# q2-diffuse-Copy1

November 21, 2022

[3]:
```
import numpy as np
import cv2
import os
from mpl_toolkits.mplot3d import Axes3D
from src.cp_hw5 import *
from matplotlib import pyplot as plt
import skimage.color
```

```
/home/aramesh/anaconda3/envs/comp-photo/lib/python3.10/site-
packages/scipy/__init__.py:146: UserWarning: A NumPy version >=1.16.5 and
<1.23.0 is required for this version of SciPy (detected version 1.23.1
  warnings.warn(f"A NumPy version >={np_minversion} and <{np_maxversion}"
```

[4]:
```
# getting mean
# this is largely the same for all other objects barring dir1 for the others..
# basedir = './data-dump/mug/'
# dir_list = ['dir'+str(i)+'/' for i in range(1,9)]
# ims = ['capt0003.tiff', 'capt0005.tiff', 'capt0007.tiff']

# for dli in dir_list :
#     mean_img = np.zeros((4000,6000,3))
#     for imf in ims :
#         filename = basedir + dli + imf
#         im = cv2.imread(filename,-1)[8:-8,8:-8]
#         mean_img += im / len(ims)
#     mean_filename = filename.replace('.tiff','_mean.tiff')
#     cv2.imwrite(mean_filename, mean_img.astype('uint16'))

# basedir = './data-dump/mug/'
# outputdir = 'mug-means/'
# dir_list = ['dir'+str(i)+'/' for i in range(1,9)]
# ims = 'capt0007_mean.tiff'
# for dli in dir_list :
#     filename = basedir + dli + ims
#     im = cv2.imread(filename,-1)
#     outfile = basedir + outputdir + ims.replace('_mean.tiff','_'+str(dli[:
 ↪-1])+'_mean.tiff')
#     print(outfile)
#     cv2.imwrite(outfile, im.astype('uint16'))
```

[56]:
```
# I have previously done this assignment to a large extent in 16720A (Fall).
# Re-using a lot of code from my submission in this assignemnt.
# Code re-used has been thrown into this cell.

# def loadData(path = "./data-dump/plant/plant-means/"):
def loadData(path = "./data-dump/robot/robot-means/"):
# def loadData(path = "./data-dump/bottle-opener/bottle-opener-means/"):
# def loadData(path = "./data-dump/robot/robot-means/"):

    """
    Question 1 (c)

    Load data from the path given. The images are stored as input_n.tif
    for n = {1...7}. The source lighting directions are stored in
    sources.mat.

    Paramters
    ---------
    path: str
        Path of the data directory

    Returns
    -------
    I : numpy.ndarray
        The 7 x P matrix of vectorized images

    s: tuple
        Image shape

    """

    I = None
    s = None

    image_array = []

    for i in range(1,8) :
        image_name = path + 'capt0007_dir' + str(i) + '_mean.tiff'
        img_rgb = cv2.imread(image_name, -1).astype('uint16')[::8,::8,:]
#         img_rgb = img_rgb[:,550//2:980//2,:] # for plant
        img_rgb = img_rgb[190:380,225:390,:] # for robot and bottle opener
#         img_rgb = img_rgb[190:380,250:470,::-1] # for mug
#         img_rgb = cv2.cvtColor(img_bgr, cv2.COLOR_BGR2RGB)
        img_xyz = skimage.color.rgb2xyz(img_rgb)
        img_y = img_xyz[:,:,1].reshape((img_xyz.shape[0]*img_xyz.shape[1]))
```

```python
        image_array.append(img_y)

    I = np.array(image_array)

    s = img_xyz.shape

    return I, s

def estimatePseudonormalsCalibrated(I, L):

    """
    Question 1 (e)

    In calibrated photometric stereo, estimate pseudonormals from the
    light direction and image matrices

    Parameters
    ----------
    I : numpy.ndarray
        The 7 x P array of vectorized images

    L : numpy.ndarray
        The 3 x 7 array of lighting directions

    Returns
    -------
    B : numpy.ndarray
        The 3 x P matrix of pesudonormals
    """

    B = None

    B = np.linalg.pinv(L.T) @ I

    return B

def estimatePseudonormalsUncalibrated(I):

    """
    Question 2 (b)

    Estimate pseudonormals without the help of light source directions.

    Parameters
    ----------
    I : numpy.ndarray
        The 7 x P matrix of loaded images
    Returns
    -------
    B : numpy.ndarray
        The 3 x P matrix of pesudonormals

    """

    B = None
    L = None

    U, S, Vt = np.linalg.svd(I, full_matrices=False)

    S[3:] = 0

    I = U @ np.diag(S) @ Vt
    Vt_prime = np.diag(np.sqrt(S)) @ Vt
    U_prime = U @ np.diag(np.sqrt(S))
    B = Vt[:3]
    L = U[:3]
    B_prime = Vt_prime[:3]
    L_prime = U_prime[:3]
    return B, L, B_prime, L_prime

def estimateAlbedosNormals(B):

    '''
    Question 1 (e)

    From the estimated pseudonormals, estimate the albedos and normals

    Parameters
    ----------
    B : numpy.ndarray
        The 3 x P matrix of estimated pseudonormals

    Returns
    -------
    albedos : numpy.ndarray
        The vector of albedos

    normals : numpy.ndarray
        The 3 x P matrix of normals
    '''

    albedos = None
    normals = None
    albedos = np.linalg.norm(B, axis=0)
    normals = B / (albedos +1e-10)

    return albedos, normals

def displayAlbedosNormals(albedos, normals, s, title=''):

    """
    Question 1 (f)

    From the estimated pseudonormals, display the albedo and normal maps

    Please make sure to use the `coolwarm` colormap for the albedo image
    and the `rainbow` colormap for the normals.

    Parameters
    ----------
    albedos : numpy.ndarray
        The vector of albedos

    normals : numpy.ndarray
        The 3 x P matrix of normals

    s : tuple
        Image shape

    Returns
    -------
    albedoIm : numpy.ndarray
        Albedo image of shape s

    normalIm : numpy.ndarray
        Normals reshaped as an s x 3 image

    """

    albedoIm = None
    normalIm = None

    albedos = (albedos - np.min(albedos)) / (np.max(albedos) - np.min(albedos))
    normals = np.transpose((normals - np.min(normals)) / (np.max(normals) - np.
 ↪min(normals)))

    albedoIm = albedos.reshape((s[0], s[1]))
    normalIm = normals.reshape((s[0], s[1], 3))
    plt.imshow(albedoIm, cmap='coolwarm')
    plt.title(title)
    plt.show()

    plt.imshow(normalIm, cmap='rainbow')
    plt.title(title)
    plt.show()

    return albedoIm, normalIm

def enforceIntegrability(N, s, sig = 3):

    """
    Finds a transform Q that makes the normals integrable and transforms them
    by it.
    Parameters
    ----------
    N : numpy.ndarray
        The 3 x P matrix of (possibly) non-integrable normals
    s : tuple
        Image shape
    Returns
    -------
    Nt : numpy.ndarray
        The 3 x P matrix of transformed, integrable normals
    """

    from scipy.ndimage import gaussian_filter

    N1 = N[0, :].reshape(s)
    N2 = N[1, :].reshape(s)
    N3 = N[2, :].reshape(s)

    N1y, N1x = np.gradient(gaussian_filter(N1, sig), edge_order = 2)
    N2y, N2x = np.gradient(gaussian_filter(N2, sig), edge_order = 2)
    N3y, N3x = np.gradient(gaussian_filter(N3, sig), edge_order = 2)

    A1 = N1*N2x-N2*N1x
    A2 = N1*N3x-N3*N1x
    A3 = N2*N3x-N3*N2x
    A4 = N2*N1y-N1*N2y
    A5 = N3*N1y-N1*N3y
    A6 = N3*N2y-N2*N3y

    A = np.hstack((A1.reshape(-1, 1),
                   A2.reshape(-1, 1),
                   A3.reshape(-1, 1),
                    A4.reshape(-1, 1),
                    A5.reshape(-1, 1),
                    A6.reshape(-1, 1)))

    AtA = A.T.dot(A)
    W, V = np.linalg.eig(AtA)
    h = V[:, np.argmin(np.abs(W))]

    delta = np.asarray([[-h[2],  h[5], 1],
                          [ h[1], -h[4], 0],
                          [-h[0],  h[3], 0]])
    Nt = np.linalg.inv(delta).dot(N)

    return Nt

def estimateShape(normals, s, mode):

    """
    Question 1 (i)

    Integrate the estimated normals to get an estimate of the depth map
    of the surface.

    Parameters
    ----------
    normals : numpy.ndarray
        The 3 x P matrix of normals

    s : tuple
        Image shape

    Returns
    ----------
    surface: numpy.ndarray
        The image, of size s, of estimated depths at each point

    """

    surface = None

    f_x = np.reshape(normals[0, :]/(-normals[2, :] + 1e-10), s[:2])
    f_y = np.reshape(normals[1, :]/(-normals[2, :] + 1e-10), s[:2])

    if mode == 0 :
        surface = integrate_poisson(f_x, f_y)
        title = 'poisson intengration'
    elif mode == 1 :
        surface = integrate_frankot(f_x, f_y)
        title = 'frankot integration'
    else :
        print('mode should be 0 or 1')
        return 0

    surface = (surface - np.min(surface)) / (np.max(surface) - np.min(surface))

    plotSurface(surface, title)

    return surface


def plotSurface(surface, title=''):

    """
    Question 1 (i)

    Plot the depth map as a surface

    Parameters
    ----------
    surface : numpy.ndarray
        The depth map to be plotted

    Returns
    -------
        None

    """

    fig = plt.figure()
    ax = fig.add_subplot(111, projection='3d')
    X, Y = np.meshgrid(np.arange(surface.shape[0]), np.arange(surface.shape[1]))
    ax.plot_surface(X.T, Y.T, surface, cmap='coolwarm')
    plt.show()

import matplotlib.pyplot as plt
from matplotlib.colors import LightSource
from mpl_toolkits.mplot3d import Axes3D
def plot_surface_ls(Z, flip_z = False) :
    # Z is an HxW array of surface depths
    H, W = Z.shape
    x, y = np.meshgrid(np.arange(0,W), np.arange(0,H))
    # set 3D figure
    fig = plt.figure()
    ax = fig.gca(projection='3d')
    # add a light and shade to the axis for visual effect
    # (use the '-' sign since our Z-axis points down)
    ls = LightSource()

    if flip_z == True : Z = -Z

    color_shade = ls.shade(-Z, plt.cm.gray)
    # display a surface
    # (control surface resolution using rstride and cstride)
    surf = ax.plot_surface(x, y, -Z, facecolors=color_shade, rstride=4,␣
↪cstride=4)
    # turn off axis
    plt.axis('off')
    plt.show()
```

