{N_p}\left(\sum_{i=1}^{N}R^f_{\phi_{t_i}}\left[s_{t_i}\right]\right)\ \sum_{j=1}^{N_p}\frac{R^u_{\phi_{t_j}}\left[s_{t_j}\right]}{R^u_{\phi_{t_j}}\left[s_{c_{t_j}}\right]} \end{aligned}$$

2.1.2 Schematic diagram



Schematic diagram of original HYPR reconstruction algorithm

Reference paper: Highly constrained backprojection for time-resolved MRI by Mistretta et. all

2.2 Wright-Huang variation of HYPR

2.2.1 Mathematical formulation

This mathematics of this algorithm will be presented by using the radon transform R notation and not the matrix projection matrix H notation.

The projection s_t is obtained by applying radon transform R on the image I_t at some angle ϕ_t

$$s_t = R_{\phi_t}[I_t]$$

The composite image C is found from the filtered back projection applied to all the s_t

$$C = \sum_{i=1}^{N} R^f_{\phi_{t_i}}[s_{t_i}]$$

Notice that the sum above is taken over N and not over N_p. Next a projection s_c is taken from C at angle ϕ as follows

$$s_{c_t} = R_{\phi_t}[C]$$

Then the unfiltered back projection 2-D image P_t is generated

$$P_t = R^u_{\phi_t}[s_t]$$

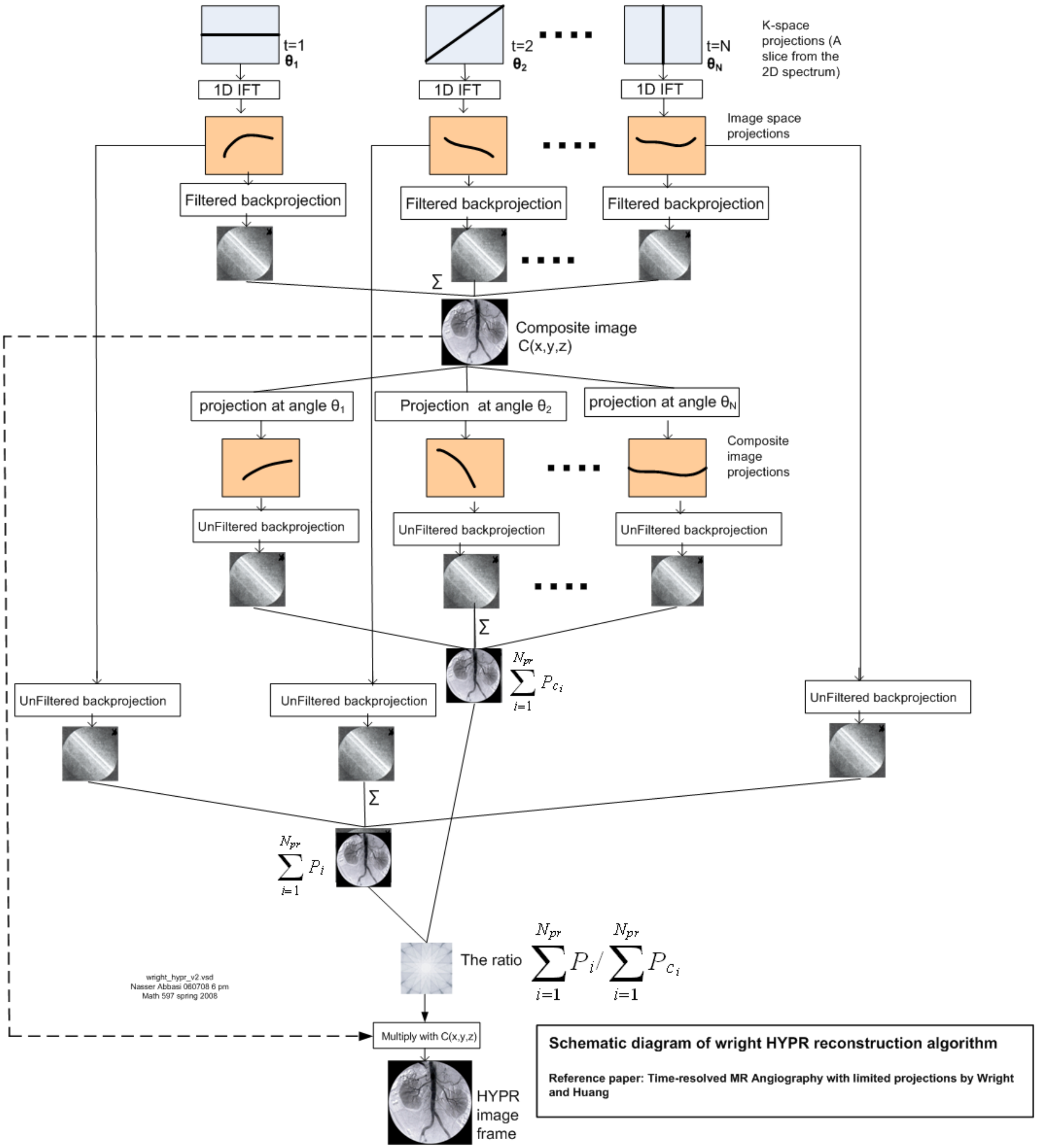
And the unfiltered back projection 2-D image P_{c_t} is generated

$$P_{c_t} = R^u_{\phi_t}[s_{c_t}]$$

Now the set of P_t and P_{c_t} over one time frame are summed the their ratio multiplied by C to obtain the k^{th} HYPR frame

$$\begin{aligned} J_k &= C \, \frac{\displaystyle\sum_{i=1}^{N_p} P_{t_i}}{\displaystyle\sum_{i=1}^{N_p} P_{c_{t_i}}} \\ &= C \, \frac{\displaystyle\sum_{i=1}^{N_{pr}} R^u_{\phi_t}[s_t]}{\displaystyle\sum_{i=1}^{N_{pr}} R^u_{\phi_t}\,[s_{c_t}]} \end{aligned}$$

2.2.2 Schematic diagram


t=1
θ_1
t=2
θ_2
t=N
θ_N
K-space projections (A slice from the 2D spectrum)
1D IFT
1D IFT
1D IFT
Image space projections
Filtered backprojection
Filtered backprojection
Filtered backprojection
Σ
Composite image C(x,y,z)
projection at angle θ_1
Projection at angle θ_2
projection at angle θ_N
Composite image projections
UnFiltered backprojection
UnFiltered backprojection
UnFiltered backprojection
Σ
$\sum_{i=1}^{N_{pr}} P_{c_i}$
UnFiltered backprojection
UnFiltered backprojection
UnFiltered backprojection
Σ
$\sum_{i=1}^{N_{pr}} P_i$
The ratio $\sum_{i=1}^{N_{pr}} P_i / \sum_{i=1}^{N_{pr}} P_{c_i}$
wright_hypr_v2.vsd
Nasser Abbasi 080708 6 pm
Math 597 spring 2008
Multiply with C(x,y,z)
HYPR image frame

Schematic diagram of wright HYPR reconstruction algorithm

Reference paper: Time-resolved MR Angiography with limited projections by Wright and Huang

3 HYPR connection to Expectation Maximization

The following is a discussion of the Mathematics that connects the MLEM algorithm to HYPR.

According to O'Halloran's paper[1] the for Maximum-Likelihood Expectation-Maximization (MLEM) algorithm is mathematically equivalent to HYPR. The MLEM algorithm can be used in image reconstruction for medical purposes. Positron Emission Tomography (PET) and Single-Photon Emission Computed Tomography (SPECT) are two types of image reconstruction processes where the MLEM algorithm is used. The purpose here is to show that the MLEM algorithm will work for HYPR reconstructions.

The MLEM algorithm is a process that approximates the solution to

$$g = H\theta \tag{1}$$

In connection to HYPR, we can view H as a forward projection matrix, θ as the original image being projected and g the projection produced. The goal is to relate the above matrix based formulation to the radon transform based formulation seen above in the HYPR mathematical section, which is

$$s_t = R_{\phi_t}[I_t] \tag{2}$$

We formulate the first iteration of the MLEM algorithm based on equation (1) and see how it can be translated into the HYPR process of image reconstruction. The first step of MLEM is

$$\hat{\theta}_n^{(1)} = \hat{\theta}_n^{(0)} * \frac{1}{z_n} \sum_{m=0}^{M} H_{mn} \frac{g_m}{\left(H\hat{\theta}^{(0)}\right)_m} \tag{3}$$

This can be rewritten in matrix form

$$\hat{\theta}_n^{(1)} = \hat{\theta}_n^{(0)} \frac{1}{z_n} \left[H^T \left[\frac{g}{\left(H\hat{\theta}^{(0)}\right)} \right] \right]_n$$

If we replace $\frac{1}{z_n}$ by $\frac{1}{[H^T[1]]_n}$ in (4), we obtain

$$\hat{\theta}_n^{(1)} = \hat{\theta}_n^{(0)} \frac{1}{\left[H^T [1]\right]_n} \left[\overbrace{H^T \left[\frac{g}{\left(H\hat{\theta}^{(0)}\right)} \right]}^{unfiltered\ back\ projection} \right]_n \tag{4}$$

The marked portion of the above equation can be viewed as the vector that is produced from unfiltered back projection on the image produced by the ratio

$$\frac{g}{H\hat{\theta}^{(0)}}$$

Here the division is done element by element to produce the vector whose elements are the ratios of the respective elements of g and $H\hat{\theta}^{(0)}$.

In HYPR the equation we want to tie to equation (3) above is as follows

$$J_t = \frac{1}{N_p}C \ \cdot R^u_{\phi_t}\left[\frac{s_t}{R_{\phi_t}(C)}\right] \tag{5}$$

Where the $\cdot$ represents an element by element multiplication, and the terms in (5) as defined in the section of the HYPR mathematical derivation shown earlier. Hence for (5) and (4) to be equivalent, We must have

$$\hat{\theta}^{(0)}_n = \frac{[H^T[1]]_n}{N_p}C$$

Which represents the initial guess for the user image. Therefore, by using for $\hat{\theta}^{(0)}$as an initial guess for the MLEM algorithm the above weighted term of the composite image C, the MLEM algorithm will produce $\hat{\theta}^{(1)}$ which is a better approximation to the original image from that of the composite C. And this is what the HYPR algorithm does. It uses the composite image C to produce the HYPR image J to approximate the original user image I. Hence a one step of MLEM is equivalent to running HYPR for one time. Therefore, iterative HYPR algorithms can be seen as a multi step application of MLEM.

4 Software simulation and results

4.1 HYPR simulation

A software simulation written in MATLAB was designed and developed to enable more extensive HYPR testing of different test configurations. The software is GUI based and all test results are saved in a tab-delimited plain text file to allow one further statistical analysis of the data generated by other software. The appendix contains a screen shot of the current version of the simulator (version 1.0).

4.1.1 Description of HYPR simulation and test results

This is a description of the different tests performed. Both the original HYPR and the Wright-Huang HYPR (WH-HYPR) were run and results compared. In the following discussion, we use N_p to mean number of projections in one time frame, and N_w to mean the number of time frames. Hence the total number of projections is $N_p N_w$

The table below describes each test. In this table, a test with the letter 'a' represents the test being run using the original HYPR and a test with the letter 'b' represents the test being run using WH-HYPR. Each test was run under both the original HYPR and WH-HYPR.

The first set of tests are designed to detect the effect of Poisson noise on the accuracy of the HYPR algorithm as compared to the WH-HYPR. This was done for different geometry of objects while keeping the number of projections per time frame and the Poisson noise parameter λ fixed.

The second set of tests are designed to detect the effect of Gaussian noise on the accuracy of the HYPR algorithm as compared to the WH-HYPR. This was done for different geometry of objects while keeping the number of projections per time frame and the Gaussian distribution parameters (mean and variance) fixed. The set of tests used here is smaller than the first set due time limitation.

The third set of tests are designed to detect the effect of increasing the number of projections on the accuracy of the HYPR and WH-HYPR. This was done under one fixed configuration and with the absence of noise.

The main measure of accuracy used was relative RMSE. This was calculated as follows: For each HYPR frame image generated, the set of user images which make up the time frame from which the HYPR frame was generated are averaged to obtain an average time frame image. Then the RMSE was obtained between these 2 images as follows: Assuming these are N total pixels in each image, the error between each corresponding pixels is found as $H_i - I_i$ where H_i is a pixel in the HYPR frame image and I_i is the corresponding pixel in the averaged time frame image. This error is then squared. This was done for each pixel. The average of these square values is found, and the square root of the result is found. Hence

$$RMSE = \sqrt{\frac{1}{N}\sum_{i}^{N}\sqrt{(H_i - I_i)^2}}$$

This quantity is normalized by dividing it by the mean intensity of the averaged time frame image found earlier. This gives a normalized RMSE value for each time frame generated. When there are more than one time frame generated then the average all these RMSE values are used to obtain one representative value of the RMSE for the test, and that is the value showed in the tables below for the purpose of comparing different tests.

Other statistics are calculated to determine the algorithms accuracy. The relative error between the HYPR image and the averaged time frame is found using the standard formula for relative error. This measure however did not appear to be a good indicator for determining the accuracy of the HYPR image. Another statistical measure used is the histogram difference, which is found as follows. The histogram for each HYPR image frame and the corresponding histogram for the averaged time frame image are calculated and the difference between these histograms found. This measure appear to give a good indication of the performance of each test and correlated well with the RMSE measure used. These results are all written to the log file for further analysis, but are not currently taken into account in the following tests due to time limitation. Only the RMSE measure is currently used to determine the accuracy of the algorithm. The following sections describe each set of tests in more details.

4.1.2 The first set of tests

Test	Test description
1a	HYPR[4] algorithm validation. Using the same parameters as the Wright-Huang paper[2] and validate output as it was described and shown in the paper. This is a fixed disk in the center of the image whose density changes linearly with time. $N_p = 8, N_w = 16$
1b	As above, but use the WH-HYPR algorithm.
2(a,b)	Repeat test 1 but with the addition of Poisson noise with $\lambda = 500$ to the projection s generated from the user images
3(a,b)	A non-time varying two small white disks close to each others in black background. $N_p = 8, N_w = 16$
4(a,b)	As above, but with Poisson noise with $\lambda = 500$ added to projection s.
5(a,b)	Small disk that moves in vertical motion off the center of image. $N_p = 8, N_w = 16$
6(a,b)	As above, but with Poisson noise with $\lambda = 500$ added to projection s.
7(a,b)	2 small disks close to each others that move in vertical motion. $N_p = 8, N_w = 16$
8(a,b)	As above, but with Poisson noise with $\lambda = 500$ added to projection s.
9(a,b)	2 small disks further apart from each others that move in vertical motion.
10(a,b)	As above, but with Poisson noise with $\lambda = 500$ added to projection s.
11(a,b)	one small disk that move across the image in the diagonal direction. $N_p = 8, N_w = 16$
12(a,b)	As above, but with Poisson noise with $\lambda = 500$ added to projection s.

The appendix shows the output obtained from the above set of tests. We now present a summary of the results

Test	(a) Original HYPR RMSE	(b) Wright HYPR RMSE	Selected algorithm
1	0.639	0.636	WH-HYPR
2 (noise)	1.7298	1.2079	WH-HYPR
3	1.0329	1.0411	Original HYPR
4 (noise)	1.9879	1.4917	WH-HYPR
5	2.6349	3.095	Original HYPR
6 (noise)	4.9216	4.3288	WH-HYPR
7	2.1157	2.3496	Original HYPR
8 (noise)	2.99	2.7793	WH-HYPR
9	2.151	2.3524	Original HYPR
10 (noise)	2.9983	2.818	WH-HYPR
11	2.558	3.083	Original HYPR
12 (noise)	4.881	4.3884	WH-HYPR

Observation from running the first set of tests The original HYPR algorithm performed better in each test when noise is absent from projection. This occurs in either time varying or non-time varying configuration. On the other hand, WH-HYPR performed better in each case when noise was present. This occurs in either time varying or non-time varying configuration.

4.1.3 The second set of tests

These tests are a repeat of the first set of tests, but with noise generated from normal distribution. Due to time limitation only test 2,6 and 10 described above are repeated since these 3 tests are good representative of the overall tests. The letter N is added to the test name to indicate the use of Normal distribution.

Test	Test description
2N (a,b)	Repeat test 1 but with the addition of Normal noise with $\mu = 0$ and $\sigma^2 = 500$ to the projection s generated from the user images
6N(a,b)	Repeat test 5, but with the addition of Normal noise with $\mu = 0$ and $\sigma^2 = 500$
10N(a,b)	Repeat test 9, but with the addition of Normal noise with $\mu = 0$ and $\sigma^2 = 500$

The appendix shows the output obtained from the above set of tests. Summary of the results is shown below. To clarify the nature of tests below a short description is given again below.

1. Test 2N is a small fixed disk, changes intensity linearly with time. $N_p = 8, N_w = 16$
2. Test 6N is one disk which moves vertically, off center. $N_p = 8, N_w = 16$
3. Test 10N is two disks separated from each others that move vertically across the image. $N_p = 8, N_w = 16$

Test	(a) Original HYPR RMSE	(b) Wright HYPR RMSE	Abs difference	Selected algorithm
2N	1.7583	1.7179	0.0404	WH-HYPR
6N	4.0069	3.9797	0.0272	WH-HYPR
10N	2.7754	2.7737	0.0017	WH-HYPR

Observations from running the second set of tests WH-HYPR performed better in all 3 cases. This correlated well with results found from the first set of tests where it was observed that WH-HYPR performed better each time Poisson noise was added. In the above 3 tests, normal noise was added and it is observed that WH-HYPR performed better.

4.1.4 Third set of tests

As was mentioned earlier, the goal of these tests is to measure the relative accuracy of the algorithms on the same configuration but with increasing number of projections per time frame. It is expected that the accuracy of each algorithm will improve, and we wish to obtain the measure of this improvement as a function of the number of projections per time frame.

For this purpose, the following test configuration was used: small white disk moving vertically and off center, no noise added. One time frame was used and the following number of projections $\{8, 16, 32, 64, 128, 256, 512, 1024\}$. These tests as named $8r, 16r, 32r, 128r, 256r, 512r$ and $1024r$ respectively. The table below show the result of the tests.

Test	(a) Original HYPR RMSE	(b) WH-HYPR RMSE	Abs difference	Selected algorithm
$8r$	1.6879	2.0836	0.3957	Original HYPR
$16r$	1.3772	1.59	0.2128	Original HYPR
$32r$	1.0994	1.18845	0.0891	Original HYPR
$64r$	0.774	0.8315	0.0575	Original HYPR
$128r$	0.5095	0.5355	0.0260	Original HYPR
$256r$	0.3722	0.3765	0.0043	Original HYPR
$512r$	0.2847	0.2825	0.0022	WH HYPR
$1024r$	0.2469	0.2459	0.0010	WH HYPR

Observations from running the third set of tests As the number of projections per time frame increased, the accuracy of WH-HYPR improved. At high number of projections (over 512 per time frame) WH-HYPR bypassed original HYPR and became more accurate. It is not clear at this time if such high number of projections per time frame will conflict with other MRI requirements (sampling rate limitation or other issues), but the above shows that, even with the absence of noise, the WH-HYPR can become more accurate than the Original HYPR but at a cost of having large number of projections per time frame.

4.1.5 Conclusions drawn from HYPR test results

Original HYPR performed better than WH-HYPR when the number of projections is relatively low (below 256 per time frame) and when there was no noise present (noise added to projections taken from the original images). This occurred in all configurations (both objects moving in time or fixed).

WH-HYPR performed better when noise is present (both Poisson and Normal noise) and for all number of projections and for all configurations.

In addition, WH-HYPR performed better when there was no noise added, but when the number of projections per time frame was increased.

These results seem to be a direct consequences of the fact that WH-HYPR sums the backprojection images over a time frame period before taking the ratio of these sums in order to obtain the mask image, while in the original HYPR the ratio for each backprojection images is first found and the ratios added and averaged. More analysis will be needed to better understand this difference and to explain mathematically this observed difference between HYPR and WH-HYPR.

Since real MRI data is characterized by low SNR, this leads one to conclude that

WH-HYPR should be the preferred choice between these 2 algorithms.

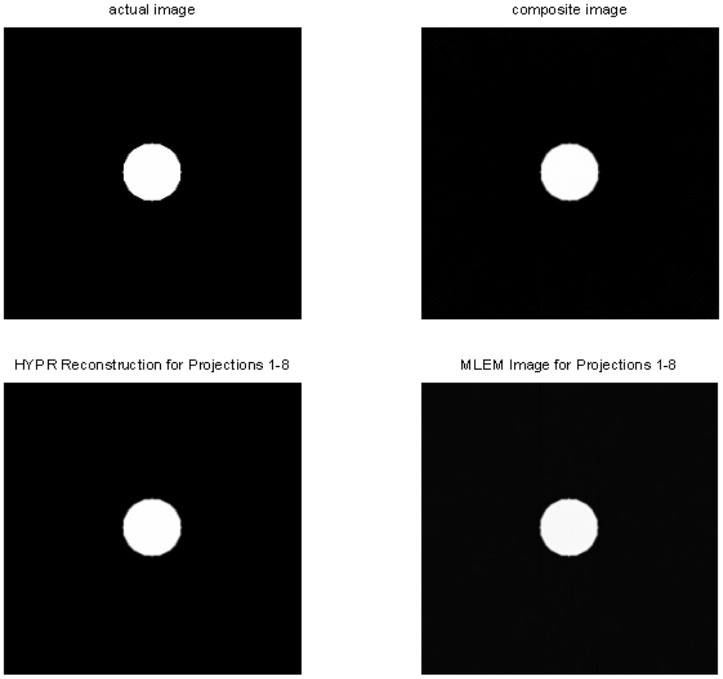
4.2 Expectation Maximization simulation

4.2.1 Description of simulation

The original HYPR algorithm was compared to 1 step of the MLEM algorithm. A time-invariant white disk with radius 25 pixels centered in a 256 by 256 black image. 128 different projection angles were used (ordered using bit-reversed ordering), and the size of the window was set to 8 projections.

4.2.2 Results of simulation

The figures below are the actual images produced. The composite image, the HYPR reconstruction for the first HYPR frame, and the corresponding MLEM image. The HYPR and the MLEM images are indistinguishable, although the mean absolute error is slightly higher for HYPR than for MLEM. More detailed comparisons of MLEM and HYPR are planned.


actual image
composite image
HYPR Reconstruction for Projections 1-8
MLEM Image for Projections 1-8

5 Future work

1. Continue research into iterative HYPR and its connection to Expectation Maximization. Both analytically and through simulation.

2. Work more on understanding the artifacts (modeling errors) and in the extreme, the pathological cases in which the HYPR algorithms will fail (worst-case scenario).

3. Characterizing the noise amplification and resolution of the HYPR algorithm through. Simulate HYPR algorithm with projection subjected to different noise distributions and determine which variations of the algorithm are most accurate and under which conditions.

4. Investigate and implement a new Iterative HYPR variation proposed during work on this project which uses the Wright-Huang as its iterative step and compare to the current standard I-HYPR which uses the original HYPR and compare performance.

5. Investigate possibility of a better measure to compare the accuracy of a HYPR image to a time frame image than was used in this report (RMSE), and if one is found, use the new measure for future testing.

6. Obtained a mathematical description of the HYPR method based on the matrix formulation and not based on the radon transform. Apply for a simple geometrical shape which is time varying.

6 Appendix

6.1 nomenclature

1. MLEM Maximum-Likelihood Expectation-Maximization

2. PET Positron Emission Tomography

3. SPECT Single-Photon Emission Computed Tomography

4. I A 2-D image. This represent the original user image at which the HYPR algorithm is applied to.

5. I_t When the original image content changes during the process, we add a subscript to indicate the image I at time instance t.

6. R radon transform.

7. R_ϕ radon transform invoked at a projection angle ϕ.

8. ϕ_t When the projection angle ϕ is not constant but changes with time during the MRI acquisition process, we add a subscript to indicate the angle at time instance t.

9. R_{ϕ_t} radon transform invoked at a projection angle ϕ_t.

10. $s = R_\phi[I]$. radon transform applied to an image I at angle ϕ. This results in a projection vector s.

11. H Forward projection matrix. The Matrix equivalent to the radon transform R.

12. θ Estimate of an image I.

13. $H\theta$ Multiply the forward projection matrix H with an image estimate θ.

14. $g = H\theta$ Multiply the forward projection matrix H with an image estimate θ to obtain a projection vector g. Notice that for the inner dimensions of the matrix multiplication operation $H\theta$ to be equal, this requires that the 2D image θ be linearized. In other words, the 2D image θ be written as a column vector.

15. $R^u_\phi[s]$ The inverse radon transform applied in unfiltered mode to a projection s which was taken at angle ϕ. This results in a 2D image.

16. $R^f_\phi[s]$ The inverse radon transform applied in filtered mode to a projection s which was taken at angle ϕ. This results in a 2D image.

17. $H^T g$ The transpose of the forward projection matrix H multiplied by the projection vector g. This is the matrix equivalent of applying the inverse radon transform in an unfiltered mode to a projection s (see item 12 above).

18. $H^+ g$ The pseudo inverse of the forward projection matrix H being multiplied by the projection vector g. This is the matrix equivalent of applying the inverse radon transform in filtered mode to a projection s (see item 13 above).

19. C Composite image generated by summing all the filtered back projections from projections s_t of the original images I_t. Hence $C = \sum\limits_{i=1}^{N} R^f_{\phi_{t_i}}[s_{t_i}]$

20. P_t The unfiltered backprojection 2D image as a result of applying $R^u_{\phi_t}[s_t]$ where s_t is projection from user image I_t taken at angle ϕ_t.

21. P_{c_t} The unfiltered backprojection 2D image as a result of applying $R^u_{\phi_t}[s_t]$ where s_t is projection from the composite image C taken at angle ϕ_t.

22. N_p Number of projections used to generate one HYPR frame image. This is the same as the number of projections per one time frame.

23. N The total number of projections used. This is the number of time frames multiplied by N_p

24. J_k The k^{th} HYPR frame image. A 2-D image generate at the end of the HYPR algorithm. There will be as many HYPR frame images J_k as there are time frames.

6.2 Simulation software screen shots

Noise distribution selection menu. Noise is added to projection from user images

The name of the log file (just the name, do not include path information)

This window is used only by the base test validation (the Wright-Huang disk)

Statistics on current frame and running average is displayed here

Use this menu to select view angles (full or limited and range)

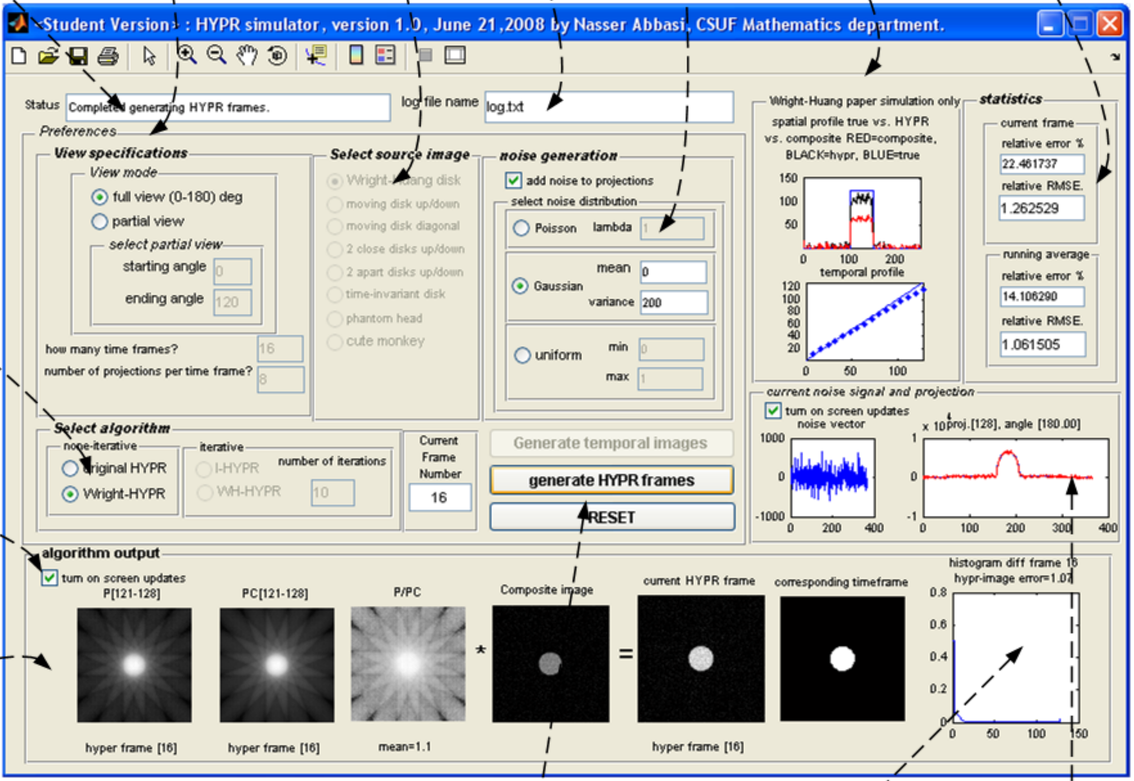
Use this menu to select the test image

Status windows. Displays current simulator state

Select the algorithm of HYPR to use. Iterative HYPR is not currently enabled as it is under development

Select this option to temporally stop displaying all outputs. This can speed up simulation.

