```python
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# Computer Vision hw1
# I pledge my honor that I have abided by the stevens honor system
# how to run: "python hw1.py <image>"

import math
import random
import sys

import numpy as np
import cv2

# given an image, square filter matrix and the length,
# outputs the filtered image
def filter(img, fm, len):
    height, width = img.shape
    # create black image
    res = np.zeros((height, width), np.uint8)
    off = len//2
    for i in range(off, height-off):
        for j in range(off, width-off):
            fval = block_sum(img, fm, len, i, j)
            res[i][j] = fval
    return res

# using the filtermatrix's weight distribution, adds all the values
def block_sum(img, fm, len, x, y):
    total = 0.0
    off = len//2
    # iterating through each matrix element
    for i in range(len):
        for j in range(len):
            curx = x + i - off
            cury = y + j - off
            total += img[curx][cury] * fm[i][j]
    if (total <= 0):
        total = 0
    if (total >= 255):
        total = 255
    return total
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# applies sobel filter and first nonmax suppression
# for the hessian function to get a clearer input
def sobel_nms(img, threshold = 0.225):
    # applying vertical and horizontal sobel filters
    hsob = [[1, 2, 1],
            [0, 0, 0],
            [-1, -2, -1]]
    I_x = filter(img, hsob, 3)
    cv2.imwrite('xsobel.png', I_x)

    vsob = [[1, 0, -1],
            [2, 0, -2],
            [1, 0, -1]]
    I_y = filter(img, vsob, 3)
    cv2.imwrite('ysobel.png', I_y)

    highthesh = 255 * threshold

    height, width = img.shape
    res = np.power(np.power(I_x, 2.0) + np.power(I_y, 2.0), 0.5)
    # Non-maximum suppression
    for i in range(height):
        for j in range(width):
            # weak pixels become black
            if (res[i][j] < highthesh):
                I_x[i][j] = 0
                I_y[i][j] = 0
                res[i][j] = 0
            # image edge pixels become 0
            if (i == 0 or i == height-1 or j == 0 or j == width - 1):
                I_x[i][j] = 0
                I_y[i][j] = 0
                res[i][j] = 0
                continue
            # left right
            elif res[i][j] <= res[i][j-1] or res[i][j] <= res[i][j+1]:
                I_x[i][j] = 0
                I_y[i][j] = 0
                res[i][j] = 0
            # / diagonal
            elif res[i][j] <= res[i-1][j+1] or res[i][j] <= res[i+1][j-1]:
                I_x[i][j] = 0
                I_y[i][j] = 0
                res[i][j] = 0
            # up down
            elif res[i][j] <= res[i-1][j] or res[i][j] <= res[i+1][j]:
                I_x[i][j] = 0
                I_y[i][j] = 0
                res[i][j] = 0
            # \ diagonal
            elif res[i][j] <= res[i-1][j-1] or res[i][j] <= res[i+1][j+1]:
                I_x[i][j] = 0
                I_y[i][j] = 0
                res[i][j] = 0
    return I_x, I_y, res

# gets the second partial derivatives and the determinants
# are thresholded. takes neighboring pixels into account
# to allow for a more well-rounded view of the overall picture
def hessian(img, x, y, threshold=35000):
    hsob = [[1, 2, 1],
            [0, 0, 0],
            [-1, -2, -1]]
    vsob = [[1, 0, -1],
            [2, 0, -2],
            [1, 0, -1]]
    xx = filter(x, hsob, 3)
    yy = filter(y, vsob, 3)
    xy = filter(x, vsob, 3)
    height, width = img.shape
    res = np.zeros((height, width), np.uint8)
    one = [[1, 1, 1],
           [1, 1, 1],
           [1, 1, 1]]
    for i in range(1, height-1):
        for j in range(1, width-1):
            totalxx = block_sum(xx, one, 3, i, j)
            totalyy = block_sum(yy, one, 3, i, j)
            totalxy = block_sum(xy, one, 3, i, j)
            deter = (totalxx * totalyy) - (totalxy)**2
            # deter = xx[i][j]* yy[i][j] - xy[i][j]**2
            if (deter > threshold):
                res[i][j] = deter
            else:
                res[i][j] = 0
    return res

