ACTIVE OPTICAL SYSTEMS

AN058

Convert Gaussian Irradiance Profile into Top-Hat or Annulus

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1 Introduction

One of the most common beam shaping requests we receive is to convert a Gaussian irradiance profile into a top-hat or annular profile. In this application note we explore a modeling technique for finding a phase profile for accomplishing this conversion with a simulated DM with a few annular actuators.

2 Modeling Approach

This modeling technique is similar to those we have used in prior work. We searched the multi-dimensional actuator position space to minimize the RMS difference between the ideal and actual modeled irradiance after imposing the phase induced through DM reflection and taking the beam to the far field (aka focus). Instead of using DM influence functions obtained through modeling plate-type deformable mirror mechanics, we used a new technique for this model. We created annular piston sections with a circle at the middle and convolved each with a Gaussian to limit the influence function spatial frequency response. Here is a code snip of the creation of the influence functions used in this modeling:

```
dact = 1.5*Dap/2/Nact;
IF{1} = (rr<dact);
for i=2:Nact
    IF{i} = (rr<(i).*dact) .* (rr>((i-1)*dact));
end;
filter = exp(-1*(rr./(dact/2)).^2);
rv = nxy/2 + (1:1:nxy);
for i=1:Nact;
    IF2 = conv2(IF{i},filter);
    IF{i} = IF2(rv,rv);
    IF{i} = 8e-6 .* (IF{i} ./ max(IF{i}(:)));
end;
```

Figure 1 shows four example influence functions obtained with this technique.

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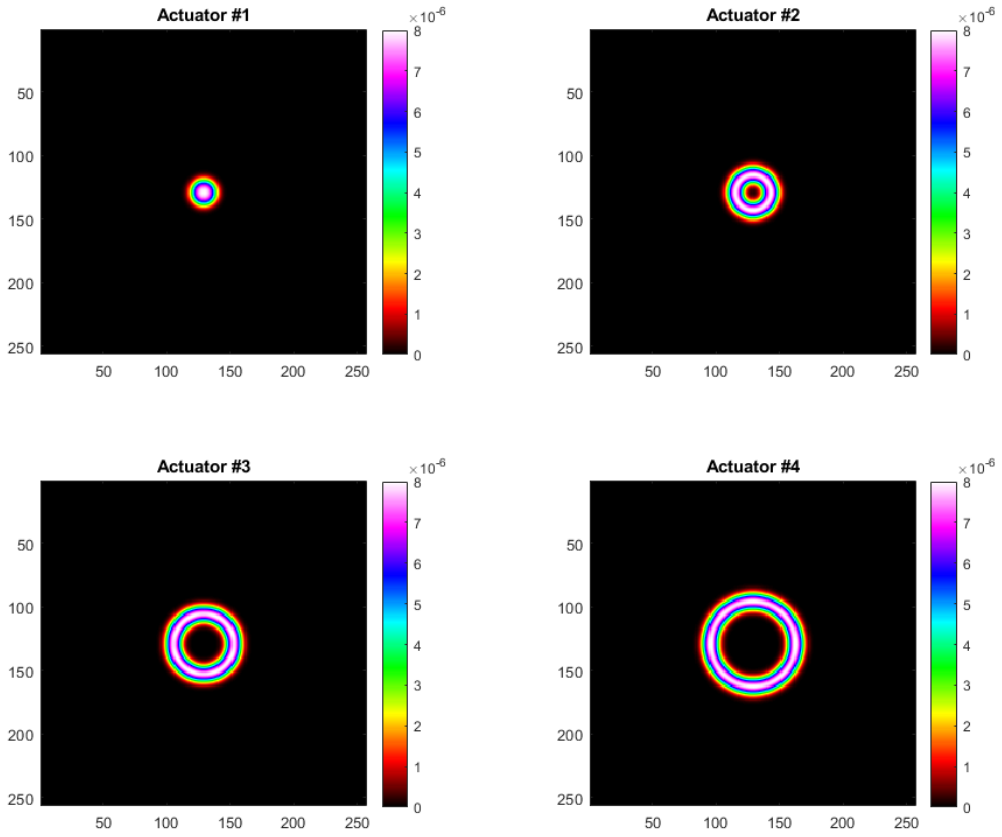

Figure 1: Example Influence Functions using the Smoothed Annular Technique

3 Results

The following sections describe the best results obtained with 10 different random number seeds on a simulated "DM" with 10 influence functions. Each model used 1-micron light and a 12 mm Gaussian beam waist. The grid was 256 samples separated by 390 microns. The beam was focused 100m from the DM plane.

