Simulating light propagation

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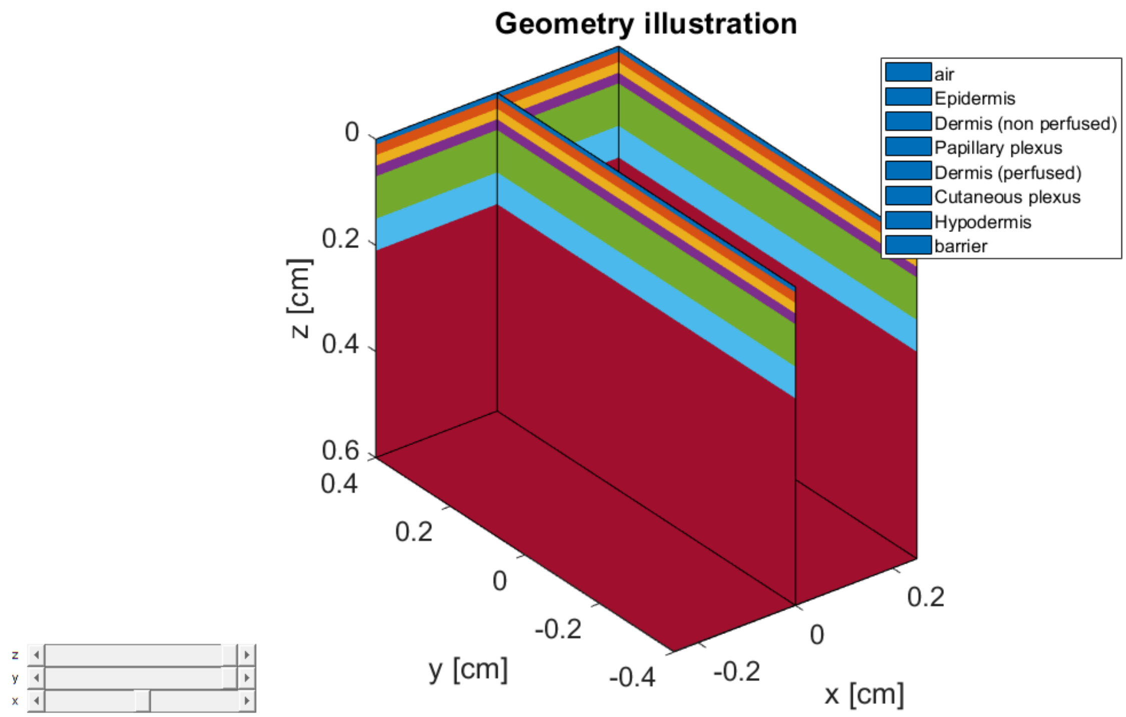
This code was developed by Miodrag Bolic for the book PERVASIVE CARDIAC AND RESPIRATORY MONITORING DEVICES: https://github.com/Health-Devices/CARDIAC-RESPIRATORY-MONITORING

Acknoledgement: the author would like to thank the developers of MCMatlab software.

```
% Changing the path from main_folder to a particular chapter
main_path=fileparts(which('Main_Content.mlx'));
if ~isempty(main_path)
    %addpath(append(main_path,'/Chapter2'))
    cd (append(main_path,'/Chapter6/SimulatingLightPropagation'))
    addpath(append(main_path,'/Service'))
end
SAVE_FLAG=1; % saving the figures in a file
```

Simulating data collection for one PPG pulse

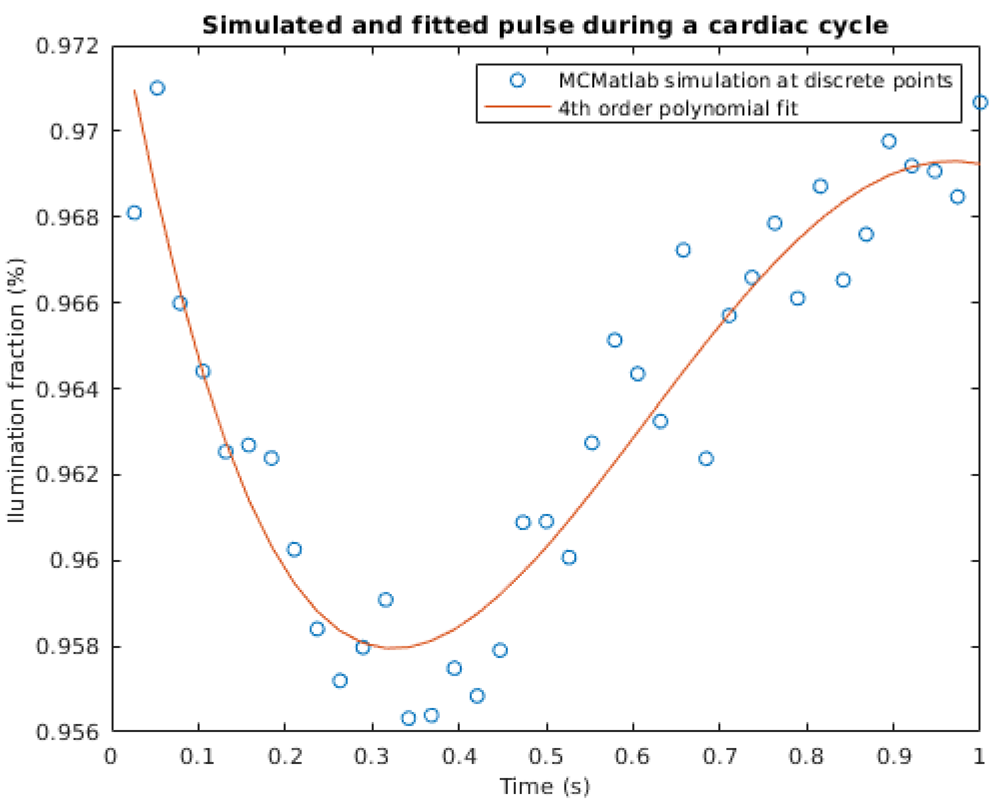
```
% Fig 7.10 Simulation
% The air gap of 0.01 mm
clear_all_but('SAVE_FLAG')
global zsurf;
zsurf=0.01;
Example4_BloodVessel_Pulse
```




```
for i=1:38;
    model = runMonteCarlo(model);

    %plotMCmatlab(model);
    if model.MC.LC.res > 1
        detFraction = 100*mean(mean(sum(model.MC.LC.image,3)))*model.MC.LC.fieldSize^2;
    else
        detFraction = 100*sum(model.MC.LC.image,3);
    end
    S(i)=detFraction;
end
save('SPulse_660_001_1.mat','S')
% Increasing the air gap to 0.2 mm
clear all
global zsurf;
zsurf=0.2;
Example4_BloodVessel_Pulse
for i=1:38;
    model = runMonteCarlo(model);

    %plotMCmatlab(model);
    if model.MC.LC.res > 1
        detFraction = 100*mean(mean(sum(model.MC.LC.image,3)))*model.MC.LC.fieldSize^2;
    else
        detFraction = 100*sum(model.MC.LC.image,3);
    end
    S(i)=detFraction;
end
save('SPulse_660_02_1.mat','S')
T=1/38;
t=T:T:length(S)*T;
```

```
figure
plot(t,S)
ylabel('Ilumination fraction (%)', 'FontSize', 10)
legend("660nm");
xlabel('Time (sec)', 'FontSize', 10)
```

```
% Fig 7.10 Plotting
%load("SPulse_660_02_1.mat")
load("SPulse_660_001_1.mat")
T=1/38;
t=T:T:length(S)*T;
[xData, yData] = prepareCurveData( t, S );
% Set up fittype and options.
ft = fittype( 'poly4' );
% Fit model to data.
[fitresult, gof] = fit( xData, yData, ft );

figure
plot(t,S,'o')
hold on
plot(t, fitresult(t) );
legend('MCMatlab simulation at discrete points','4th order polynomial fit')
ylabel('Ilumination fraction (%)', 'FontSize', 10)
xlabel('Time (s)', 'FontSize', 10)
title('Simulated and fitted pulse during a cardiac cycle')
annonation_save('',"Fig6.10.jpg", SAVE_FLAG);
```



```
disp('Percentage of the AC component is:')
```

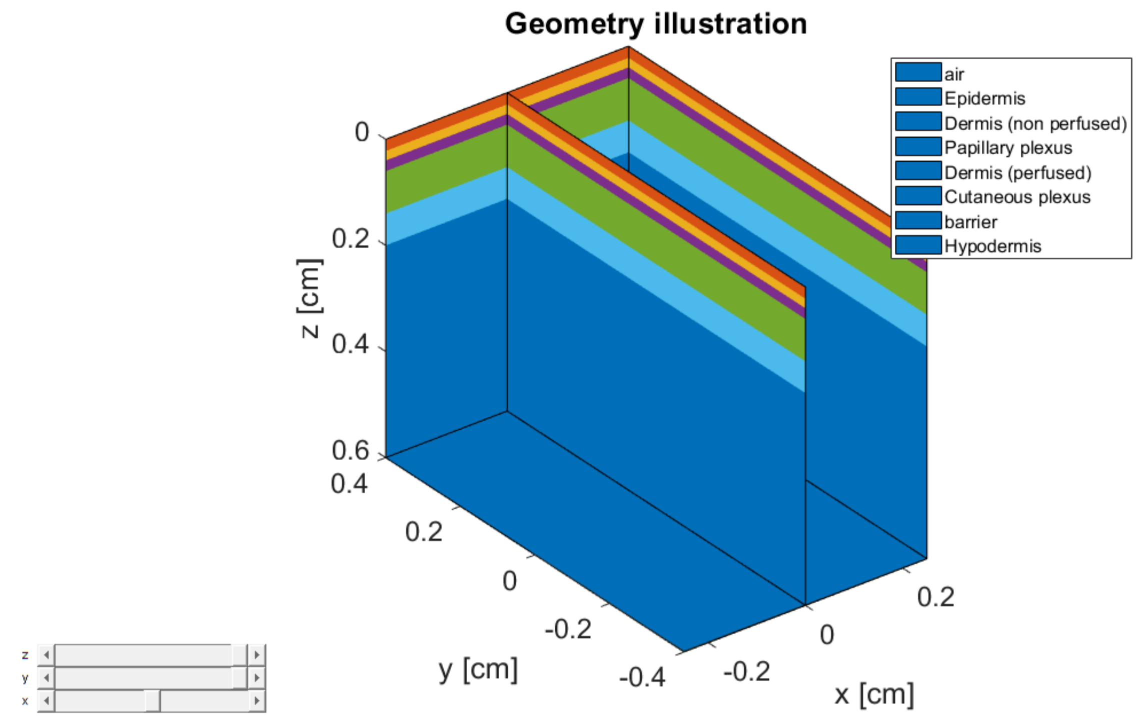
```
Percentage of the AC component is:
```

```
100*(max(fitresult(t))-min(fitresult(t)))/max(fitresult(t))
```