This row of images shows the P, PC, mask, composite and HYPR frame image, and averaged time frame image. These are updated for each time frame.



<Student Version> : HYPR simulator, version 1.0, June 21,2008 by Nasser Abbasi, CSUF Mathematics department.

Status: Completed generating HYPR frames.

log file name: log.txt

Preferences

View specifications

View mode

● full view (0-180) deg

○ partial view

select partial view

starting angle: 0

ending angle: 120

how many time frames? 16

number of projections per time frame? 8

Select source image

● Wright-Huang disk

○ moving disk up/down

○ moving disk diagonal

○ 2 close disks up/down

○ 2 apart disks up/down

○ time-invariant disk

○ phantom head

○ cute monkey

noise generation

☑ add noise to projections

select noise distribution

○ Poisson lambda: 1

● Gaussian mean: 0 variance: 200

○ uniform min: 0 max: 1

Select algorithm

none-iterative

○ Original HYPR

● Wright-HYPR

iterative

○ I-HYPR

○ WH-HYPR

number of iterations: 10

Current Frame Number: 16

Wright-Huang paper simulation only

spatial profile true vs. HYPR vs. composite RED=composite, BLACK=hypr, BLUE=true

statistics

current frame

relative error %: 22.461737

relative RMSE.: 1.262529

running average

relative error %: 14.106290

relative RMSE.: 1.061505

current noise signal and projection

☑ turn on screen updates

algorithm output

☑ turn on screen updates

histogram diff frame 16

hypr-image error=1.07

mean=1.1

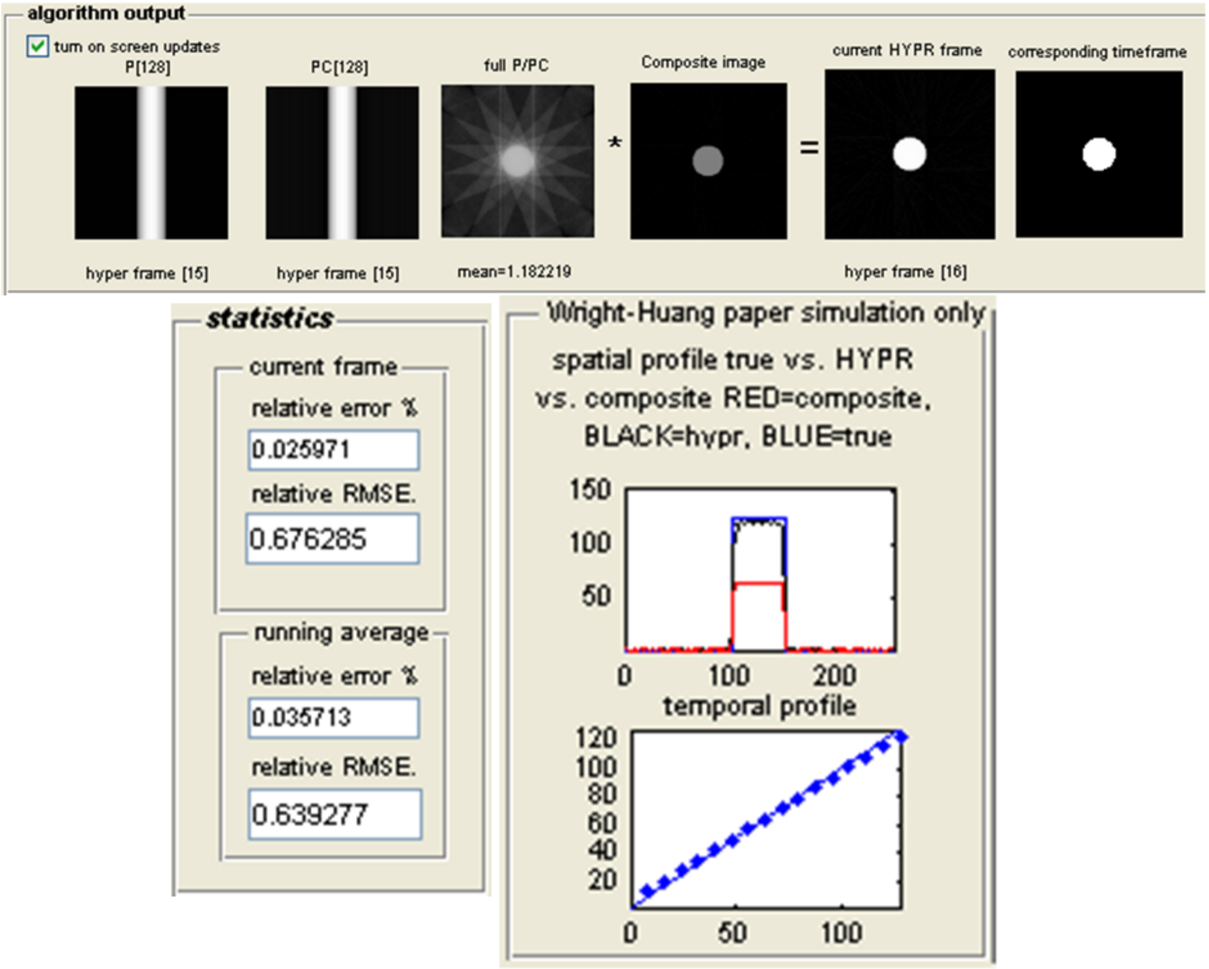
Main control of the simulator is located here. Allows one to generate user images, then HYPR images. User RESET to select a new test

Histogram difference between HYPR image and corresponding averaged time frame is displayed here (bins are gray levels). And running average of error found

Current projection vector is displayed here with noise vector if any

6.3 HYPR simulation results

6.3.1 Test 1a



☑ turn on screen updates

statistics

current frame

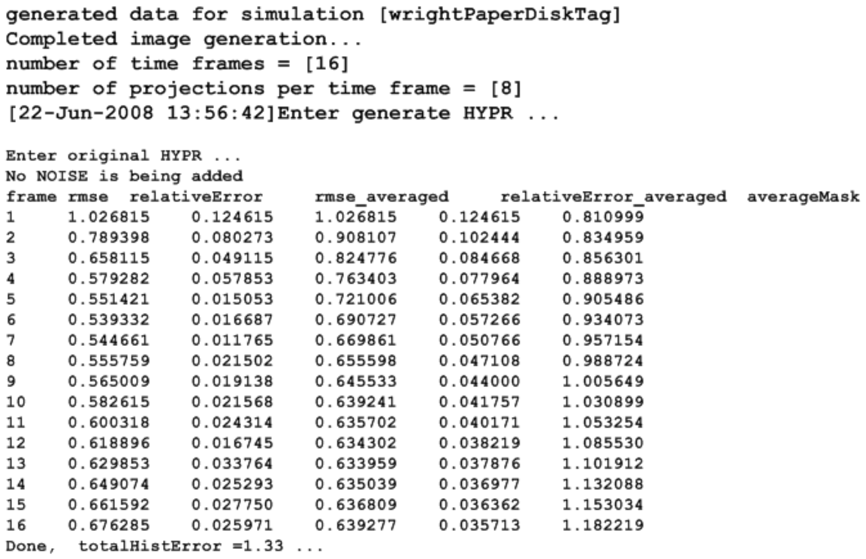
relative error %: 0.025971

relative RMSE.: 0.676285

running average

relative error %: 0.035713

relative RMSE.: 0.639277

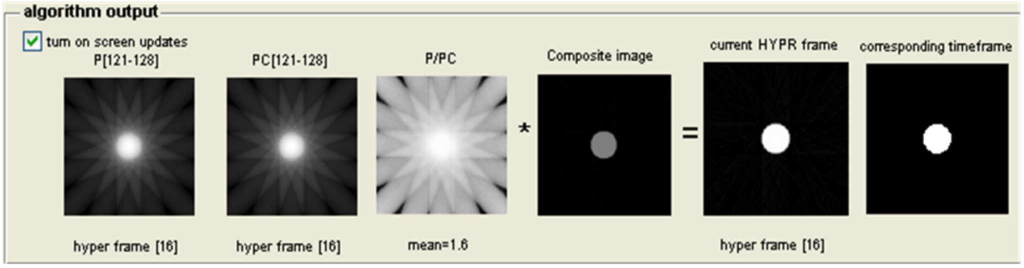


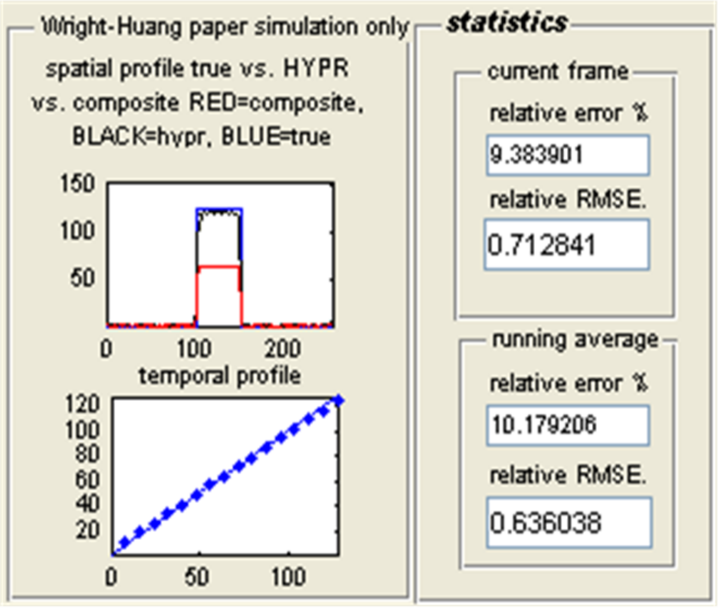
```
generated data for simulation [wrightPaperDiskTag]
Completed image generation...
number of time frames = [16]
number of projections per time frame = [8]
[22-Jun-2008 13:56:42]Enter generate HYPR ...

Enter original HYPR ...
No NOISE is being added
frame rmse  relativeError     rmse_averaged     relativeError_averaged  averageMask
1     1.026815    0.124615    1.026815    0.124615    0.810999
2     0.789398    0.080273    0.908107    0.102444    0.834959
3     0.658115    0.049115    0.824776    0.084668    0.856301
4     0.579282    0.057853    0.763403    0.077964    0.888973
5     0.551421    0.015053    0.721006    0.065382    0.905486
6     0.539332    0.016687    0.690727    0.057266    0.934073
7     0.544661    0.011765    0.669861    0.050766    0.957154
8     0.555759    0.021502    0.655598    0.047108    0.988724
9     0.565009    0.019138    0.645533    0.044000    1.005649
10    0.582615    0.021568    0.639241    0.041757    1.030899
11    0.600318    0.024314    0.635702    0.040171    1.053254
12    0.618896    0.016745    0.634302    0.038219    1.085530
13    0.629853    0.033764    0.633959    0.037876    1.101912
14    0.649074    0.025293    0.635039    0.036977    1.132088
15    0.661592    0.027750    0.636809    0.036362    1.153034
16    0.676285    0.025971    0.639277    0.035713    1.182219
Done,  totalHistError =1.33 ...
```

Running the Wright-Huang test case using the original HYPR algorithm

6.3.2 Test 1b




Wright-Huang paper simulation only
spatial profile true vs. HYPR
vs. composite RED=composite,
BLACK=hypr, BLUE=true
150
100
50
0
100
200
temporal profile
120
100
80
60
40
20
0
50
100
statistics

current frame

relative error %

9.383901

relative RMSE.

0.712841

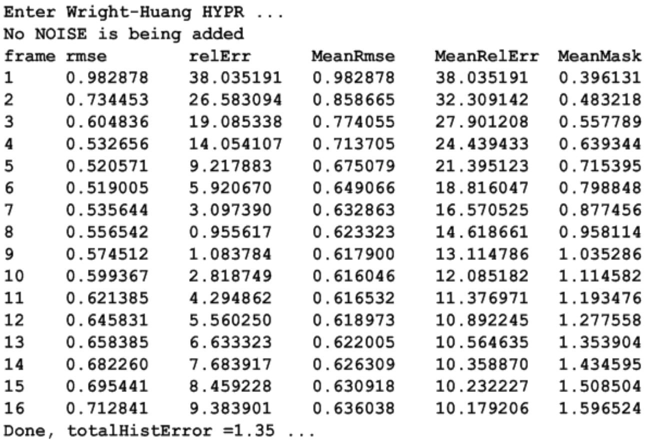
running average

relative error %

10.179206

relative RMSE.

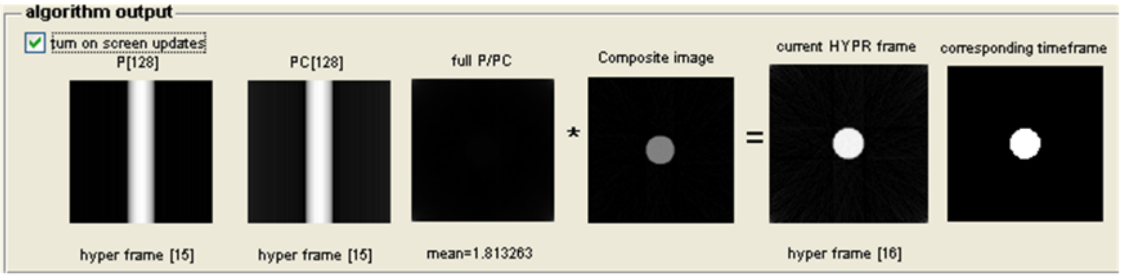
0.636038



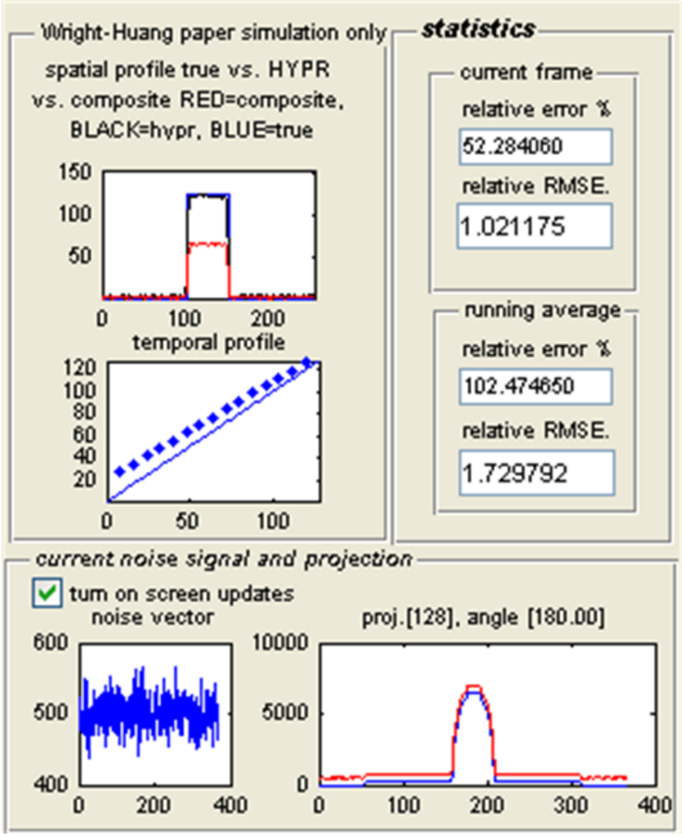
```
Enter Wright-Huang HYPR ...
No NOISE is being added
frame rmse       relErr     MeanRmse    MeanRelErr  MeanMask
1     0.982878   38.035191  0.982878    38.035191   0.396131
2     0.734453   26.583094  0.858665    32.309142   0.483218
3     0.604836   19.085338  0.774055    27.901208   0.557789
4     0.532656   14.054107  0.713705    24.439433   0.639344
5     0.520571   9.217883   0.675079    21.395123   0.715395
6     0.519005   5.920670   0.649066    18.816047   0.798848
7     0.535644   3.097390   0.632863    16.570525   0.877456
8     0.556542   0.955617   0.623323    14.618661   0.958114
9     0.574512   1.083784   0.617900    13.114786   1.035286
10    0.599367   2.818749   0.616046    12.085182   1.114582
11    0.621385   4.294862   0.616532    11.376971   1.193476
12    0.645831   5.560250   0.618973    10.892245   1.277558
13    0.658385   6.633323   0.622005    10.564635   1.353904
14    0.682260   7.683917   0.626309    10.358870   1.434595
15    0.695441   8.459228   0.630918    10.232227   1.508504
16    0.712841   9.383901   0.636038    10.179206   1.596524
Done, totalHistError =1.35 ...
```

Test 1b results

6.3.3 Test 2a



☑ turn on screen updates



current frame

relative error % 52.284060

relative RMSE. 1.021175

running average

relative error % 102.474650

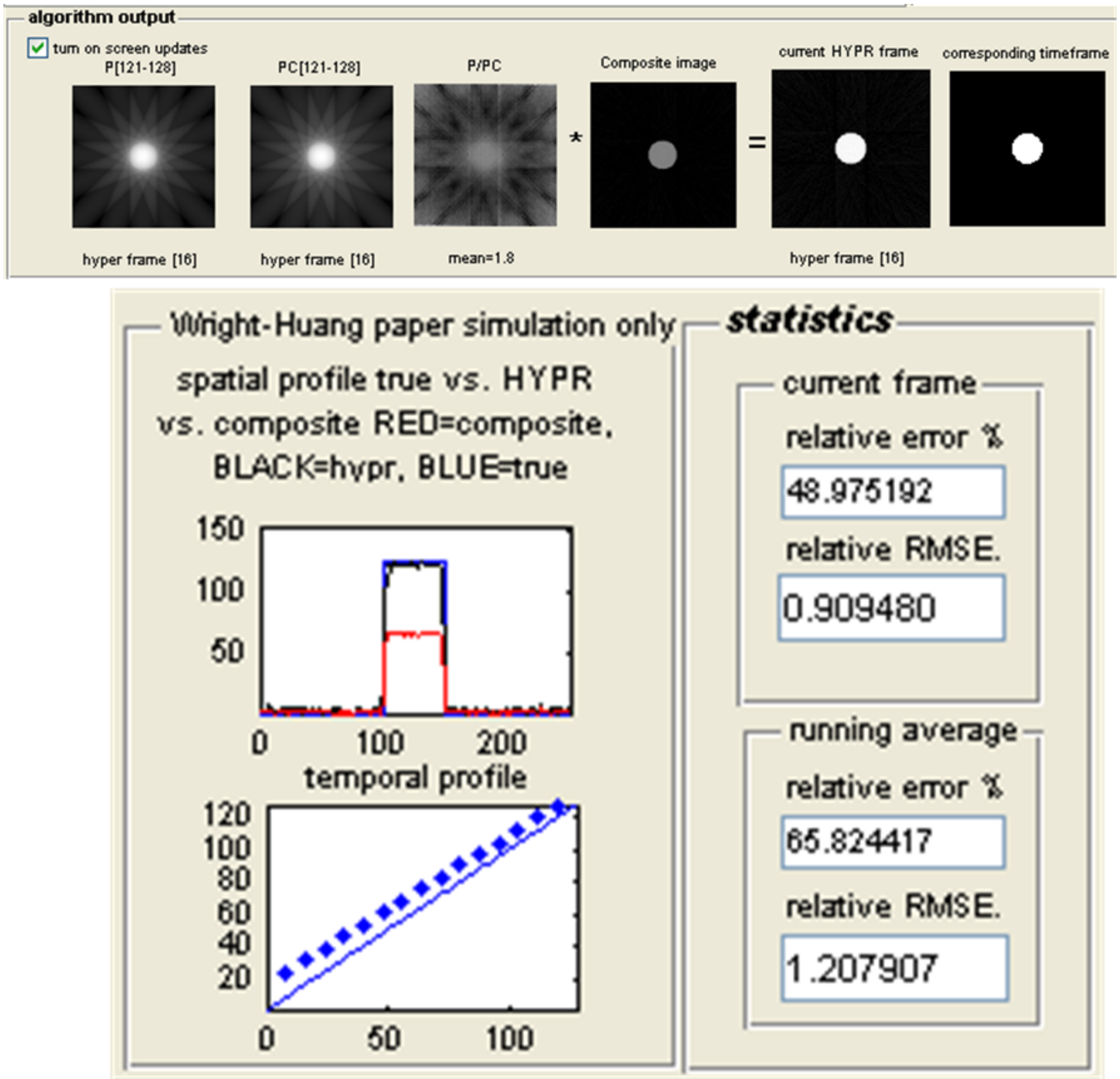
relative RMSE. 1.729792

☑ turn on screen updates

```
Enter original HYPR ...
NOISE is being added
Using Poisson noise, lambda=500.000000
frame rmse      relErr     MeanRmse   MeanRelErr MeanMask
1     3.794379  221.763762 3.794379   221.763762 1.474255
2     3.166966  185.358053 3.480673   203.560907 1.508603
3     2.608558  156.888440 3.189968   188.003418 1.527144
4     2.221155  136.067387 2.947765   175.019410 1.554850
5     1.930149  119.771893 2.744241   163.969907 1.567517
6     1.747583  108.147509 2.578132   154.666174 1.599652
7     1.590956  98.060255  2.437106   146.579614 1.621458
8     1.416717  88.445097  2.309558   139.312799 1.640420
9     1.320464  81.505980  2.199658   132.889820 1.654478
10    1.276373  76.376848  2.107330   127.238522 1.687263
11    1.208729  71.138666  2.025639   122.138535 1.708348
12    1.145390  66.167579  1.952285   117.474289 1.733409
13    1.108661  62.349480  1.887391   113.233919 1.749685
14    1.083650  58.885952  1.829981   109.351922 1.777842
15    1.062933  55.908463  1.778844   105.789024 1.799599
16    1.019940  52.258520  1.731413   102.443368 1.813701
Done,  totalHistError =1.71 ...
```

Test 2a

6.3.4 Test 2b



current frame

relative error % 48.975192

relative RMSE. 0.909480

running average

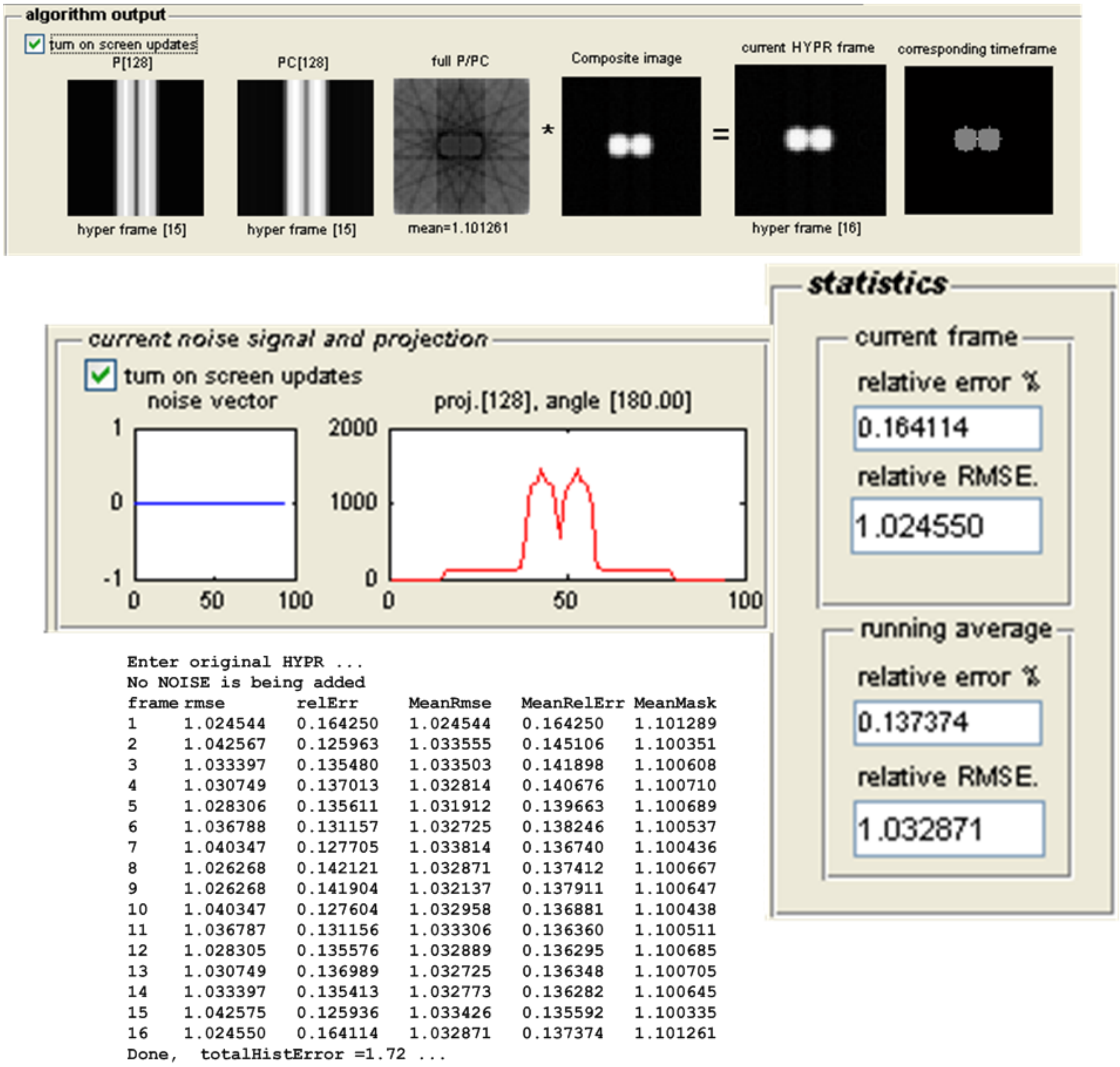
relative error % 65.824417

relative RMSE. 1.207907

Test 2b

```
Enter Wright-Huang HYPR ...
NOISE is being added
Using Poisson noise, lambda=500.000000
frame rmse      relErr     MeanRmse   MeanRelErr MeanMask
1     2.537686  103.394281 2.537686   103.394281 0.852526
2     2.063792  95.447458  2.300739   99.420870  0.934455
3     1.673412  84.548348  2.091630   94.463363  0.986322
4     1.384630  75.808737  1.914880   89.799706  1.047637
5     1.241278  71.417355  1.780160   86.123236  1.101549
6     1.126402  68.027509  1.671200   83.107281  1.174521
7     1.051424  64.998822  1.582660   80.520359  1.236801
8     0.956893  60.108881  1.504440   77.968924  1.286315
9     0.936989  58.614646  1.441389   75.818449  1.345422
10    0.928753  57.735384  1.390126   74.010142  1.419706
11    0.912443  55.866211  1.346700   72.360694  1.478030
12    0.894692  53.402971  1.309033   70.780884  1.535107
13    0.897935  52.682674  1.277410   69.388714  1.595649
14    0.902629  51.445255  1.250640   68.107038  1.660646
15    0.908081  50.716949  1.227803   66.947699  1.723549
16    0.909480  48.975192  1.207907   65.824417  1.773860
Done, totalHistError =1.80 ...
```

6.3.5 test 3a



☑ turn on screen updates

☑ turn on screen updates

current frame

relative error %

0.164114

relative RMSE.

1.024550

running average

relative error %

0.137374

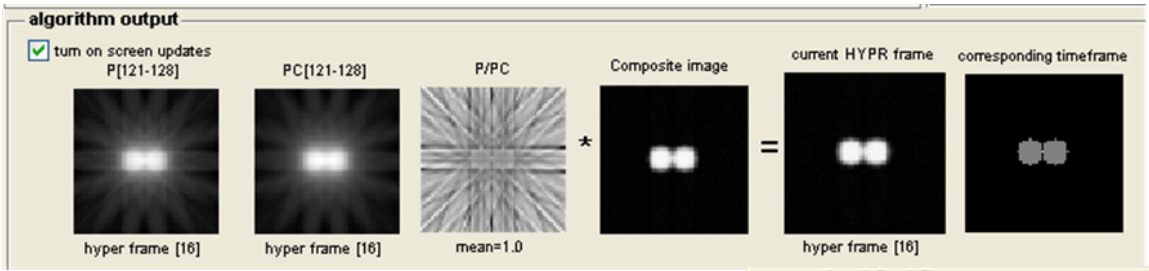
relative RMSE.