3.1 Top-Hat Profile

Below are several different results from a beam shaping search. Each result shows the initial field magnitude, final irradiance profile, the imposed phase in false color, the imposed phase cross section with the Gaussian irradiance cross-section overlay, and a bar chart of the actuator commands. Each of the results have similar shapes, but none of them are exactly the same.

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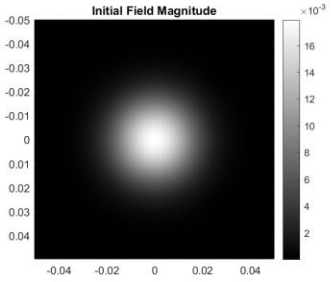

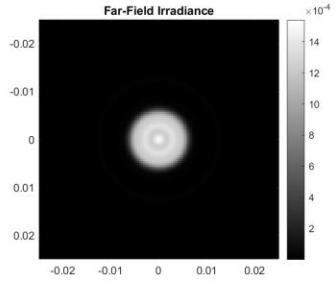

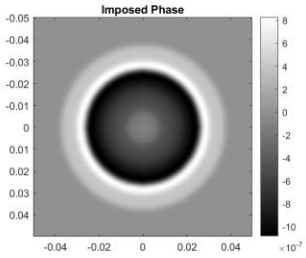

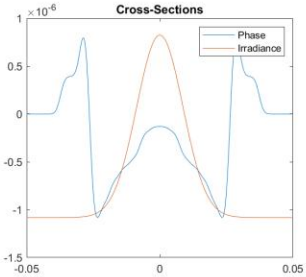

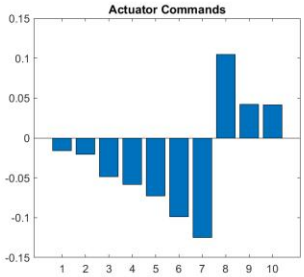

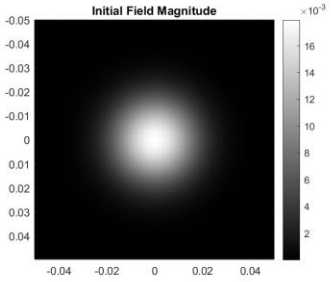

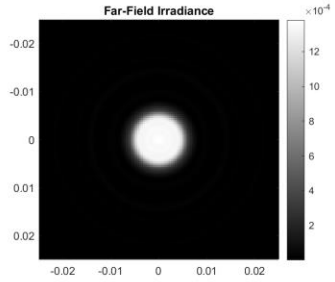