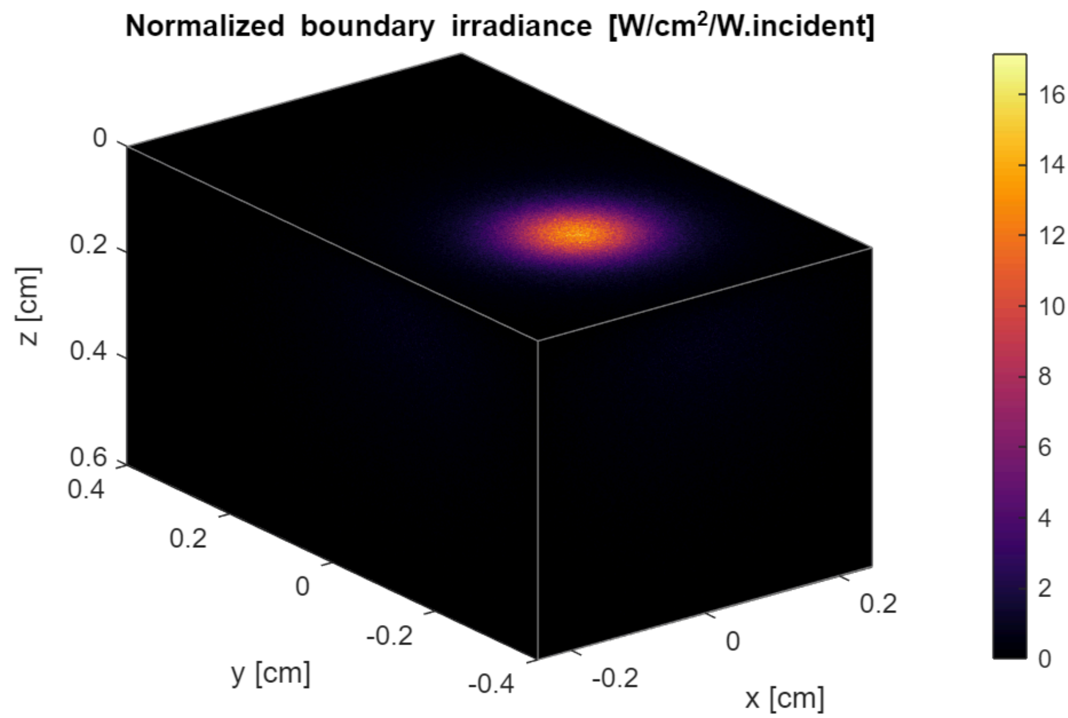
```
ans = 1.3402
```

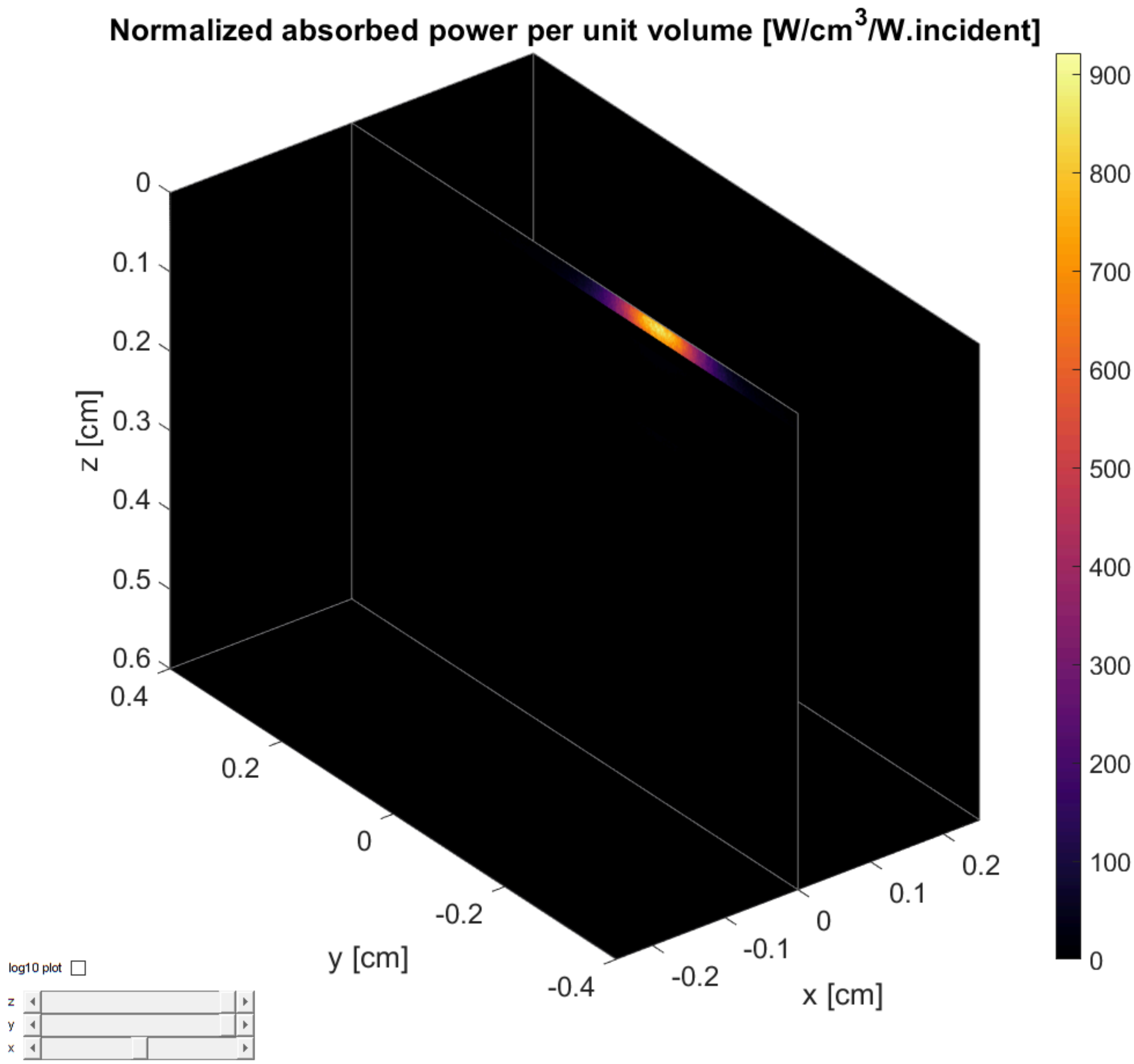
Simulation of the airgap at different frequencies

```
% Fig 7.7 simulation
clear all
global zsurf;
global wave_l;
global B_Cutaneous;
B=[0.2037, 0.2454];
wavelen=[660, 940];
depth=[0.001, 0.01, 0.2, 0.3]; % 0.4 is too much

for j=1:2
for k=1:2
    for i=1:4;
    zsurf=depth(i);
    wave_l=wavelen(j);
    B_Cutaneous=B(k);
    clear_all_but('zsurf','wave_l','B_Cutaneous', 'i', 'j', 'k', 'S','depth','wavelen',
    Example4_BloodVessel_changeS_barrier1

    model = runMonteCarlo(model);

    plotMCmatlab(model);
    if model.MC.LC.res > 1
        detFraction = 100*mean(mean(sum(model.MC.LC.image,3)))*model.MC.LC.fieldSize^2;
    else
        detFraction = 100*sum(model.MC.LC.image,3);
    end
    S(j,k,i)=detFraction;
end
end
end
```

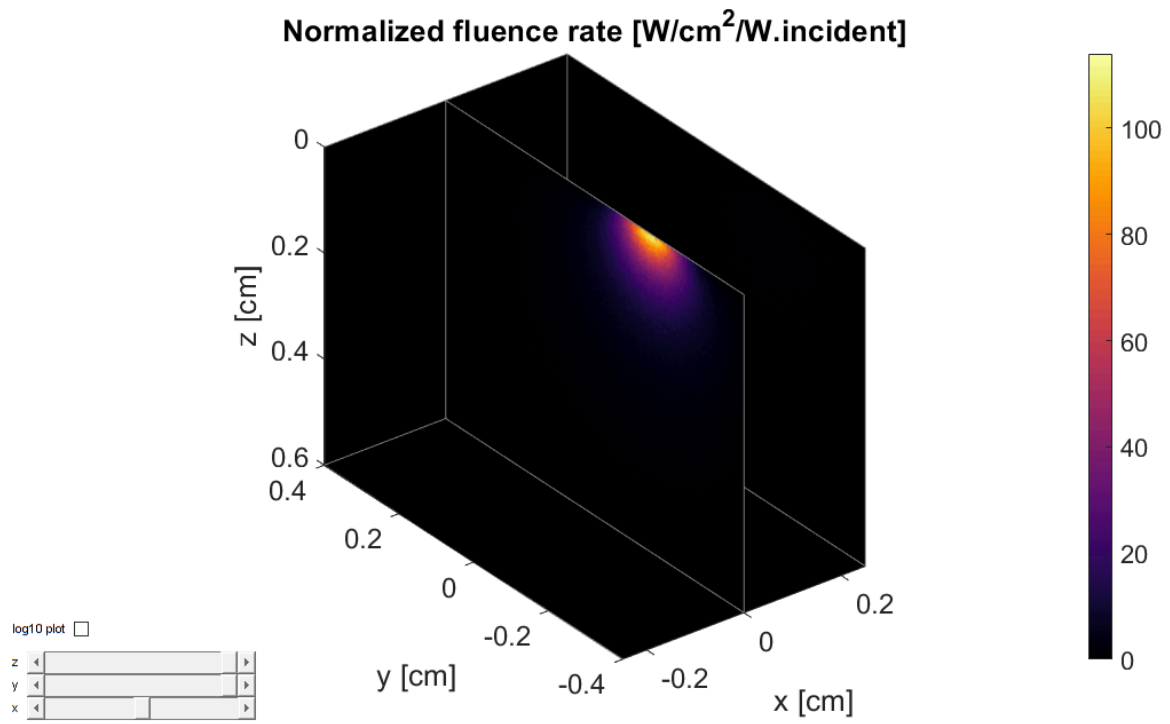



```
-----------------Monte Carlo Simulation-----------------
Simulation duration = 1.000 min
Calculating... 100% done
Simulated 2.04e+06 photons at a rate of 2.04e+06 photons per minute
----------------------plotMCmatlab----------------------
55.1% of incident light hits the cuboid boundaries.
```