1.032871

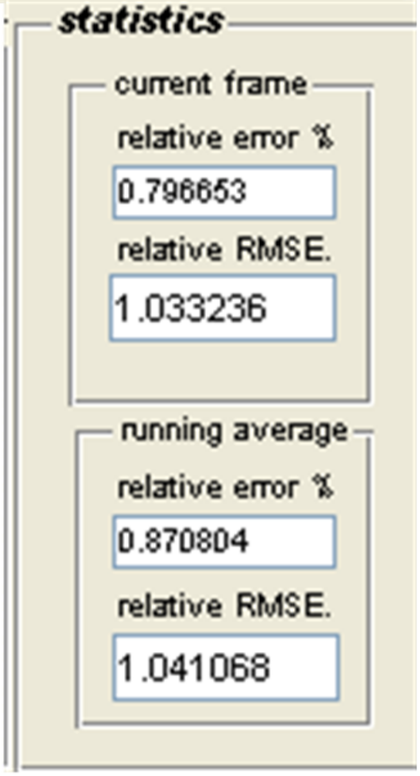
```
Enter original HYPR ...
No NOISE is being added
frame rmse       relErr     MeanRmse   MeanRelErr MeanMask
1     1.024544   0.164250   1.024544   0.164250   1.101289
2     1.042567   0.125963   1.033555   0.145106   1.100351
3     1.033397   0.135480   1.033503   0.141898   1.100608
4     1.030749   0.137013   1.032814   0.140676   1.100710
5     1.028306   0.135611   1.031912   0.139663   1.100689
6     1.036788   0.131157   1.032725   0.138246   1.100537
7     1.040347   0.127705   1.033814   0.136740   1.100436
8     1.026268   0.142121   1.032871   0.137412   1.100667
9     1.026268   0.141904   1.032137   0.137911   1.100647
10    1.040347   0.127604   1.032958   0.136881   1.100438
11    1.036787   0.131156   1.033306   0.136360   1.100511
12    1.028305   0.135576   1.032889   0.136295   1.100685
13    1.030749   0.136989   1.032725   0.136348   1.100705
14    1.033397   0.135413   1.032773   0.136282   1.100645
15    1.042575   0.125936   1.033426   0.135592   1.100335
16    1.024550   0.164114   1.032871   0.137374   1.101261
Done,  totalHistError =1.72 ...
```

Test 3a

6.3.6 Test 3b



```
Enter Wright-Huang HYPR ...
No NOISE is being added
frame rmse      relErr     MeanRmse   MeanRelErr MeanMask
1     1.033230  0.796456   1.033230   0.796456   1.038977
2     1.048957  0.887767   1.041093   0.842111   1.037790
3     1.041920  0.884762   1.041369   0.856328   1.038249
4     1.039824  0.887151   1.040983   0.864034   1.038365
5     1.037571  0.882855   1.040300   0.867798   1.038507
6     1.044559  0.885161   1.041010   0.870692   1.038137
7     1.047245  0.892601   1.041901   0.873822   1.037962
8     1.035236  0.849602   1.041068   0.870794   1.038600
9     1.035236  0.849525   1.040420   0.868431   1.038602
10    1.047245  0.892414   1.041102   0.870829   1.037970
11    1.044558  0.885209   1.041416   0.872137   1.038135
12    1.037571  0.882776   1.041096   0.873023   1.038515
13    1.039824  0.887281   1.040998   0.874120   1.038361
14    1.041921  0.884700   1.041064   0.874876   1.038251
15    1.048960  0.887956   1.041590   0.875748   1.037768
16    1.033236  0.796653   1.041068   0.870804   1.038961
Done, totalHistError =1.69 ...
```



statistics

current frame

relative error %

0.796653

relative RMSE.

1.033236

running average

relative error %

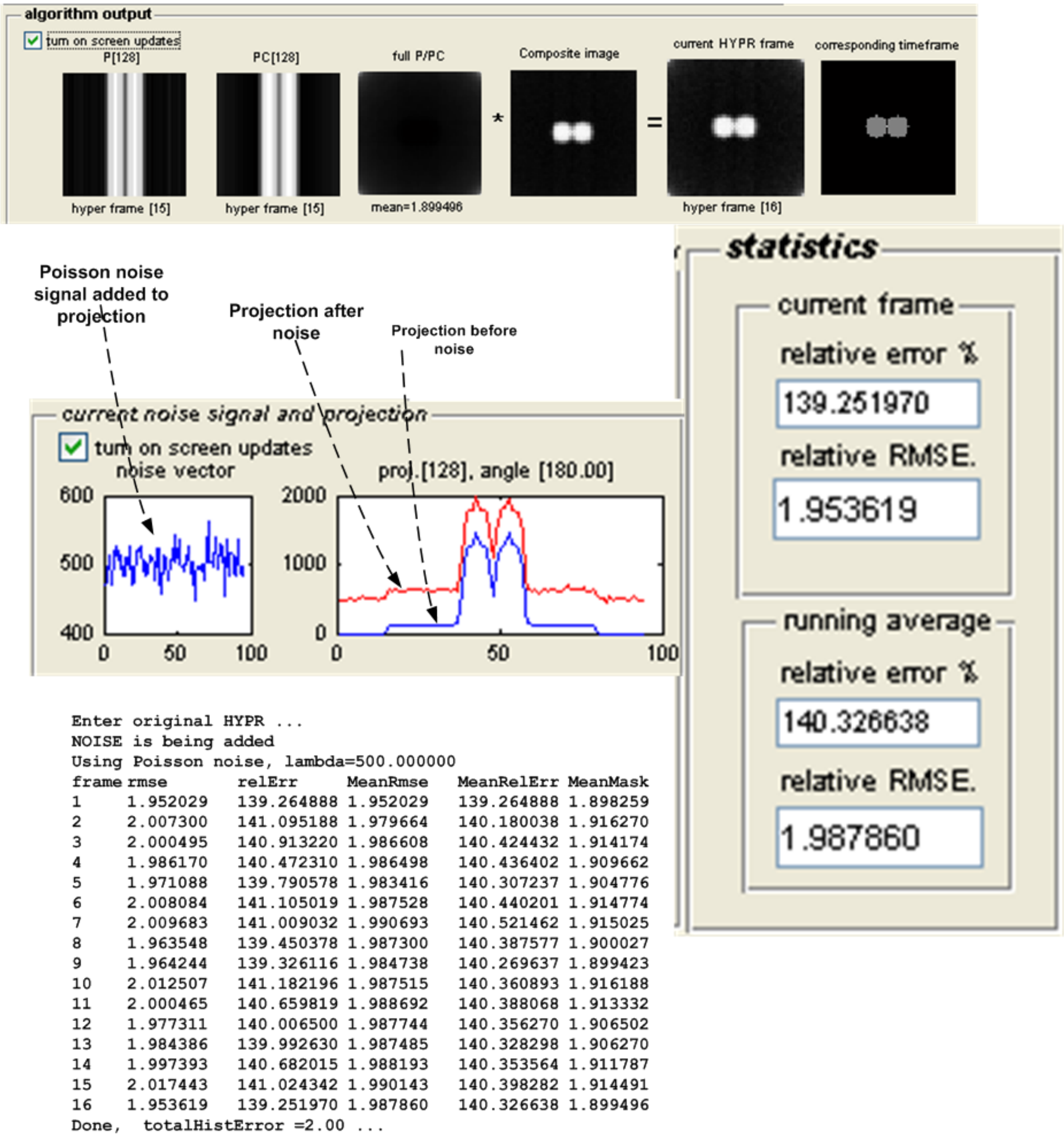
0.870804

relative RMSE.

1.041068

Test 3b

6.3.7 Test 4a



relative error %

139.251970

relative RMSE.

1.953619

relative error %

140.326638

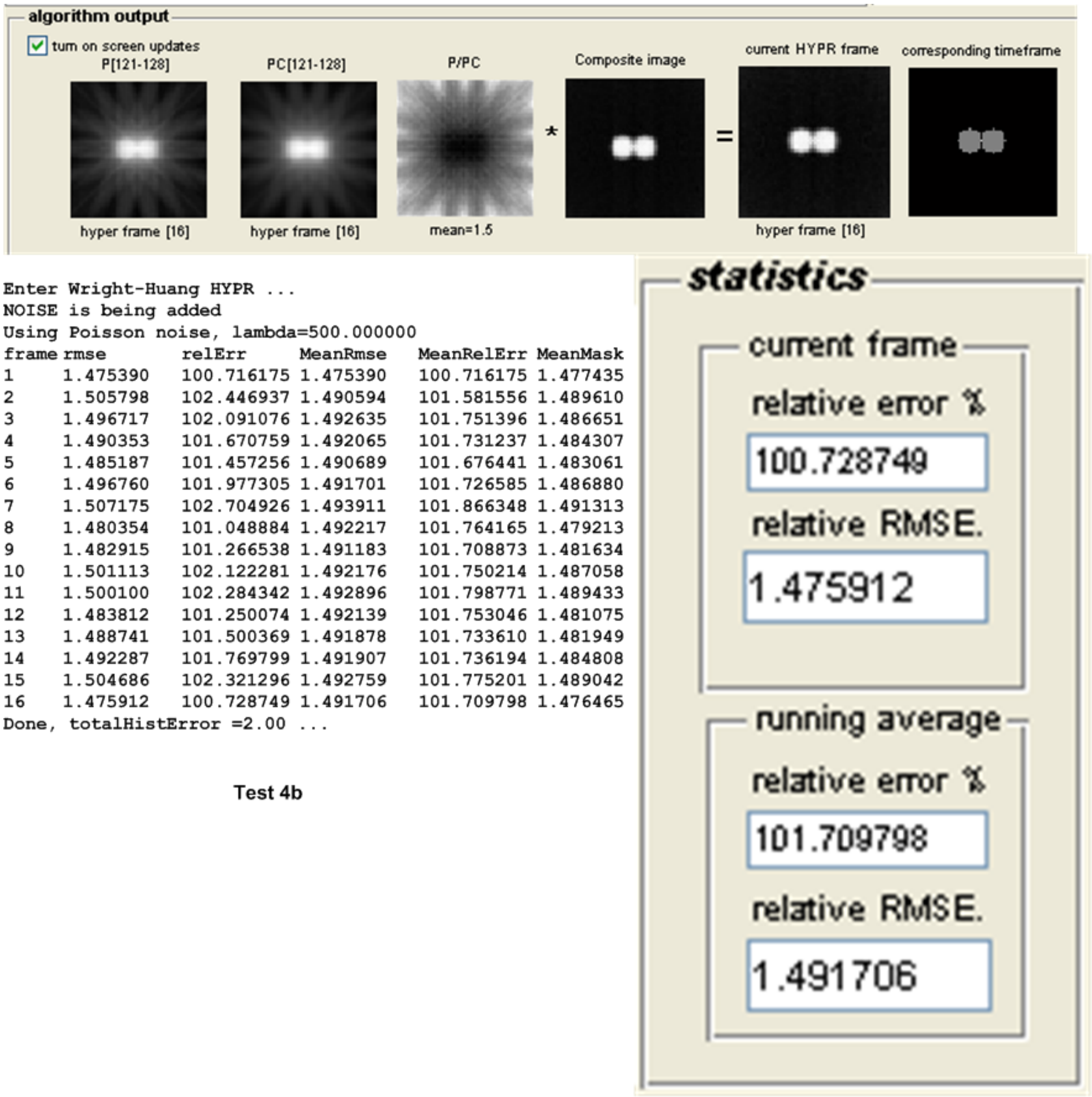
relative RMSE.

1.987860

```
Enter original HYPR ...
NOISE is being added
Using Poisson noise, lambda=500.000000
frame rmse       relErr     MeanRmse   MeanRelErr MeanMask
1     1.952029   139.264888 1.952029   139.264888 1.898259
2     2.007300   141.095188 1.979664   140.180038 1.916270
3     2.000495   140.913220 1.986608   140.424432 1.914174
4     1.986170   140.472310 1.986498   140.436402 1.909662
5     1.971088   139.790578 1.983416   140.307237 1.904776
6     2.008084   141.105019 1.987528   140.440201 1.914774
7     2.009683   141.009032 1.990693   140.521462 1.915025
8     1.963548   139.450378 1.987300   140.387577 1.900027
9     1.964244   139.326116 1.984738   140.269637 1.899423
10    2.012507   141.182196 1.987515   140.360893 1.916188
11    2.000465   140.659819 1.988692   140.388068 1.913332
12    1.977311   140.006500 1.987744   140.356270 1.906502
13    1.984386   139.992630 1.987485   140.328298 1.906270
14    1.997393   140.682015 1.988193   140.353564 1.911787
15    2.017443   141.024342 1.990143   140.398282 1.914491
16    1.953619   139.251970 1.987860   140.326638 1.899496
Done,  totalHistError =2.00 ...
```

Test 4a

6.3.8 Test 4b



```
Enter Wright-Huang HYPR ...
NOISE is being added
Using Poisson noise, lambda=500.000000
frame rmse      relErr     MeanRmse   MeanRelErr MeanMask
1     1.475390  100.716175 1.475390   100.716175 1.477435
2     1.505798  102.446937 1.490594   101.581556 1.489610
3     1.496717  102.091076 1.492635   101.751396 1.486651
4     1.490353  101.670759 1.492065   101.731237 1.484307
5     1.485187  101.457256 1.490689   101.676441 1.483061
6     1.496760  101.977305 1.491701   101.726585 1.486880
7     1.507175  102.704926 1.493911   101.866348 1.491313
8     1.480354  101.048884 1.492217   101.764165 1.479213
9     1.482915  101.266538 1.491183   101.708873 1.481634
10    1.501113  102.122281 1.492176   101.750214 1.487058
11    1.500100  102.284342 1.492896   101.798771 1.489433
12    1.483812  101.250074 1.492139   101.753046 1.481075
13    1.488741  101.500369 1.491878   101.733610 1.481949
14    1.492287  101.769799 1.491907   101.736194 1.484808
15    1.504686  102.321296 1.492759   101.775201 1.489042
16    1.475912  100.728749 1.491706   101.709798 1.476465
Done, totalHistError =2.00 ...
```

statistics

current frame

relative error %

100.728749

relative RMSE.

1.475912

running average

relative error %

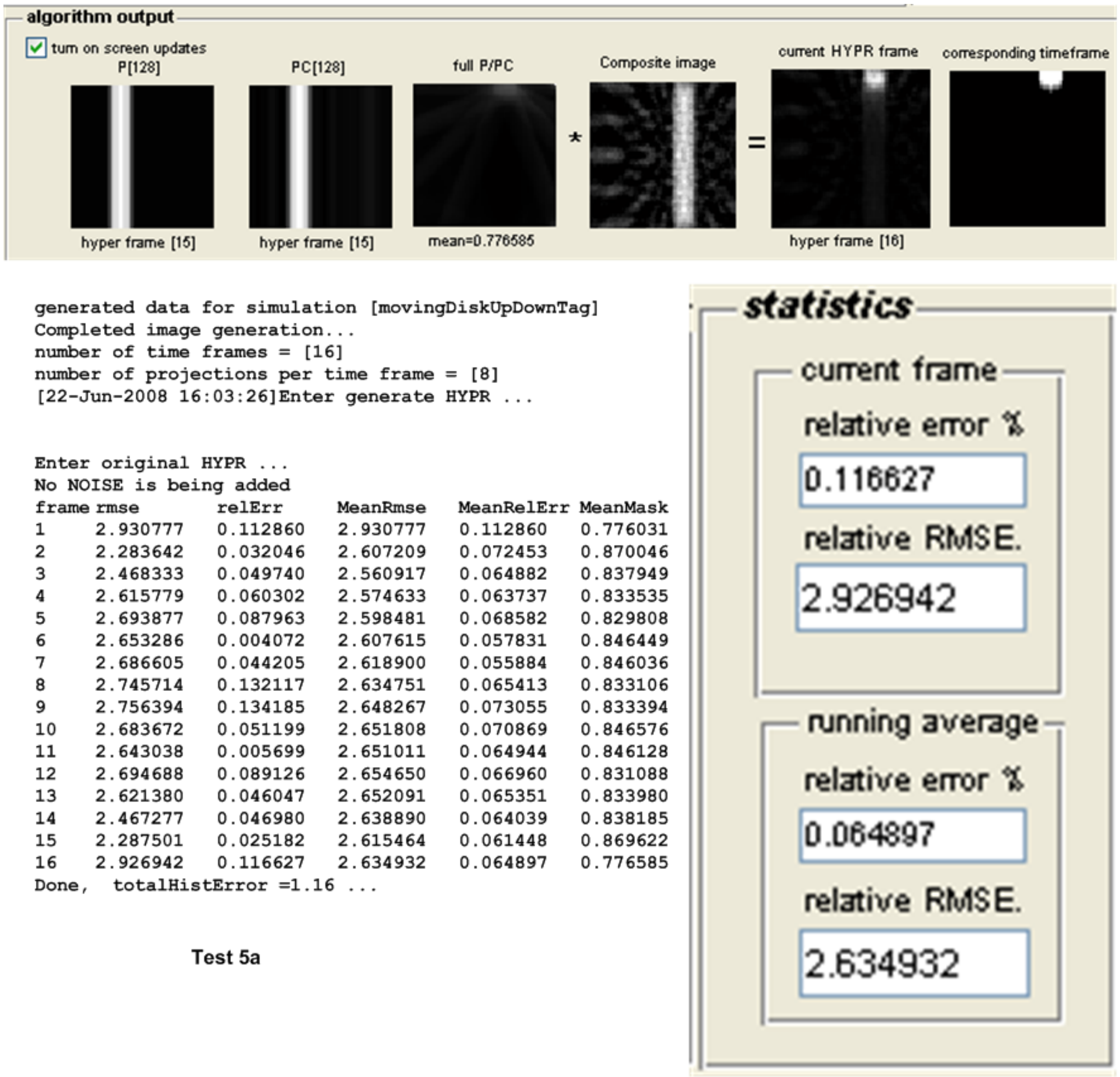
101.709798

relative RMSE.

1.491706

Test 4b

6.3.9 Test 5a



```
generated data for simulation [movingDiskUpDownTag]
Completed image generation...
number of time frames = [16]
number of projections per time frame = [8]
[22-Jun-2008 16:03:26]Enter generate HYPR ...


Enter original HYPR ...
No NOISE is being added
frame rmse      relErr      MeanRmse    MeanRelErr MeanMask
1     2.930777  0.112860    2.930777    0.112860   0.776031
2     2.283642  0.032046    2.607209    0.072453   0.870046
3     2.468333  0.049740    2.560917    0.064882   0.837949
4     2.615779  0.060302    2.574633    0.063737   0.833535
5     2.693877  0.087963    2.598481    0.068582   0.829808
6     2.653286  0.004072    2.607615    0.057831   0.846449
7     2.686605  0.044205    2.618900    0.055884   0.846036
8     2.745714  0.132117    2.634751    0.065413   0.833106
9     2.756394  0.134185    2.648267    0.073055   0.833394
10    2.683672  0.051199    2.651808    0.070869   0.846576
11    2.643038  0.005699    2.651011    0.064944   0.846128
12    2.694688  0.089126    2.654650    0.066960   0.831088
13    2.621380  0.046047    2.652091    0.065351   0.833980
14    2.467277  0.046980    2.638890    0.064039   0.838185
15    2.287501  0.025182    2.615464    0.061448   0.869622
16    2.926942  0.116627    2.634932    0.064897   0.776585
Done,  totalHistError =1.16 ...
```

Test 5a

statistics

current frame

relative error %

0.116627

relative RMSE.

2.926942

running average

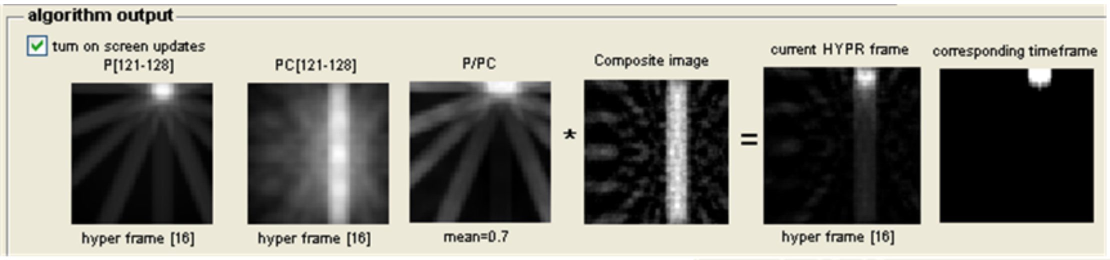
relative error %

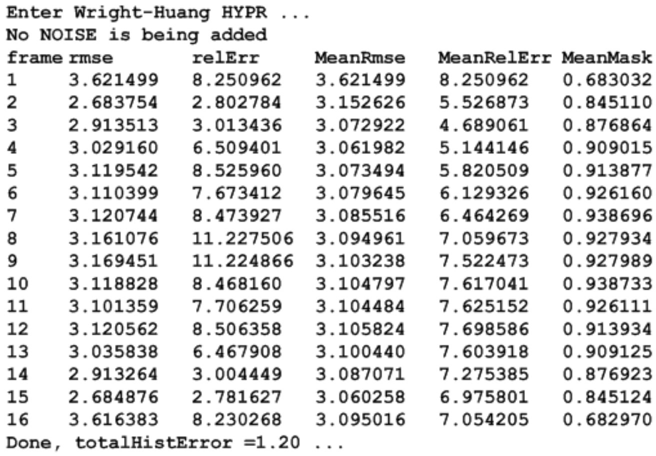
0.064897

relative RMSE.

2.634932

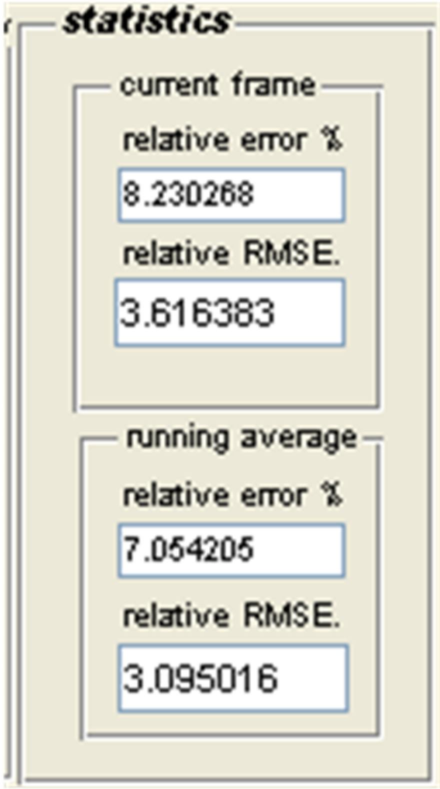
6.3.10 Test 5b





```
Enter Wright-Huang HYPR ...
No NOISE is being added
frame rmse        relErr     MeanRmse   MeanRelErr MeanMask
1     3.621499    8.250962   3.621499   8.250962   0.683032
2     2.683754    2.802784   3.152626   5.526873   0.845110
3     2.913513    3.013436   3.072922   4.689061   0.876864
4     3.029160    6.509401   3.061982   5.144146   0.909015
5     3.119542    8.525960   3.073494   5.820509   0.913877
6     3.110399    7.673412   3.079645   6.129326   0.926160
7     3.120744    8.473927   3.085516   6.464269   0.938696
8     3.161076    11.227506  3.094961   7.059673   0.927934
9     3.169451    11.224866  3.103238   7.522473   0.927989
10    3.118828    8.468160   3.104797   7.617041   0.938733
11    3.101359    7.706259   3.104484   7.625152   0.926111
12    3.120562    8.506358   3.105824   7.698586   0.913934
13    3.035838    6.467908   3.100440   7.603918   0.909125
14    2.913264    3.004449   3.087071   7.275385   0.876923
15    2.684876    2.781627   3.060258   6.975801   0.845124
16    3.616383    8.230268   3.095016   7.054205   0.682970
Done, totalHistError =1.20 ...
```

Test 5b



statistics

current frame

relative error %

8.230268

relative RMSE.

3.616383

running average

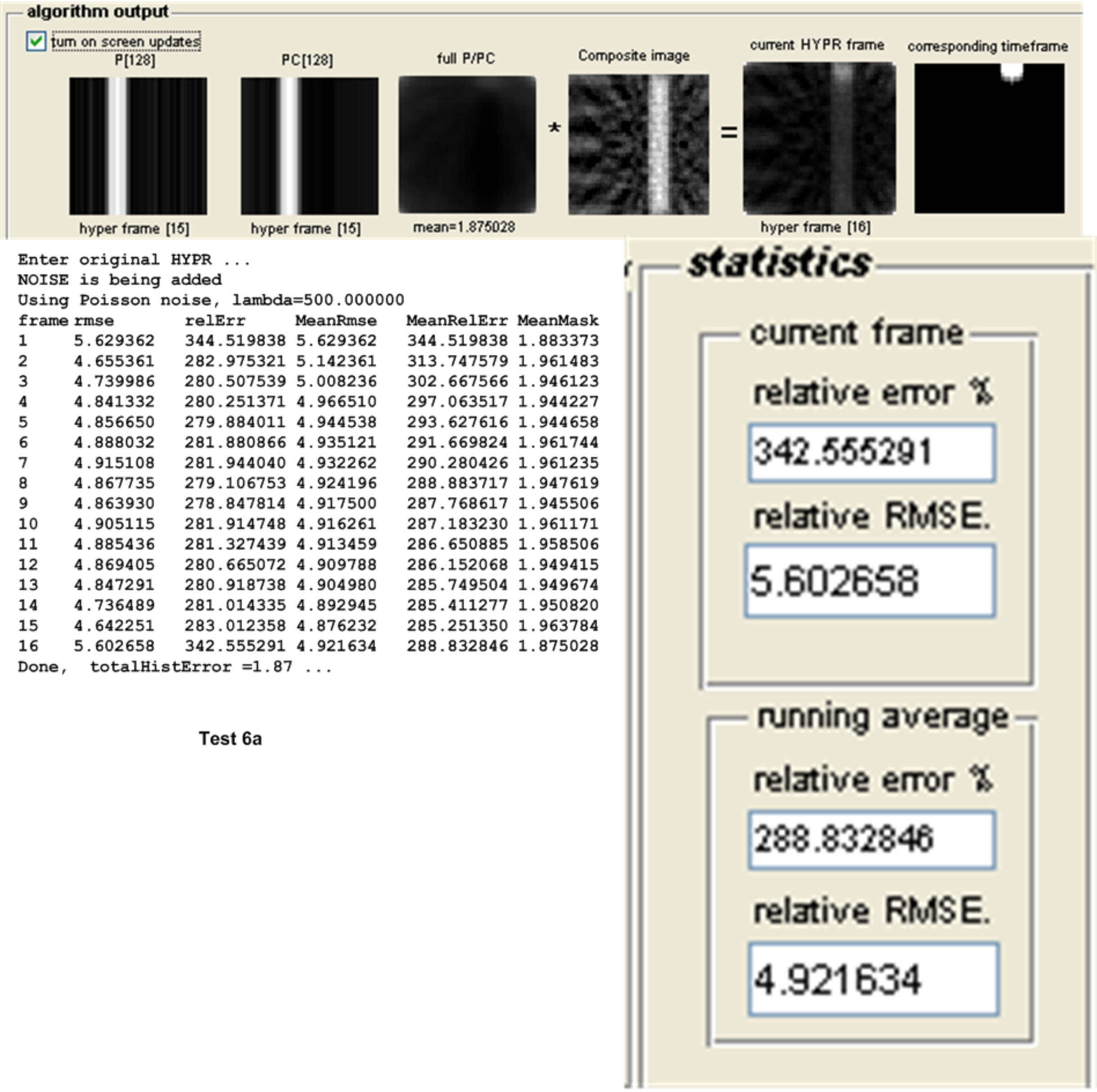
relative error %

7.054205

relative RMSE.