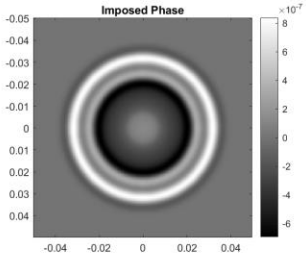

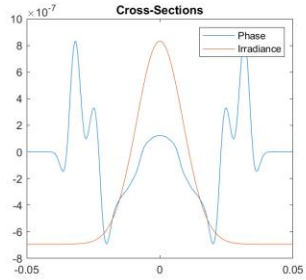

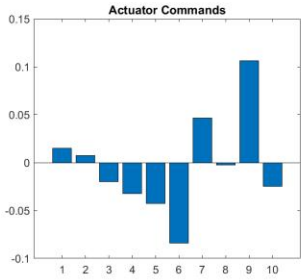

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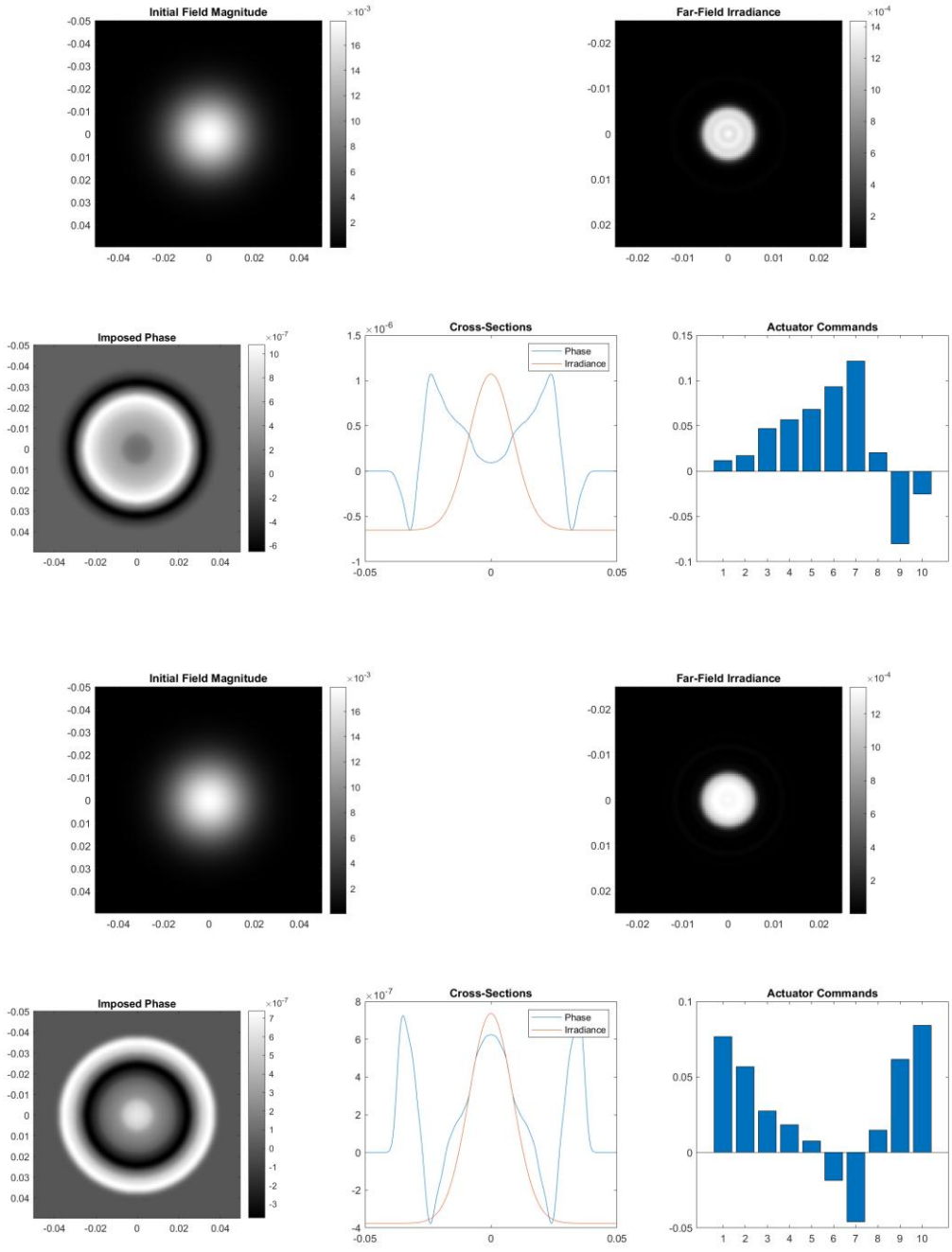

The simple DM used here was very successful at achieving a good approximation of the desired far-field irradiance profile with fairly minimal phase amplitude and very limited spatial frequency content. The phase amplitude required for this shaping was only about 1 or 2 microns (waves). The only sharp transition was near the outer edge of the Gaussian irradiance.

3.2 Annular Profile

The following results are from several different runs attempting an annular shape.

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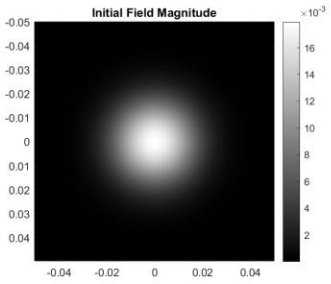