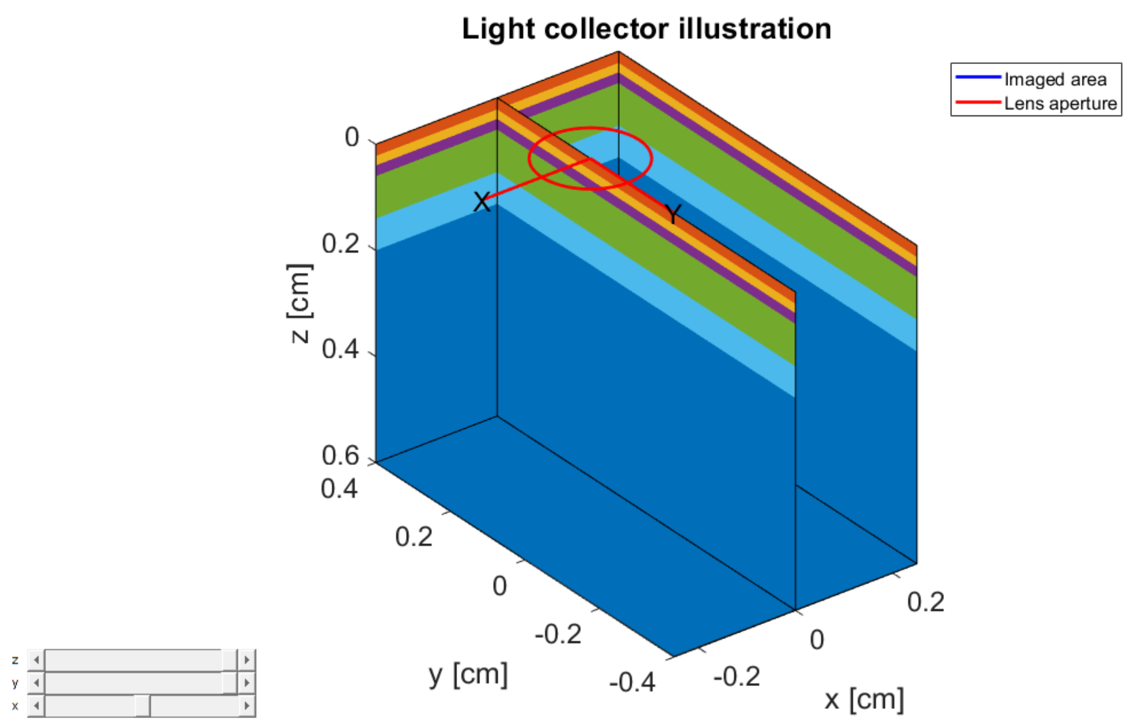




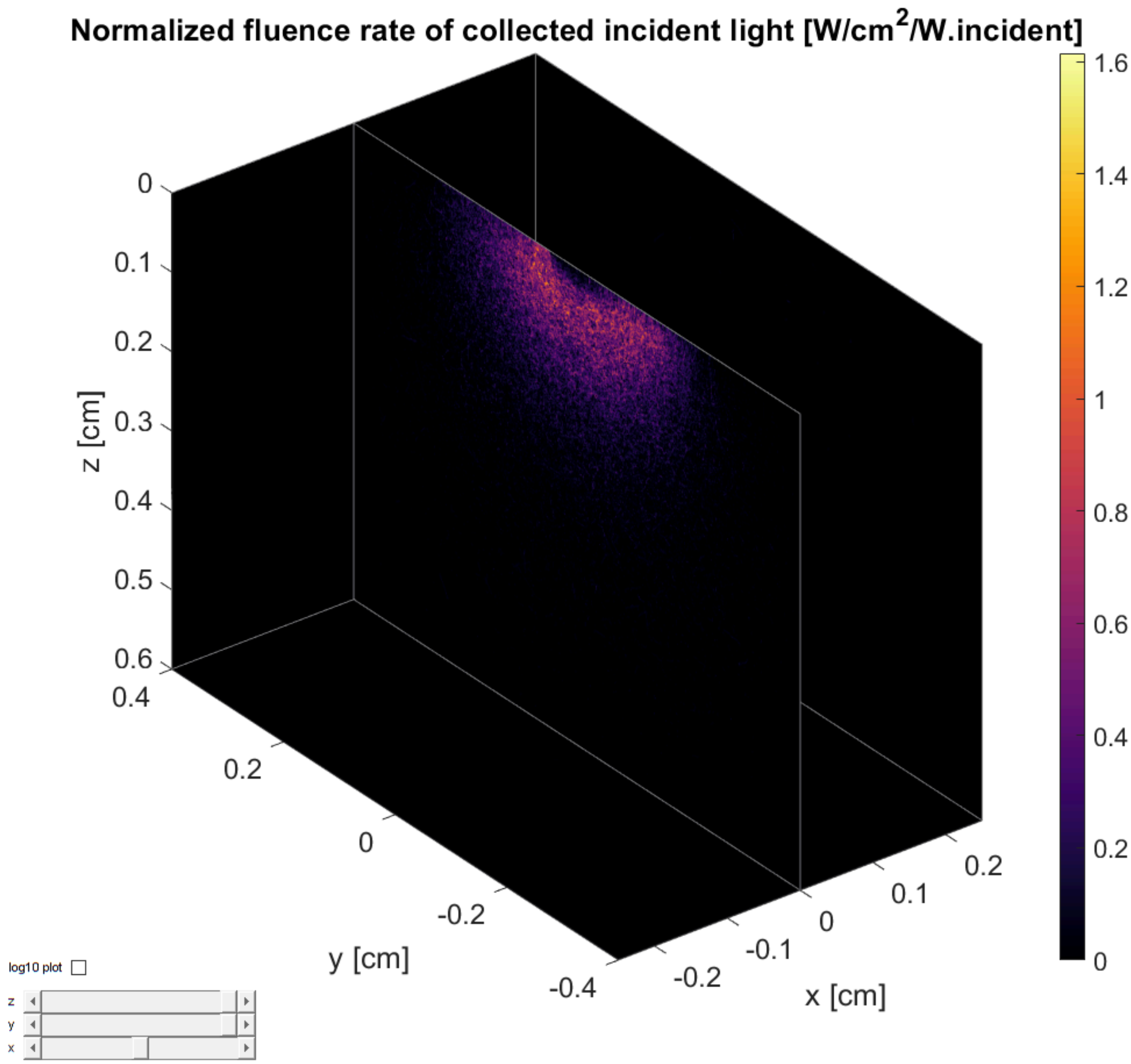
Normalized absorbed power per unit volume [W/cm^3/W.incident]
z [cm]
0
0.1
0.2
0.3
0.4
0.5
0.6
y [cm]
0.4
0.2
0
-0.2
-0.4
x [cm]
-0.2
-0.1
0
0.1
0.2
900
800
700
600
500
400
300
200
100
0
log10 plot
z
y
x

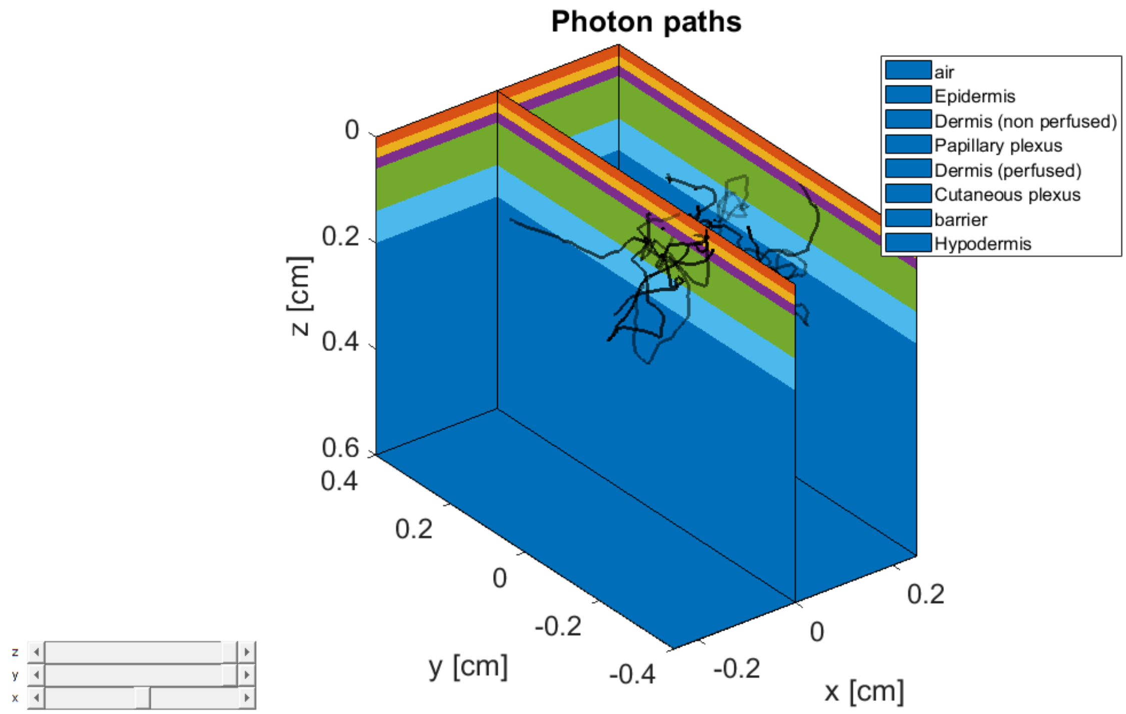


44.9% of incident light was absorbed within the cuboid.