3.095016

6.3.11 Test 6a



```
Enter original HYPR ...
NOISE is being added
Using Poisson noise, lambda=500.000000
frame rmse      relErr     MeanRmse    MeanRelErr MeanMask
1     5.629362  344.519838 5.629362    344.519838 1.883373
2     4.655361  282.975321 5.142361    313.747579 1.961483
3     4.739986  280.507539 5.008236    302.667566 1.946123
4     4.841332  280.251371 4.966510    297.063517 1.944227
5     4.856650  279.884011 4.944538    293.627616 1.944658
6     4.888032  281.880866 4.935121    291.669824 1.961744
7     4.915108  281.944040 4.932262    290.280426 1.961235
8     4.867735  279.106753 4.924196    288.883717 1.947619
9     4.863930  278.847814 4.917500    287.768617 1.945506
10    4.905115  281.914748 4.916261    287.183230 1.961171
11    4.885436  281.327439 4.913459    286.650885 1.958506
12    4.869405  280.665072 4.909788    286.152068 1.949415
13    4.847291  280.918738 4.904980    285.749504 1.949674
14    4.736489  281.014335 4.892945    285.411277 1.950820
15    4.642251  283.012358 4.876232    285.251350 1.963784
16    5.602658  342.555291 4.921634    288.832846 1.875028
Done,  totalHistError =1.87 ...
```

statistics

current frame

relative error %: 342.555291

relative RMSE.: 5.602658

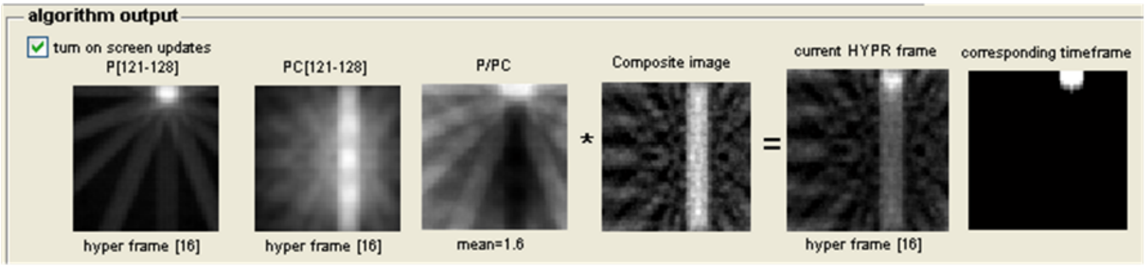
running average

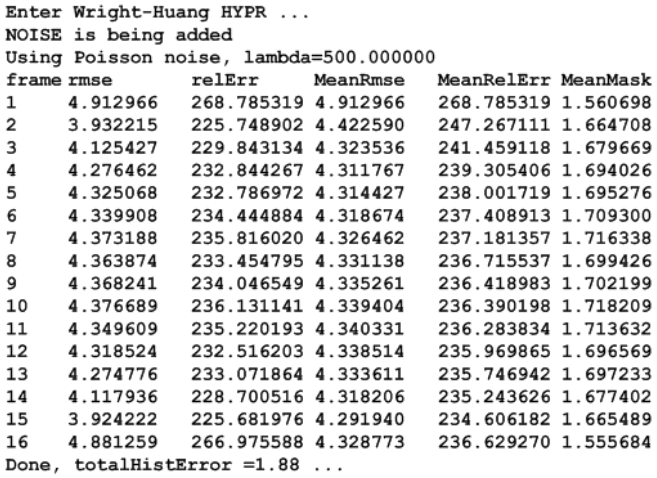
relative error %: 288.832846

relative RMSE.: 4.921634

Test 6a

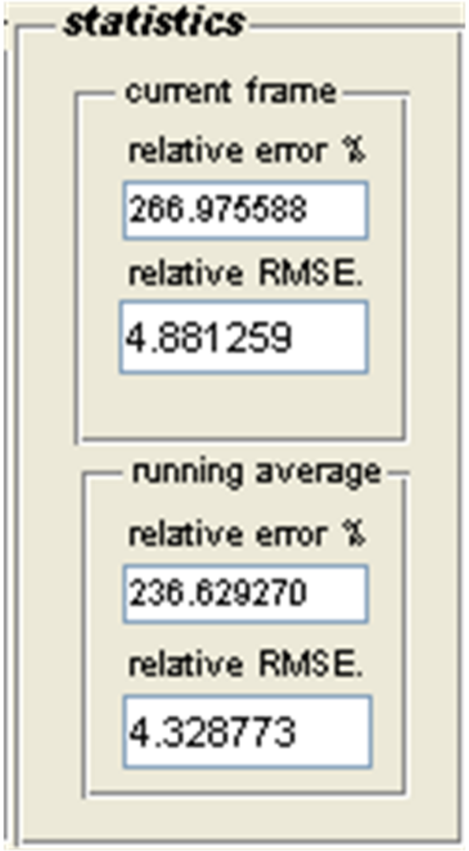
6.3.12 Test 6b





```
Enter Wright-Huang HYPR ...
NOISE is being added
Using Poisson noise, lambda=500.000000
frame rmse      relErr     MeanRmse   MeanRelErr MeanMask
1     4.912966   268.785319 4.912966   268.785319 1.560698
2     3.932215   225.748902 4.422590   247.267111 1.664708
3     4.125427   229.843134 4.323536   241.459118 1.679669
4     4.276462   232.844267 4.311767   239.305406 1.694026
5     4.325068   232.786972 4.314427   238.001719 1.695276
6     4.339908   234.444884 4.318674   237.408913 1.709300
7     4.373188   235.816020 4.326462   237.181357 1.716338
8     4.363874   233.454795 4.331138   236.715537 1.699426
9     4.368241   234.046549 4.335261   236.418983 1.702199
10    4.376689   236.131141 4.339404   236.390198 1.718209
11    4.349609   235.220193 4.340331   236.283834 1.713632
12    4.318524   232.516203 4.338514   235.969865 1.696569
13    4.274776   233.071864 4.333611   235.746942 1.697233
14    4.117936   228.700516 4.318206   235.243626 1.677402
15    3.924222   225.681976 4.291940   234.606182 1.665489
16    4.881259   266.975588 4.328773   236.629270 1.555684
Done, totalHistError =1.88 ...
```

Test 6b



statistics

current frame

relative error %

266.975588

relative RMSE.

4.881259

running average

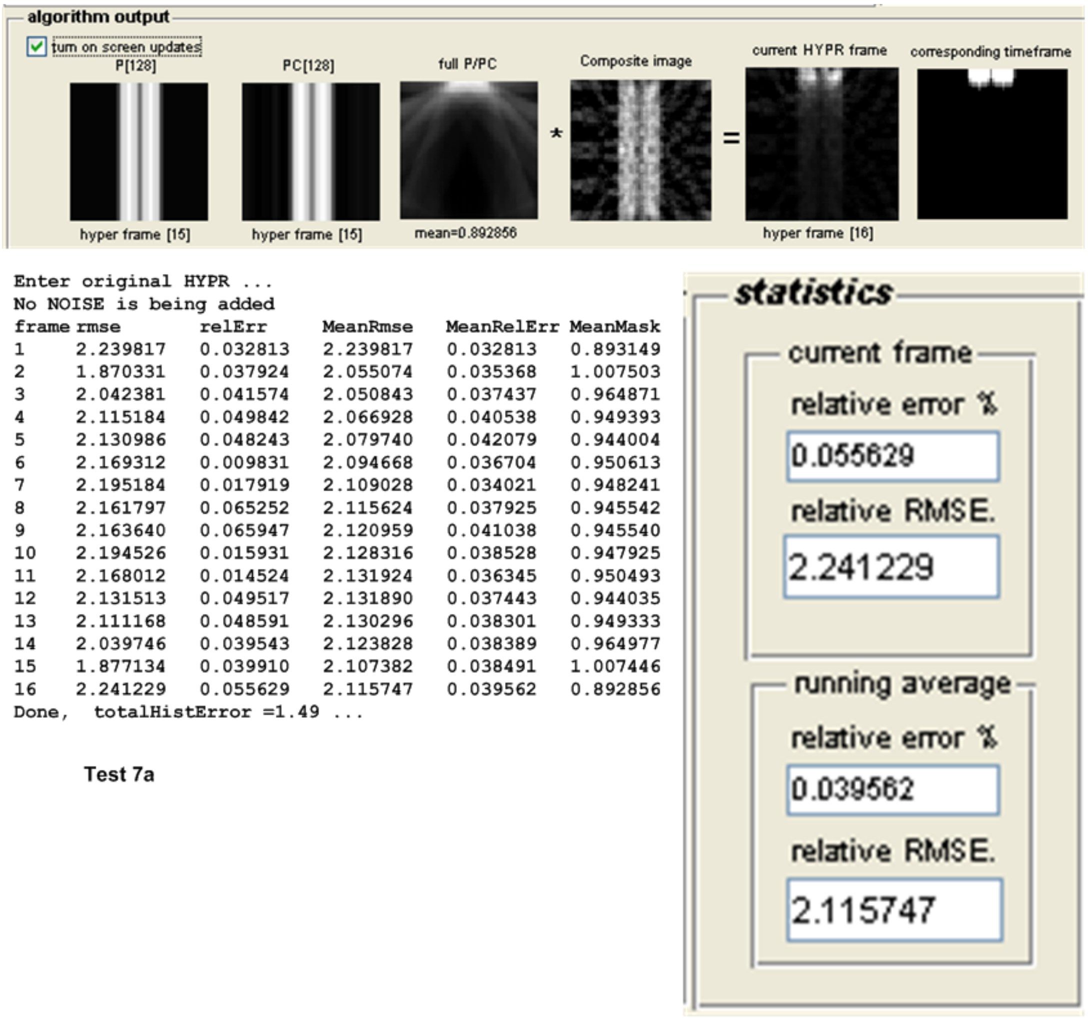
relative error %

236.629270

relative RMSE.

4.328773

6.3.13 Test 7a



```
Enter original HYPR ...
No NOISE is being added
frame rmse      relErr    MeanRmse  MeanRelErr MeanMask
1     2.239817  0.032813  2.239817  0.032813  0.893149
2     1.870331  0.037924  2.055074  0.035368  1.007503
3     2.042381  0.041574  2.050843  0.037437  0.964871
4     2.115184  0.049842  2.066928  0.040538  0.949393
5     2.130986  0.048243  2.079740  0.042079  0.944004
6     2.169312  0.009831  2.094668  0.036704  0.950613
7     2.195184  0.017919  2.109028  0.034021  0.948241
8     2.161797  0.065252  2.115624  0.037925  0.945542
9     2.163640  0.065947  2.120959  0.041038  0.945540
10    2.194526  0.015931  2.128316  0.038528  0.947925
11    2.168012  0.014524  2.131924  0.036345  0.950493
12    2.131513  0.049517  2.131890  0.037443  0.944035
13    2.111168  0.048591  2.130296  0.038301  0.949333
14    2.039746  0.039543  2.123828  0.038389  0.964977
15    1.877134  0.039910  2.107382  0.038491  1.007446
16    2.241229  0.055629  2.115747  0.039562  0.892856
Done,  totalHistError =1.49 ...
```

statistics

current frame

relative error %: 0.055629

relative RMSE.: 2.241229

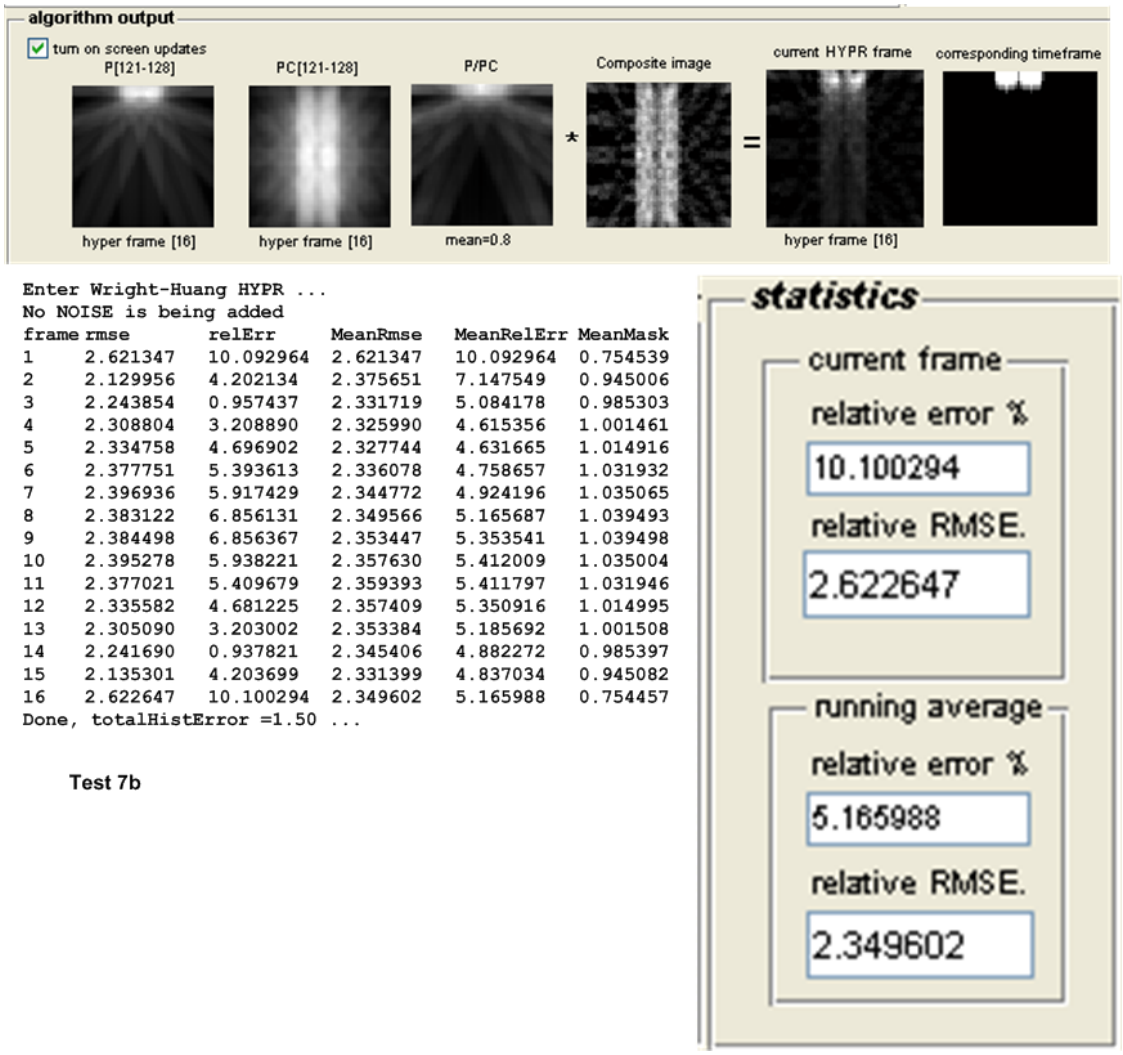
running average

relative error %: 0.039562

relative RMSE.: 2.115747

Test 7a

6.3.14 Test 7b



```
Enter Wright-Huang HYPR ...
No NOISE is being added
frame rmse      relErr     MeanRmse   MeanRelErr  MeanMask
1     2.621347  10.092964  2.621347   10.092964   0.754539
2     2.129956  4.202134   2.375651   7.147549    0.945006
3     2.243854  0.957437   2.331719   5.084178    0.985303
4     2.308804  3.208890   2.325990   4.615356    1.001461
5     2.334758  4.696902   2.327744   4.631665    1.014916
6     2.377751  5.393613   2.336078   4.758657    1.031932
7     2.396936  5.917429   2.344772   4.924196    1.035065
8     2.383122  6.856131   2.349566   5.165687    1.039493
9     2.384498  6.856367   2.353447   5.353541    1.039498
10    2.395278  5.938221   2.357630   5.412009    1.035004
11    2.377021  5.409679   2.359393   5.411797    1.031946
12    2.335582  4.681225   2.357409   5.350916    1.014995
13    2.305090  3.203002   2.353384   5.185692    1.001508
14    2.241690  0.937821   2.345406   4.882272    0.985397
15    2.135301  4.203699   2.331399   4.837034    0.945082
16    2.622647  10.100294  2.349602   5.165988    0.754457
Done, totalHistError =1.50 ...
```

Test 7b

statistics

current frame

relative error %

10.100294

relative RMSE.

2.622647

running average

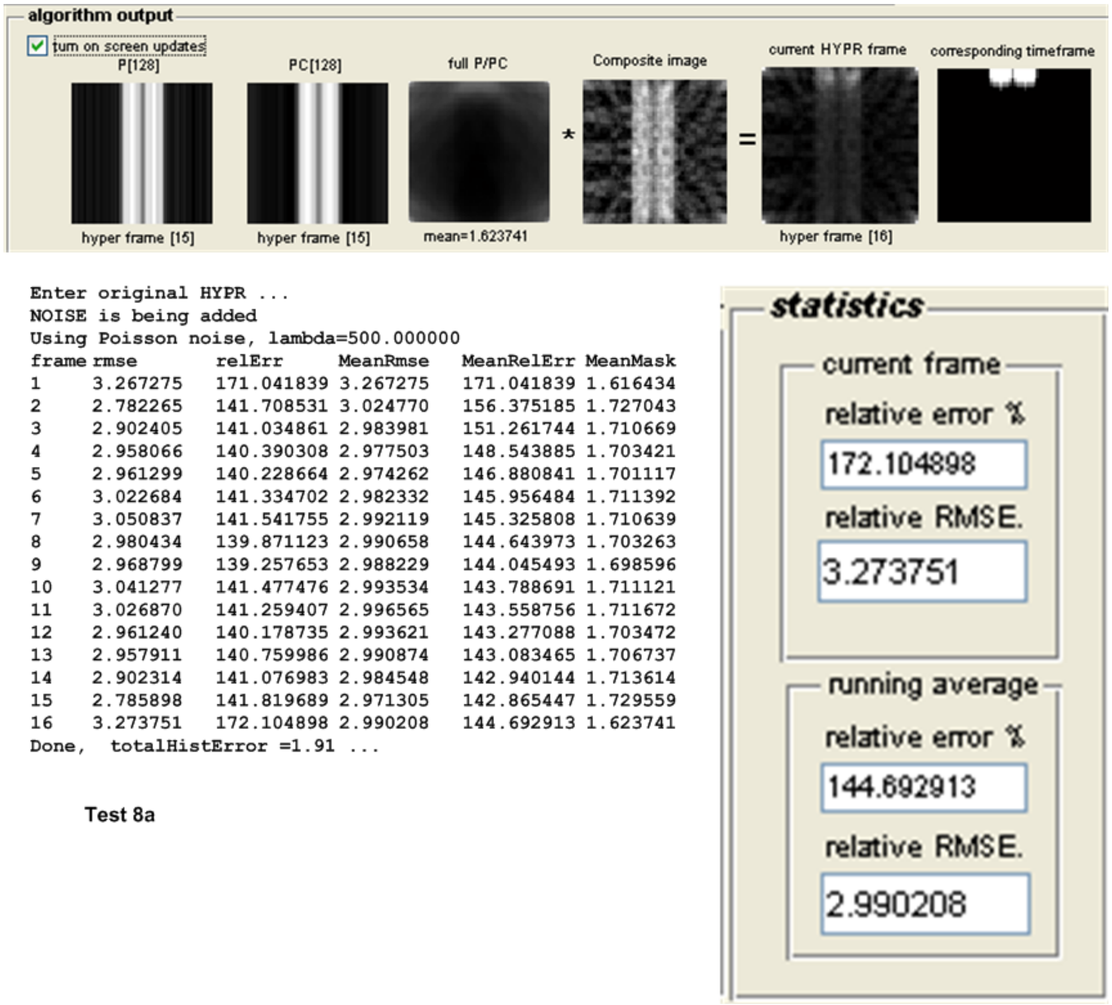
relative error %

5.165988

relative RMSE.

2.349602

6.3.15 Test 8a



```
Enter original HYPR ...
NOISE is being added
Using Poisson noise, lambda=500.000000
frame rmse       relErr     MeanRmse    MeanRelErr MeanMask
1     3.267275   171.041839 3.267275    171.041839 1.616434
2     2.782265   141.708531 3.024770    156.375185 1.727043
3     2.902405   141.034861 2.983981    151.261744 1.710669
4     2.958066   140.390308 2.977503    148.543885 1.703421
5     2.961299   140.228664 2.974262    146.880841 1.701117
6     3.022684   141.334702 2.982332    145.956484 1.711392
7     3.050837   141.541755 2.992119    145.325808 1.710639
8     2.980434   139.871123 2.990658    144.643973 1.703263
9     2.968799   139.257653 2.988229    144.045493 1.698596
10    3.041277   141.477476 2.993534    143.788691 1.711121
11    3.026870   141.259407 2.996565    143.558756 1.711672
12    2.961240   140.178735 2.993621    143.277088 1.703472
13    2.957911   140.759986 2.990874    143.083465 1.706737
14    2.902314   141.076983 2.984548    142.940144 1.713614
15    2.785898   141.819689 2.971305    142.865447 1.729559
16    3.273751   172.104898 2.990208    144.692913 1.623741
Done,  totalHistError =1.91 ...
```

Test 8a

current frame

relative error %: 172.104898

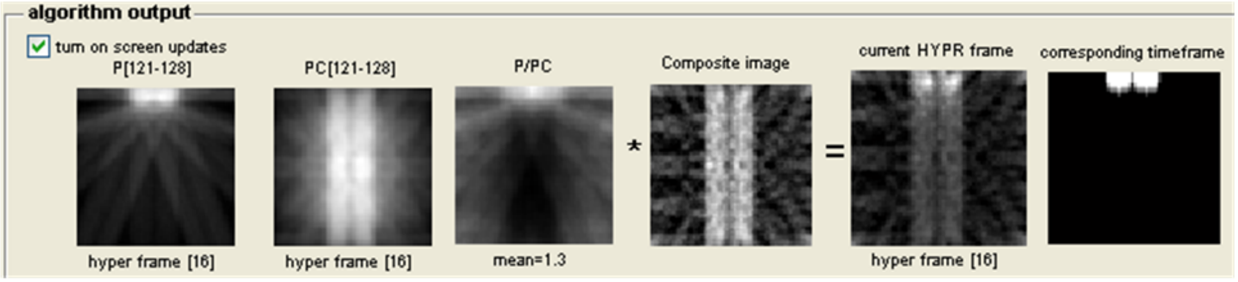
relative RMSE.: 3.273751

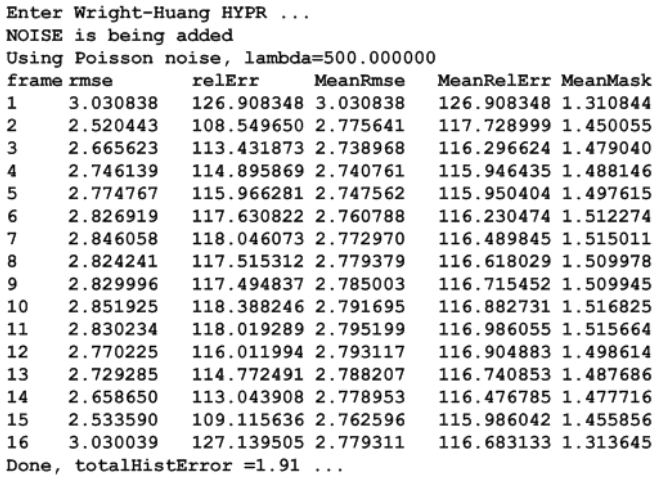
running average

relative error %: 144.692913

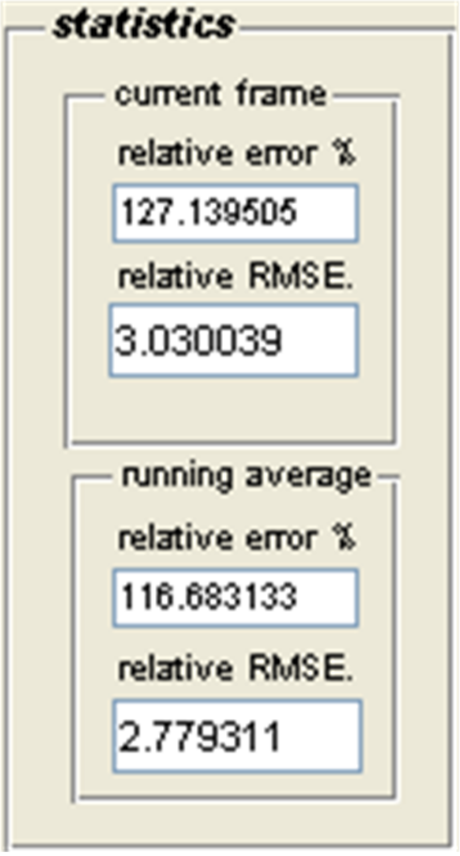
relative RMSE.: 2.990208

6.3.16 Test 8b





```
Enter Wright-Huang HYPR ...
NOISE is being added
Using Poisson noise, lambda=500.000000
frame rmse       relErr     MeanRmse   MeanRelErr MeanMask
1     3.030838   126.908348 3.030838   126.908348 1.310844
2     2.520443   108.549650 2.775641   117.728999 1.450055
3     2.665623   113.431873 2.738968   116.296624 1.479040
4     2.746139   114.895869 2.740761   115.946435 1.488146
5     2.774767   115.966281 2.747562   115.950404 1.497615
6     2.826919   117.630822 2.760788   116.230474 1.512274
7     2.846058   118.046073 2.772970   116.489845 1.515011
8     2.824241   117.515312 2.779379   116.618029 1.509978
9     2.829996   117.494837 2.785003   116.715452 1.509945
10    2.851925   118.388246 2.791695   116.882731 1.516825
11    2.830234   118.019289 2.795199   116.986055 1.515664
12    2.770225   116.011994 2.793117   116.904883 1.498614
13    2.729285   114.772491 2.788207   116.740853 1.487686
14    2.658650   113.043908 2.778953   116.476785 1.477716
15    2.533590   109.115636 2.762596   115.986042 1.455856
16    3.030039   127.139505 2.779311   116.683133 1.313645
Done, totalHistError =1.91 ...
```



statistics

current frame

relative error %: 127.139505

relative RMSE.: 3.030039

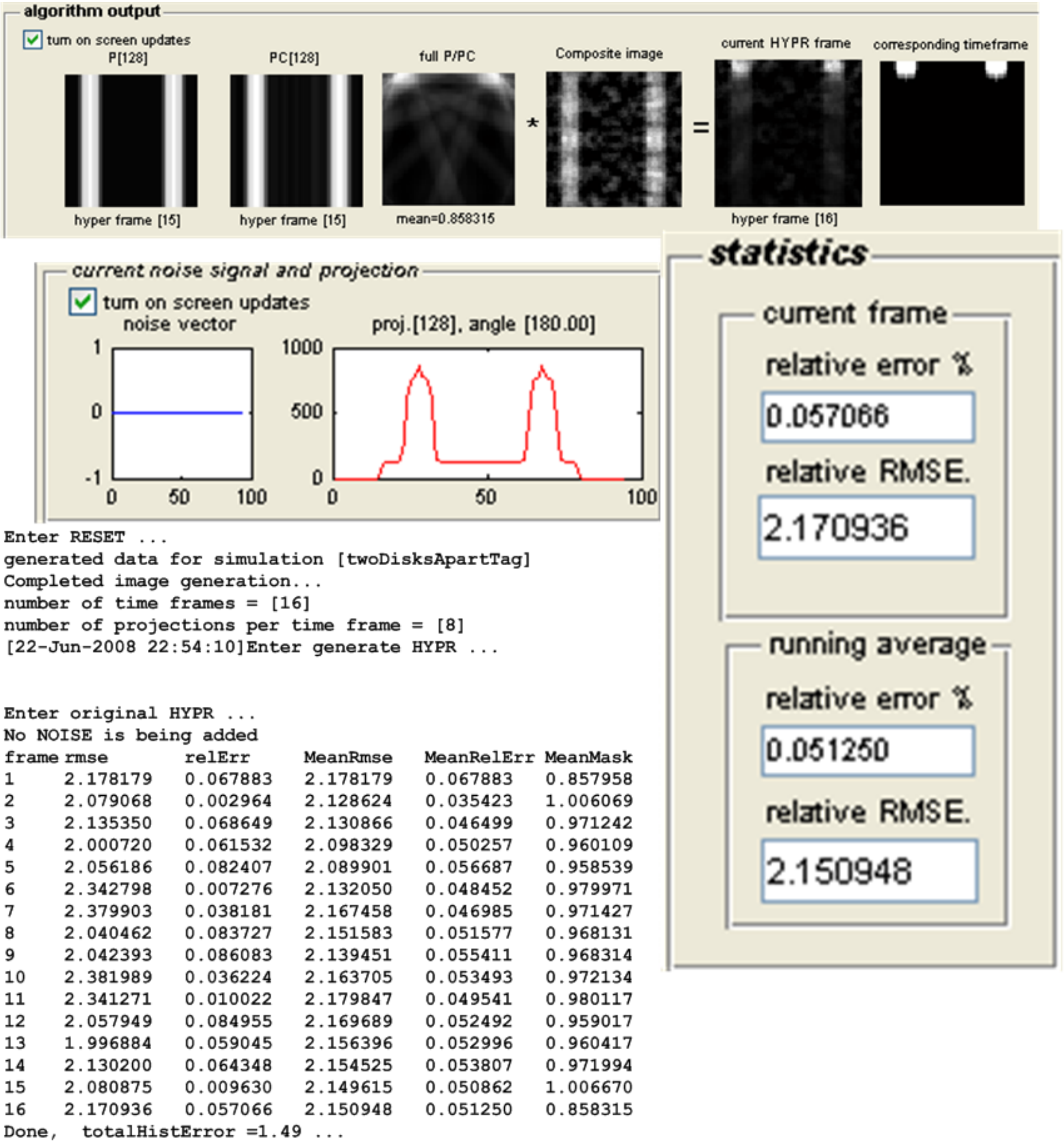
running average

relative error %: 116.683133

relative RMSE.: 2.779311

Test 8b

6.3.17 Test 9a



statistics

current frame

relative error %

0.057066

relative RMSE.

2.170936

running average

relative error %

0.051250

relative RMSE.