[57]:
```
I, s = loadData()
Be,Le, Be_prime, Le_prime = estimatePseudonormalsUncalibrated(I)
Be = Be_prime
```

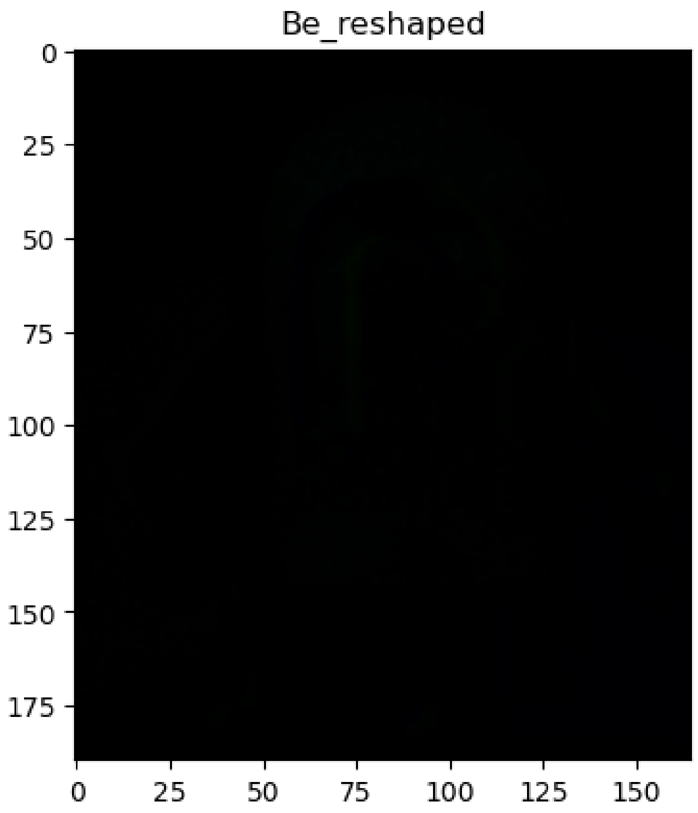
[58]:
```
Be.shape
```

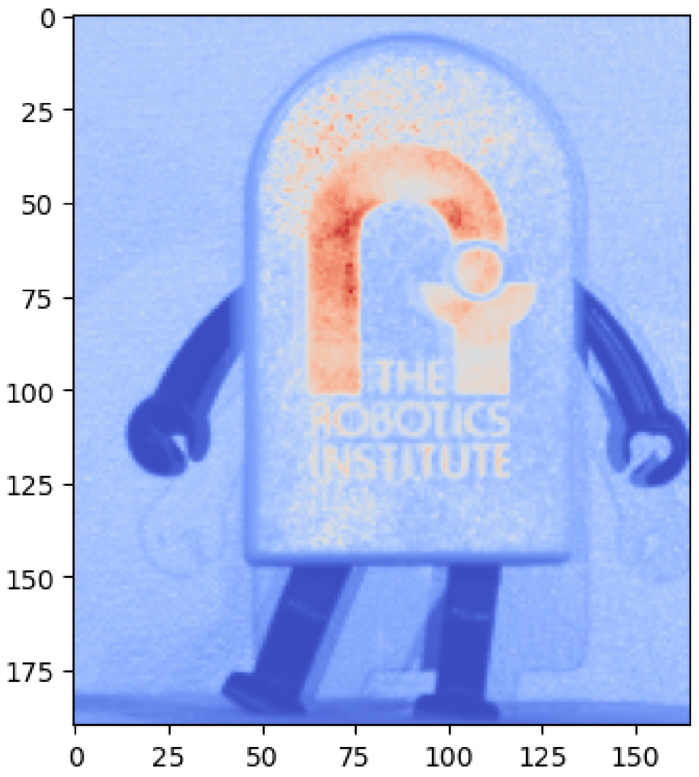
[58]:
```
(3, 31350)
```

[59]:
```
Be_reshaped = Be.T.reshape((s[0], s[1],3))
plt.figure()
plt.imshow(Be_reshaped)
plt.title('Be_reshaped')
plt.show()

albedos, normals = estimateAlbedosNormals(Be)
albedoIm, normalIM = displayAlbedosNormals(albedos, normals,s)

# generate random invertible matrix
randmat = np.random.rand(3,3)
eps = 0.00000001
Q = np.eye(3) * eps + randmat@randmat.T
Q_inv = np.linalg.inv(Q)

LQ = Q @ Le
BQ = Q_inv.T @ Be

albedosQ, normalsQ = estimateAlbedosNormals(BQ)
_, _ = displayAlbedosNormals(albedosQ, normalsQ,s, 'From randomly generated BQ')

# enforcing integratability on Be
Be_enf_int = enforceIntegrability(Be, s[:2])
albedos_enf_int, normals_enf_int = estimateAlbedosNormals(Be_enf_int)
```

```
albedoIm_int_enf, normalIM_int_enf = displayAlbedosNormals(albedos_enf_int,␣
↪normals_enf_int, s, 'PseudoNormals integratability enforced')

# Applying GBR inversion transform
Gf = np.array([[1,0,0],[0,1,0],[0,0,-1]])
Be_enf_int = Gf @ Be_enf_int
albedos_enf_int, normals_enf_int = estimateAlbedosNormals(Be_enf_int)
albedoIm_int_enf, normalIM_int_enf = displayAlbedosNormals(albedos_enf_int,␣
↪normals_enf_int, s, 'PseudoNormals integratability enforced after inversion␣
↪of direction')

# normals_enf_int_n = enforceIntegrability(normals, s[:2])
# _ , normalIM_int_enf_n = displayAlbedosNormals(albedos, normals_enf_int_n, s,␣
↪'Normals integratability enforced')
```

```
Clipping input data to the valid range for imshow with RGB data ([0..1] for
floats or [0..255] for integers).
```