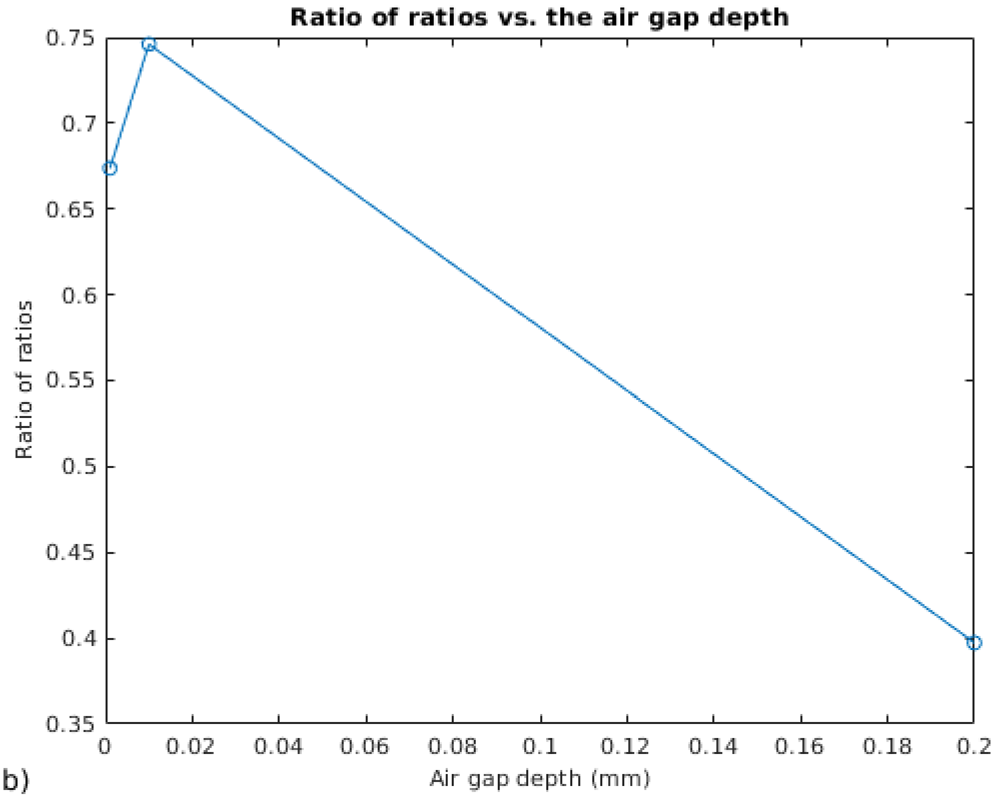
0.449% of incident light ends up on the detector.


Normalized fluence rate of collected incident light [W/cm2/W.incident]
z [cm]
0
0.1
0.2
0.3
0.4
0.5
0.6
y [cm]
0.4
0.2
0
-0.2
-0.4
x [cm]
-0.2
-0.1
0
0.1
0.2
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
log10 plot
z
y
x

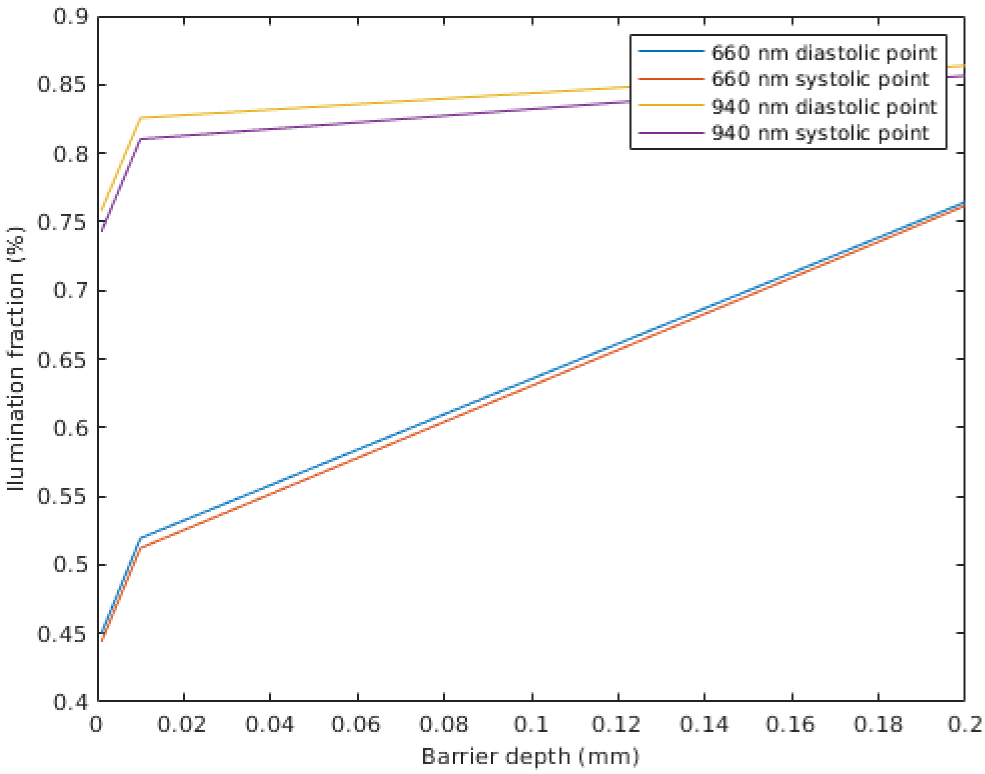



```
save('SBarrier1.mat','S')
```

```
% Fig 7.7 plotting
load('SBarrier1.mat')
depth=[0.001, 0.01, 0.2, 0.3]; % 0.4 is too much
figure
N=3;
Dia660=reshape(S(1,1,:),[4,1]);
Sys660=reshape(S(1,2,:),[4,1]);
Dia940=reshape(S(2,1,:),[4,1]);
Sys940=reshape(S(2,2,:),[4,1]);
plot(depth(1:N),Dia660(1:N))
hold on
plot(depth(1:N),Sys660(1:N))
plot(depth(1:N),Dia940(1:N))
plot(depth(1:N),Sys940(1:N))
legend('660 nm diastolic point','660 nm systolic point','940 nm diastolic point','940 n
ylabel('Ilumination fraction (%)', 'FontSize', 10)
xlabel('Barrier depth (mm)', 'FontSize', 10)

figure
plot(depth(1:N),((Dia660(1:N)-Sys660(1:N))./Dia660(1:N))./((Dia940(1:N)-Sys940(1:N))./D
ylabel('Ratio of ratios', 'FontSize', 10)
xlabel('Air gap depth (mm)', 'FontSize', 10)
title('Ratio of ratios vs. the air gap depth')
annonation_save('b)',"Fig6.7b.jpg", SAVE_FLAG);
```

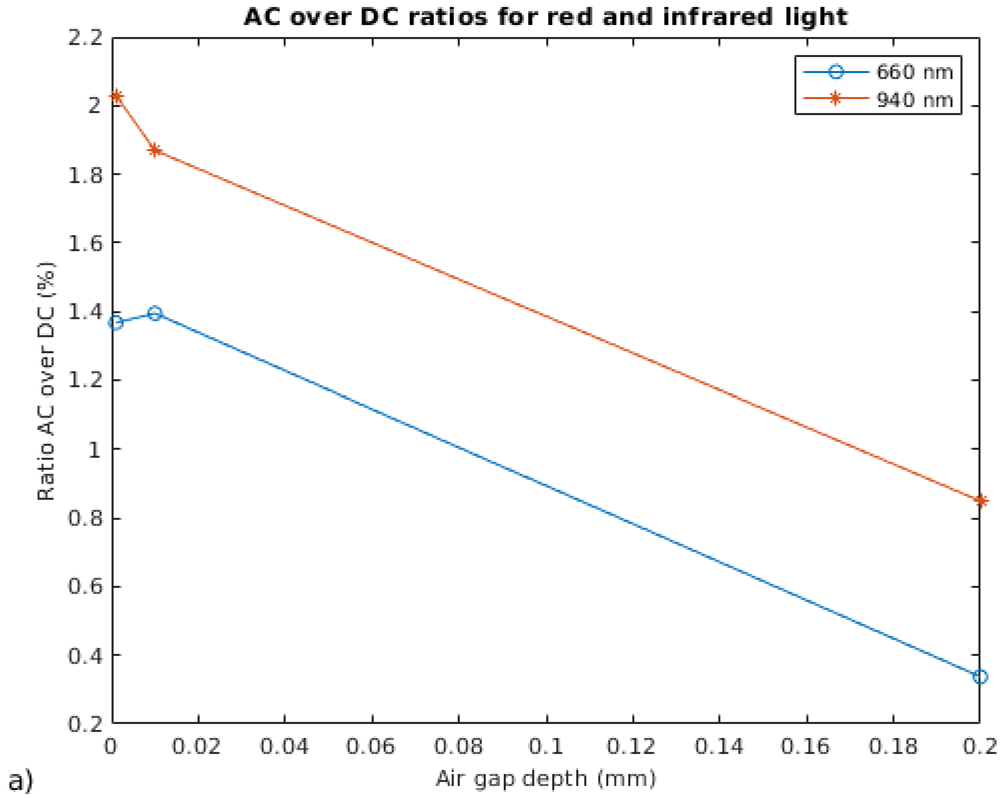


b)