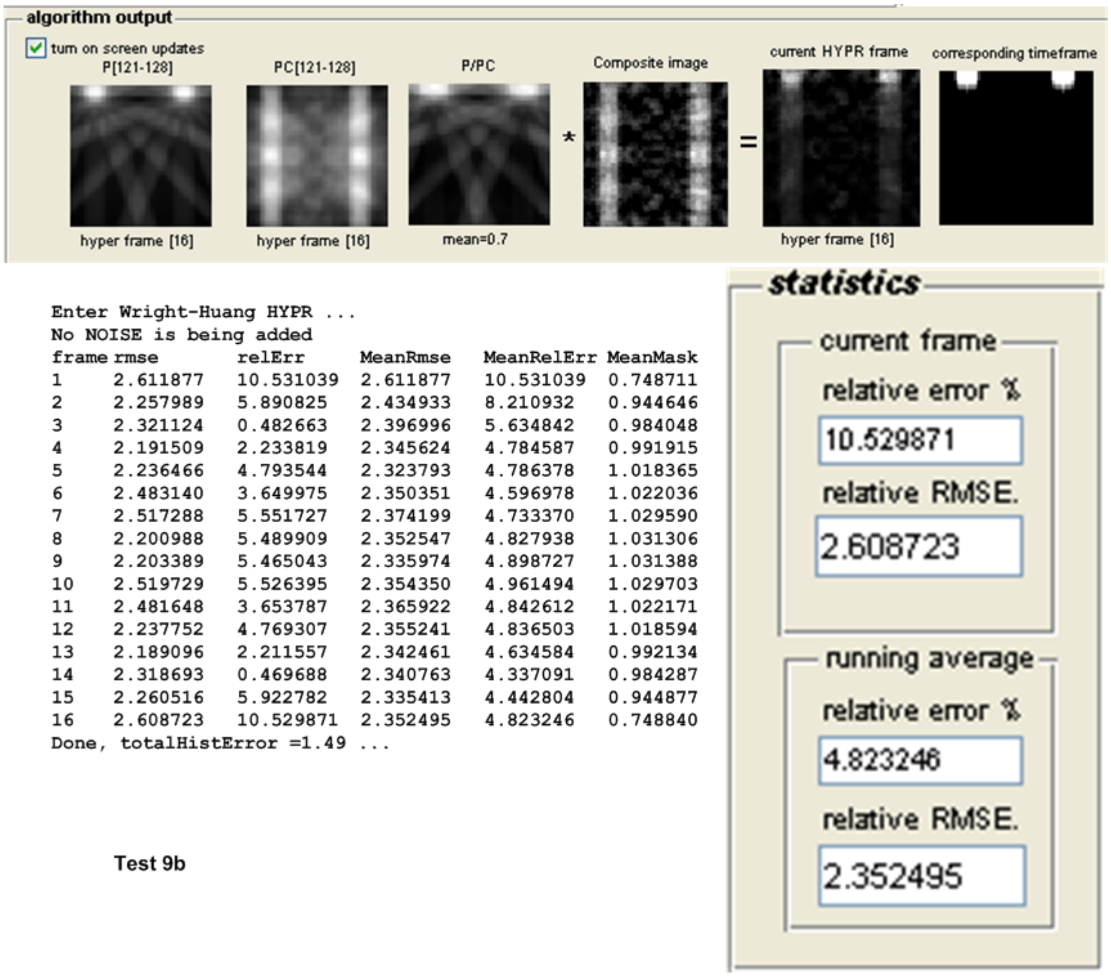
2.150948

```
Enter RESET ...
generated data for simulation [twoDisksApartTag]
Completed image generation...
number of time frames = [16]
number of projections per time frame = [8]
[22-Jun-2008 22:54:10]Enter generate HYPR ...


Enter original HYPR ...
No NOISE is being added
frame rmse      relErr     MeanRmse   MeanRelErr MeanMask
1     2.178179  0.067883   2.178179   0.067883   0.857958
2     2.079068  0.002964   2.128624   0.035423   1.006069
3     2.135350  0.068649   2.130866   0.046499   0.971242
4     2.000720  0.061532   2.098329   0.050257   0.960109
5     2.056186  0.082407   2.089901   0.056687   0.958539
6     2.342798  0.007276   2.132050   0.048452   0.979971
7     2.379903  0.038181   2.167458   0.046985   0.971427
8     2.040462  0.083727   2.151583   0.051577   0.968131
9     2.042393  0.086083   2.139451   0.055411   0.968314
10    2.381989  0.036224   2.163705   0.053493   0.972134
11    2.341271  0.010022   2.179847   0.049541   0.980117
12    2.057949  0.084955   2.169689   0.052492   0.959017
13    1.996884  0.059045   2.156396   0.052996   0.960417
14    2.130200  0.064348   2.154525   0.053807   0.971994
15    2.080875  0.009630   2.149615   0.050862   1.006670
16    2.170936  0.057066   2.150948   0.051250   0.858315
Done,  totalHistError =1.49 ...
```

Test 9a

6.3.18 Test 9b



```
Enter Wright-Huang HYPR ...
No NOISE is being added
frame rmse      relErr     MeanRmse   MeanRelErr MeanMask
1     2.611877  10.531039  2.611877   10.531039  0.748711
2     2.257989  5.890825   2.434933   8.210932   0.944646
3     2.321124  0.482663   2.396996   5.634842   0.984048
4     2.191509  2.233819   2.345624   4.784587   0.991915
5     2.236466  4.793544   2.323793   4.786378   1.018365
6     2.483140  3.649975   2.350351   4.596978   1.022036
7     2.517288  5.551727   2.374199   4.733370   1.029590
8     2.200988  5.489909   2.352547   4.827938   1.031306
9     2.203389  5.465043   2.335974   4.898727   1.031388
10    2.519729  5.526395   2.354350   4.961494   1.029703
11    2.481648  3.653787   2.365922   4.842612   1.022171
12    2.237752  4.769307   2.355241   4.836503   1.018594
13    2.189096  2.211557   2.342461   4.634584   0.992134
14    2.318693  0.469688   2.340763   4.337091   0.984287
15    2.260516  5.922782   2.335413   4.442804   0.944877
16    2.608723  10.529871  2.352495   4.823246   0.748840
Done, totalHistError =1.49 ...
```

Test 9b

statistics

current frame

relative error %: 10.529871

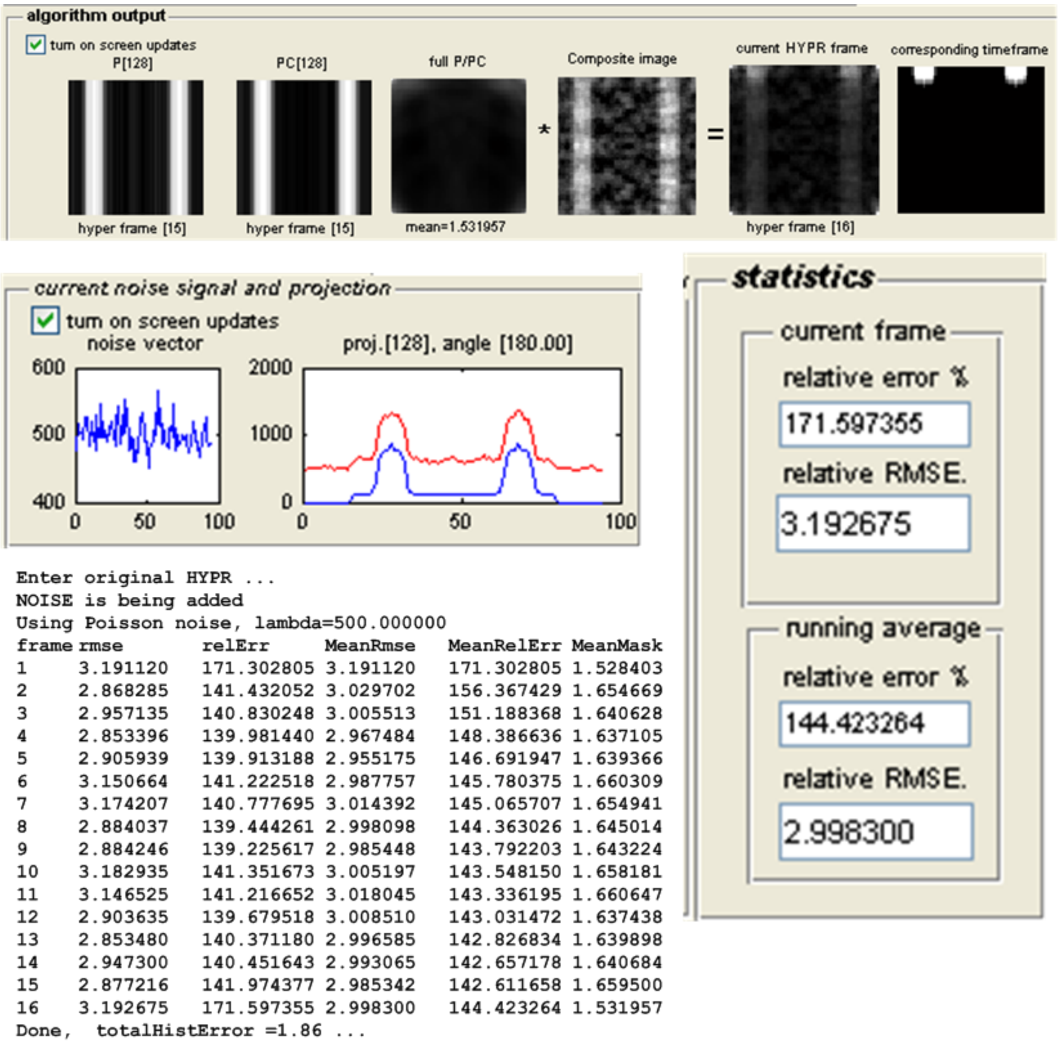
relative RMSE.: 2.608723

running average

relative error %: 4.823246

relative RMSE.: 2.352495

6.3.19 Test 10a



current frame

relative error %

171.597355

relative RMSE.

3.192675

running average

relative error %

144.423264

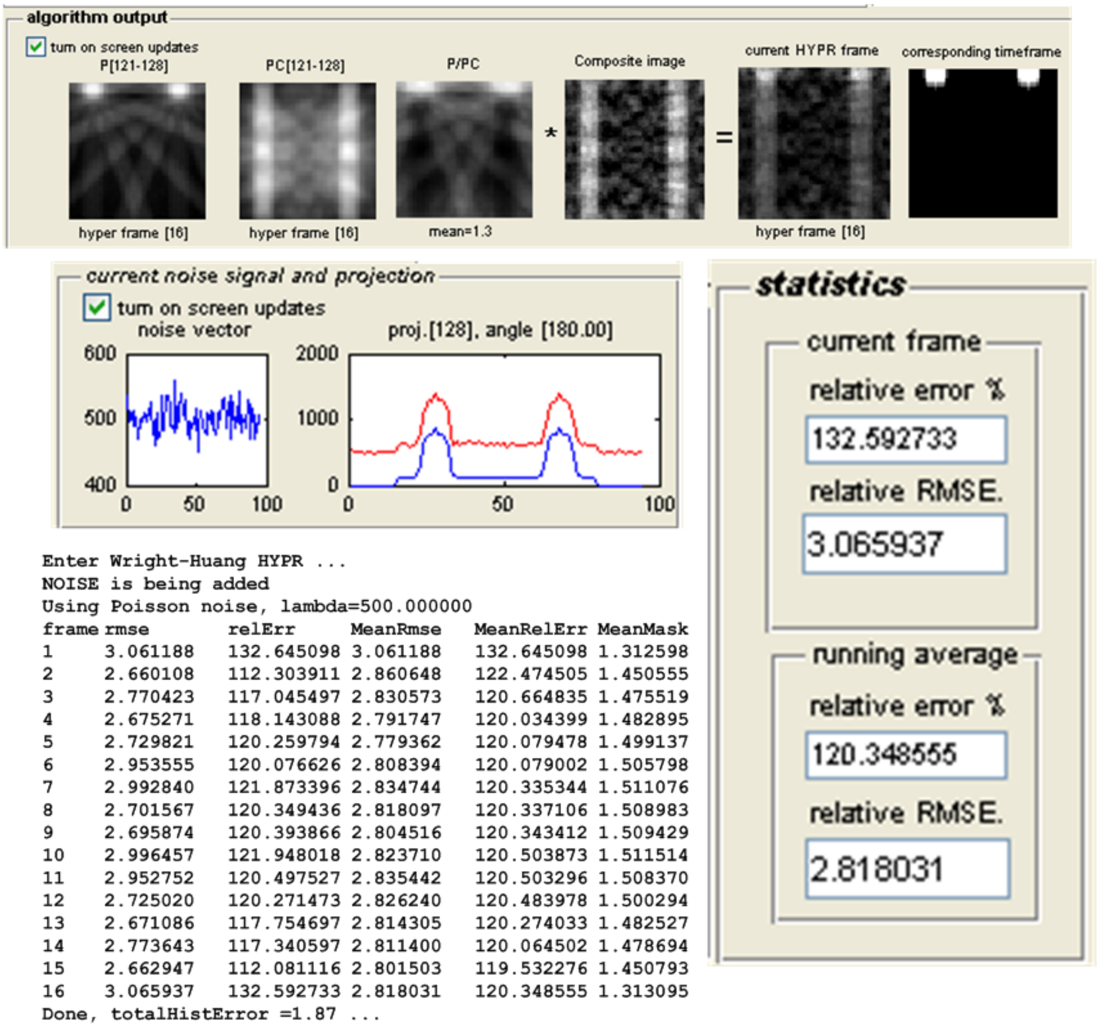
relative RMSE.

2.998300

```
Enter original HYPR ...
NOISE is being added
Using Poisson noise, lambda=500.000000
frame rmse       relErr     MeanRmse    MeanRelErr MeanMask
1     3.191120   171.302805 3.191120    171.302805 1.528403
2     2.868285   141.432052 3.029702    156.367429 1.654669
3     2.957135   140.830248 3.005513    151.188368 1.640628
4     2.853396   139.981440 2.967484    148.386636 1.637105
5     2.905939   139.913188 2.955175    146.691947 1.639366
6     3.150664   141.222518 2.987757    145.780375 1.660309
7     3.174207   140.777695 3.014392    145.065707 1.654941
8     2.884037   139.444261 2.998098    144.363026 1.645014
9     2.884246   139.225617 2.985448    143.792203 1.643224
10    3.182935   141.351673 3.005197    143.548150 1.658181
11    3.146525   141.216652 3.018045    143.336195 1.660647
12    2.903635   139.679518 3.008510    143.031472 1.637438
13    2.853480   140.371180 2.996585    142.826834 1.639898
14    2.947300   140.451643 2.993065    142.657178 1.640684
15    2.877216   141.974377 2.985342    142.611658 1.659500
16    3.192675   171.597355 2.998300    144.423264 1.531957
Done,  totalHistError =1.86 ...
```

Test 10a

6.3.20 Test 10b



current frame

relative error %

132.592733

relative RMSE.

3.065937

running average

relative error %

120.348555

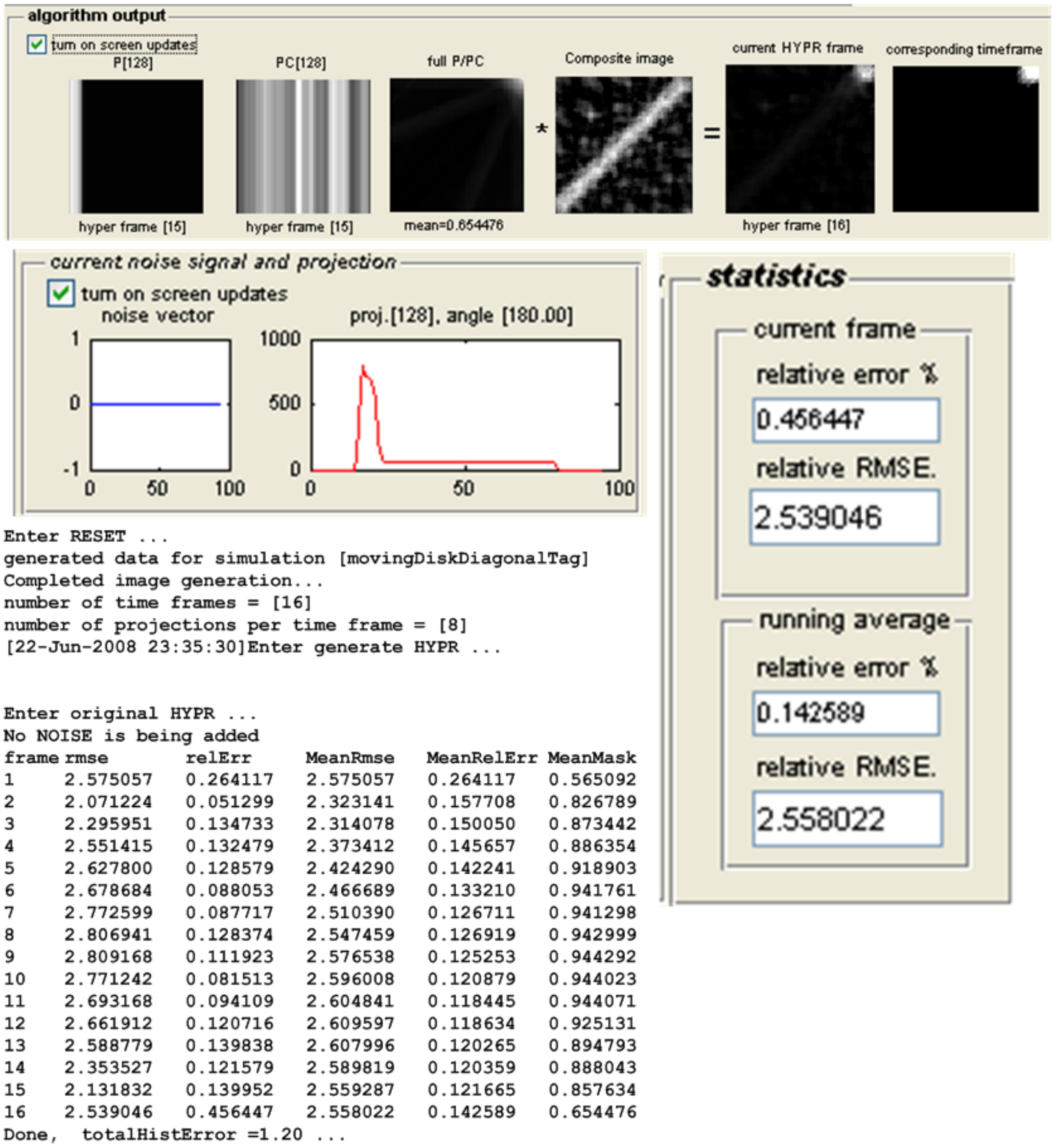
relative RMSE.

2.818031

```
Enter Wright-Huang HYPR ...
NOISE is being added
Using Poisson noise, lambda=500.000000
frame rmse       relErr     MeanRmse    MeanRelErr MeanMask
1     3.061188   132.645098 3.061188    132.645098 1.312598
2     2.660108   112.303911 2.860648    122.474505 1.450555
3     2.770423   117.045497 2.830573    120.664835 1.475519
4     2.675271   118.143088 2.791747    120.034399 1.482895
5     2.729821   120.259794 2.779362    120.079478 1.499137
6     2.953555   120.076626 2.808394    120.079002 1.505798
7     2.992840   121.873396 2.834744    120.335344 1.511076
8     2.701567   120.349436 2.818097    120.337106 1.508983
9     2.695874   120.393866 2.804516    120.343412 1.509429
10    2.996457   121.948018 2.823710    120.503873 1.511514
11    2.952752   120.497527 2.835442    120.503296 1.508370
12    2.725020   120.271473 2.826240    120.483978 1.500294
13    2.671086   117.754697 2.814305    120.274033 1.482527
14    2.773643   117.340597 2.811400    120.064502 1.478694
15    2.662947   112.081116 2.801503    119.532276 1.450793
16    3.065937   132.592733 2.818031    120.348555 1.313095
Done, totalHistError =1.87 ...
```

Test 10b

6.3.21 Test 11a



current frame

relative error %

0.456447

relative RMSE.

2.539046

running average

relative error %

0.142589

relative RMSE.

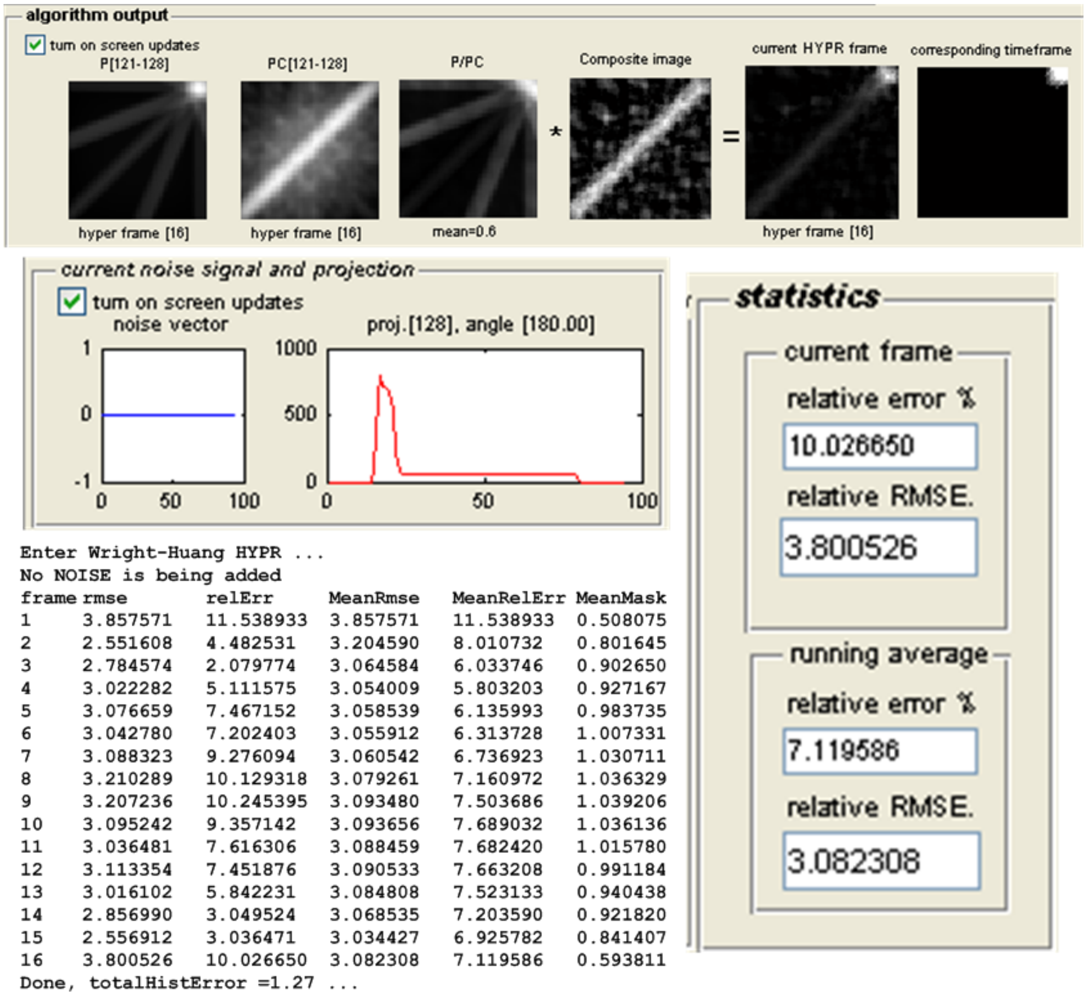
2.558022

```
Enter RESET ...
generated data for simulation [movingDiskDiagonalTag]
Completed image generation...
number of time frames = [16]
number of projections per time frame = [8]
[22-Jun-2008 23:35:30]Enter generate HYPR ...


Enter original HYPR ...
No NOISE is being added
frame rmse      relErr    MeanRmse  MeanRelErr MeanMask
1     2.575057  0.264117  2.575057  0.264117  0.565092
2     2.071224  0.051299  2.323141  0.157708  0.826789
3     2.295951  0.134733  2.314078  0.150050  0.873442
4     2.551415  0.132479  2.373412  0.145657  0.886354
5     2.627800  0.128579  2.424290  0.142241  0.918903
6     2.678684  0.088053  2.466689  0.133210  0.941761
7     2.772599  0.087717  2.510390  0.126711  0.941298
8     2.806941  0.128374  2.547459  0.126919  0.942999
9     2.809168  0.111923  2.576538  0.125253  0.944292
10    2.771242  0.081513  2.596008  0.120879  0.944023
11    2.693168  0.094109  2.604841  0.118445  0.944071
12    2.661912  0.120716  2.609597  0.118634  0.925131
13    2.588779  0.139838  2.607996  0.120265  0.894793
14    2.353527  0.121579  2.589819  0.120359  0.888043
15    2.131832  0.139952  2.559287  0.121665  0.857634
16    2.539046  0.456447  2.558022  0.142589  0.654476
Done,  totalHistError =1.20 ...
```

Test 11a

6.3.22 Test 11b



current frame

relative error %
10.026650

relative RMSE.
3.800526

running average

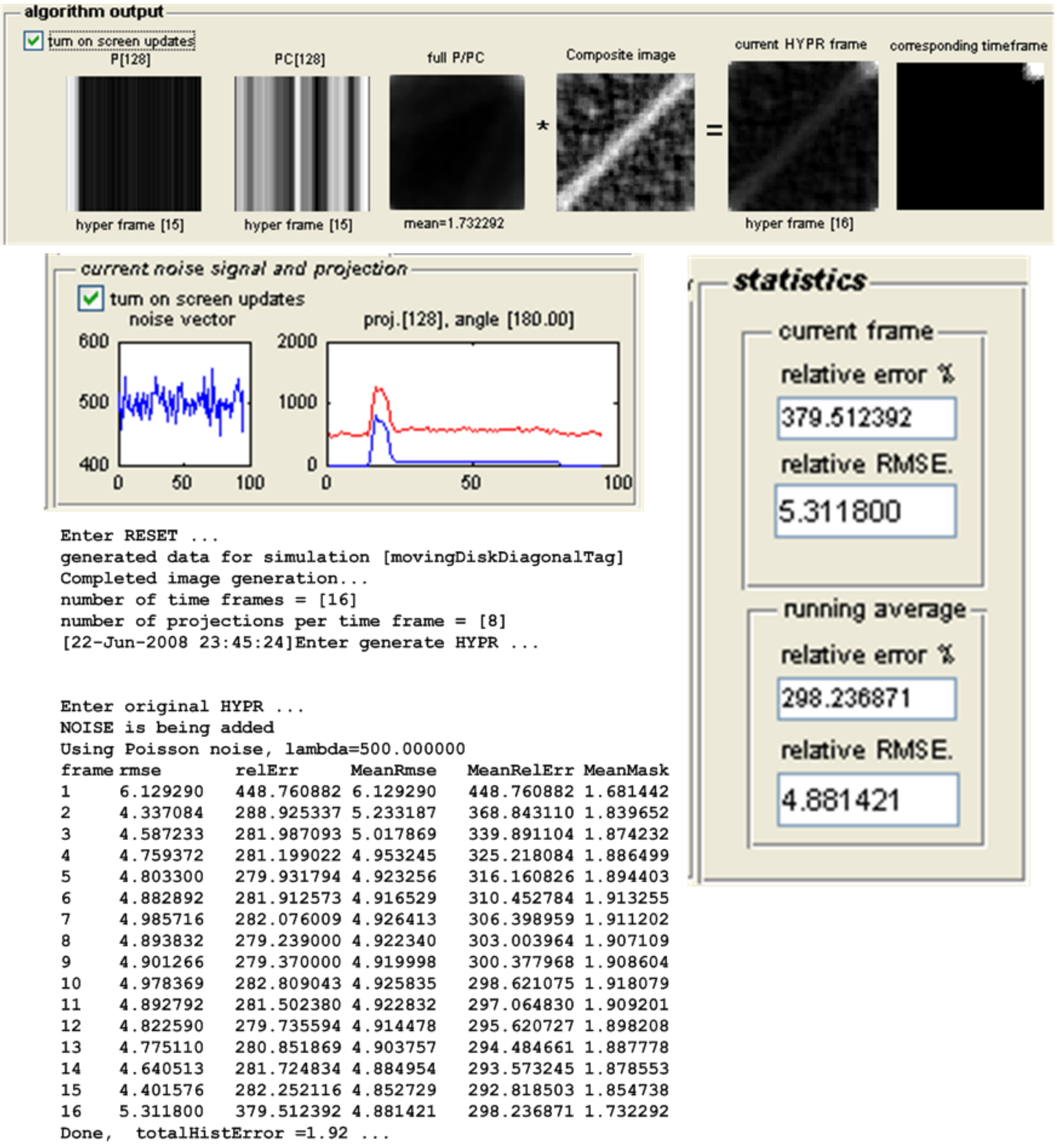
relative error %
7.119586

relative RMSE.
3.082308

```
Enter Wright-Huang HYPR ...
No NOISE is being added
frame rmse      relErr     MeanRmse    MeanRelErr MeanMask
1     3.857571  11.538933  3.857571    11.538933  0.508075
2     2.551608  4.482531   3.204590    8.010732   0.801645
3     2.784574  2.079774   3.064584    6.033746   0.902650
4     3.022282  5.111575   3.054009    5.803203   0.927167
5     3.076659  7.467152   3.058539    6.135993   0.983735
6     3.042780  7.202403   3.055912    6.313728   1.007331
7     3.088323  9.276094   3.060542    6.736923   1.030711
8     3.210289  10.129318  3.079261    7.160972   1.036329
9     3.207236  10.245395  3.093480    7.503686   1.039206
10    3.095242  9.357142   3.093656    7.689032   1.036136
11    3.036481  7.616306   3.088459    7.682420   1.015780
12    3.113354  7.451876   3.090533    7.663208   0.991184
13    3.016102  5.842231   3.084808    7.523133   0.940438
14    2.856990  3.049524   3.068535    7.203590   0.921820
15    2.556912  3.036471   3.034427    6.925782   0.841407
16    3.800526  10.026650  3.082308    7.119586   0.593811
Done, totalHistError =1.27 ...
```

Test 11b

6.3.23 Test 12a



current frame

relative error %

379.512392

relative RMSE.