0
25
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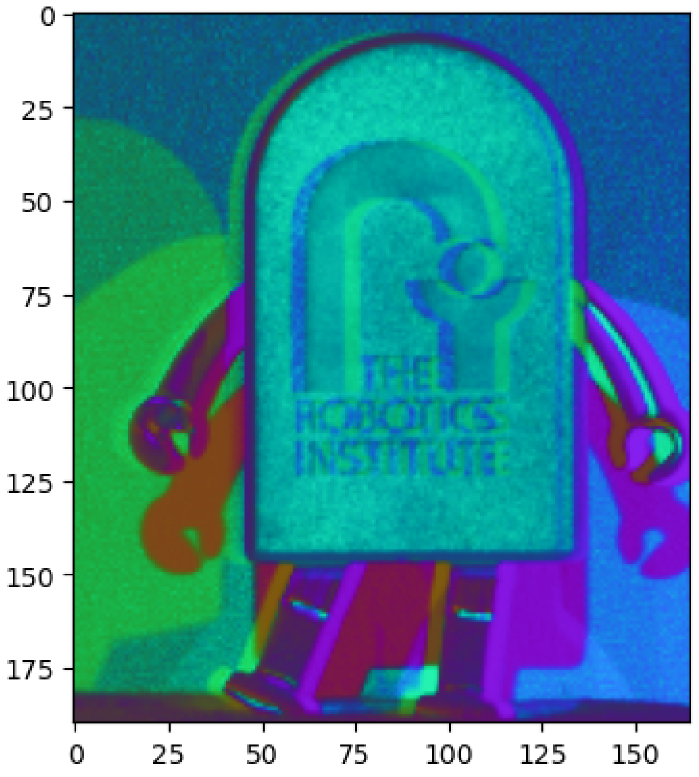
THE
ROBOTICS
INSTITUTE