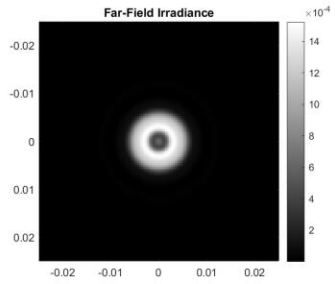

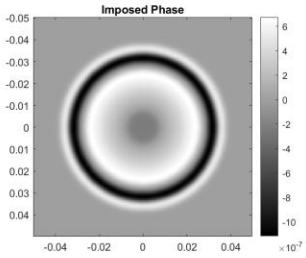

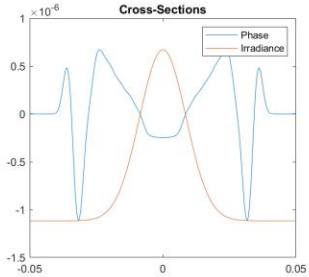

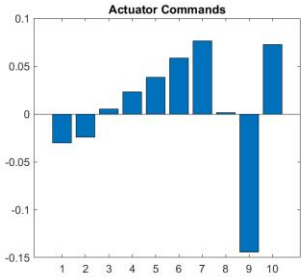

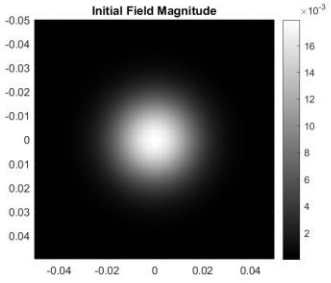

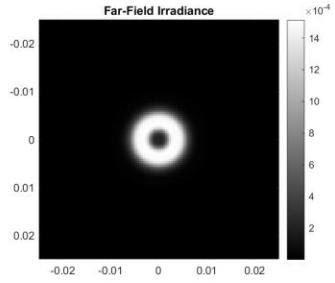

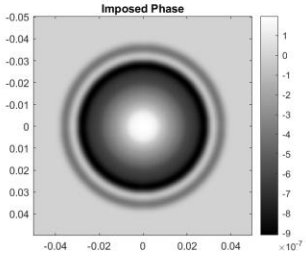

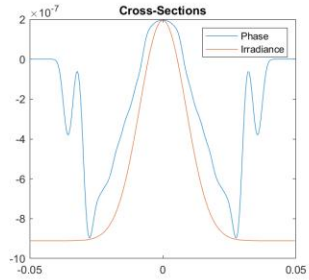

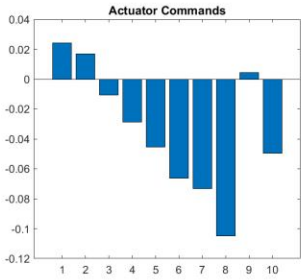

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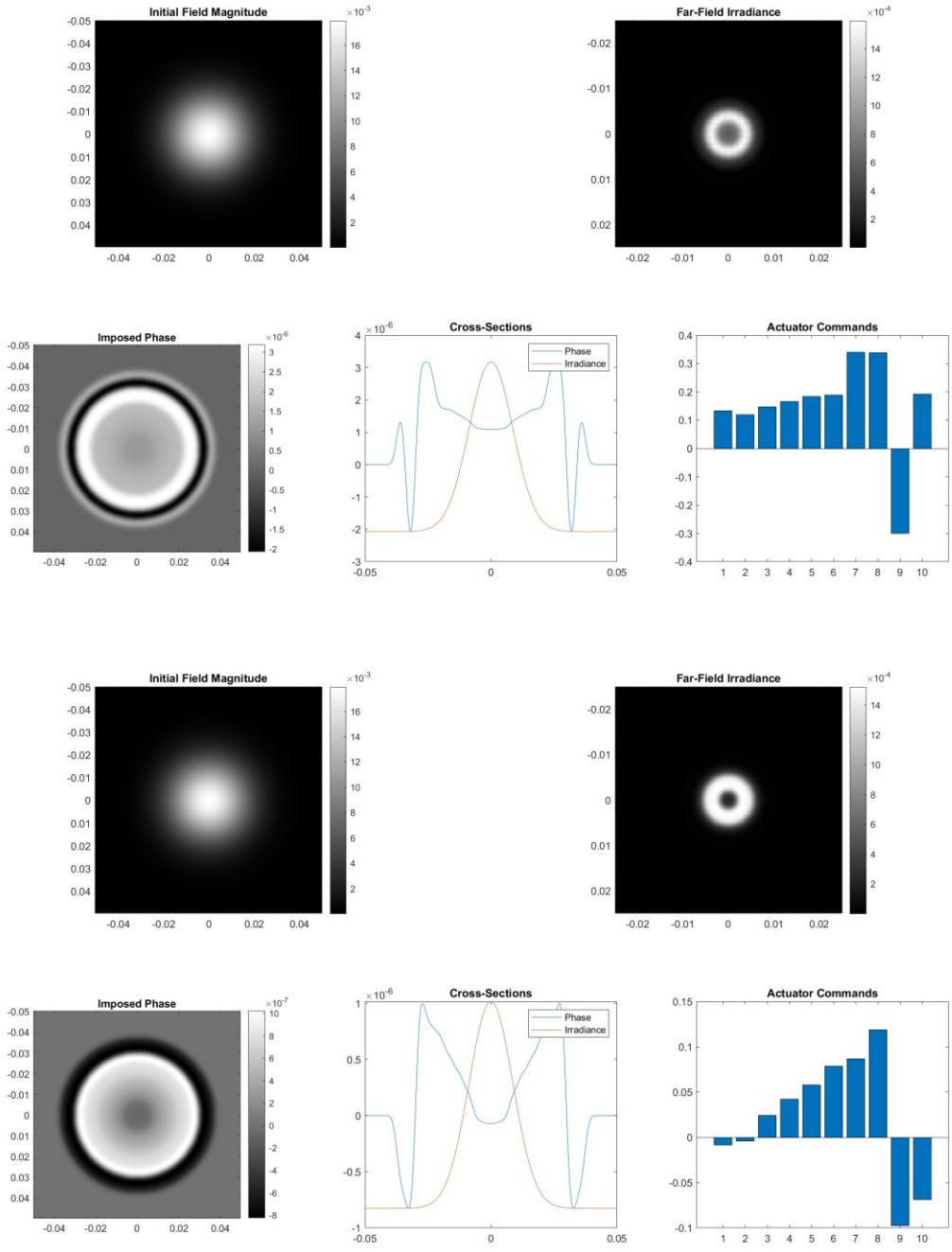