5.311800

running average

relative error %

298.236871

relative RMSE.

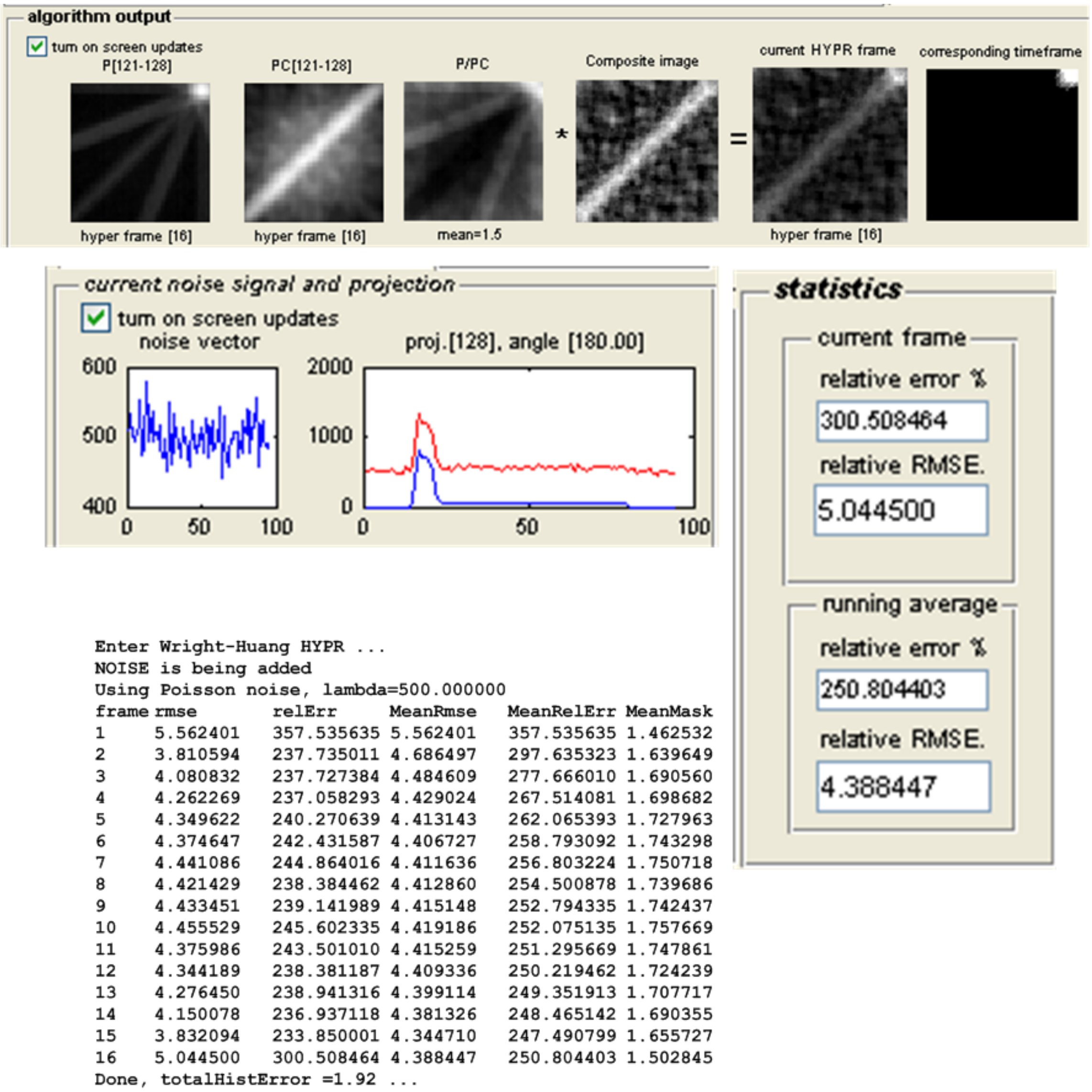
4.881421

```
Enter RESET ...
generated data for simulation [movingDiskDiagonalTag]
Completed image generation...
number of time frames = [16]
number of projections per time frame = [8]
[22-Jun-2008 23:45:24]Enter generate HYPR ...


Enter original HYPR ...
NOISE is being added
Using Poisson noise, lambda=500.000000
frame rmse       relErr     MeanRmse   MeanRelErr MeanMask
1     6.129290   448.760882 6.129290   448.760882 1.681442
2     4.337084   288.925337 5.233187   368.843110 1.839652
3     4.587233   281.987093 5.017869   339.891104 1.874232
4     4.759372   281.199022 4.953245   325.218084 1.886499
5     4.803300   279.931794 4.923256   316.160826 1.894403
6     4.882892   281.912573 4.916529   310.452784 1.913255
7     4.985716   282.076009 4.926413   306.398959 1.911202
8     4.893832   279.239000 4.922340   303.003964 1.907109
9     4.901266   279.370000 4.919998   300.377968 1.908604
10    4.978369   282.809043 4.925835   298.621075 1.918079
11    4.892792   281.502380 4.922832   297.064830 1.909201
12    4.822590   279.735594 4.914478   295.620727 1.898208
13    4.775110   280.851869 4.903757   294.484661 1.887778
14    4.640513   281.724834 4.884954   293.573245 1.878553
15    4.401576   282.252116 4.852729   292.818503 1.854738
16    5.311800   379.512392 4.881421   298.236871 1.732292
Done,  totalHistError =1.92 ...
```

Test 12a

6.3.24 Test 12b



current frame

relative error %

300.508464

relative RMSE.

5.044500

running average

relative error %

250.804403

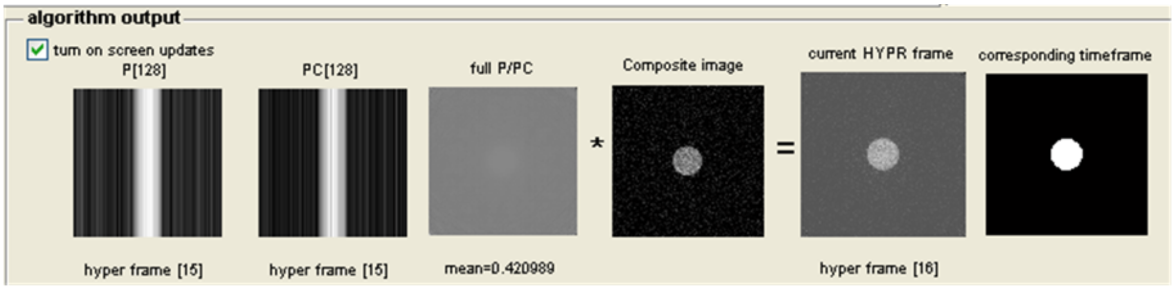
relative RMSE.

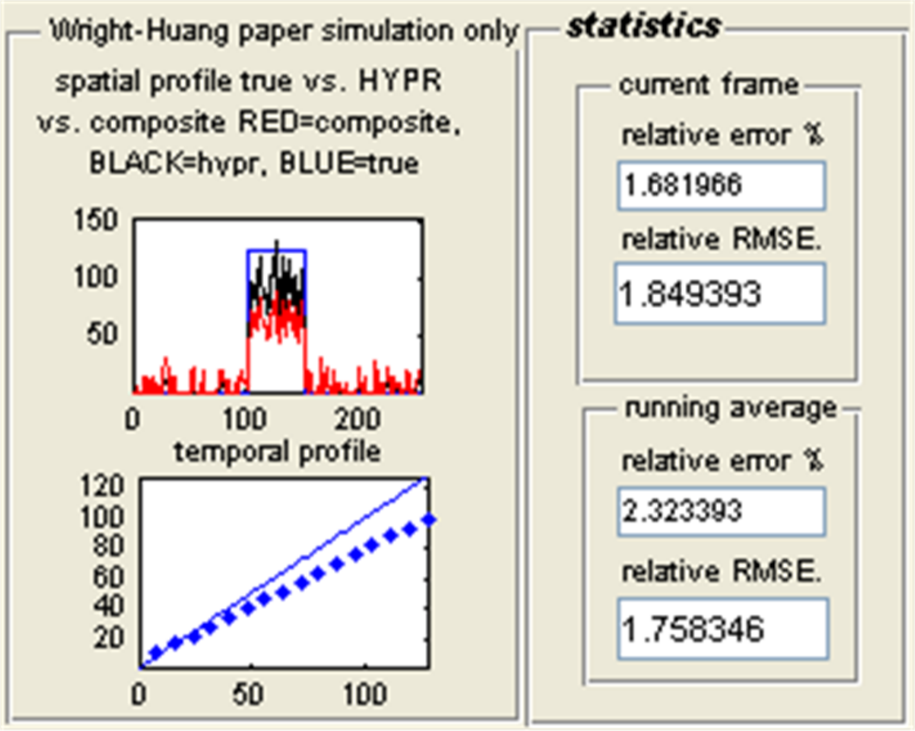
4.388447

```
Enter Wright-Huang HYPR ...
NOISE is being added
Using Poisson noise, lambda=500.000000
frame rmse      relErr     MeanRmse    MeanRelErr MeanMask
1     5.562401  357.535635 5.562401    357.535635 1.462532
2     3.810594  237.735011 4.686497    297.635323 1.639649
3     4.080832  237.727384 4.484609    277.666010 1.690560
4     4.262269  237.058293 4.429024    267.514081 1.698682
5     4.349622  240.270639 4.413143    262.065393 1.727963
6     4.374647  242.431587 4.406727    258.793092 1.743298
7     4.441086  244.864016 4.411636    256.803224 1.750718
8     4.421429  238.384462 4.412860    254.500878 1.739686
9     4.433451  239.141989 4.415148    252.794335 1.742437
10    4.455529  245.602335 4.419186    252.075135 1.757669
11    4.375986  243.501010 4.415259    251.295669 1.747861
12    4.344189  238.381187 4.409336    250.219462 1.724239
13    4.276450  238.941316 4.399114    249.351913 1.707717
14    4.150078  236.937118 4.381326    248.465142 1.690355
15    3.832094  233.850001 4.344710    247.490799 1.655727
16    5.044500  300.508464 4.388447    250.804403 1.502845
Done, totalHistError =1.92 ...
```

Test 12b

6.3.25 Test 2N a




Wright-Huang paper simulation only
spatial profile true vs. HYPR vs. composite RED=composite, BLACK=hypr, BLUE=true
150
100
50
0
100
200
temporal profile
120
100
80
60
40
20
0
50
100
statistics

current frame

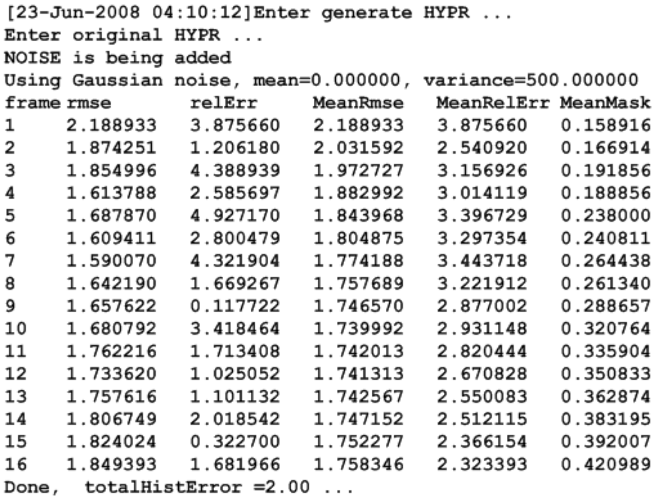
relative error % 1.681966

relative RMSE. 1.849393

running average

relative error % 2.323393

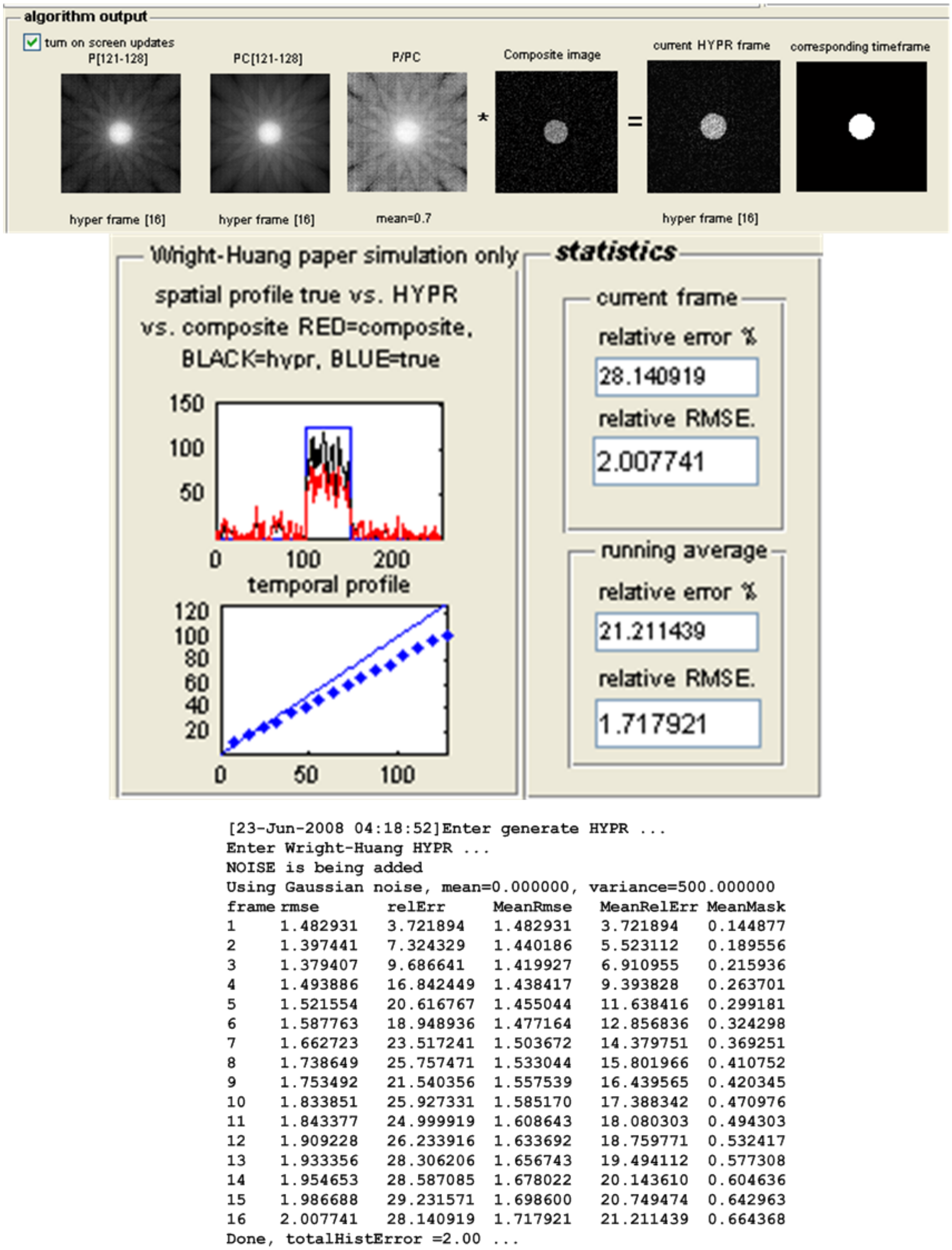
relative RMSE. 1.758346



```
[23-Jun-2008 04:10:12]Enter generate HYPR ...
Enter original HYPR ...
NOISE is being added
Using Gaussian noise, mean=0.000000, variance=500.000000
frame rmse      relErr     MeanRmse   MeanRelErr MeanMask
1     2.188933  3.875660   2.188933   3.875660   0.158916
2     1.874251  1.206180   2.031592   2.540920   0.166914
3     1.854996  4.388939   1.972727   3.156926   0.191856
4     1.613788  2.585697   1.882992   3.014119   0.188856
5     1.687870  4.927170   1.843968   3.396729   0.238000
6     1.609411  2.800479   1.804875   3.297354   0.240811
7     1.590070  4.321904   1.774188   3.443718   0.264438
8     1.642190  1.669267   1.757689   3.221912   0.261340
9     1.657622  0.117722   1.746570   2.877002   0.288657
10    1.680792  3.418464   1.739992   2.931148   0.320764
11    1.762216  1.713408   1.742013   2.820444   0.335904
12    1.733620  1.025052   1.741313   2.670828   0.350833
13    1.757616  1.101132   1.742567   2.550083   0.362874
14    1.806749  2.018542   1.747152   2.512115   0.383195
15    1.824024  0.322700   1.752277   2.366154   0.392007
16    1.849393  1.681966   1.758346   2.323393   0.420989
Done,  totalHistError =2.00 ...
```

Test 2N a

6.3.26 Test 2N b



statistics

current frame

relative error %

28.140919

relative RMSE.

2.007741

running average

relative error %

21.211439

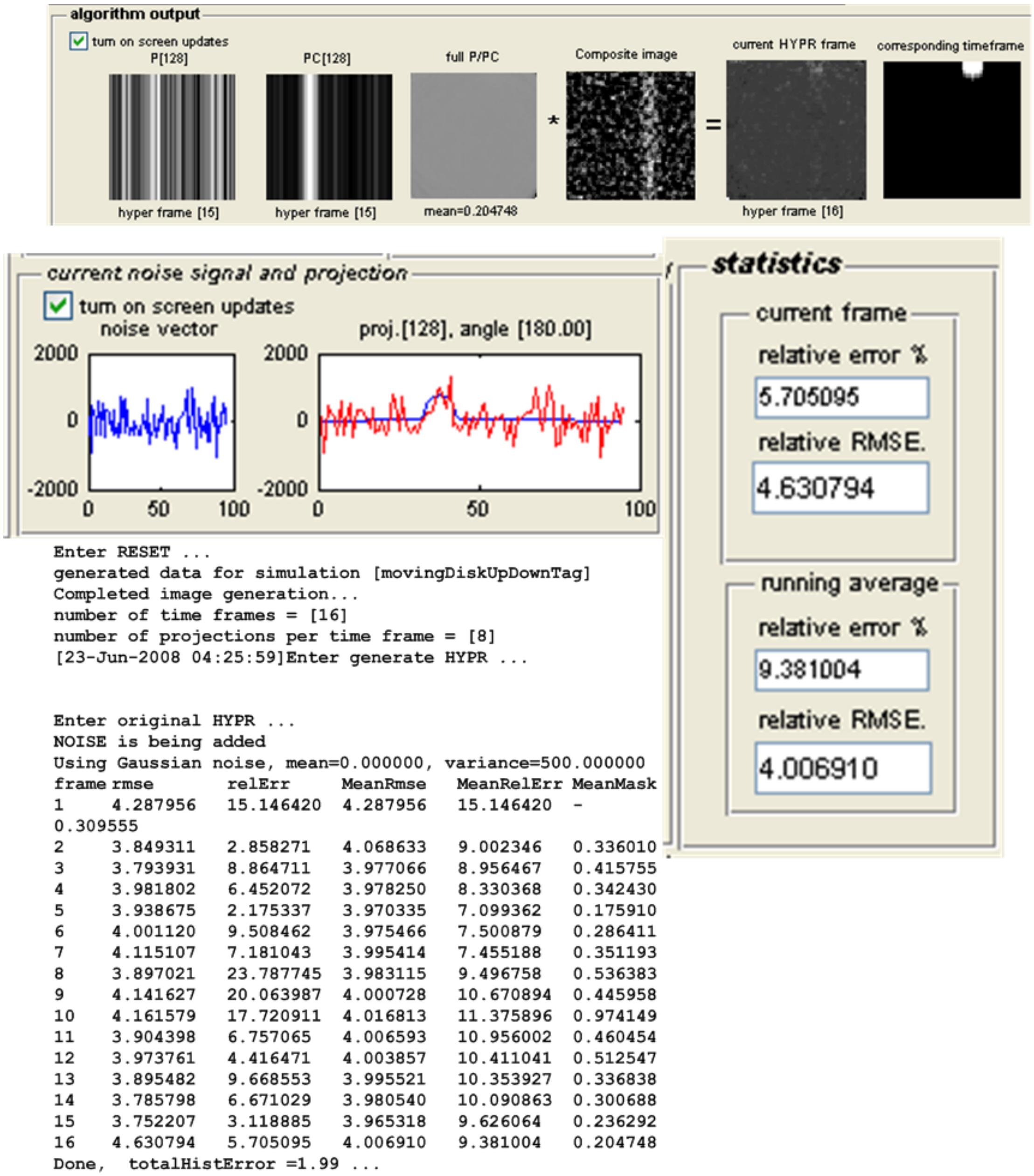
relative RMSE.

1.717921

```
[23-Jun-2008 04:18:52]Enter generate HYPR ...
Enter Wright-Huang HYPR ...
NOISE is being added
Using Gaussian noise, mean=0.000000, variance=500.000000
frame rmse      relErr     MeanRmse   MeanRelErr MeanMask
1     1.482931  3.721894   1.482931   3.721894   0.144877
2     1.397441  7.324329   1.440186   5.523112   0.189556
3     1.379407  9.686641   1.419927   6.910955   0.215936
4     1.493886  16.842449  1.438417   9.393828   0.263701
5     1.521554  20.616767  1.455044   11.638416  0.299181
6     1.587763  18.948936  1.477164   12.856836  0.324298
7     1.662723  23.517241  1.503672   14.379751  0.369251
8     1.738649  25.757471  1.533044   15.801966  0.410752
9     1.753492  21.540356  1.557539   16.439565  0.420345
10    1.833851  25.927331  1.585170   17.388342  0.470976
11    1.843377  24.999919  1.608643   18.080303  0.494303
12    1.909228  26.233916  1.633692   18.759771  0.532417
13    1.933356  28.306206  1.656743   19.494112  0.577308
14    1.954653  28.587085  1.678022   20.143610  0.604636
15    1.986688  29.231571  1.698600   20.749474  0.642963
16    2.007741  28.140919  1.717921   21.211439  0.664368
Done, totalHistError =2.00 ...
```

Test 2N b

6.3.27 Test 6N a



current frame

relative error %

5.705095

relative RMSE.

4.630794

running average

relative error %

9.381004

relative RMSE.

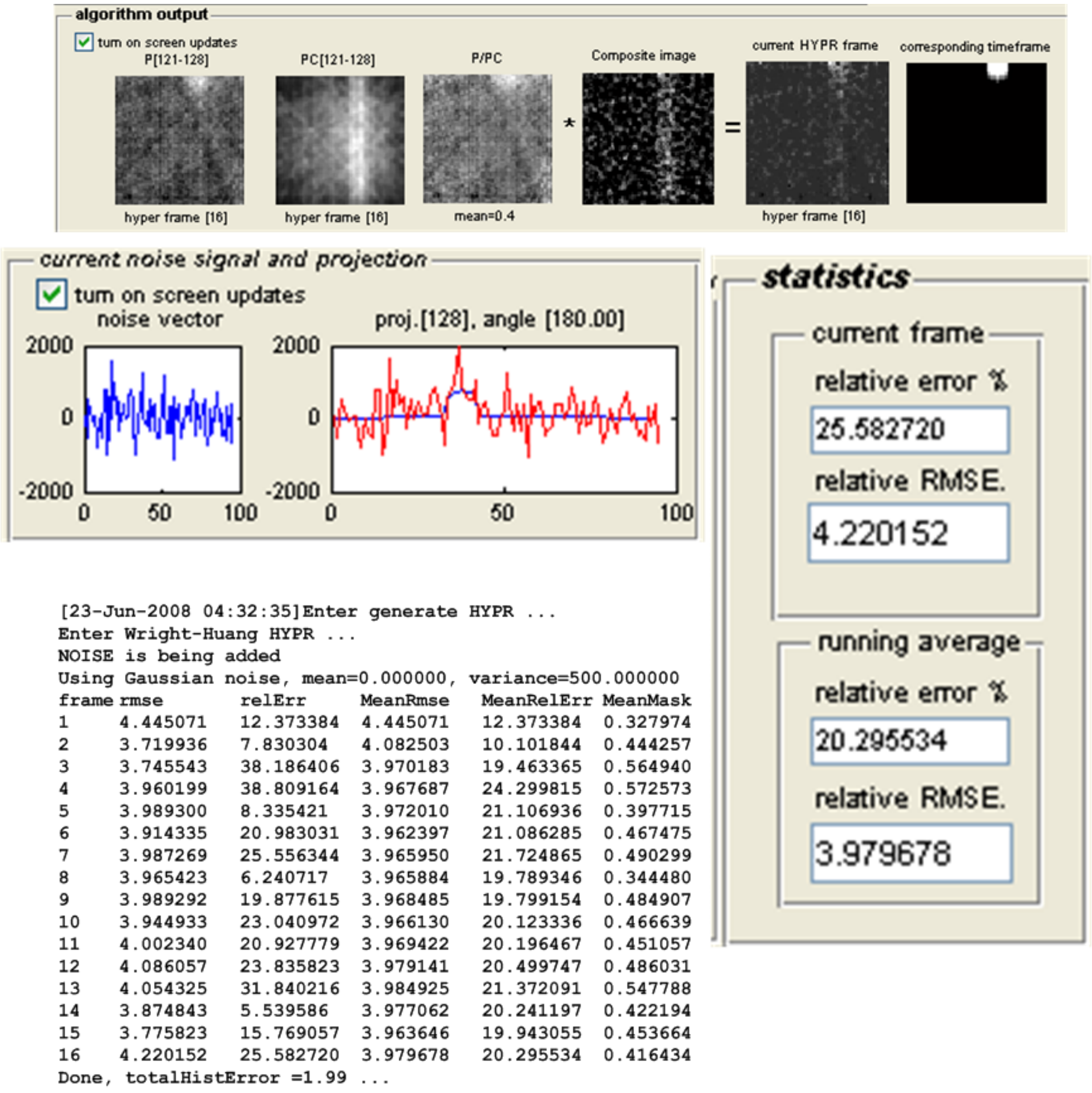
4.006910

```
Enter RESET ...
generated data for simulation [movingDiskUpDownTag]
Completed image generation...
number of time frames = [16]
number of projections per time frame = [8]
[23-Jun-2008 04:25:59]Enter generate HYPR ...


Enter original HYPR ...
NOISE is being added
Using Gaussian noise, mean=0.000000, variance=500.000000
frame rmse      relErr     MeanRmse    MeanRelErr MeanMask
1     4.287956  15.146420  4.287956    15.146420  -
0.309555
2     3.849311  2.858271   4.068633    9.002346   0.336010
3     3.793931  8.864711   3.977066    8.956467   0.415755
4     3.981802  6.452072   3.978250    8.330368   0.342430
5     3.938675  2.175337   3.970335    7.099362   0.175910
6     4.001120  9.508462   3.975466    7.500879   0.286411
7     4.115107  7.181043   3.995414    7.455188   0.351193
8     3.897021  23.787745  3.983115    9.496758   0.536383
9     4.141627  20.063987  4.000728    10.670894  0.445958
10    4.161579  17.720911  4.016813    11.375896  0.974149
11    3.904398  6.757065   4.006593    10.956002  0.460454
12    3.973761  4.416471   4.003857    10.411041  0.512547
13    3.895482  9.668553   3.995521    10.353927  0.336838
14    3.785798  6.671029   3.980540    10.090863  0.300688
15    3.752207  3.118885   3.965318    9.626064   0.236292
16    4.630794  5.705095   4.006910    9.381004   0.204748
Done,  totalHistError =1.99 ...
```

Test 6N a

6.3.28 Test 6N b



current frame

relative error %

25.582720

relative RMSE.