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THE
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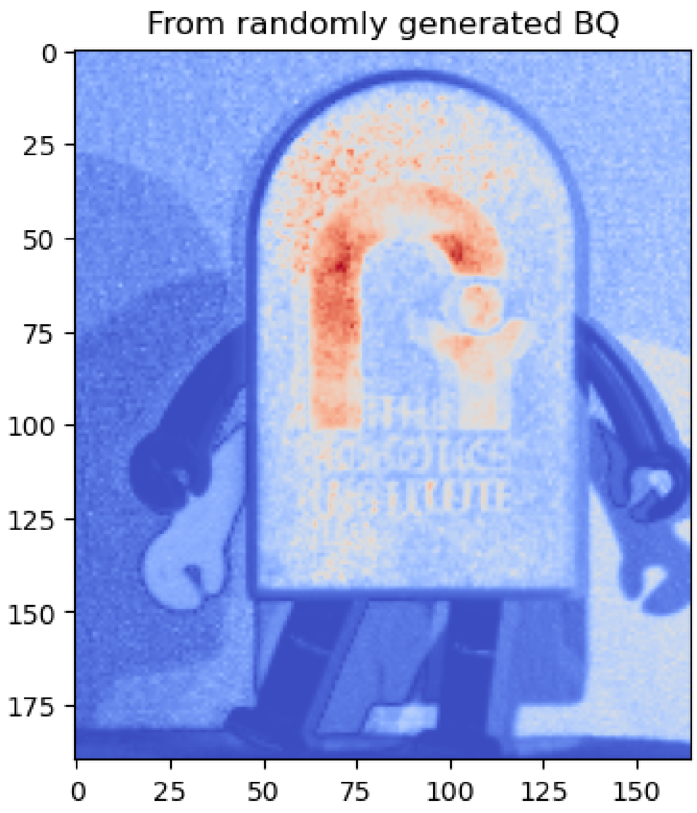
From randomly generated BQ
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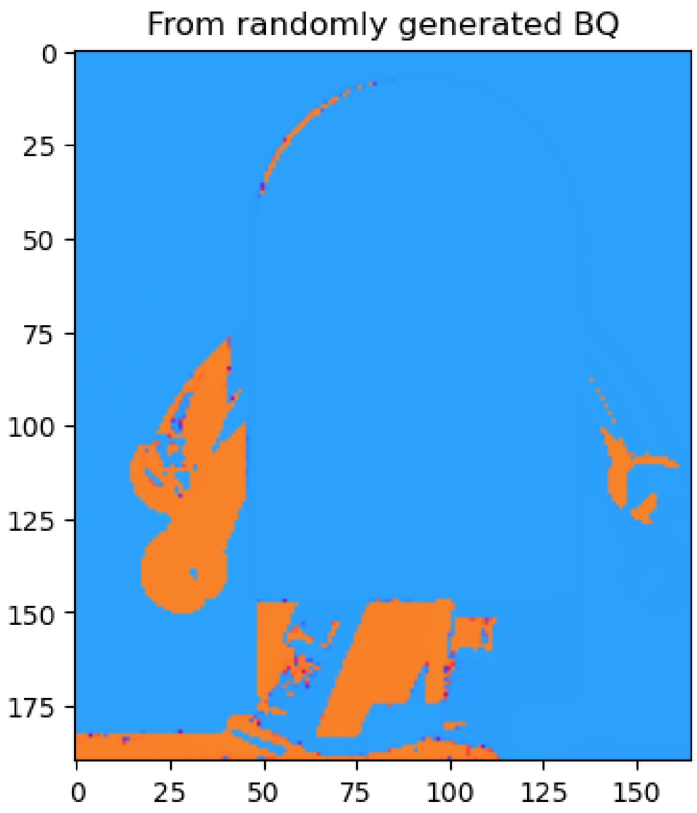
From randomly generated BQ
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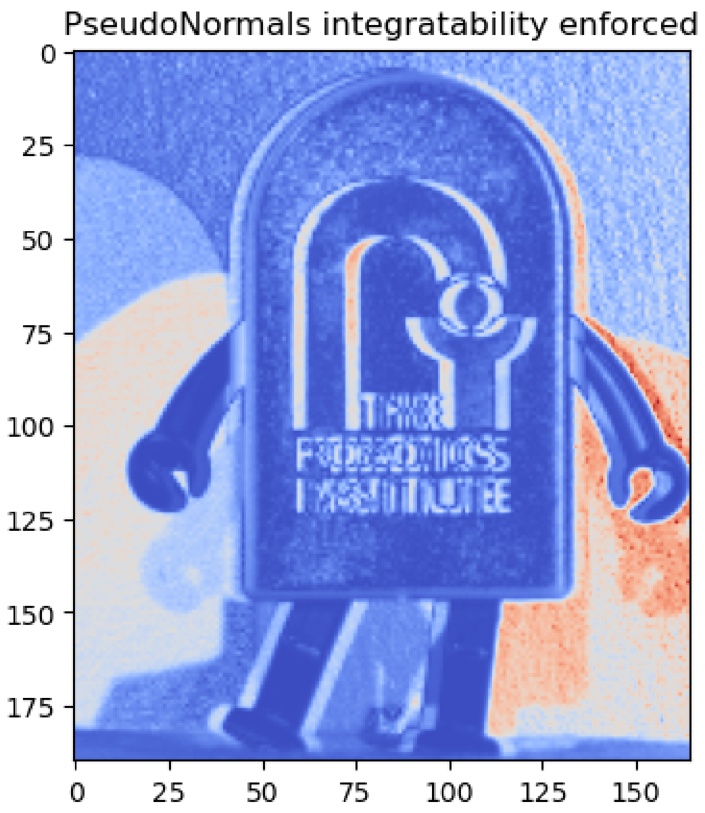
PseudoNormals integratability enforced
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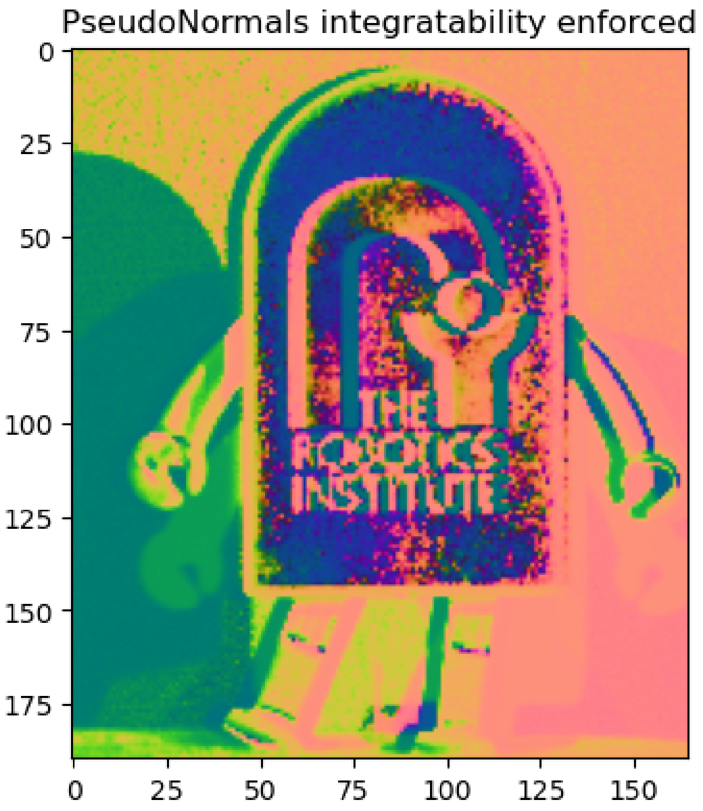
PseudoNormals integratability enforced
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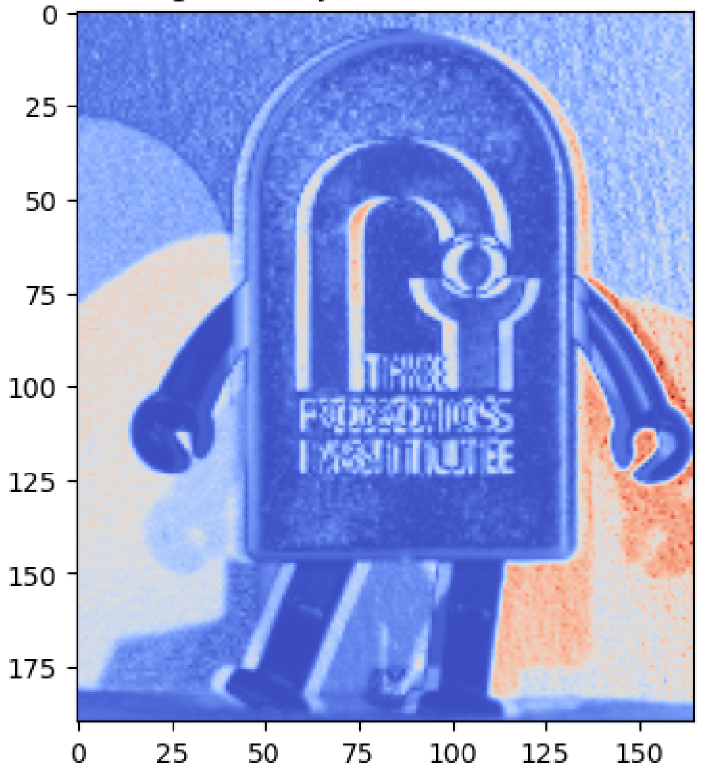
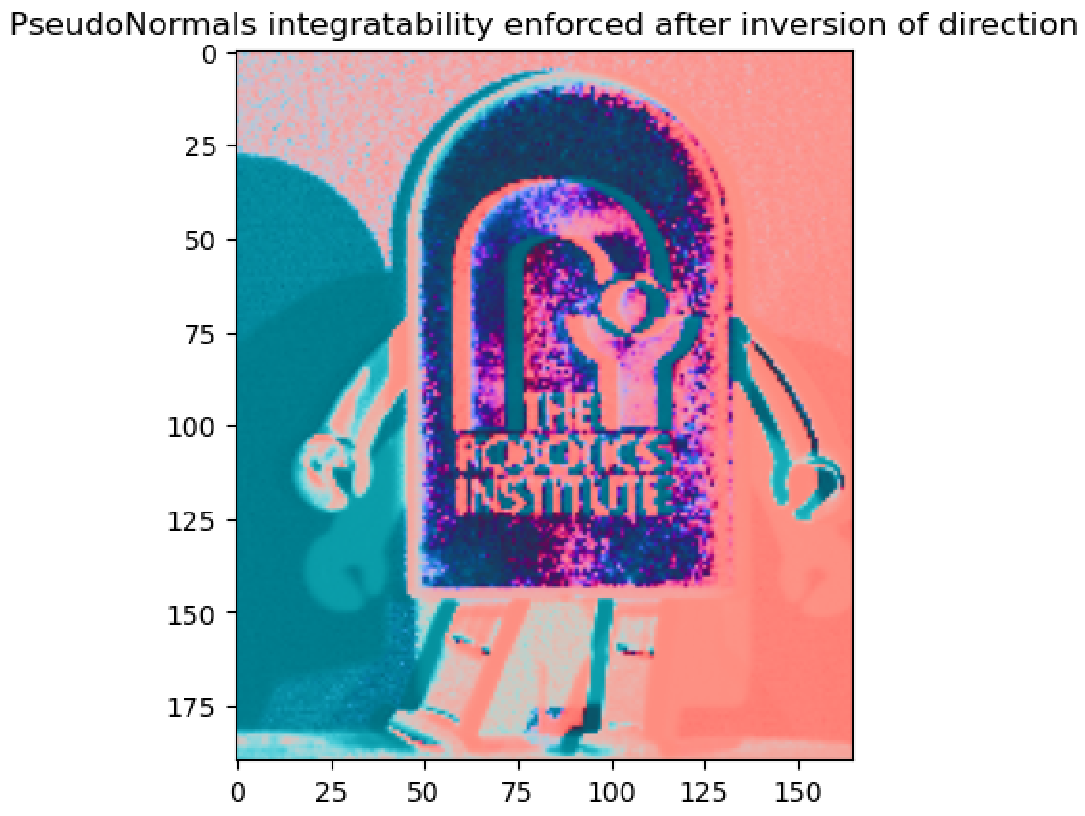
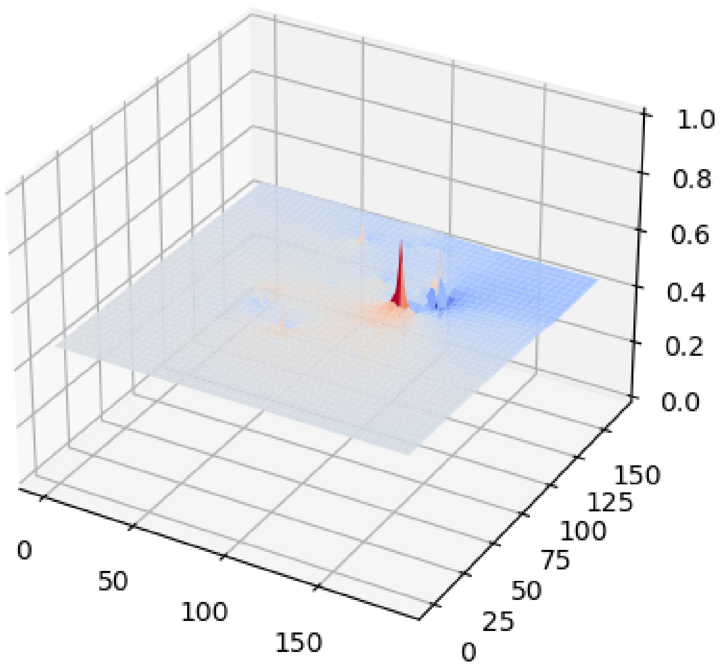
PseudoNormals integratability enforced after inversion of direction