Again the shapes for these results were all different, but each only required only about 1-2 microns (waves) of phase to achieve the desired shape. Most of the variations in these solutions are in the perimeter where the input Gaussian irradiance is very low amplitude.

4 Conclusions

In this application note, we demonstrated beam shaping of a Gaussian beam into a top-hat and an annular beam using a DM model with spatial frequency limited annular influence functions. We showed that this simple DM could be used in different ways to achieve approximations of the desired irradiance profile.

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5 Appendix: Code for Shaping

```
for shapeIndex = 1:3;
    Ii = exp(-1 * (rr.^2/w.^2)); %initial irradiance
    switch shapeIndex
        case 2
            if (ppt) TitleSlidePowerPoint('Donut'); end;
            If = exp(-1 * ((rr./wf).^10)) - exp(-1 * ((rr./(wf/3)).^10));; %final irradiance - circular donut
        case 3
            if (ppt) TitleSlidePowerPoint('Tophat (50th order Super-Gaussian)'); end;
            If = exp(-1 * ((rr./wf).^50)); %final irradiance - circular tophat
        otherwise
            if (ppt) TitleSlidePowerPoint('10th order Irradiance Super-Gaussian'); end;
            If = exp(-1 * ((rr./wf).^10)); %final irradiance - circular tophat
    end;
    %                 WEIGHT = exp(-1 * ((rr./wf).^2)) + 0.1;
    %                 WEIGHT = WEIGHT ./ sum(sum(WEIGHT));
    wDL = 2.44*z*wavelength/(3*w);
    WEIGHT = exp(-1 * ((rr./wf).^4)) + 0.1 + (exp(-1*((rr/(wDL/4)).^2)));
    WEIGHT = WEIGHT - min(WEIGHT(:));
    WEIGHT = WEIGHT + 0.1;
    WEIGHT = WEIGHT.*0 + 1.0;

    If = If ./ sum(If(:)); %conserve power
    Ii = Ii ./ sum(Ii(:)); %conserve power
    Pi = sum(Ii(:))
    Pf = sum(If(:))

    Itarget = If;

    [EffIdeal] = p.FresnelPropagate(z,apDM.*sqrt(Ii).*p.QPF(nxy,dxy,z,wavelength),dxy,wavelength);
    IffIdeal = abs(EffIdeal).^2;

    nf([0.8 0.5]);
    subplot(1,3,1); imagesc(Ii); axis image; title('Initial Irradiance');
    subplot(1,3,2); imagesc(If); axis image; title('Final Irradiance');
    subplot(1,3,3); imagesc(IffIdeal); axis image; title('Ideal Far-Field (flat phase)');
    drawnow;
    if (ppt) ToPPT2(); end;

    %% Shape the beam
    for dseed = dseedVec;
        randn('seed',dseed+seed0);
        %cmds = zeros(Nact,1);
        vec = zeros(Nact,1);
        dvec = stepSF .* randn(Nact,1); %note: max stroke at 1.0 is 4 microns or 8 microns typically
        close all;
        nf([0.8 0.8]);
        best = vec;
        showBest = 0;
        showNextBest = 0;
        cmdmax = 1e3;
        clear error;
        for iter = 1:itermax;

            %convert search vector to commands
            cmds = vec; % S * vec;

            %     % limit PV of commands
            %     cmds(cmds>cmdmax)=cmdmax;
            %     cmds(cmds<-1*cmdmax)=-1*cmdmax;
            %
            %     % calculate IA stroke
            %     for k=1:Npairs;
            %         IAcmd(k) = cmds(pairs(k,1))-cmds(pairs(k,2));
            %     end;

            % calculate phase as weighted sum of IFs
            phs = reshape(Ptotal * cmds, nxy,nxy);

            % propagate to the far-field
            E = apDM .* sqrt(Ii) .* exp(1j.*wavenumber.*phs);
            NaNCheck = sum(sum(isnan(E)));
            if (NaNCheck)
                error('Finding NaNs in the Field!');
            end;
            [Eout] = p.FresnelPropagate(z,E.*p.QPF(nxy,dxy,z,wavelength),dxy,wavelength,1);
            Iout = (abs(Eout).^2);
            dI = Iout - Itarget;
            if (iter==1)
                lasterr = -1;
            else
                lasterr = error(iter-1);
            end;
            error(iter) = sum(abs(WEIGHT(:).*dI(:)));

            %new best
            if (iter==1 || error(iter)==min(error))
                best = vec;
                disp(sprintf('New Best at %i',iter));
```