4.220152

running average

relative error %

20.295534

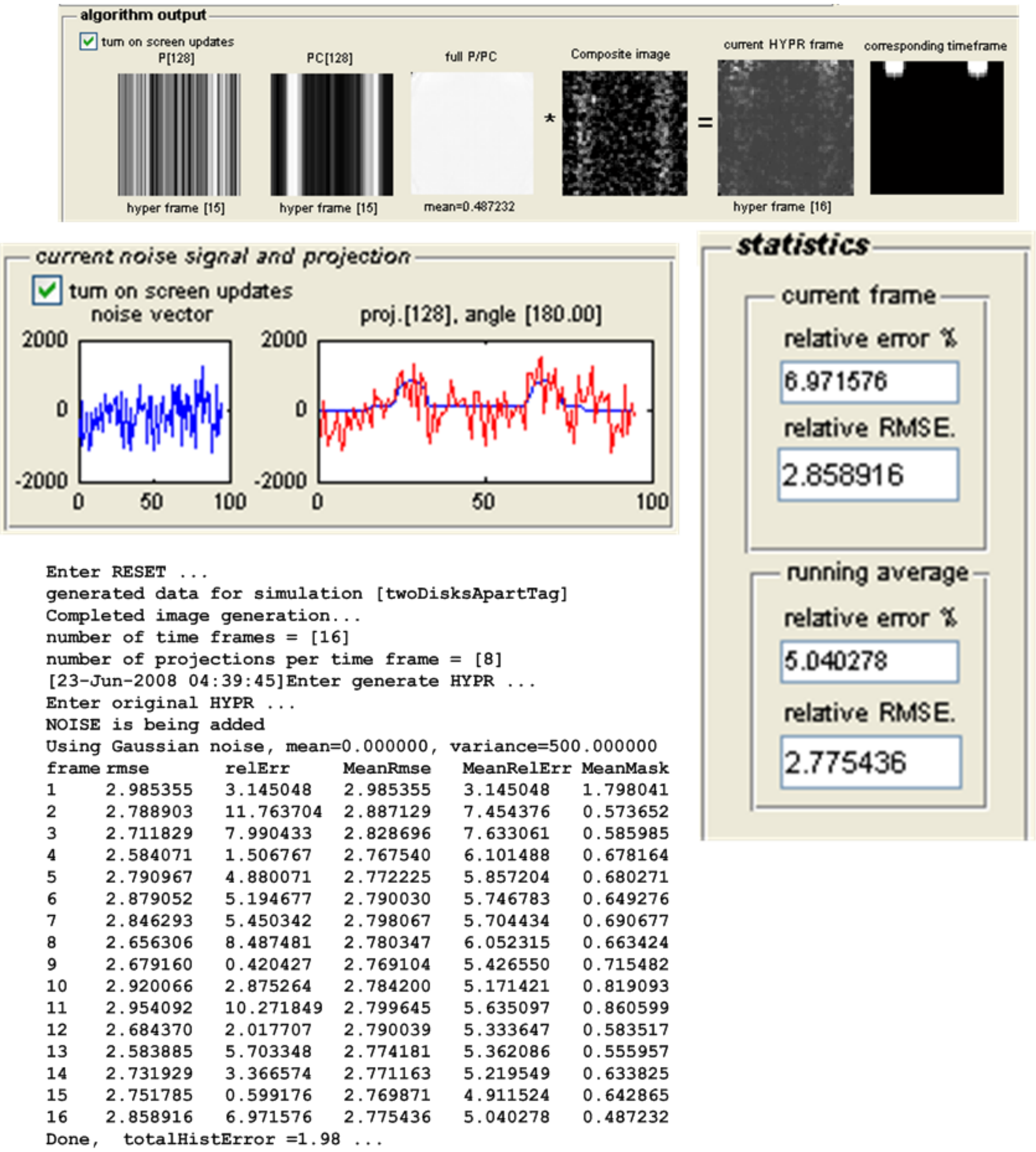
relative RMSE.

3.979678

```
[23-Jun-2008 04:32:35]Enter generate HYPR ...
Enter Wright-Huang HYPR ...
NOISE is being added
Using Gaussian noise, mean=0.000000, variance=500.000000
frame rmse      relErr    MeanRmse   MeanRelErr MeanMask
1     4.445071  12.373384 4.445071   12.373384  0.327974
2     3.719936  7.830304  4.082503   10.101844  0.444257
3     3.745543  38.186406 3.970183   19.463365  0.564940
4     3.960199  38.809164 3.967687   24.299815  0.572573
5     3.989300  8.335421  3.972010   21.106936  0.397715
6     3.914335  20.983031 3.962397   21.086285  0.467475
7     3.987269  25.556344 3.965950   21.724865  0.490299
8     3.965423  6.240717  3.965884   19.789346  0.344480
9     3.989292  19.877615 3.968485   19.799154  0.484907
10    3.944933  23.040972 3.966130   20.123336  0.466639
11    4.002340  20.927779 3.969422   20.196467  0.451057
12    4.086057  23.835823 3.979141   20.499747  0.486031
13    4.054325  31.840216 3.984925   21.372091  0.547788
14    3.874843  5.539586  3.977062   20.241197  0.422194
15    3.775823  15.769057 3.963646   19.943055  0.453664
16    4.220152  25.582720 3.979678   20.295534  0.416434
Done, totalHistError =1.99 ...
```

Test 6N b

6.3.29 Test 10N a



current frame

relative error %

6.971576

relative RMSE.

2.858916

running average

relative error %

5.040278

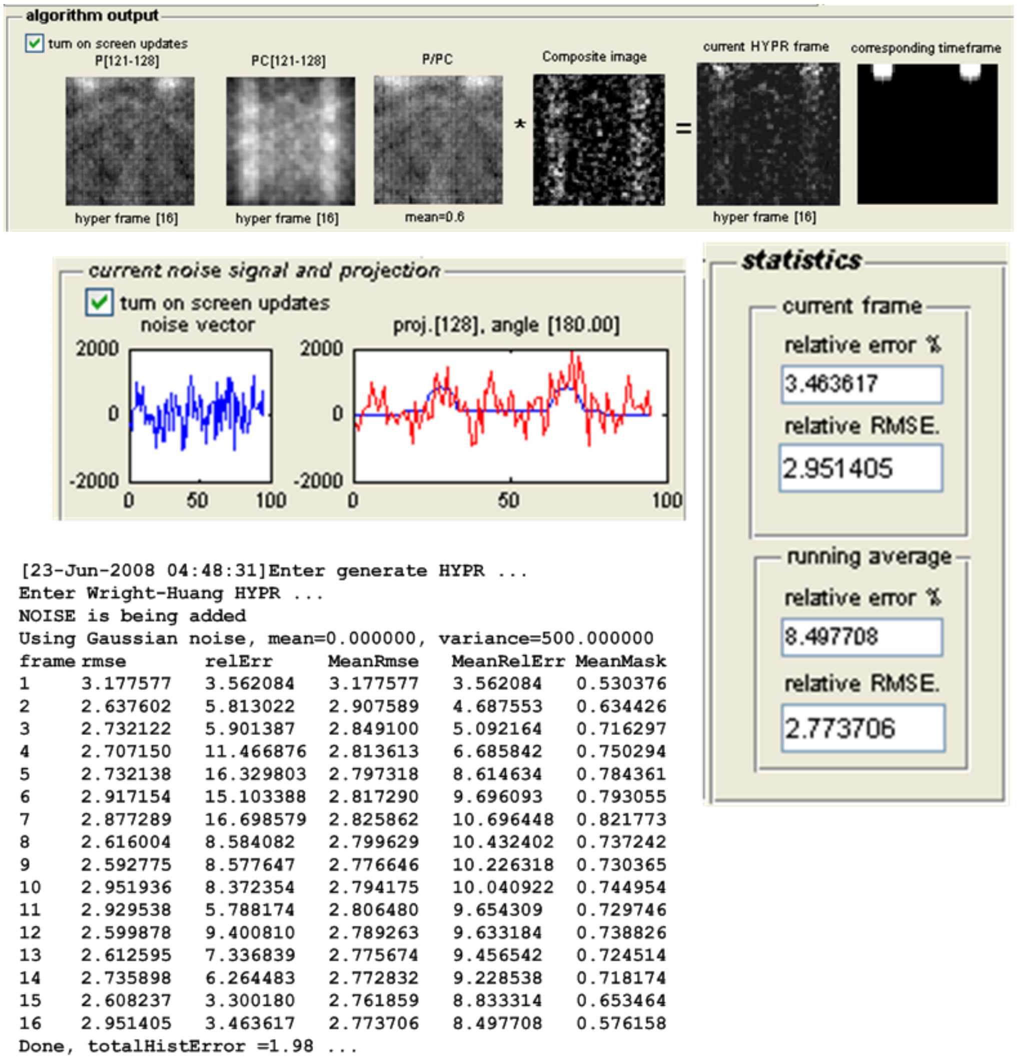
relative RMSE.

2.775436

```
Enter RESET ...
generated data for simulation [twoDisksApartTag]
Completed image generation...
number of time frames = [16]
number of projections per time frame = [8]
[23-Jun-2008 04:39:45]Enter generate HYPR ...
Enter original HYPR ...
NOISE is being added
Using Gaussian noise, mean=0.000000, variance=500.000000
frame rmse      relErr     MeanRmse   MeanRelErr MeanMask
1     2.985355  3.145048   2.985355   3.145048   1.798041
2     2.788903  11.763704  2.887129   7.454376   0.573652
3     2.711829  7.990433   2.828696   7.633061   0.585985
4     2.584071  1.506767   2.767540   6.101488   0.678164
5     2.790967  4.880071   2.772225   5.857204   0.680271
6     2.879052  5.194677   2.790030   5.746783   0.649276
7     2.846293  5.450342   2.798067   5.704434   0.690677
8     2.656306  8.487481   2.780347   6.052315   0.663424
9     2.679160  0.420427   2.769104   5.426550   0.715482
10    2.920066  2.875264   2.784200   5.171421   0.819093
11    2.954092  10.271849  2.799645   5.635097   0.860599
12    2.684370  2.017707   2.790039   5.333647   0.583517
13    2.583885  5.703348   2.774181   5.362086   0.555957
14    2.731929  3.366574   2.771163   5.219549   0.633825
15    2.751785  0.599176   2.769871   4.911524   0.642865
16    2.858916  6.971576   2.775436   5.040278   0.487232
Done,  totalHistError =1.98 ...
```

Test 10N a

6.3.30 Test 10N b



current frame

relative error %

3.463617

relative RMSE.

2.951405

running average

relative error %

8.497708

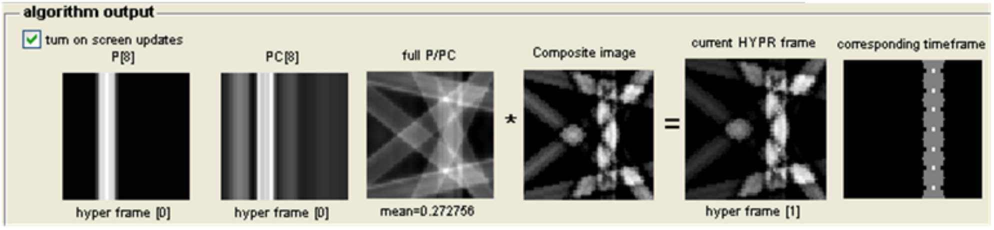
relative RMSE.

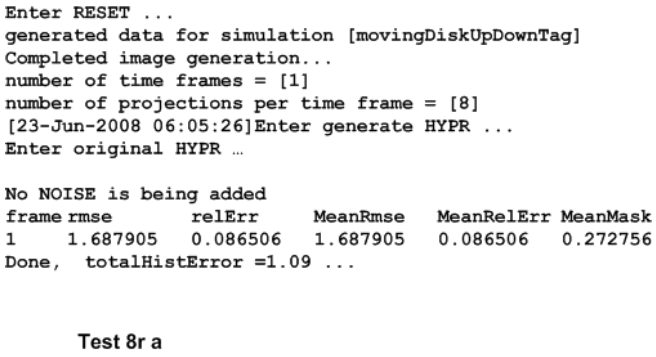
2.773706

```
[23-Jun-2008 04:48:31]Enter generate HYPR ...
Enter Wright-Huang HYPR ...
NOISE is being added
Using Gaussian noise, mean=0.000000, variance=500.000000
frame rmse      relErr    MeanRmse   MeanRelErr MeanMask
1     3.177577  3.562084  3.177577   3.562084   0.530376
2     2.637602  5.813022  2.907589   4.687553   0.634426
3     2.732122  5.901387  2.849100   5.092164   0.716297
4     2.707150  11.466876 2.813613   6.685842   0.750294
5     2.732138  16.329803 2.797318   8.614634   0.784361
6     2.917154  15.103388 2.817290   9.696093   0.793055
7     2.877289  16.698579 2.825862   10.696448  0.821773
8     2.616004  8.584082  2.799629   10.432402  0.737242
9     2.592775  8.577647  2.776646   10.226318  0.730365
10    2.951936  8.372354  2.794175   10.040922  0.744954
11    2.929538  5.788174  2.806480   9.654309   0.729746
12    2.599878  9.400810  2.789263   9.633184   0.738826
13    2.612595  7.336839  2.775674   9.456542   0.724514
14    2.735898  6.264483  2.772832   9.228538   0.718174
15    2.608237  3.300180  2.761859   8.833314   0.653464
16    2.951405  3.463617  2.773706   8.497708   0.576158
Done, totalHistError =1.98 ...
```

Test 10N b

6.3.31 Test 8r a

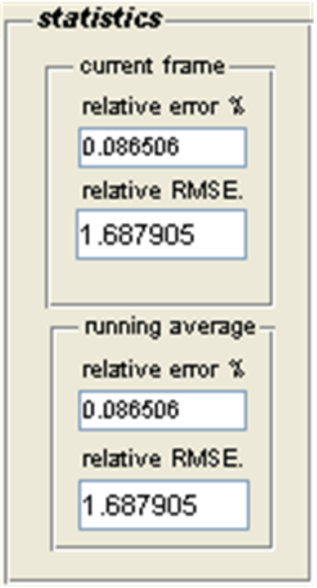




```
Enter RESET ...
generated data for simulation [movingDiskUpDownTag]
Completed image generation...
number of time frames = [1]
number of projections per time frame = [8]
[23-Jun-2008 06:05:26]Enter generate HYPR ...
Enter original HYPR ...

No NOISE is being added
frame rmse       relErr     MeanRmse   MeanRelErr MeanMask
1     1.687905   0.086506   1.687905   0.086506   0.272756
Done,  totalHistError =1.09 ...
```

Test 8r a



statistics

current frame

relative error %

0.086506

relative RMSE.

1.687905

running average

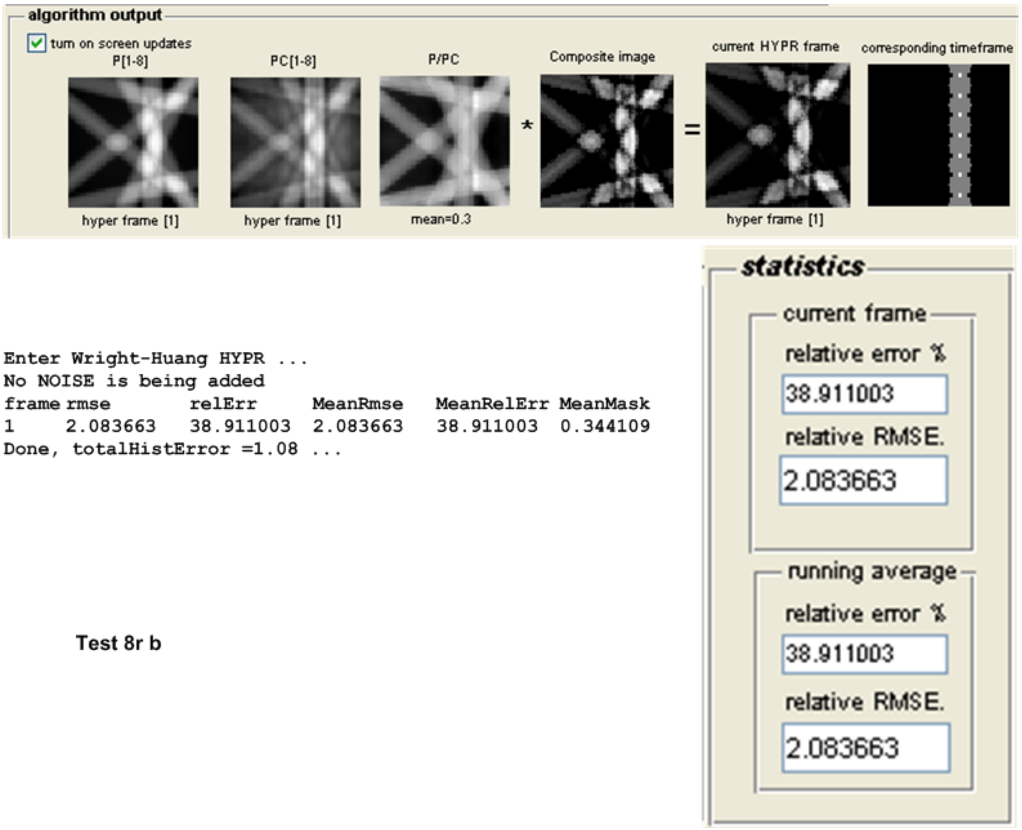
relative error %

0.086506

relative RMSE.

1.687905

6.3.32 Test 8r b



```
Enter Wright-Huang HYPR ...
No NOISE is being added
frame rmse       relErr     MeanRmse   MeanRelErr MeanMask
1     2.083663   38.911003  2.083663   38.911003  0.344109
Done, totalHistError =1.08 ...
```

Test 8r b

statistics

current frame

relative error %

38.911003

relative RMSE.

2.083663

running average

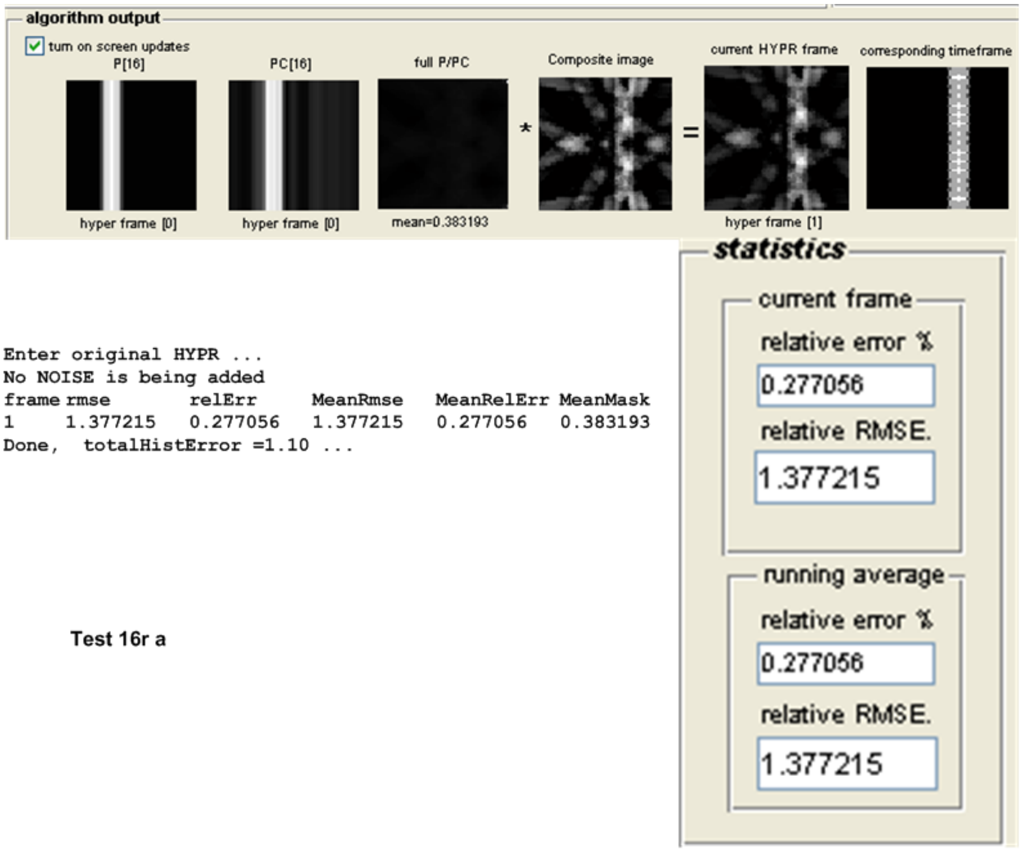
relative error %

38.911003

relative RMSE.

2.083663

6.3.33 Test 16r a



```
Enter original HYPR ...
No NOISE is being added
frame rmse        relErr     MeanRmse    MeanRelErr MeanMask
1     1.377215    0.277056   1.377215    0.277056   0.383193
Done,  totalHistError =1.10 ...
```

Test 16r a

statistics

current frame

relative error %: 0.277056

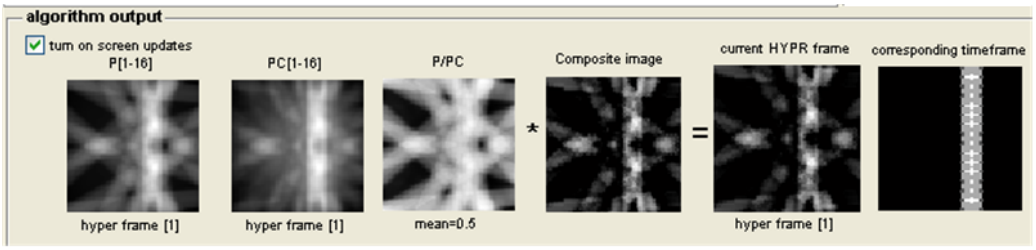
relative RMSE.: 1.377215

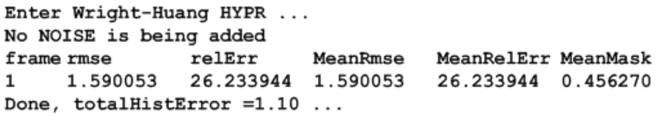
running average

relative error %: 0.277056

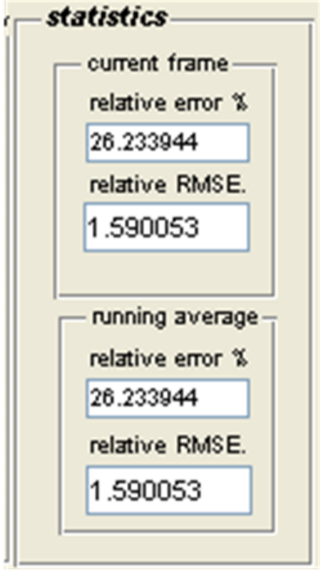
relative RMSE.: 1.377215

6.3.34 Test 16r b





```
Enter Wright-Huang HYPR ...
No NOISE is being added
frame rmse       relErr     MeanRmse   MeanRelErr MeanMask
1    1.590053   26.233944  1.590053   26.233944  0.456270
Done, totalHistError =1.10 ...
```



statistics

current frame

relative error %

26.233944

relative RMSE.

1.590053

running average

relative error %

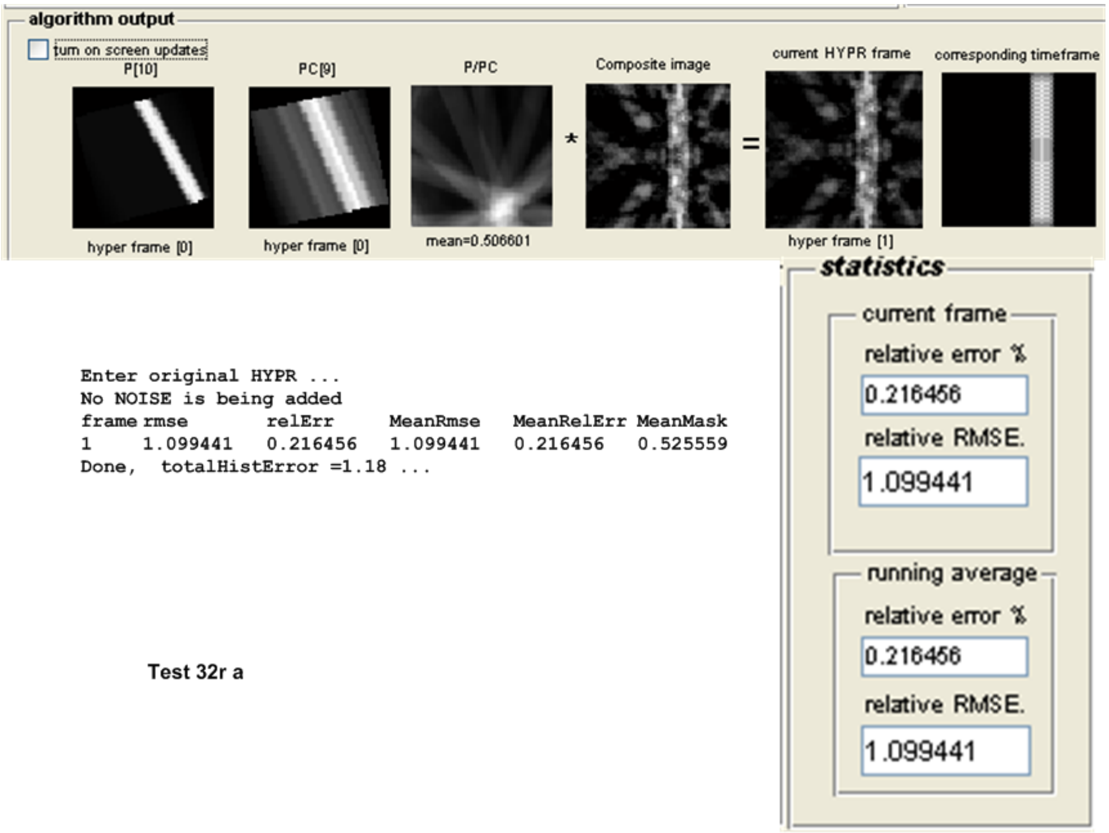
26.233944

relative RMSE.

