Distortion, noise, and strain

The lambdaChoose() function is employed here, and there are some other minor developments from DNaS_2.mlx, which was a revision of DNaS_1.mlx. Additionally, the undistort() function was successfully employede here.In this live script, the developments in all the previous major scripts will be applied to study the effects of noise in elucidating the total distortion using the Lawler-Fujita algorithm and how this combination affects the calculated physical strain according to Gao et al. (2017)'s method.

Let's define the initial parameters. If new to this live script, I suggest you change the values here and here only.

Image specifications

```
image_length = 4096; % [pixel]
image_height = 4096; % [pixel]
atom_diameter = 8; % [pixel]

lambda_scoring_weights = [1 1 0.05];
% distortion, noise, proportion weights in selecting lambda

Q_x = [1 0]; % [atom^-1]
Q_y = [-Q_x(2) Q_x(1)]; % just to ensure orthogonality

confidence_level = 0.9999999;
```

Distortion parameters

```
drift      =  [-64 -64]; % [atom/scan]
hysteresis =  [10 10]; % [atom]
creep      =  [10 10]; % [atom]
```

Noise parameters

```
noise_minimumLength = 10; % [atom]
noise_stdMagnitude = 1; % [atom]
```

Pre-processing the inputs, converting units. You probably would't want to edit these.

```
if image_length==256 && image_height==256
    lambda = lambdaChoose(drift,hysteresis,creep, ...
        noise_minimumLength,noise_stdMagnitude,lambda_scoring_weights); % [atom^-1]
    % works only for 256 by 256 images
else
    lambda = 0.2;
end

disp("Lambda used = " + lambda);
```

```
Lambda used = 0.2
```

```


lambda = lambda*2*pi/atom_diameter;
Q_x = Q_x * 2*pi / (norm(Q_x)*atom_diameter);
```

```
Q_y = Q_y * 2*pi / (norm(Q_y)*atom_diameter);
zscore = zscorer(confidence_level);

disp("Q_x = (" + Q_x(1)/(2*pi) + ", " +  Q_x(2)/(2*pi) + ...
    ") and Q_y = (" + Q_y(1)/(2*pi) + ", " +  Q_y(2)/(2*pi) + ") [pixel^-1]");
```

```
Q_x = (0.125, 0) and Q_y = (0, 0.125) [pixel^-1]
```

```
disp("Lattice constant a = " + atom_diameter + " [pixel]");
```