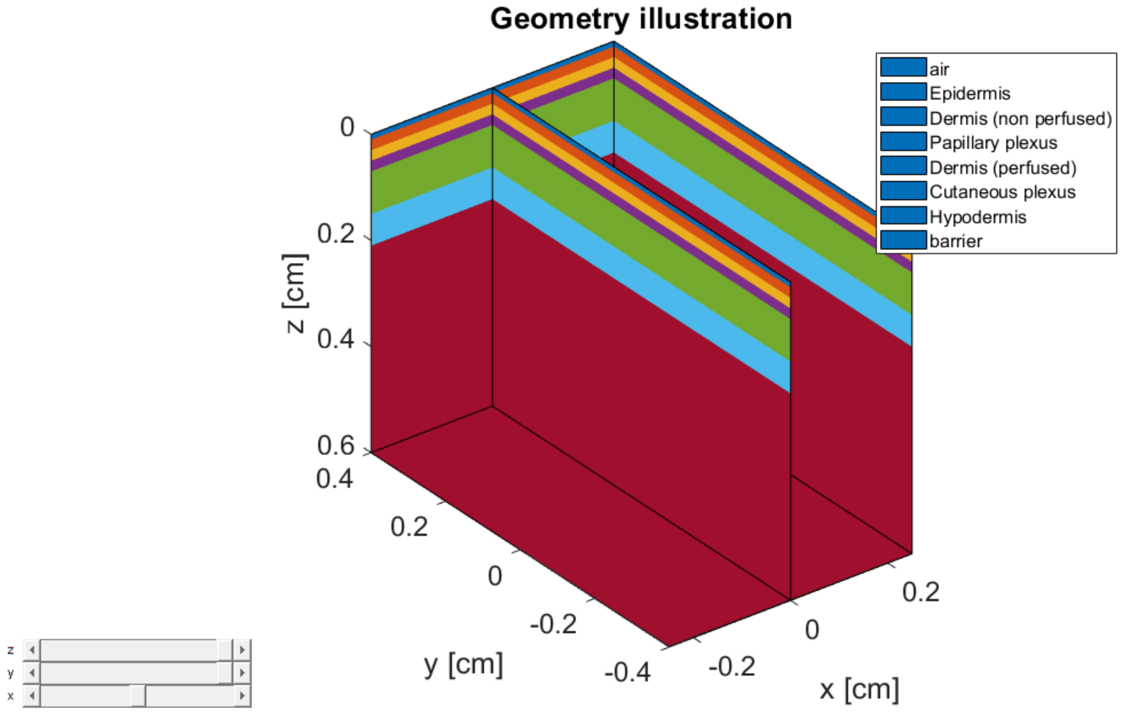

```
figure
plot(depth(1:N),100*((Dia660(1:N)-Sys660(1:N))./Dia660(1:N)),'o-')
```

```
hold on
plot(depth(1:N),100*((Dia940(1:N)-Sys940(1:N))./Dia940(1:N)),'*-')
legend('660 nm','940 nm')
ylabel('Ratio AC over DC (%)', 'FontSize', 10)
xlabel('Air gap depth (mm)', 'FontSize', 10)
title('AC over DC ratios for red and infrared light')
annonation_save('a)',"Fig6.7a.jpg", SAVE_FLAG);
```



Plotting the normalized absorbed power and normalized fluence rate of collected light

```
%Fig 7.3 and 7.8
clear_all_but('SAVE_FLAG')
global zsurf;
zsurf=0.01;
Example4_BloodVessel_Pulse
```

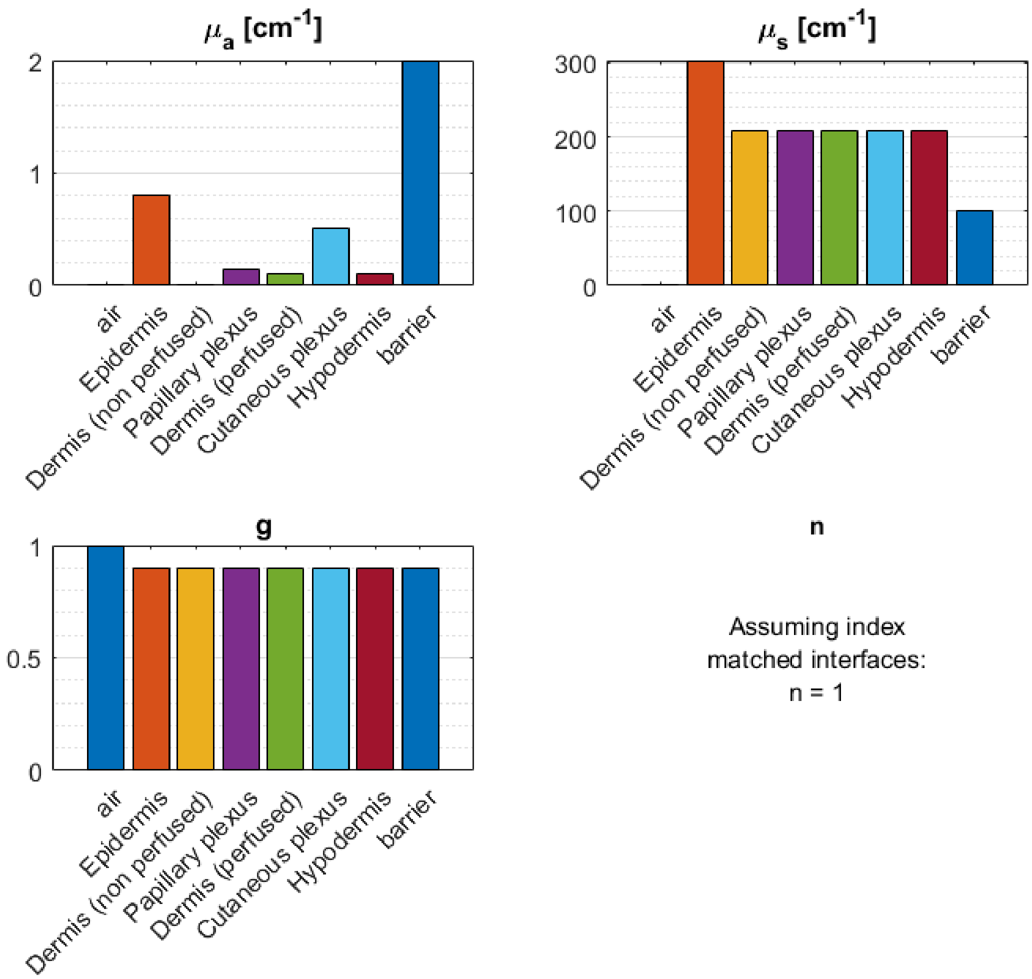



```
model = runMonteCarlo(model);
```

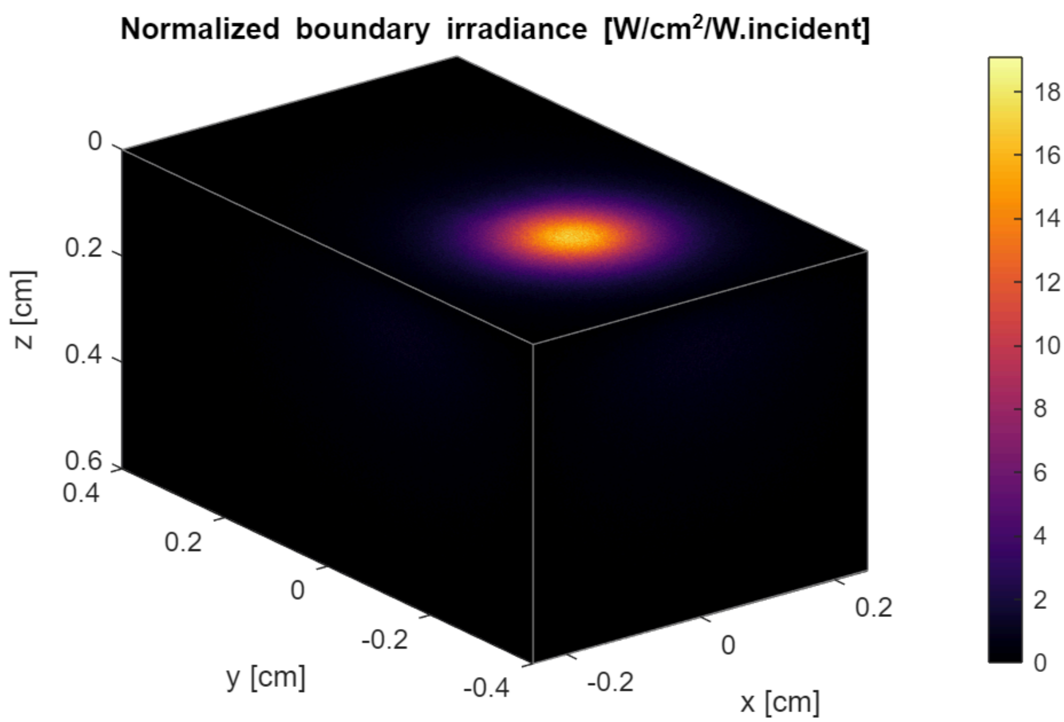
```
-----------------Monte Carlo Simulation-----------------
Simulation duration = 5.000 min
Calculating... 100% done
Simulated 1.04e+07 photons at a rate of 2.09e+06 photons per minute
```