1.590053

Test 16r b

6.3.35 Test 32r a



```
Enter original HYPR ...
No NOISE is being added
frame rmse       relErr     MeanRmse   MeanRelErr MeanMask
1     1.099441   0.216456   1.099441   0.216456   0.525559
Done,  totalHistError =1.18 ...
```

Test 32r a

current frame

relative error % 0.216456

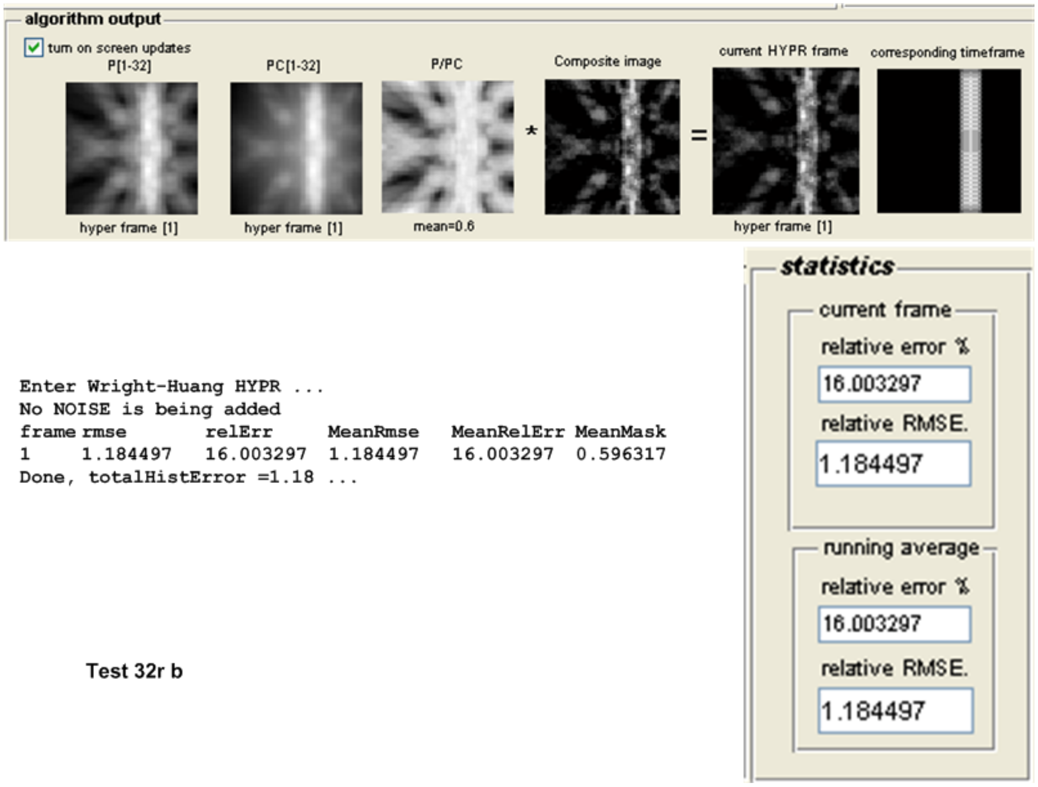
relative RMSE. 1.099441

running average

relative error % 0.216456

relative RMSE. 1.099441

6.3.36 Test 32r b



```
Enter Wright-Huang HYPR ...
No NOISE is being added
frame rmse       relErr     MeanRmse   MeanRelErr MeanMask
1     1.184497   16.003297  1.184497   16.003297  0.596317
Done, totalHistError =1.18 ...
```

Test 32r b

statistics

current frame

relative error % 16.003297

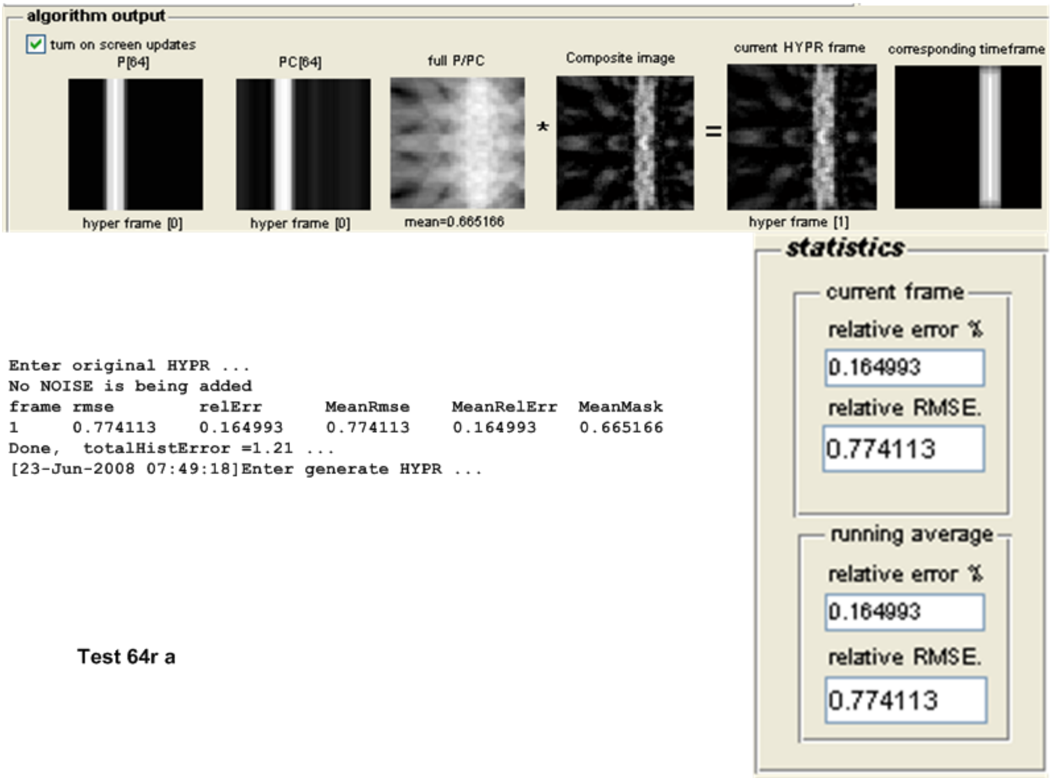
relative RMSE. 1.184497

running average

relative error % 16.003297

relative RMSE. 1.184497

6.3.37 Test 64r a



```
Enter original HYPR ...
No NOISE is being added
frame rmse        relErr      MeanRmse    MeanRelErr  MeanMask
1     0.774113    0.164993    0.774113    0.164993    0.665166
Done,  totalHistError =1.21 ...
[23-Jun-2008 07:49:18]Enter generate HYPR ...
```

Test 64r a

statistics

current frame

relative error % 0.164993

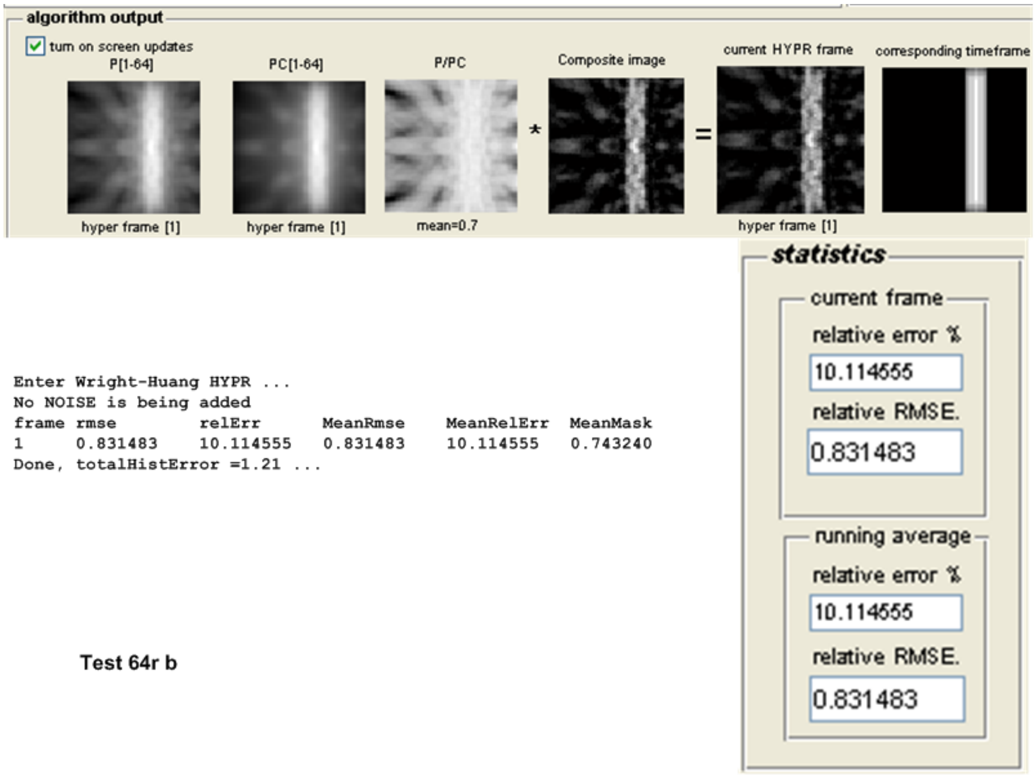
relative RMSE. 0.774113

running average

relative error % 0.164993

relative RMSE. 0.774113

6.3.38 Test 64r b



```
Enter Wright-Huang HYPR ...
No NOISE is being added
frame rmse        relErr      MeanRmse    MeanRelErr  MeanMask
1     0.831483    10.114555   0.831483    10.114555   0.743240
Done, totalHistError =1.21 ...
```

Test 64r b

statistics

current frame

relative error %
10.114555

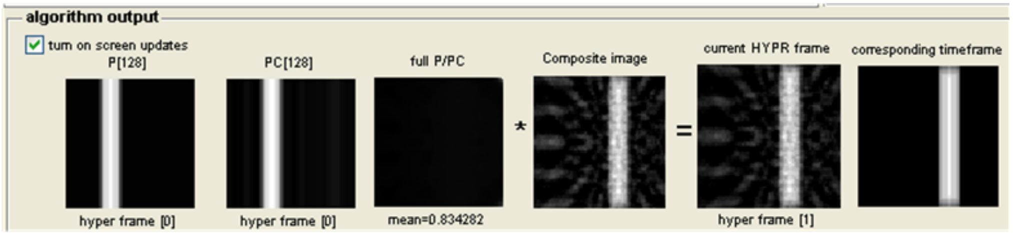
relative RMSE.
0.831483

running average

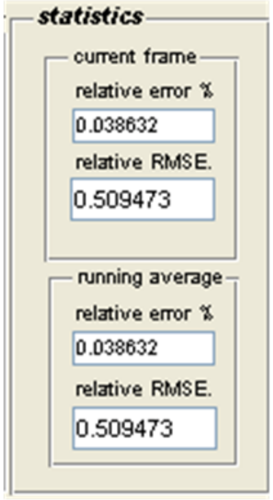
relative error %
10.114555

relative RMSE.
0.831483

6.3.39 Test 128r a



☑ turn on screen updates



statistics

current frame

relative error %

0.038632

relative RMSE.

0.509473

running average

relative error %

0.038632

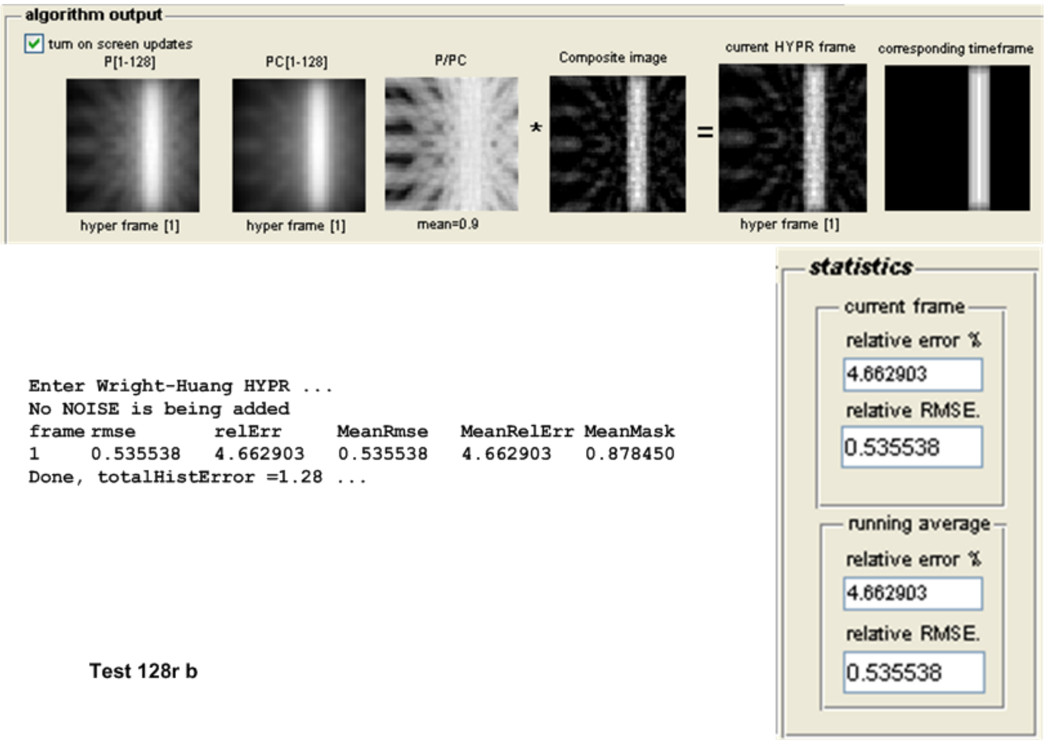
relative RMSE.

0.509473

```
Enter original HYPR ...
No NOISE is being added
frame rmse       relErr     MeanRmse   MeanRelErr MeanMask
1     0.509473   0.038632   0.509473   0.038632   0.834282
Done,  totalHistError =1.28 ...
```

Test 128r a

6.3.40 Test 128r b



```
Enter Wright-Huang HYPR ...
No NOISE is being added
frame rmse       relErr     MeanRmse    MeanRelErr MeanMask
1     0.535538   4.662903   0.535538    4.662903   0.878450
Done, totalHistError =1.28 ...
```

Test 128r b

current frame

relative error % 4.662903

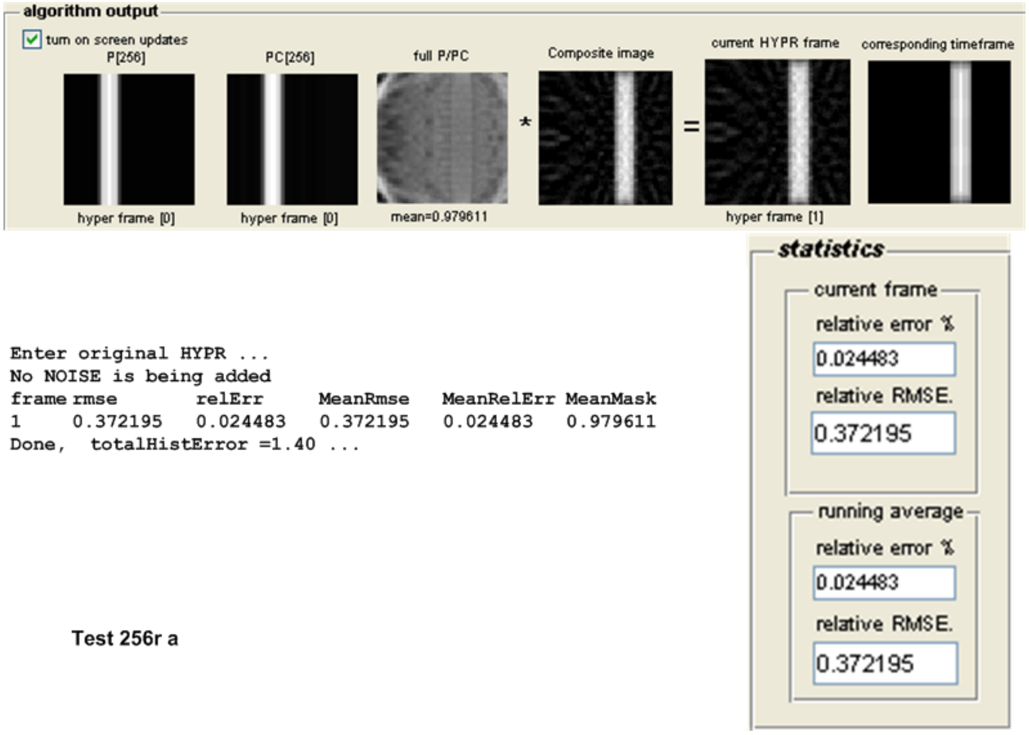
relative RMSE. 0.535538

running average

relative error % 4.662903

relative RMSE. 0.535538

6.3.41 Test 256r a



```
Enter original HYPR ...
No NOISE is being added
frame rmse      relErr     MeanRmse   MeanRelErr MeanMask
1     0.372195   0.024483   0.372195   0.024483   0.979611
Done,  totalHistError =1.40 ...
```

Test 256r a

statistics

current frame

relative error %

0.024483

relative RMSE.

0.372195

running average

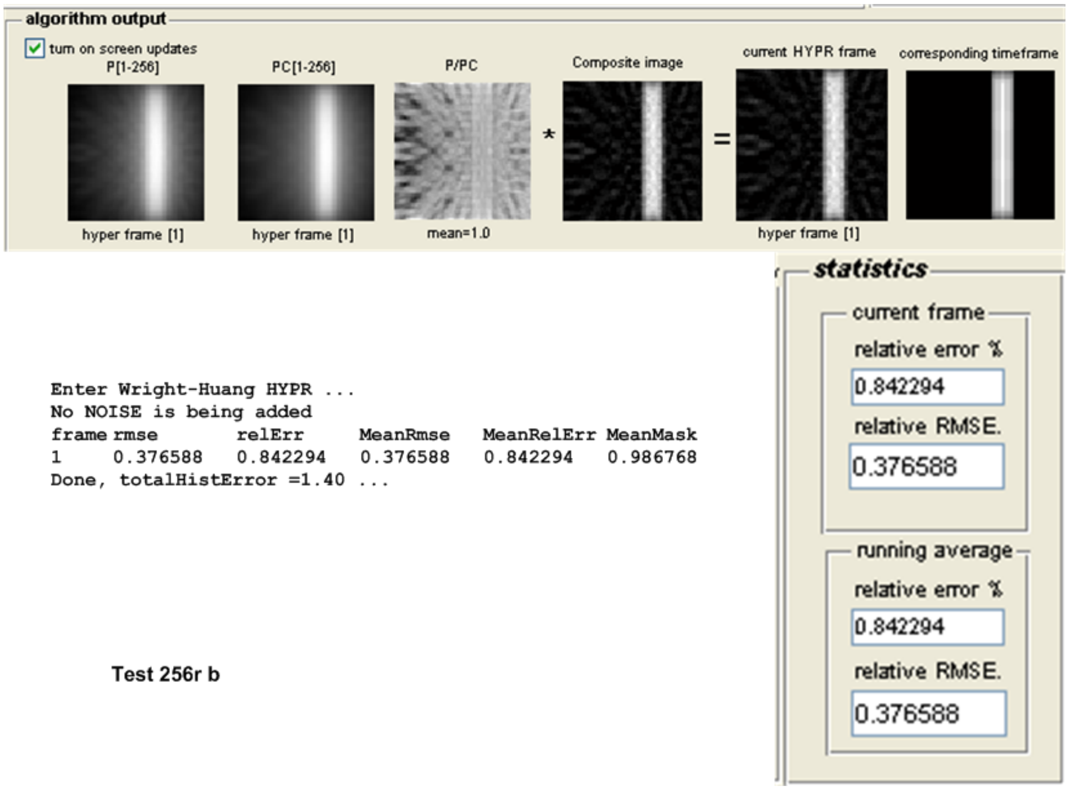
relative error %

0.024483

relative RMSE.

0.372195

6.3.42 Test 256r b



```
Enter Wright-Huang HYPR ...
No NOISE is being added
frame rmse       relErr     MeanRmse   MeanRelErr MeanMask
1     0.376588   0.842294   0.376588   0.842294   0.986768
Done, totalHistError =1.40 ...
```

Test 256r b

current frame

relative error % 0.842294

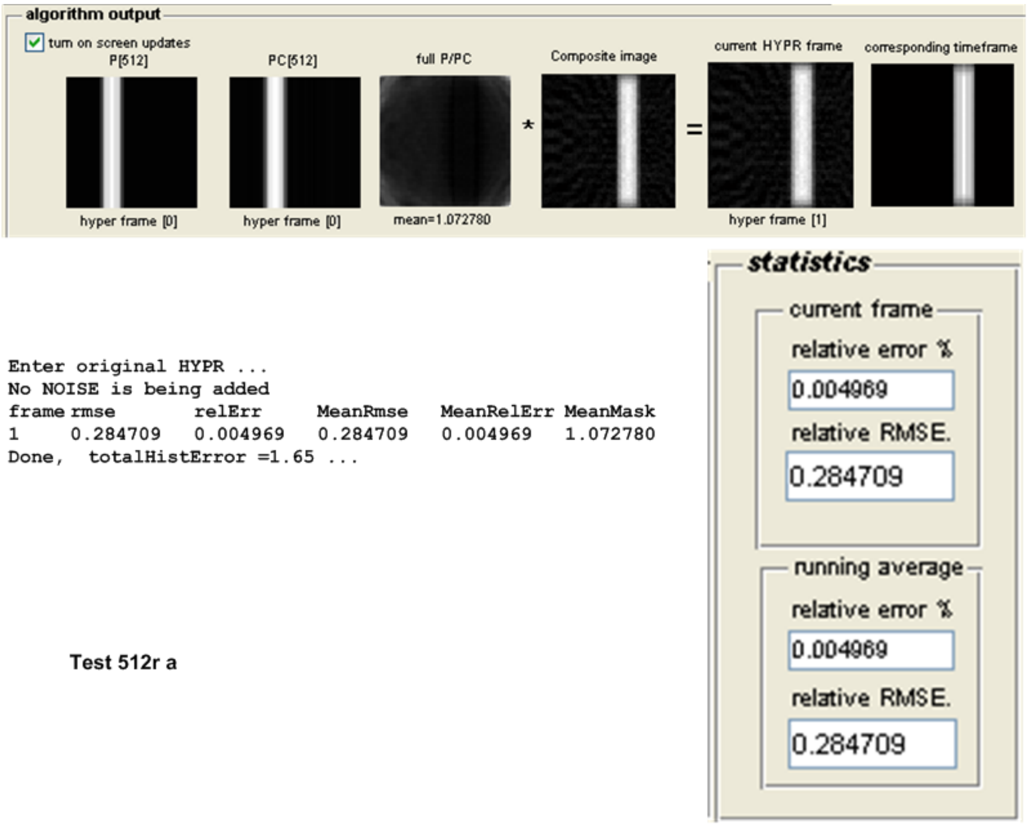
relative RMSE. 0.376588

running average

relative error % 0.842294

relative RMSE. 0.376588

6.3.43 Test 512r a



```
Enter original HYPR ...
No NOISE is being added
frame rmse       relErr     MeanRmse   MeanRelErr MeanMask
1     0.284709   0.004969   0.284709   0.004969   1.072780
Done,  totalHistError =1.65 ...
```

Test 512r a

statistics

current frame

relative error %

0.004969

relative RMSE.

0.284709

running average

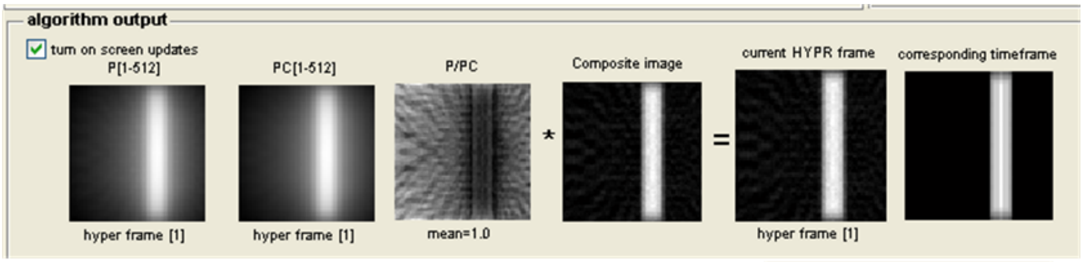
relative error %

0.004969

relative RMSE.

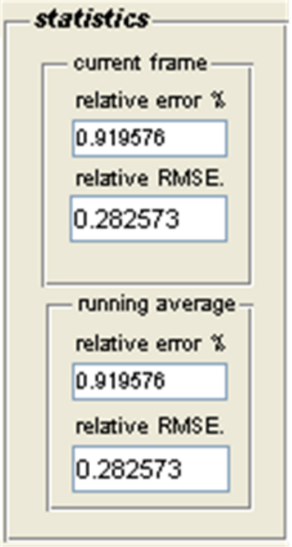
0.284709

6.3.44 Test 512r b



```
Enter Wright-Huang HYPR ...
No NOISE is being added
frame rmse       relErr     MeanRmse   MeanRelErr MeanMask
1     0.282573   0.919576   0.282573   0.919576   1.039760
Done, totalHistError =1.66 ...
```

Test 512r b



statistics

current frame

relative error %

0.919576

relative RMSE.

0.282573

running average

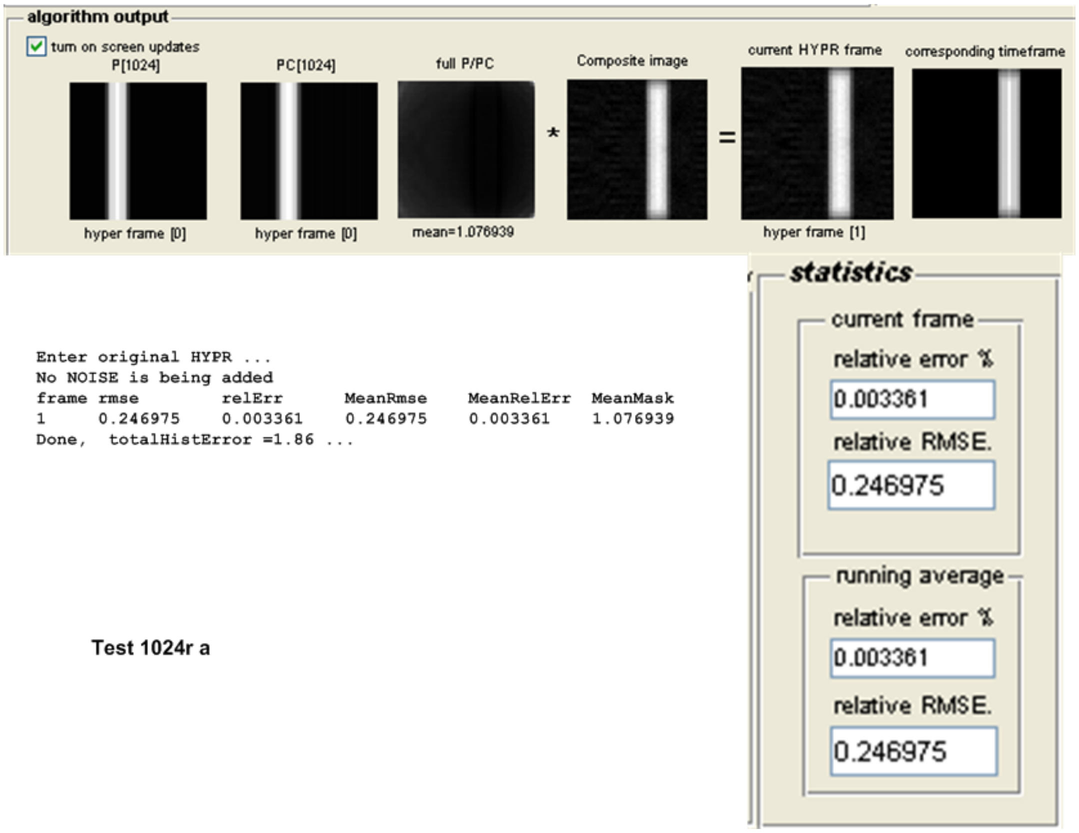
relative error %

0.919576

relative RMSE.

0.282573

6.3.45 Test 1024r a



☑ turn on screen updates

mean=1.076939

```
Enter original HYPR ...
No NOISE is being added
frame rmse       relErr     MeanRmse    MeanRelErr  MeanMask
1     0.246975   0.003361   0.246975    0.003361    1.076939
Done,  totalHistError =1.86 ...
```

Test 1024r a

current frame

relative error %: 0.003361

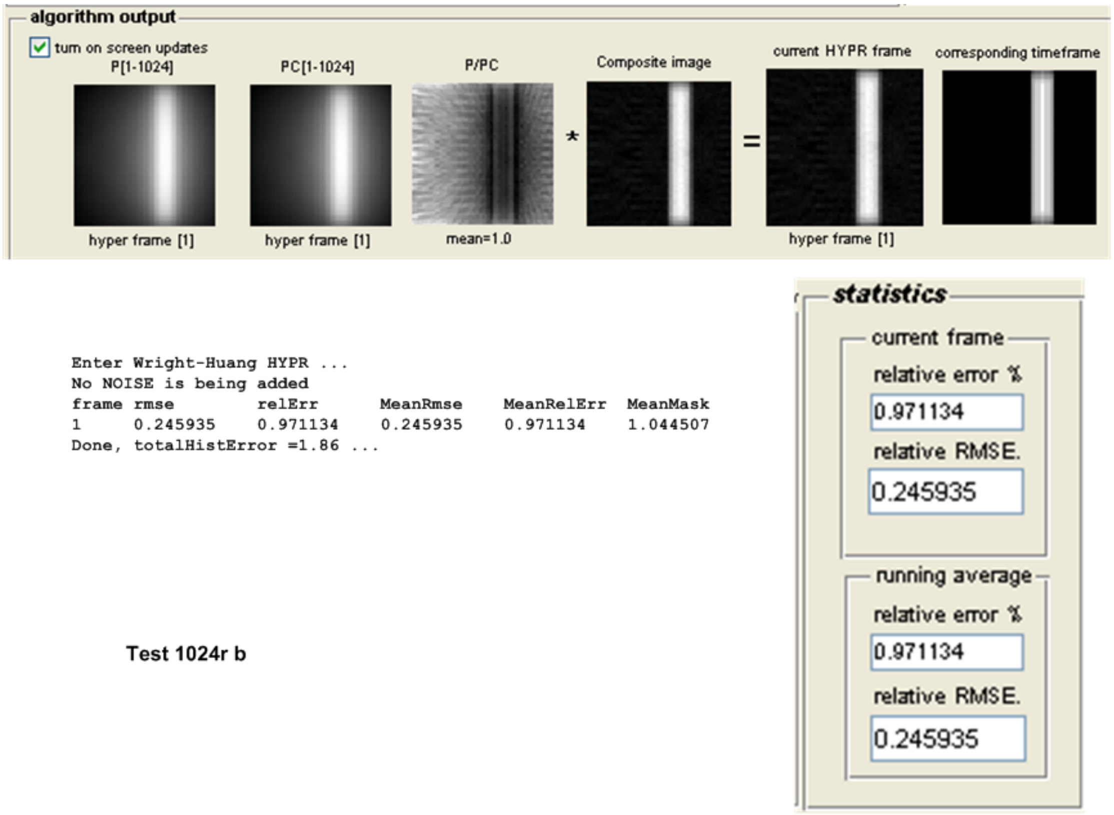
relative RMSE.: 0.246975

running average

relative error %: 0.003361

relative RMSE.: 0.246975

6.3.46 Test 1024r b



```
Enter Wright-Huang HYPR ...
No NOISE is being added
frame rmse      relErr     MeanRmse    MeanRelErr  MeanMask
1     0.245935  0.971134   0.245935    0.971134    1.044507
Done, totalHistError =1.86 ...
```

Test 1024r b

current frame

relative error %: 0.971134

relative RMSE.: 0.245935

running average

relative error %: 0.971134

relative RMSE.: 0.245935

6.4 References

References

[1] Iterative projection reconstruction of time-resolved images using highly-constrained back-projection (HYPR) by Rafael L. O'Halloran, Zhifei Wen, James H. Holmes, Sean B. Fain

[2] Highly Constrained Back projection for Time-Resolved MRI by C. A. Mistretta, O. Wieben, J. Velikina, W. Block, J. Perry, Y. Wu, K. Johnson, and Y. Wu

[3] Principles of computerized Tomographic imaging by Kak and Staney

[4] Highly Constrained Backprojection for Time-Resolved MRI by C. A. Mistretta, Wieben,z J, Velikina,W. Block,J. Perry,Y. Wu. K. ohnson and Y. Wu.