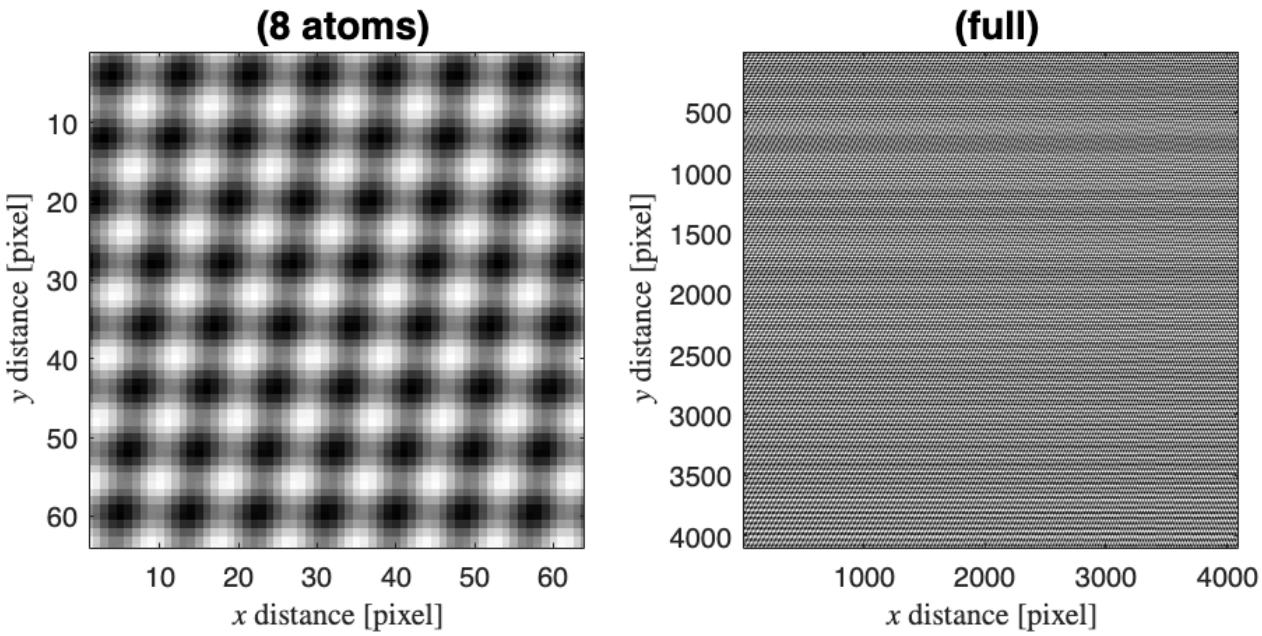
```
Lattice constant a = 8 [pixel]
```

1 Adding distortion

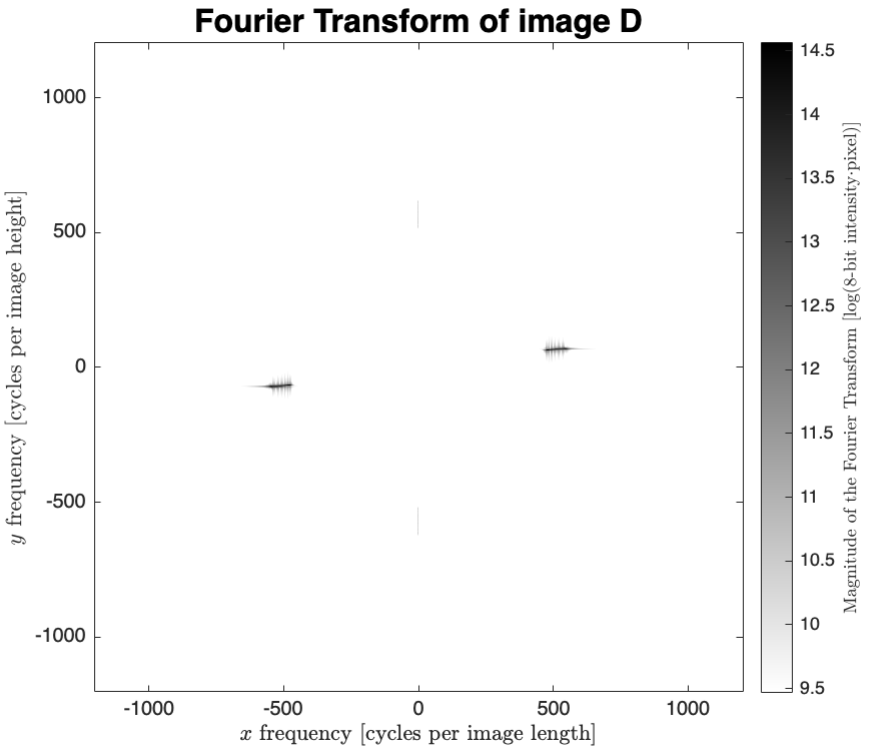
The perfect square lattice is distorted according to the Lawler et al. (2010) paper with an atom centered at the origin (0,0) — matrix indices (1,1) for MATLAB.

```
u = uCreate(image_height,image_length,atom_diameter,drift,hysteresis,creep);

lattice = normies(uTransform(u,Q_x,Q_y))*atom_diameter/2; % check the sign of u in uTra
comboPlot(lattice,"D",atom_diameter);
```

Intensity plot of D



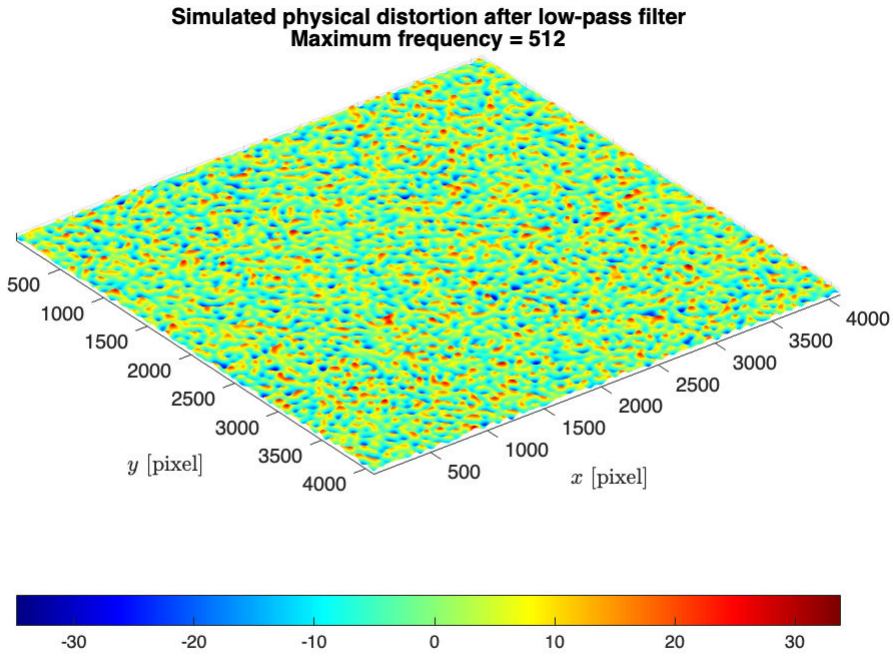

```
lattice_fft = myFFT(lattice,"D");
```