[60]:
```
# Normal Integration
surface_poisson = estimateShape(normals_enf_int, s, 0)
plt.imshow(surface_poisson)
plt.show()
plot_surface_ls(surface_poisson)
plt.show()

surface_frankot = estimateShape(normals_enf_int, s, 1)
plt.imshow(surface_frankot)
plt.show()
plot_surface_ls(surface_frankot)
plt.show()
```


1.0
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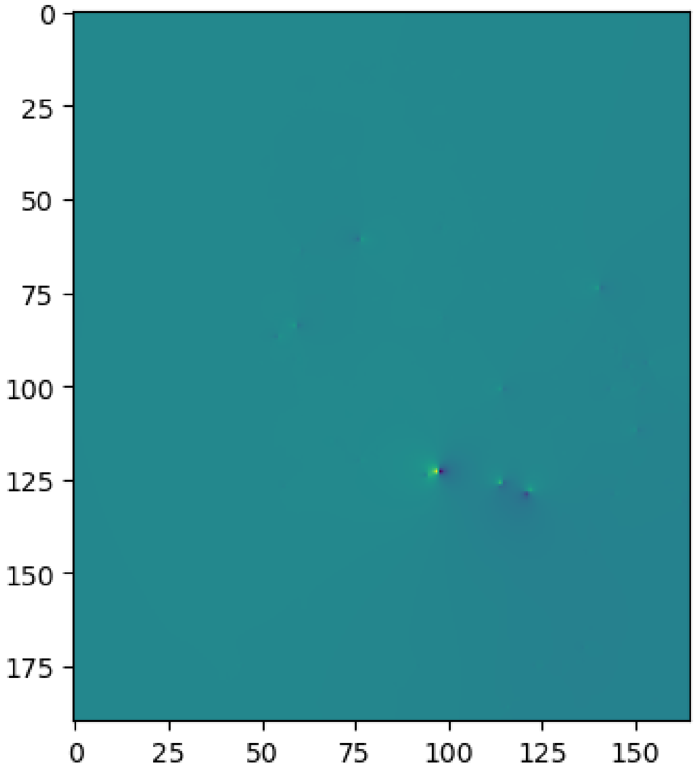
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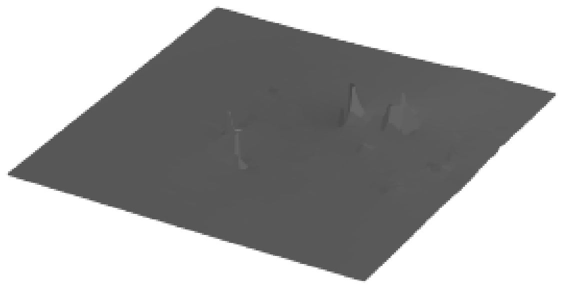
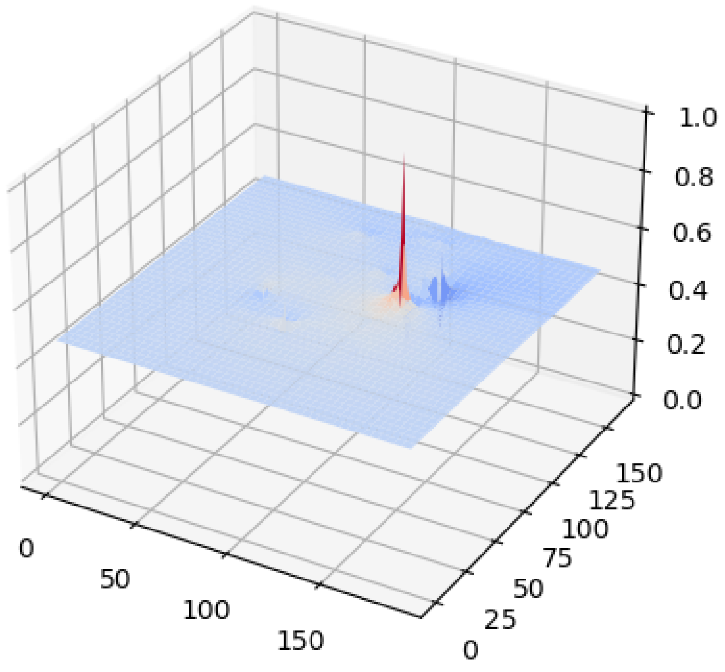
```
/tmp/ipykernel_110276/1074651019.py:326: MatplotlibDeprecationWarning: Calling
gca() with keyword arguments was deprecated in Matplotlib 3.4. Starting two
minor releases later, gca() will take no keyword arguments. The gca() function
should only be used to get the current axes, or if no axes exist, create new
axes with default keyword arguments. To create a new axes with non-default
arguments, use plt.axes() or plt.subplot().
  ax = fig.gca(projection='3d')
```

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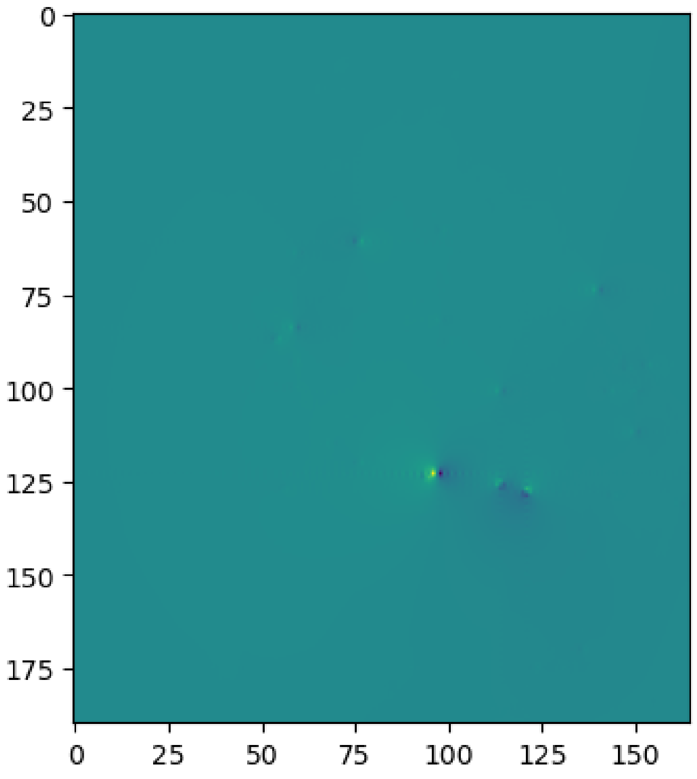
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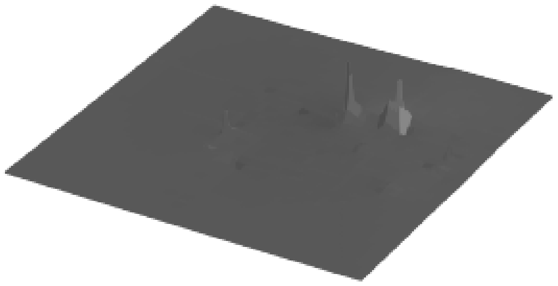
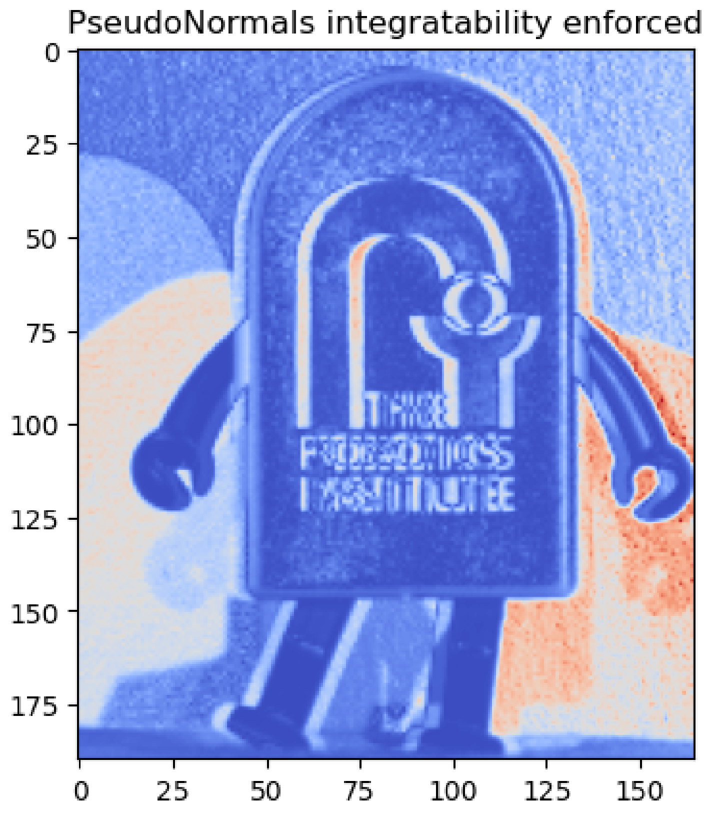
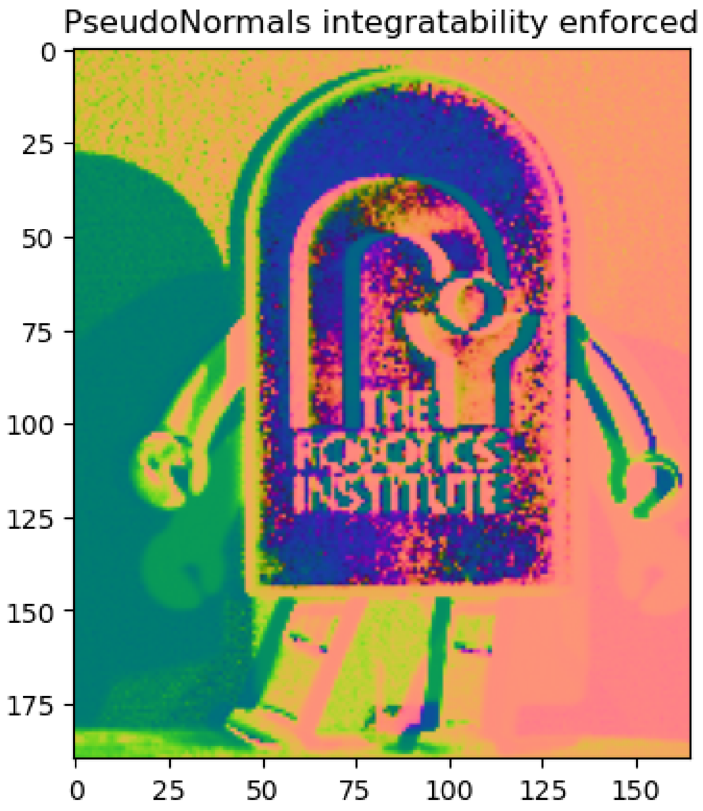