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```
            if (showNextBest==1) showBest=1; end;
        end;

        % calculate new command
        if (iter==1 || error(iter)<lasterr)
            % keep stepping
            %cmds = cmds + stepSize .* dcmds;
            vec = vec + stepSize .* dvec;
            %disp('  Keep Stepping');
        else
            %cmds = cmds - dcmds;
            %dcmds = 0.01 .* randn(Nact,1);
            if (abs(stepSize)<stepMin) %change direction and reset step size
                vec = vec - stepSize.*dvec;
                vec = best;
                stepSize = 1.0;
                dvec = stepSF .* randn(Nact,1);
                vec = vec + dvec;
                %disp('  Change Vector');
            else
                vec = vec - dvec;
                vec = best;
                stepSize = stepSize .* -0.5;
                vec = vec + stepSize.*dvec;
                %disp('  Change direction');
            end;
        end;

        if (iter>itermax-3) vec = best; end;

        % display results
        if (mod(iter,200)==0) showNextBest=1; end;
        if (showBest || (iter>itermax-3))
            clf;
            subplot(2,3,1); semilogy(error); title('Search Error'); grid on; ax=axis; ax(3)=ax(3) - 0.2.*ax(3); axis(ax);
%show(x,x,abs(E));
            subplot(2,3,2); show(x,x,apDM.*phs,'xc'); title('Phase'); %hold on; plot(model.xact,model.yact,'k*'); %.*ap);
            subplot(2,3,3); %ShowDMPatch(model.xact,model.yact,dactDrawing,cmds);
            subplot(2,3,3); show(x,x,Ii); title('Initial Intensity');
            %subplot(2,3,4); show(x,x,Iout,'xc'); axis(2*wf.*[-2 2 -2 2]); hold on; plotCircle(2*wf,0,0,'w--'); title('Iout')
            subplot(2,3,4); show(x,x,Iout); hold on; plotCircle(2*wf,0,0,'w--'); title('Shaped Irradiance');
            axis(2*wf.*[-1 1 -1 1]);
            subplot(2,3,5); show(x,x,Itarget); axis(2*wf.*[-2 2 -2 2]); title('Target Irradiance');
            subplot(2,3,6); show(x,x,dI); axis(2*wf.*[-2 2 -2 2]); hold on; plotCircle(2*wf,0,0,'w--'); title('Delta
Irradiance');
            drawnow;
            showNextBest=0;
            showBest=0;
        end;

    end; %iteration
    if (ppt)
        ToPPT2();
        colormap(gray);
        ToPPT2();
        close;
    end;
    if (sav)
        save(sprintf('AnnularShapes%i_%i.mat',shapeIndex,dseed));
    end;
  end;
end;
```


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