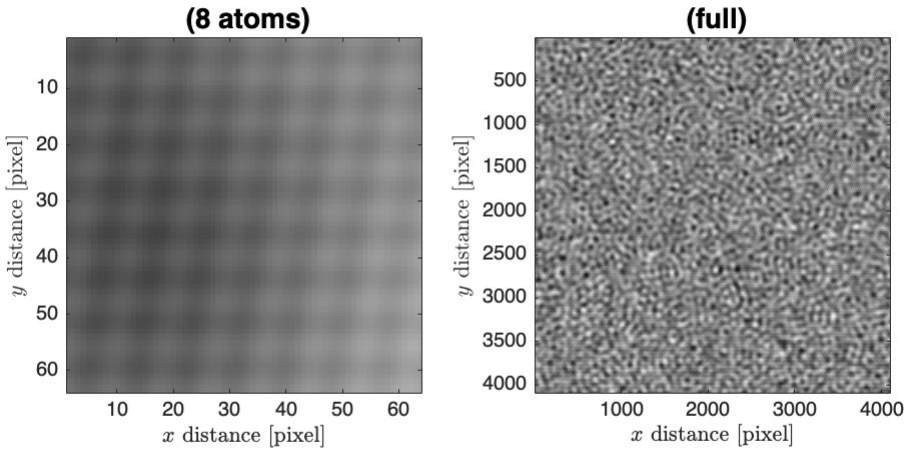
2 Adding noise

Noise is added to the lattice created above with an average magnitude and undulation length specified in the first code cell.

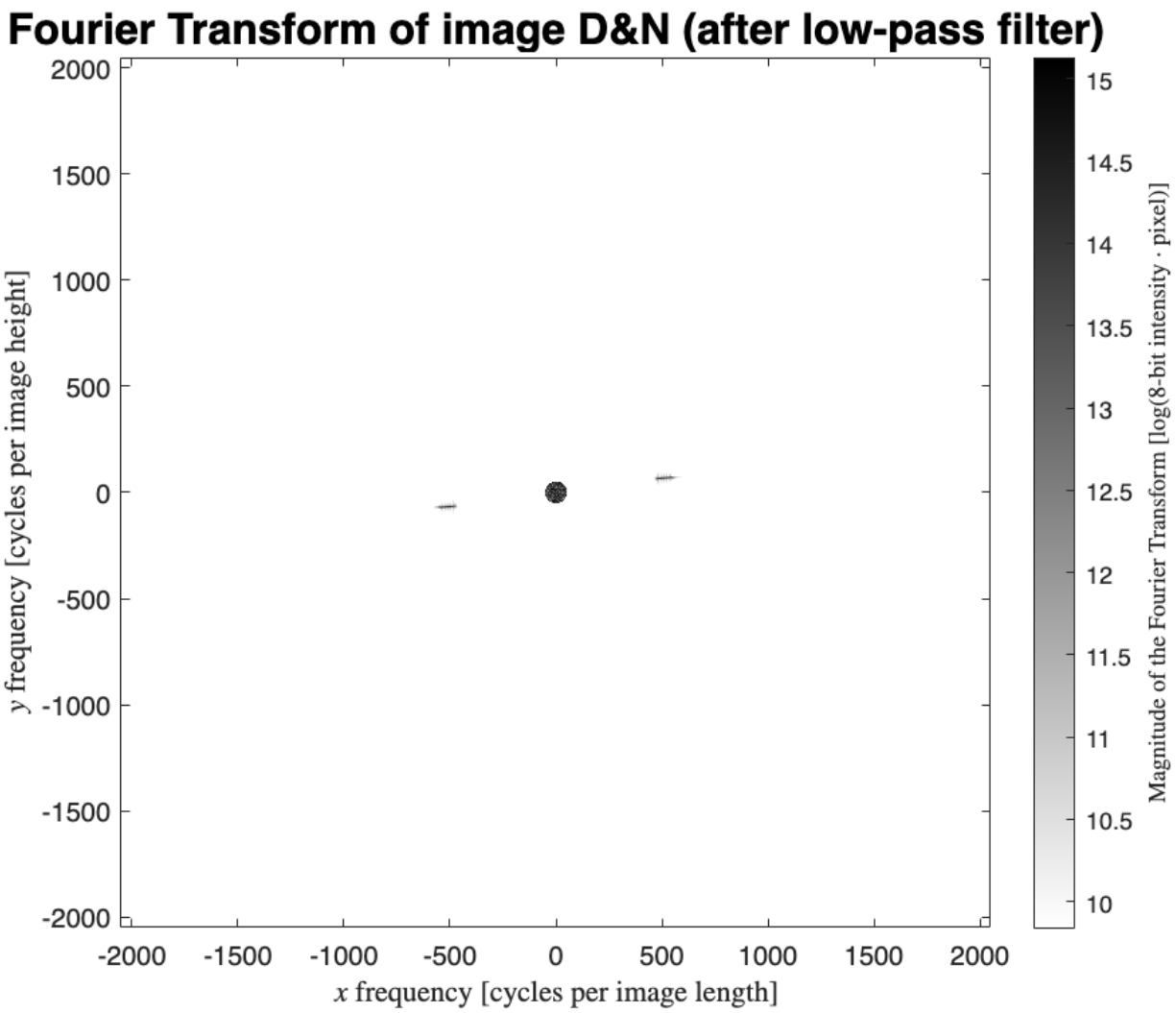
```
noise = noiseCreate(image_height,image_length,atom_diameter, ...
    noise_minimumLength,noise_stdMagnitude);
noisePlot(image_height,image_length,noise,[],atom_diameter);
```