# non-maximum suppression: if the current pixel is darker than a
# neighboring pixel, the current pixel is turned to black.
def nms(img):
    height, width = img.shape
    res = img.copy()
    # Non-maximum suppression
    for i in range(height):
        for j in range(width):
            # image edge pixels become 0
            if (i == 0 or i == height-1 or j == 0 or j == width - 1):
                res[i][j] = 0
                continue
            # left right
            elif res[i][j] <= res[i][j-1] or res[i][j] <= res[i][j+1]:
                res[i][j] = 0
            # / diagonal
            elif res[i][j] <= res[i-1][j+1] or res[i][j] <= res[i+1][j-1]:
                res[i][j] = 0
            # up down
            elif res[i][j] <= res[i-1][j] or res[i][j] <= res[i+1][j]:
                res[i][j] = 0
            # \ diagonal
            elif res[i][j] <= res[i-1][j-1] or res[i][j] <= res[i+1][j+1]:
                res[i][j] = 0
    # brighten up points
    points = []
    for i2 in range(1, height-1):
        for j2 in range(1, width-2):
            if res[i2][j2] != 0:
                res[i2][j2] = 255
                points.append([i2, j2])
    return res, points

# takes the shortest distance between a line formed by
# two points(x1,y1 and x2, y2) and a point x0,y0
def shortest_dist(x1, y1, x2, y2, x0, y0):
    numerator = abs((y2 - y1)*x0 - (x2-x1)*y0 + x2*y1 - y2*x1)
    denom = math.sqrt((y2-y1)**2 + (x2-x1)**2)
    return numerator/denom
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# out of a list of coordinates, pulls the two furthest points
def get_extreme(lst):
    dist = 0
    a = (lst[0][1], lst[0][0])
    b = (lst[1][1], lst[1][0])
    for i in range(0, len(lst)-1):
        for j in range(i+1, len(lst)):
            y1,x1= lst[i]
            y2,x2= lst[j]
            curdist = math.sqrt((x1-x2)**2 + (y1-y2)**2)
            if (curdist>dist) :
                dist = curdist
                a = (x1,y1)
                b = (x2, y2)
    return a,b

# picks two random points and sees if there is enough support for that line
# dist_thresh is the max distance allowed to be considered part of the line
# inlier_thresh is the number of points needed to be considered a viable line
def ransac(img, pt_lst, dist_thresh = 7, inlier_thresh = 20):
    blue=[255, 0, 0]
    green=[0, 255, 0]
    red=[0,0, 255]
    cyan=[255, 255, 0]
    colors = [blue, green, red, cyan]

    lines_needed = 4
    numlines= 0
    pt_used = []

    while (numlines<lines_needed):
        rand1 = random.randint(0, len(pt_lst)-1)
        rand2 = random.randint(0, len(pt_lst)-1)

        x1,y1= pt_lst[rand1]
        x2,y2 = pt_lst[rand2]
        if (pt_lst[rand1] in pt_used or pt_lst[rand2] in pt_used or rand1
==rand2):
            continue
        cur_line = [pt_lst[rand1], pt_lst[rand2]]
        for p in range(len(pt_lst)):
            if (len(cur_line) >= inlier_thresh):
                # have enough points
                break
            if (pt_lst[p]in pt_used or pt_lst[p] in cur_line):
                # point is used, next point
                continue
            dist = shortest_dist(x1, y1, x2, y2, pt_lst[p][0], pt_lst[p][1])
            if (dist <= dist_thresh):
                cur_line.append(pt_lst[p])
        if (len(cur_line) < inlier_thresh):
            # line does not have enough, next line
            continue

        # line has enough points
        for q in range(len(cur_line)):
            i,j = cur_line[q]
            img[i-1][j-1] = img[i][j-1]= img[i+1][j-1] = colors[numlines]
            img[i-1][j] = img[i][j] = img[i+1][j] = colors[numlines]
            img[i-1][j+1] = img[i][j+1] = img[i+1][j+1] = colors[numlines]
            # set point to used
            pt_used.append(cur_line[q])

        # get outliers
        out1, out2 = get_extreme(cur_line)
        # plot line
        cv2.line(img,out1,out2,colors[numlines],1)
        cur_line =[]
        numlines+= 1
    return img