[61]:
```
# Lets try this for different G matrices

u = 0
v = 0
l = 1000000 # bottle opener
# l = 0.001 # plant
G = np.array([[1,0,0],[0,1,0],[u,v,l]])
Be_new = np.linalg.inv(G.T) @ Be

# Estimate normals and enforce integratability

# enforcing integratability on Be
Be_enf_int = enforceIntegrability(Be_new, s[:2])
albedos_enf_int, normals_enf_int = estimateAlbedosNormals(Be_enf_int)
albedoIm_int_enf, normalIM_int_enf = displayAlbedosNormals(albedos_enf_int,␣
 ↪normals_enf_int, s, 'PseudoNormals integratability enforced')

# Applying GBR inversion transform. Flip not needed here, but still added to␣
 ↪make depth map easier to discern.
Gf = np.array([[1,0,0],[0,1,0],[0,0,-1]])
Be_enf_int = Gf @ Be_enf_int
albedos_enf_int, normals_enf_int = estimateAlbedosNormals(Be_enf_int)
```

```
albedoIm_int_enf, normalIM_int_enf = displayAlbedosNormals(albedos_enf_int,␣
    ↪normals_enf_int, s, 'PseudoNormals integratability enforced after inversion␣
    ↪of direction')

# %matplotlib
# # Normal Integration
surface_poisson = estimateShape(normals_enf_int, s, 0)
plt.imshow(surface_poisson)
plt.show()
plot_surface_ls(surface_poisson, False)
plt.show()

surface_frankot = estimateShape(normals_enf_int, s, 1)
plt.imshow(surface_frankot)
plt.show()
plot_surface_ls(surface_frankot, False)
plt.show()
```




PseudoNormals integratability enforced
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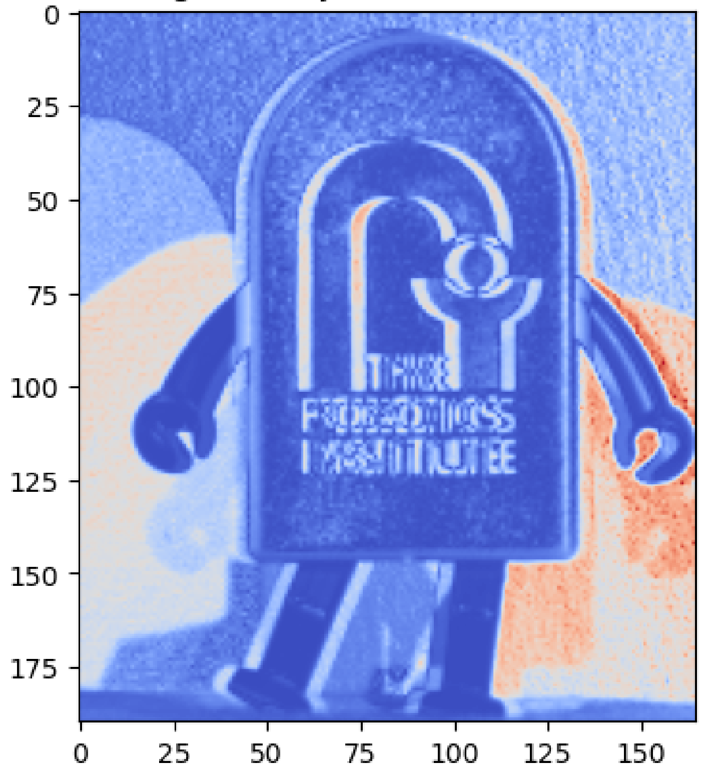
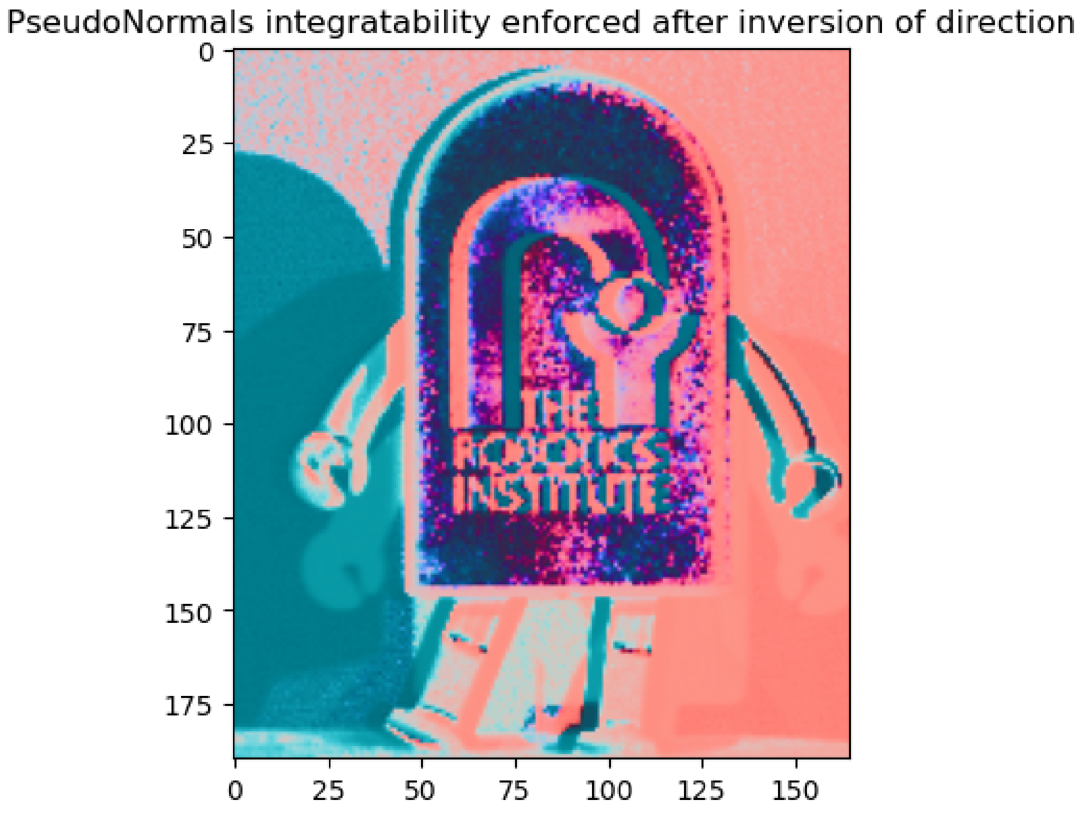
PseudoNormals integratability enforced after inversion of direction