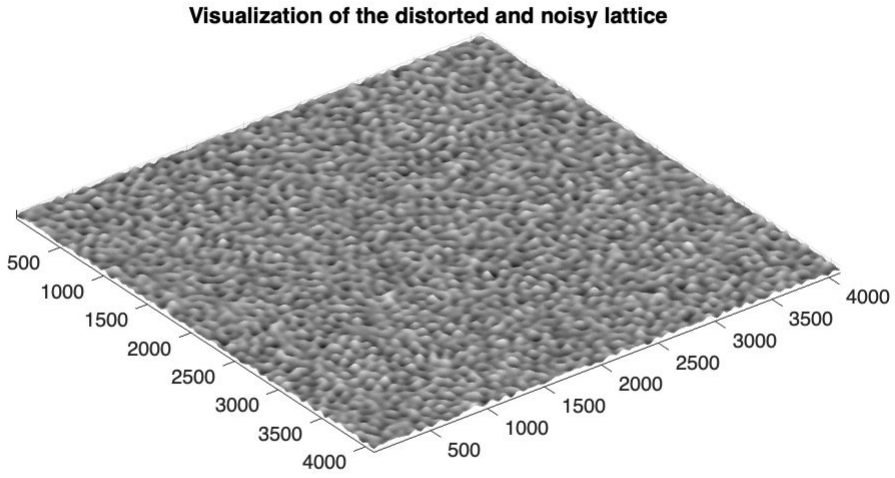

```
nlattice = lattice+noise;
comboPlot(nlattice,"D&N",atom_diameter);
```



```
nlattice_fft = myFFT(nlattice,"D&N",[],atom_diameter/100);
```




```
surf(nlattice);
shading interp;
axis equal;
set(gca,"YDir","reverse");
colormap(gray);
title("Visualization of the distorted and noisy lattice");
```