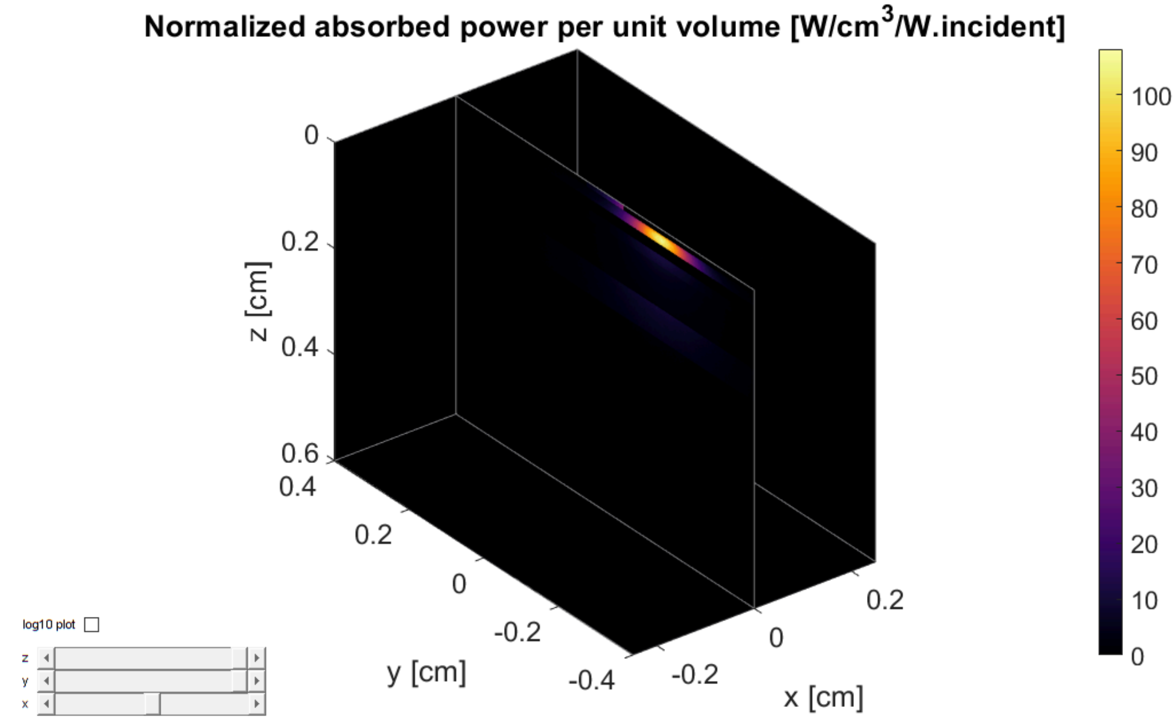
```
plotMCmatlab(model);
```

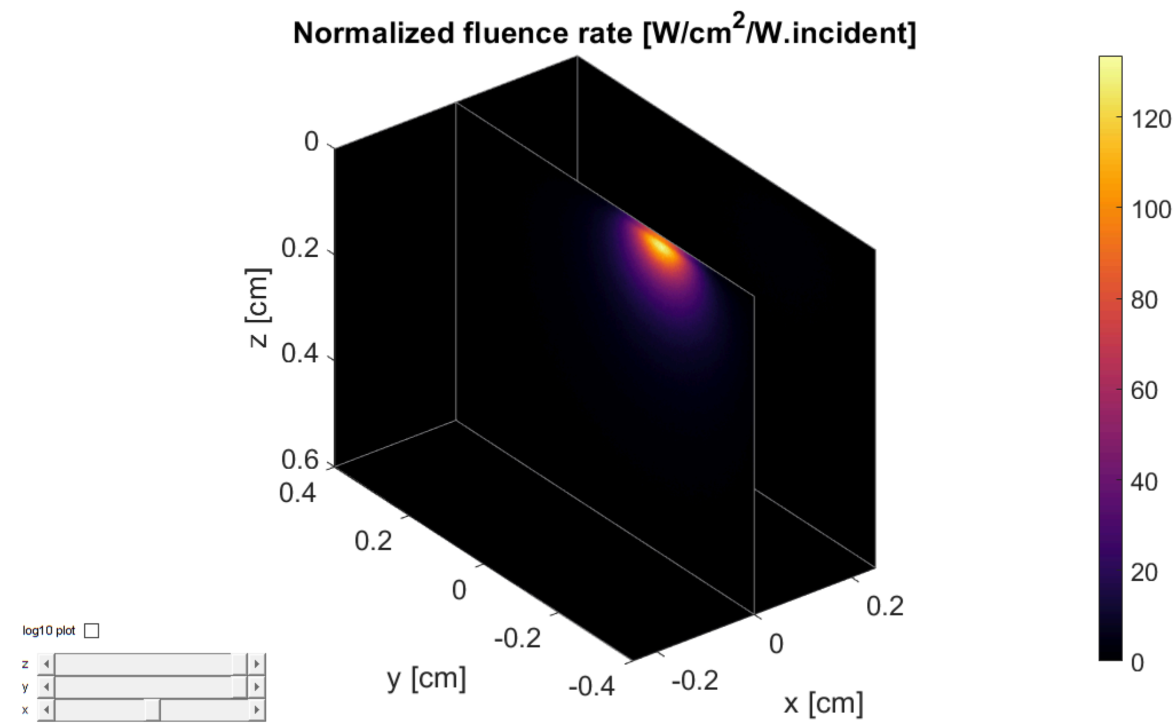
```
----------------------plotMCmatlab----------------------
```



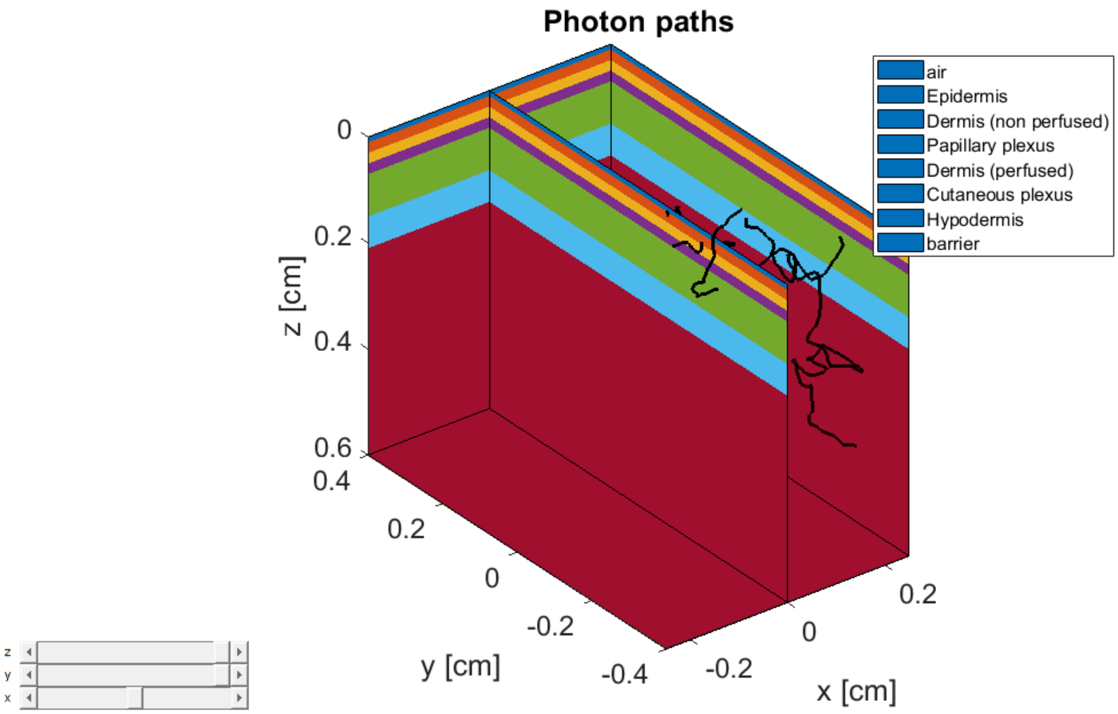
86.9% of incident light hits the cuboid boundaries.