PseudoNormals integratability enforced after inversion of direction
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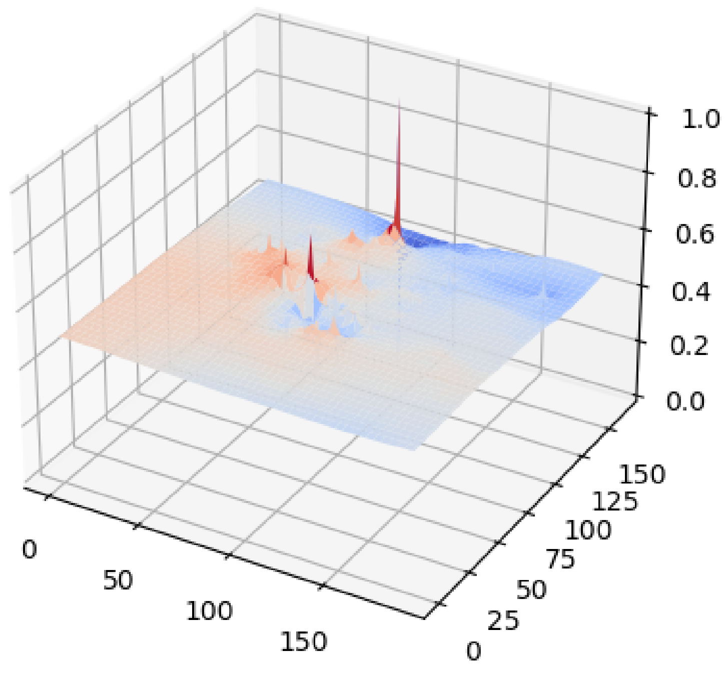
THE
ROBOTICS
INSTITUTE


1.0
0.8
0.6
0.4
0.2
0.0
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100
150
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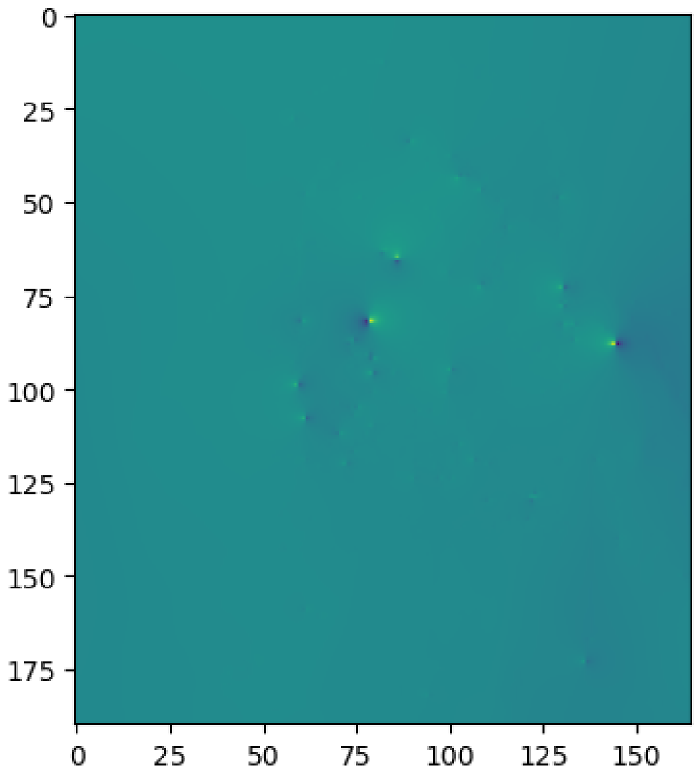
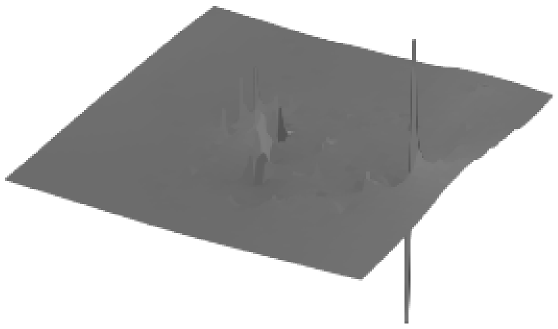
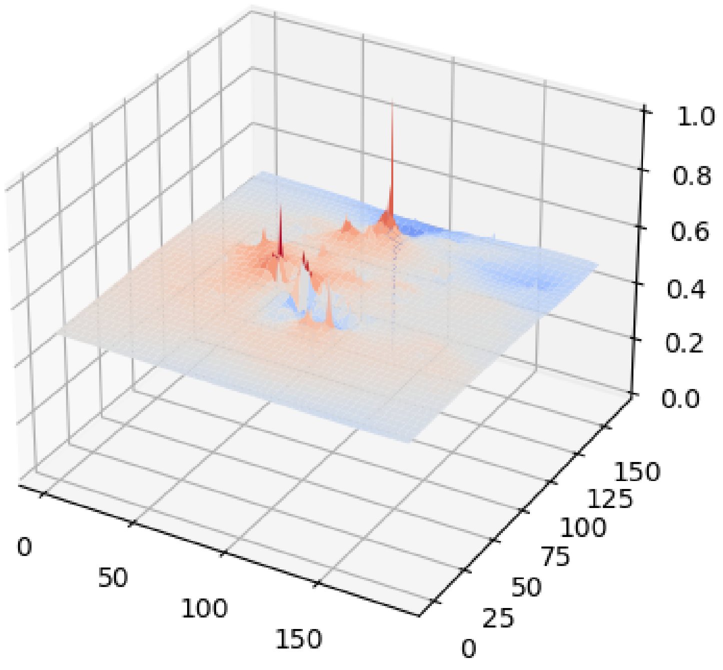
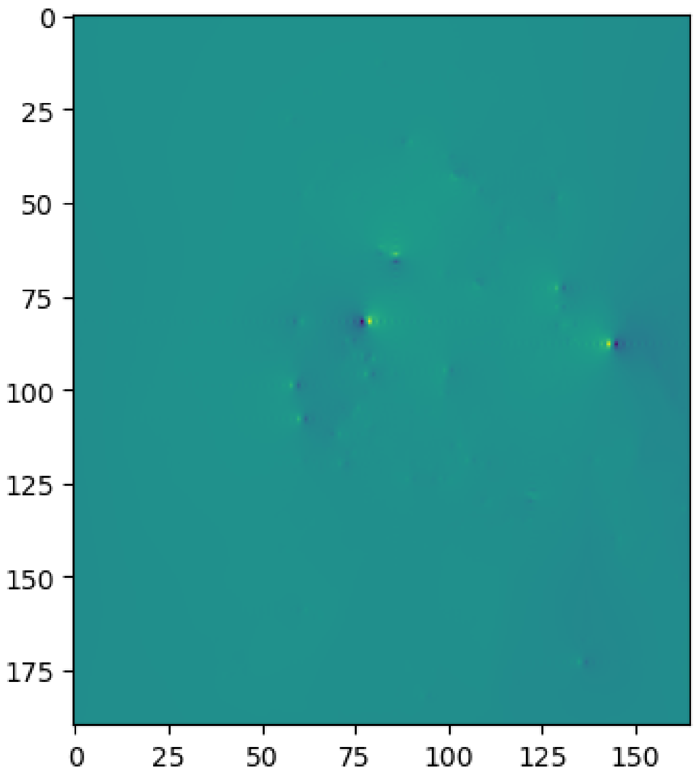
50
75
100
125
150