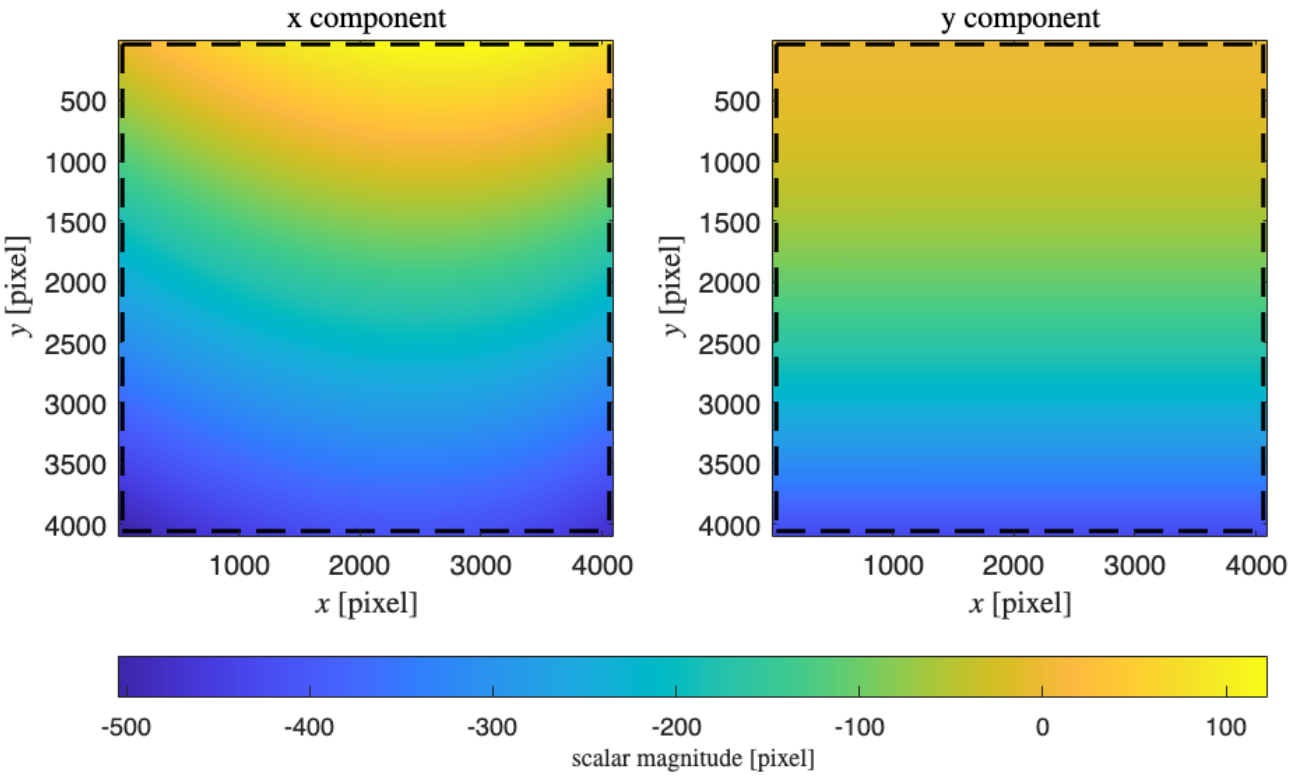


3 Calculating total distortion

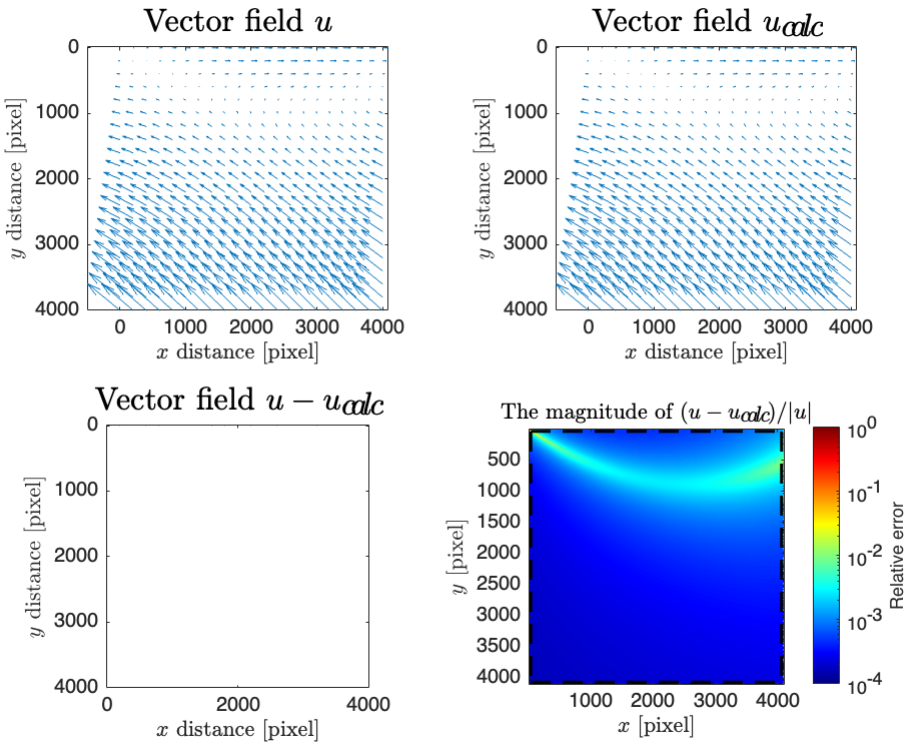
Using the Lawler-Fujita algorithm, the total distortion as the sum of the imaging distortion and the physical strain, $\vec{u}_{calc} = \vec{d} + \vec{s}$, is calculated. The effects of noise and the magnitude and type of tolerable distortion could be studied using the previous and the following code.

```
ucalc = myConv(nlattice,Q_x,Q_y,lambda,zscore,true); % true as last argument to plot u
```

Values of calculated total distortion




```
uComboPlot(u,ucalc,lambda,zscore);
```




```
if image_length-2*ceil(zscore/lambda)<=0 && image_height-2*ceil(zscore/lambda)<=0
    error("ERROR! No pixels without padded zeros remain.");
else
    npixel = (image_length-2*ceil(zscore/lambda))*(image_height-2*ceil(zscore/lambda))
    % the number of pixels averaged
    disp("Number of pixels averaged: " + npixel + " (" + ...
        npixel/(image_length*image_height)*100 + "%)");
end
```

```
Number of pixels averaged: 16176484 (96.4194%)
```

```
[meanErr, stdErr] = uCompare(u,ucalc,lambda,zscore);
disp("Error is: " + meanErr + "+/-" + stdErr*zscore + " (" + confidence_level*100 + "%
```

```
Error is: 0.00075851+/-0.0058361 (100% confidence)
```

```
disp("Total error is: " + (meanErr+stdErr*zscore) + " (" + confidence_level*100 + "% c
```

```
Total error is: 0.0065946 (100% confidence)
```

```
disp("Errors are relative unless stated otherwise.");
```

```
Errors are relative unless stated otherwise.
```

4 Calculating physical strain

From the equation given above, the physical strain can be obtained by subtracting the smooth, third-digree polynomial imaging distortion from the total distortion.

```
[fitresultx, gofx,outputx] = createFit(ucalc(:,:,1), lambda,zscore);
```