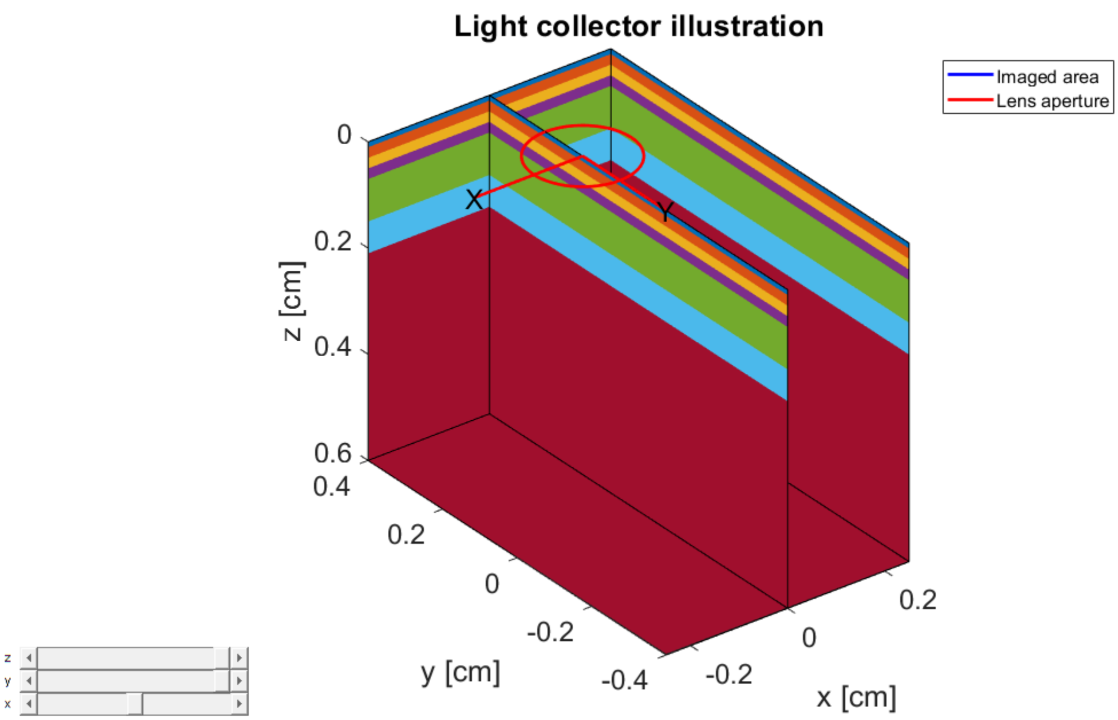




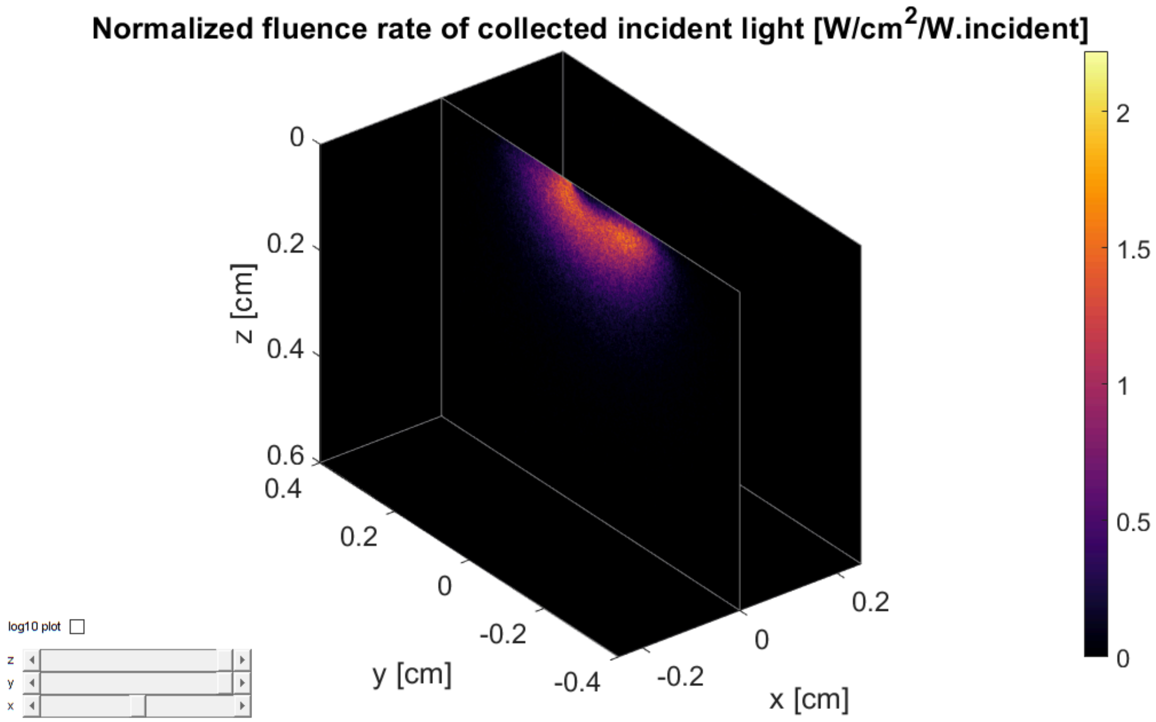


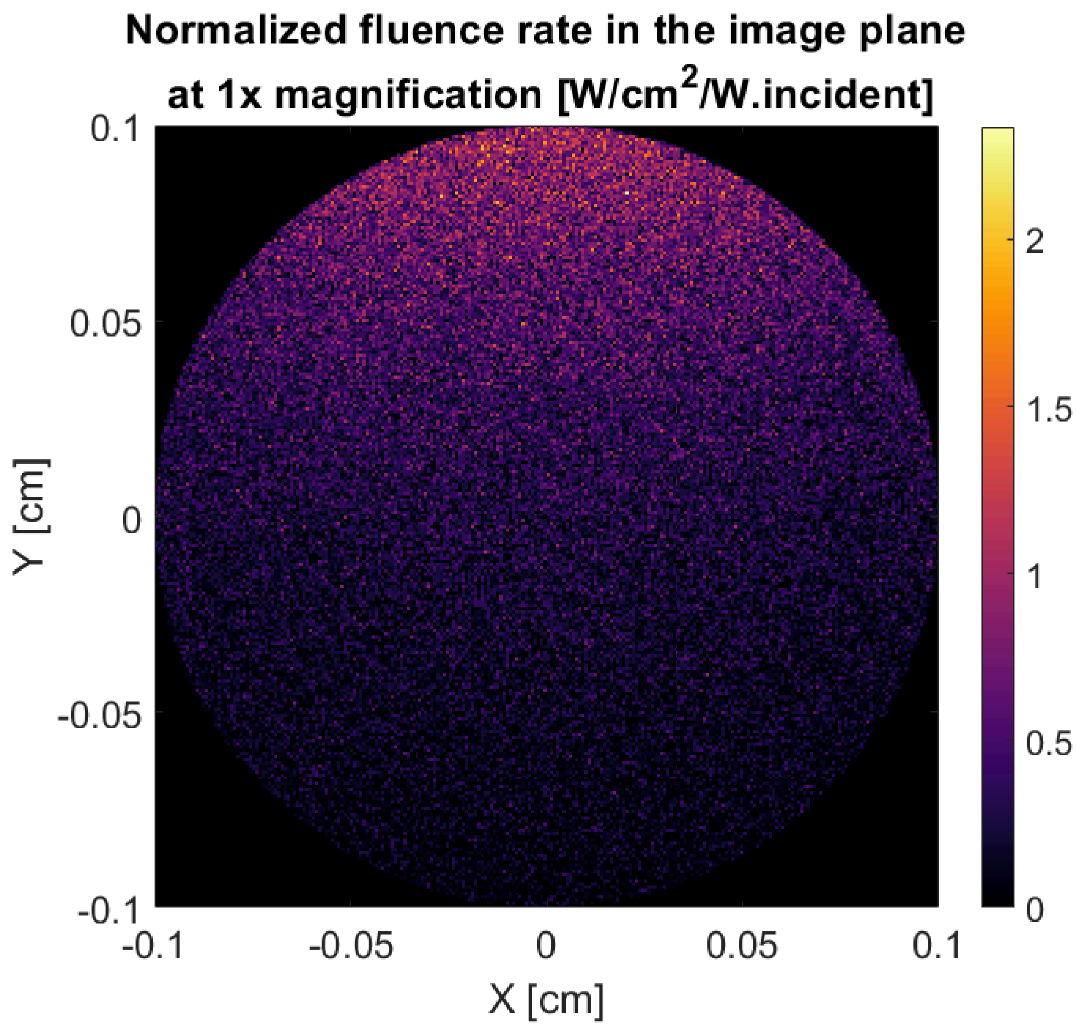

```
13.1% of incident light was absorbed within the cuboid.
```






```
0.974% of incident light ends up on the detector.
```






```
    if model.MC.LC.res > 1
```

```
        detFraction = 100*mean(mean(sum(model.MC.LC.image,3)))*model.MC.LC.fieldSize^2;
    else
        detFraction = 100*sum(model.MC.LC.image,3);
    end
    S(i)=detFraction;
```

```
Array indices must be positive integers or logical values.
```

Effects of air gap to the ratio of ratios

```
    % Fig 7.9 simulation
    clear all
global ii;
global wave_l;
global B_Cutaneous;
B=[0.2037, 0.2454];
wavelen=[660, 940];

for j=1:2
    for k=1:2
        clear_all_but('wave_l','B_Cutaneous', 'i1', 'j', 'k', 'S','B','wavelen','ii');
        wave_l=wavelen(j);
        B_Cutaneous=B(k);
        ii=0.45;
        Example4_BloodVessel_changeS_new1
        for i1=1:11;

            ii=0.45+0.05*i1;

            model = runMonteCarlo(model);

            %plotMCmatlab(model);
            if model.MC.LC.res > 1
                detFraction = 100*mean(mean(sum(model.MC.LC.image,3)))*model.MC.LC.fiel
            else
                detFraction = 100*sum(model.MC.LC.image,3);
            end

            S(j,k,i1)=detFraction;
        end
    end
end
```

```
-----------------Monte Carlo Simulation------------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 2.40e+07 photons at a rate of 2.40e+06 photons per minute
-----------------Monte Carlo Simulation------------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 2.34e+07 photons at a rate of 2.34e+06 photons per minute
-----------------Monte Carlo Simulation------------------
Simulation duration = 10.000 min
Calculating... 100% done
```