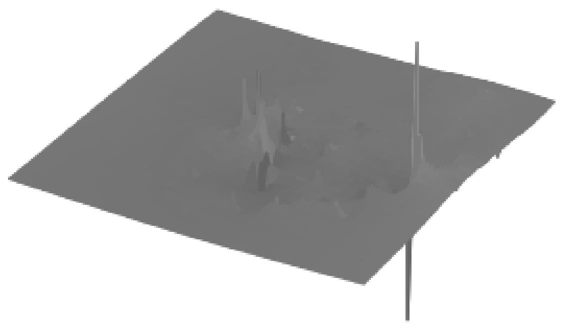


```
/tmp/ipykernel_110276/1074651019.py:326: MatplotlibDeprecationWarning: Calling
gca() with keyword arguments was deprecated in Matplotlib 3.4. Starting two
minor releases later, gca() will take no keyword arguments. The gca() function
should only be used to get the current axes, or if no axes exist, create new
axes with default keyword arguments. To create a new axes with non-default
arguments, use plt.axes() or plt.subplot().
  ax = fig.gca(projection='3d')
```




1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
0
25
50
75
100
125
150

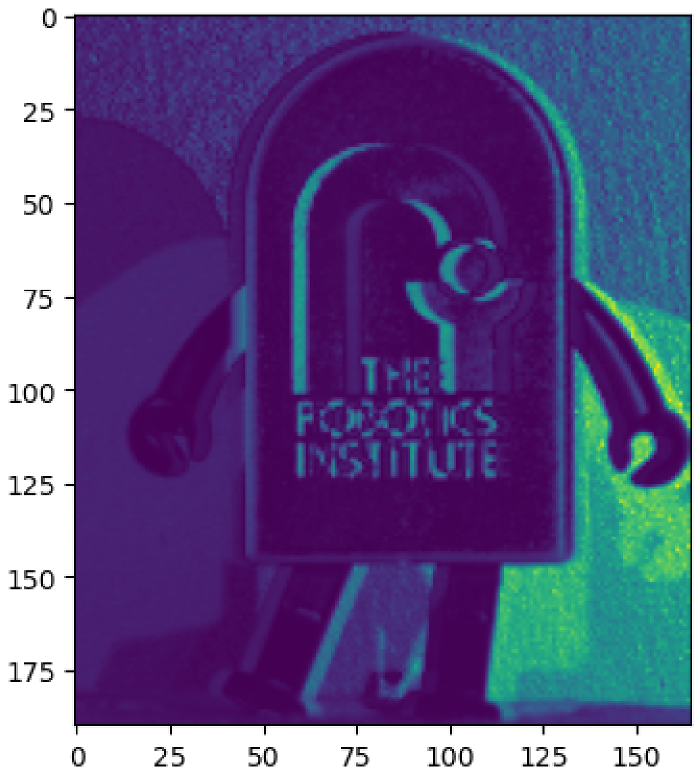

0
25
50
75
100
125
150
175
0
25
50
75
100
125
150

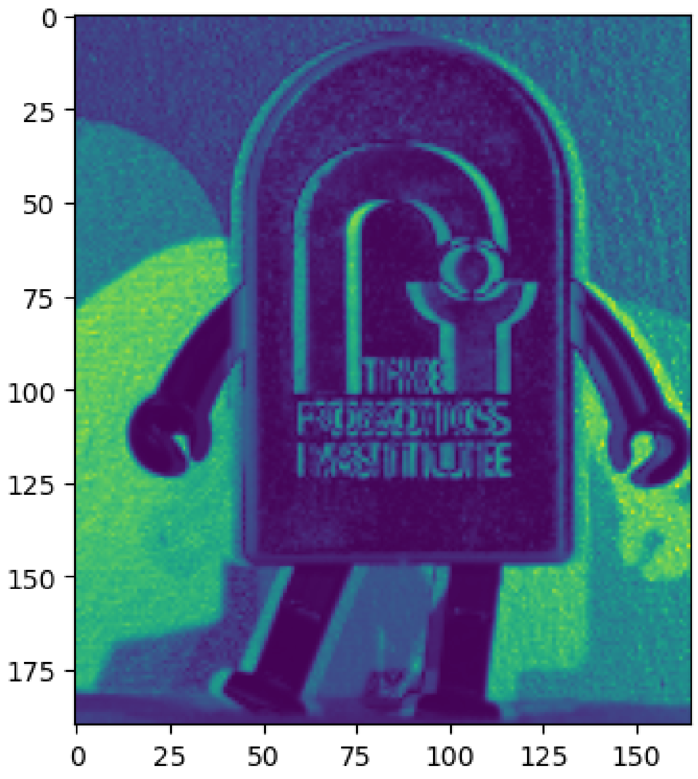


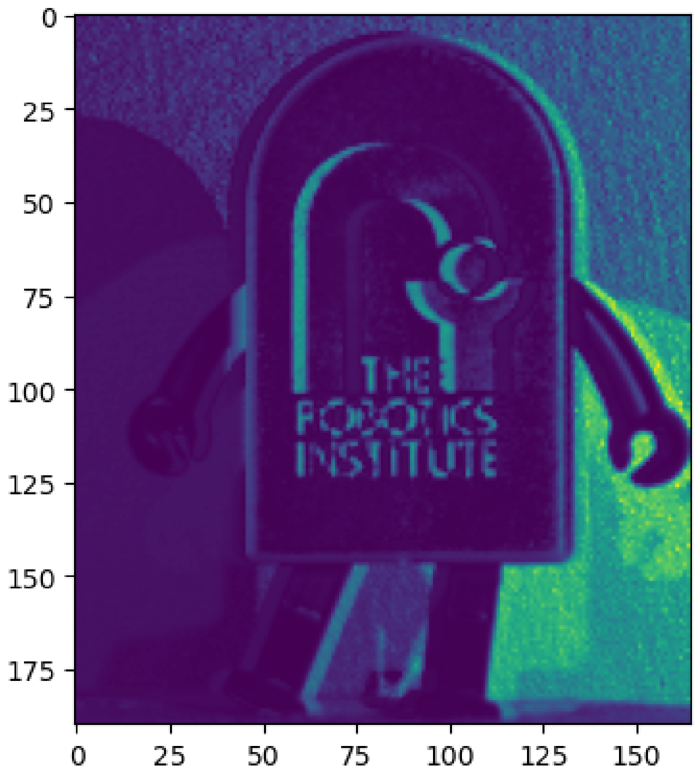
[63]:
```
# lighting the object
# verifying with known lighting
# From straight-right top
# if you get empty image, flip the normal sign
ndotl = np.dot(-normalIM_int_enf,Le[:,0])
rad_field = albedoIm_int_enf * ndotl
rad_field[rad_field < 0] = 0
plt.imshow(rad_field)
plt.show()

# From left side
ndotl = np.dot(-normalIM_int_enf,Le[:,2])
rad_field = albedoIm_int_enf * ndotl
rad_field[rad_field < 0] = 0
plt.imshow(rad_field)
plt.show()

# Custom light, far right
L_custom = np.array([10,1,1])
L_custom = L_custom / np.linalg.norm(L_custom)
ndotl = np.dot(normalIM_int_enf,L_custom)
rad_field = albedoIm_int_enf * ndotl
rad_field[rad_field < 0] = 0
plt.imshow(rad_field)
plt.show()
```


THE
ROBOTICS
INSTITUTE


THE
ROBOTICS
INSTITUTE



```
[71]:
```

```
[71]: array([ 0.62972695, -0.00245773, -0.36757835])
```

```
[39]:
```

```
[39]: (190, 220, 3)
```

```
[ ]:
```