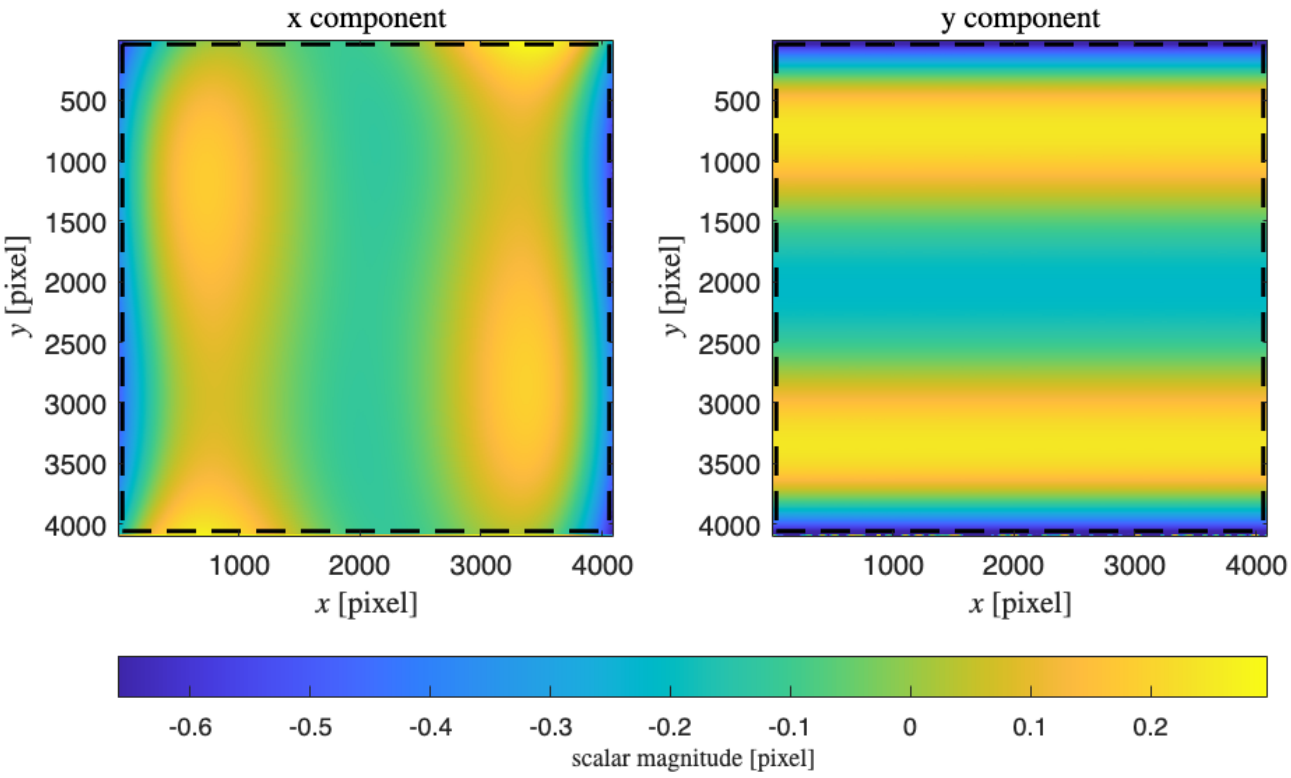
```
Warning: Equation is badly conditioned. Remove repeated data points or try centering and scaling.
```

```
% fitPlot(fitresultx, ucalc(:,:,1), "$u_x$", lambda,zscore);
[fitresulty, gofy,outputy] = createFit(ucalc(:,:,2), lambda,zscore);
```

```
Warning: Equation is badly conditioned. Remove repeated data points or try centering and scaling.
Warning: Iteration limit reached for robust fitting.
```

```
% fitPlot(fitresulty, ucalc(:,:,2), "$u_y$", lambda,zscore);

resx = reshape(outputx.residuals,image_height-2*ceil(zscore/lambda),[]);
resy = reshape(outputy.residuals,image_height-2*ceil(zscore/lambda),[]);
mu = zeros(2,1); sigma = zeros(2,1);
mu(1) = mean(resx,"all")/atom_diameter; % [lattice constant]
sigma(1) = std(resx,1,"all")/atom_diameter; % [lattice constant]
mu(2) = mean(resy,"all")/atom_diameter; % [lattice constant]
sigma(2) = std(resy,1,"all")/atom_diameter; % [lattice constant]

[xi,yi] = meshgrid(1:image_length,1:image_height);

strain = zeros(size(ucalc));
strain(:,:,1) = ucalc(:,:,1)-fitresultx(xi,yi);
strain(:,:,2) = ucalc(:,:,2)-fitresulty(xi,yi);

convPlot(strain(:,:,1),"calculated physical strain",strain(:,:,2),lambda,zscore);
```

Values of calculated physical strain




```
disp("Physical strain along x = " + (sigma(1)) + " [lattice constant]");
```

```
Physical strain along x = 0.015614 [lattice constant]
```