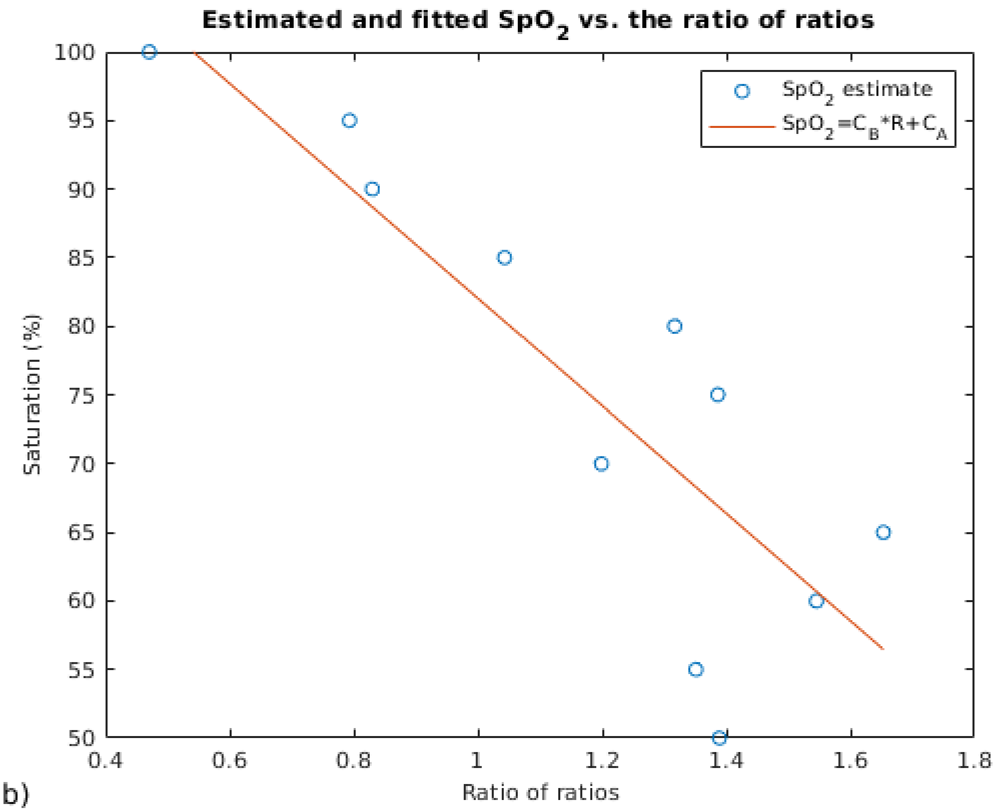
```
Simulated 2.46e+07 photons at a rate of 2.46e+06 photons per minute
-----------------Monte Carlo Simulation------------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 2.36e+07 photons at a rate of 2.36e+06 photons per minute
-----------------Monte Carlo Simulation------------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 2.35e+07 photons at a rate of 2.35e+06 photons per minute
-----------------Monte Carlo Simulation------------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 2.39e+07 photons at a rate of 2.39e+06 photons per minute
-----------------Monte Carlo Simulation------------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 2.59e+07 photons at a rate of 2.59e+06 photons per minute
-----------------Monte Carlo Simulation------------------
Simulation duration = 10.000 min
Calculating...  76% done
100% done
Simulated 2.48e+07 photons at a rate of 2.48e+06 photons per minute
-----------------Monte Carlo Simulation------------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 2.34e+07 photons at a rate of 2.34e+06 photons per minute
-----------------Monte Carlo Simulation------------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 2.32e+07 photons at a rate of 2.32e+06 photons per minute
-----------------Monte Carlo Simulation------------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 2.37e+07 photons at a rate of 2.37e+06 photons per minute
-----------------Monte Carlo Simulation------------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 2.77e+07 photons at a rate of 2.77e+06 photons per minute
-----------------Monte Carlo Simulation------------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 2.71e+07 photons at a rate of 2.71e+06 photons per minute
-----------------Monte Carlo Simulation------------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 2.66e+07 photons at a rate of 2.66e+06 photons per minute
-----------------Monte Carlo Simulation------------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 2.77e+07 photons at a rate of 2.77e+06 photons per minute
-----------------Monte Carlo Simulation------------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 2.67e+07 photons at a rate of 2.67e+06 photons per minute
-----------------Monte Carlo Simulation------------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 2.66e+07 photons at a rate of 2.66e+06 photons per minute
-----------------Monte Carlo Simulation------------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 2.78e+07 photons at a rate of 2.78e+06 photons per minute
-----------------Monte Carlo Simulation------------------
Simulation duration = 10.000 min
Calculating... 100% done
```

```
Simulated 2.70e+07 photons at a rate of 2.70e+06 photons per minute
-----------------Monte Carlo Simulation------------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 2.65e+07 photons at a rate of 2.65e+06 photons per minute
-----------------Monte Carlo Simulation------------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 2.77e+07 photons at a rate of 2.77e+06 photons per minute
-----------------Monte Carlo Simulation------------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 2.68e+07 photons at a rate of 2.68e+06 photons per minute
-----------------Monte Carlo Simulation------------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 3.19e+07 photons at a rate of 3.19e+06 photons per minute
-----------------Monte Carlo Simulation------------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 3.37e+07 photons at a rate of 3.37e+06 photons per minute
-----------------Monte Carlo Simulation------------------
Simulation duration = 10.000 min
Calculating...  91% done
 92% done
100% done
Simulated 3.22e+07 photons at a rate of 3.22e+06 photons per minute
-----------------Monte Carlo Simulation------------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 3.09e+07 photons at a rate of 3.08e+06 photons per minute
-----------------Monte Carlo Simulation------------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 3.05e+07 photons at a rate of 3.05e+06 photons per minute
-----------------Monte Carlo Simulation------------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 2.97e+07 photons at a rate of 2.97e+06 photons per minute
-----------------Monte Carlo Simulation------------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 3.29e+07 photons at a rate of 3.29e+06 photons per minute
-----------------Monte Carlo Simulation------------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 3.36e+07 photons at a rate of 3.36e+06 photons per minute
-----------------Monte Carlo Simulation------------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 3.26e+07 photons at a rate of 3.26e+06 photons per minute
-----------------Monte Carlo Simulation------------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 3.46e+07 photons at a rate of 3.46e+06 photons per minute
-----------------Monte Carlo Simulation------------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 3.35e+07 photons at a rate of 3.35e+06 photons per minute
-----------------Monte Carlo Simulation------------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 3.18e+07 photons at a rate of 3.18e+06 photons per minute
-----------------Monte Carlo Simulation------------------
Simulation duration = 10.000 min
```

```
Calculating... 100% done
Simulated 3.44e+07 photons at a rate of 3.44e+06 photons per minute
-----------------Monte Carlo Simulation-----------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 3.33e+07 photons at a rate of 3.33e+06 photons per minute
-----------------Monte Carlo Simulation-----------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 3.25e+07 photons at a rate of 3.25e+06 photons per minute
-----------------Monte Carlo Simulation-----------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 3.43e+07 photons at a rate of 3.43e+06 photons per minute
-----------------Monte Carlo Simulation-----------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 3.33e+07 photons at a rate of 3.33e+06 photons per minute
-----------------Monte Carlo Simulation-----------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 3.24e+07 photons at a rate of 3.24e+06 photons per minute
-----------------Monte Carlo Simulation-----------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 3.44e+07 photons at a rate of 3.44e+06 photons per minute
-----------------Monte Carlo Simulation-----------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 3.33e+07 photons at a rate of 3.33e+06 photons per minute
-----------------Monte Carlo Simulation-----------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 3.05e+07 photons at a rate of 3.05e+06 photons per minute
-----------------Monte Carlo Simulation-----------------
Simulation duration = 10.000 min
Calculating... 100% done
Simulated 3.42e+07 photons at a rate of 3.42e+06 photons per minute
```

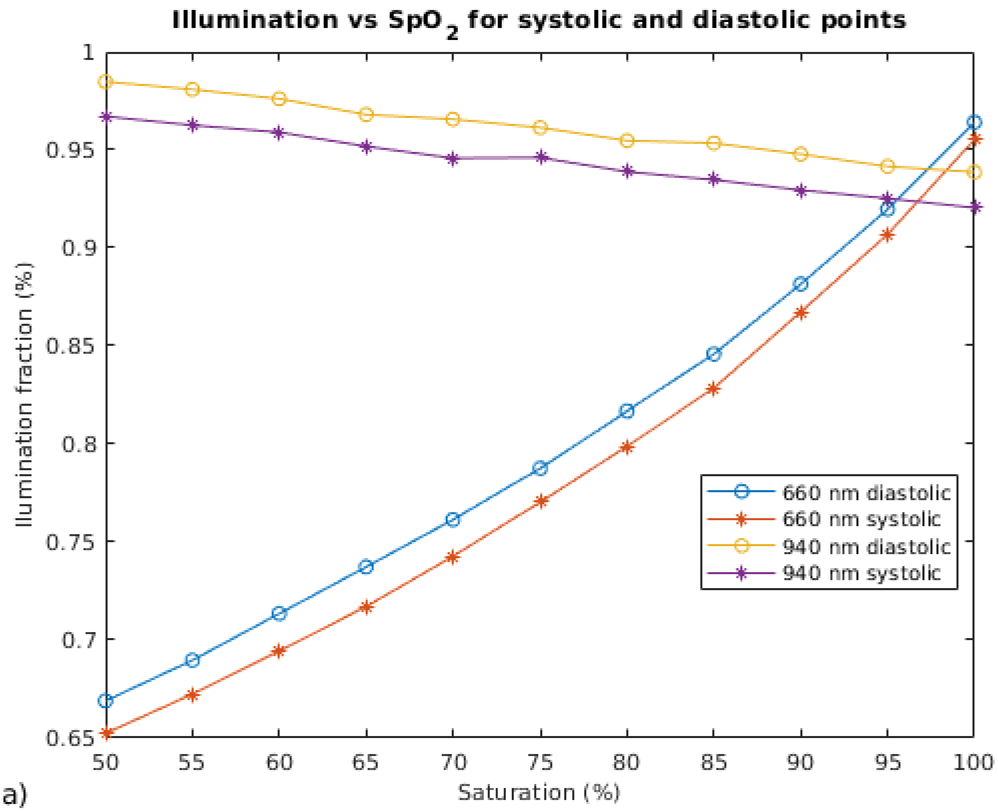
```
save('SChange.mat','S')
test=1;
```

```
% Fig 7.9 plotting
load('SChange.mat')
SpO2=50:5:100;
RatioOfRatios=((reshape(S(1,2,:),[11,1])-reshape(S(1,1,:),[11,1]))./reshape(S(1,2,:),[1
%% Fit: 'untitled fit 1'.
p = polyfit(RatioOfRatios',SpO2,1);
y1 = polyval(p,RatioOfRatios');
figure
plot(RatioOfRatios,SpO2,'o')
hold on
plot(RatioOfRatios,y1,'-')
xlabel('Ratio of ratios', 'FontSize', 10)
ylabel('Saturation (%)', 'FontSize', 10)
legend('SpO_2 estimate','SpO_2=C_B*R+C_A')
ylim([50,100])
title('Estimated and fitted SpO_2 vs. the ratio of ratios')
annonation_save('b)',"Fig6.9b.jpg", SAVE_FLAG);
```



b)

```
figure
plot(SpO2,reshape(S(1,1,:),[11,1]),'o-')
hold on
plot(SpO2,reshape(S(1,2,:),[11,1]),'*-')
plot(SpO2,reshape(S(2,1,:),[11,1]),'o-')
plot(SpO2,reshape(S(2,2,:),[11,1]),'*-')
legend('660 nm diastolic','660 nm systolic','940 nm diastolic','940 nm systolic',"Locat
ylabel('Ilumination fraction (%)', 'FontSize', 10)
xlabel('Saturation (%)', 'FontSize', 10)
title('Illumination vs SpO_2 for systolic and diastolic points')
annonation_save('a)',"Fig6.9a.jpg", SAVE_FLAG);
```


Illumination vs SpO 2 for systolic and diastolic points
Ilumination fraction (%)
Saturation (%)
660 nm diastolic
660 nm systolic
940 nm diastolic
940 nm systolic
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
50
55
60
65
70
75
80
85
90
95
100

a)