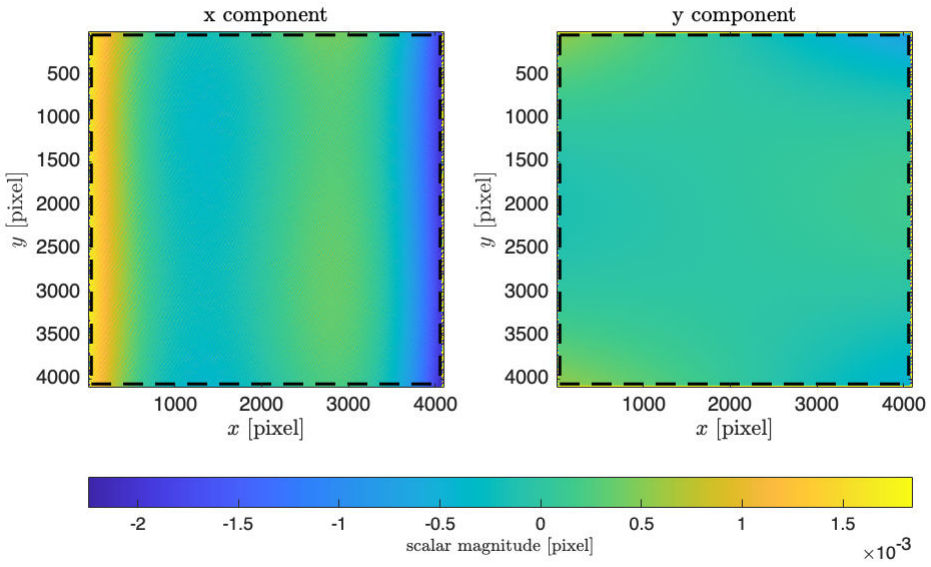
```
disp("Physical strain along y = " + (sigma(2)) + " [lattice constant]");
```

```
Physical strain along y = 0.025447 [lattice constant]
```

The strain and it's first order partial derivatives are calculated and plotted. Biaxial and approximate uniaxial strain maps are also generated from the previous calculations.

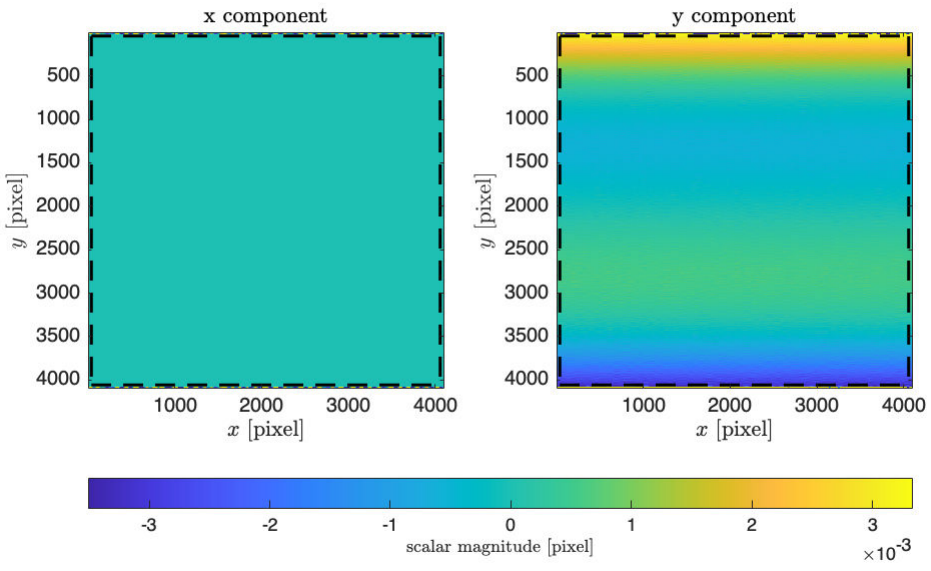
```
Sxdx = diff(strain(1:end-1,:,1),1,2);
Sxdy = diff(strain(:,1:end-1,1));
Sydx = diff(strain(1:end-1,:,2),1,2);
Sydy = diff(strain(:,1:end-1,2));
convPlot(Sxdx,"derivative of physical strain in x",Sxdy,lambda,zscore);
```

Values of derivative of physical strain in x



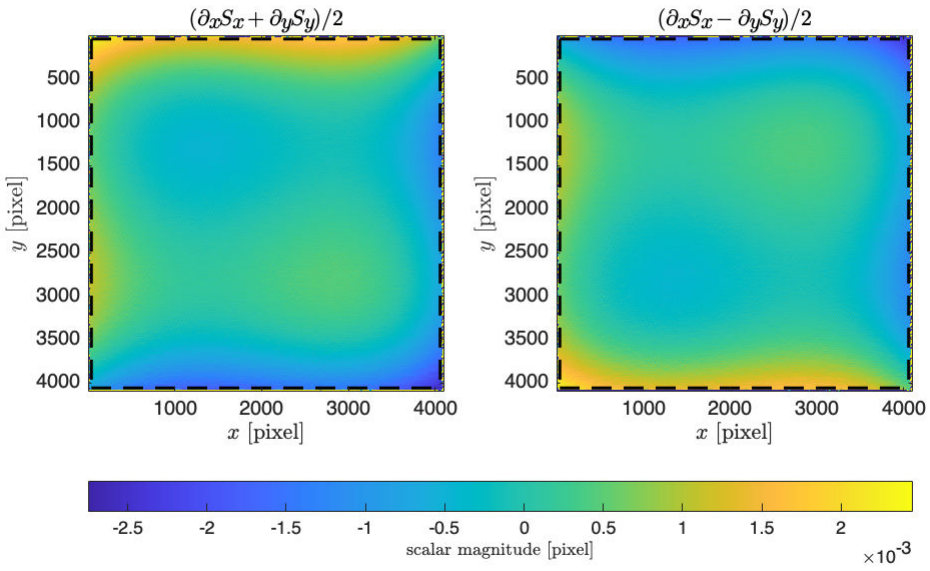

```
convPlot(Sydx,"derivative of physical strain in y",Sydy,lambda,zscore);
```

Values of derivative of physical strain in y




```
convPlot((Sxdx+Sydy)/2,"biaxial and uniaxial strain",(Sxdx-Sydy)/2,lambda,zscore);
```

Values of biaxial and uniaxial strain

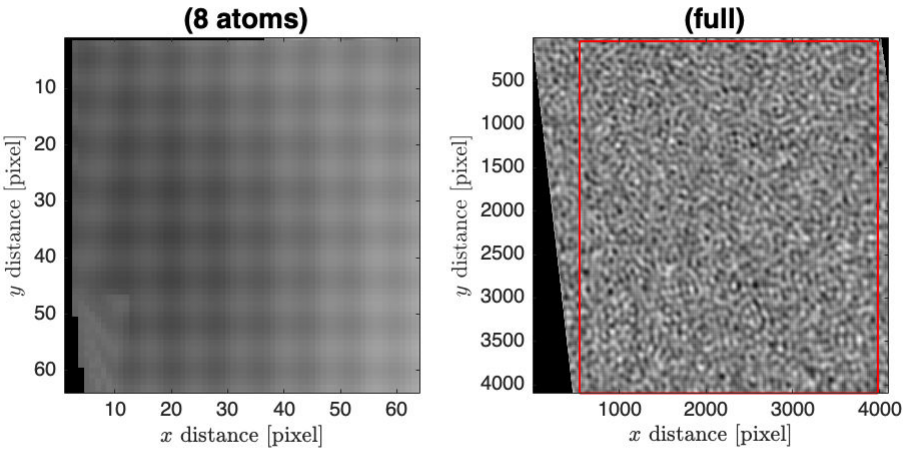


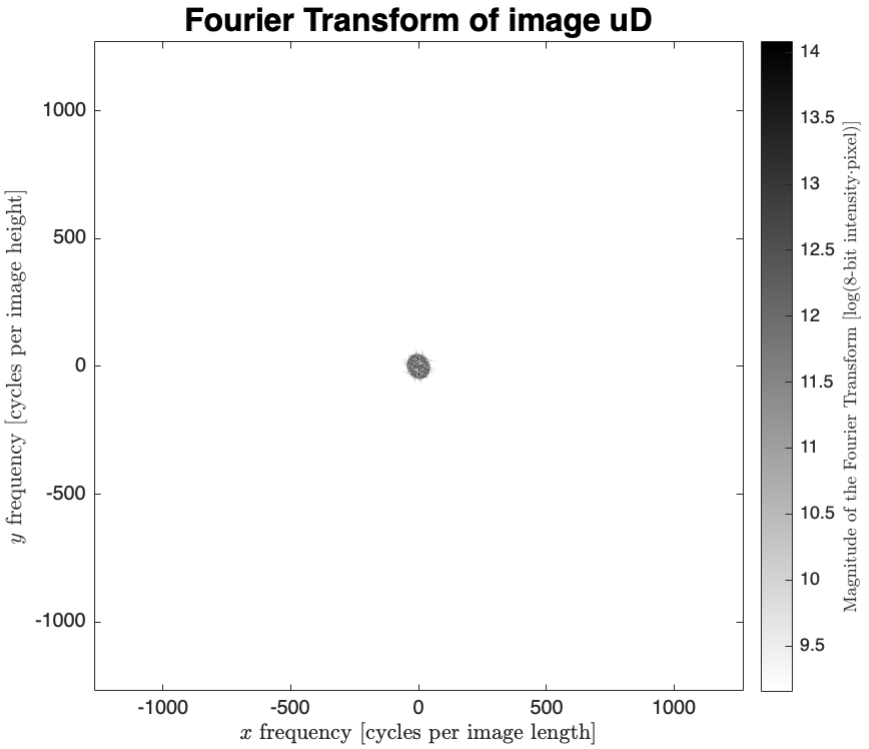
5 Undistorting the image

Lastly, we undistort the image using my own undistort() function that in turn uses the imwarpConverse() function that I also built.

```
ucalc(isnan(ucalc)) = ucalc(find(isnan(ucalc))-1);
ulattice = undistort(nlattice,-ucalc,atom_diameter,lambda,zscore);
```

Intensity plot of uD





Intensity plot of D&N (adjusted)