# for every point, there is exists a rho and theta s.t.
# rho =xcos(theta) + ysin(theta). for every theta (0->180),
# add a "vote" in H[theta][rho].
# extract the theta and rho combo with the most votes and
# that is the line with the most support
def hough(img, pts, numlines=4):
    height = img.shape[0]
    width = img.shape[1]
    H = np.zeros(shape=(181, int(math.sqrt(height**2 + width**2))))
    for p in pts:
        for theta in range(181):
            x,y = p
            rho = x*math.cos(np.deg2rad(theta)) + y*math.sin(np.deg2rad(theta))
            H[theta][int(rho)] += 1

    largest =[(0,0)]
    min = 0
    for t in range(181):
        for r in range(int(math.sqrt(height**2 + width**2))):
            if len(largest) < 4:
                largest.append([t, r])
            else:
                if (H[t][r] > min):
                    for lpt in range(len(largest)):
                        if min == H[largest[lpt][0]][largest[lpt][1]]:
                            largest[lpt] = (t,r)
                            break
                    # readjusting min of largests
                    min = H[largest[0][0]][largest[0][1]]
                    for f in range(len(largest)):
                        if H[largest[f][0]][largest[f][1]]<min:
                            min = H[largest[f][0]][largest[f][1]]
    # has the theta and rho of lines, need to plot the lines
    for i in largest:
        j,k = i
        j= math.radians(j)
        y1 = 0
        x1 = int((k/math.sin(j)) -(y1*math.cos(j)/math.sin(j)))
        if (x1>width):
            x1 = width
            y1 = int((k/math.cos(j)) - (x1*math.sin(j)/math.cos(j)))
        elif (x1<0):
            x1 = 0
            y1 = int((k/math.cos(j)) - (x1*math.sin(j)/math.cos(j)))

        x2 = 0
        y2 = int((k/math.cos(j)) - (x2*math.sin(j)/math.cos(j)))
        if (y2>height):
            y2= height
            x2 = int((k/math.sin(j)) -(y2*math.cos(j)/math.sin(j)))
        elif (y2<0):
            y2 = 0
            x2 = int((k/math.sin(j)) -(y2*math.cos(j)/math.sin(j)))
        cv2.line(img, (x1, y1), (x2, y2), (255, 255, 0),1)
    return img


if __name__ == '__main__':
    if (len(sys.argv) != 2):
        sys.exit("usage: python hw1.py <img>")
    orig = cv2.imread(sys.argv[1], 0)

    print("Working on it!")

    # applying gaussian filter
    gaussian = [[0.077847, 0.123317, 0.077847],
                [0.123317, 0.195346, 0.123317],
                [0.077847, 0.123317, 0.077847]]
    g_res = filter(orig, gaussian, 3)
    cv2.imwrite('gauss.png', g_res)

    x, y, together = sobel_nms(g_res)
    cv2.imwrite('xnms.png', x)
    cv2.imwrite('ynms.png', y)
    cv2.imwrite('tnms.png', together)

    hes = hessian(together, x, y)
    cv2.imwrite('hessian.png', hes)

    partone, pts = nms(hes)
    cv2.imwrite('partone.png', partone)
    print("Part one finished.")

    rsc = ransac(cv2.cvtColor(orig, cv2.COLOR_GRAY2RGB), pts)
    cv2.imwrite('ransac.png', rsc)
    print("Part two finished.")

    huff = hough(cv2.cvtColor(partone, cv2.COLOR_GRAY2RGB), pts)
    cv2.imwrite('hough.png', huff)
    print("Part three finished.")

    print("Done!")
```
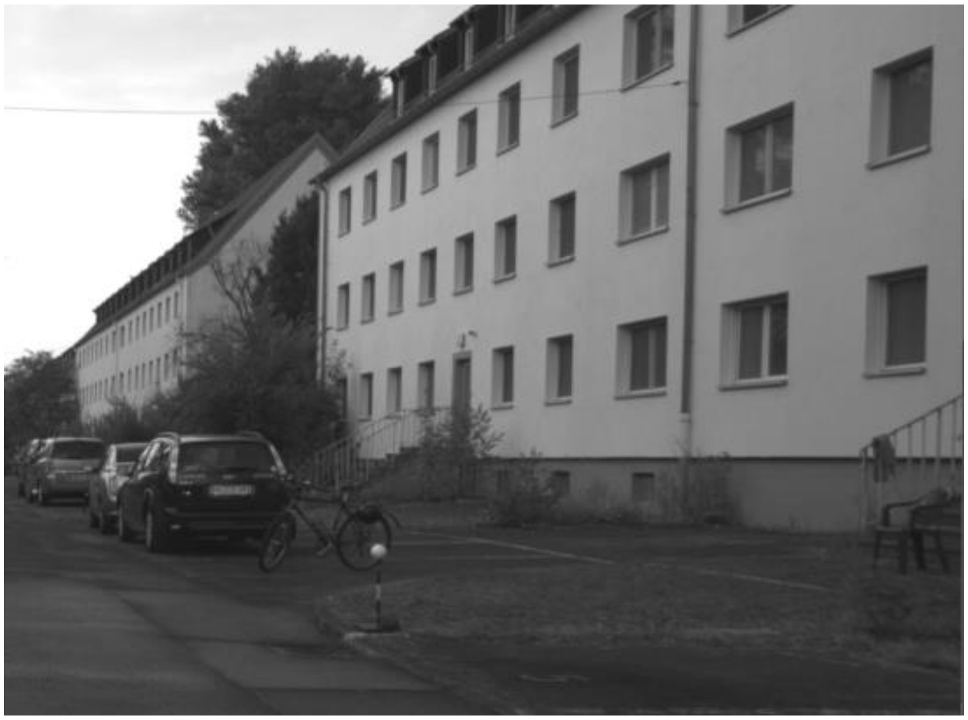
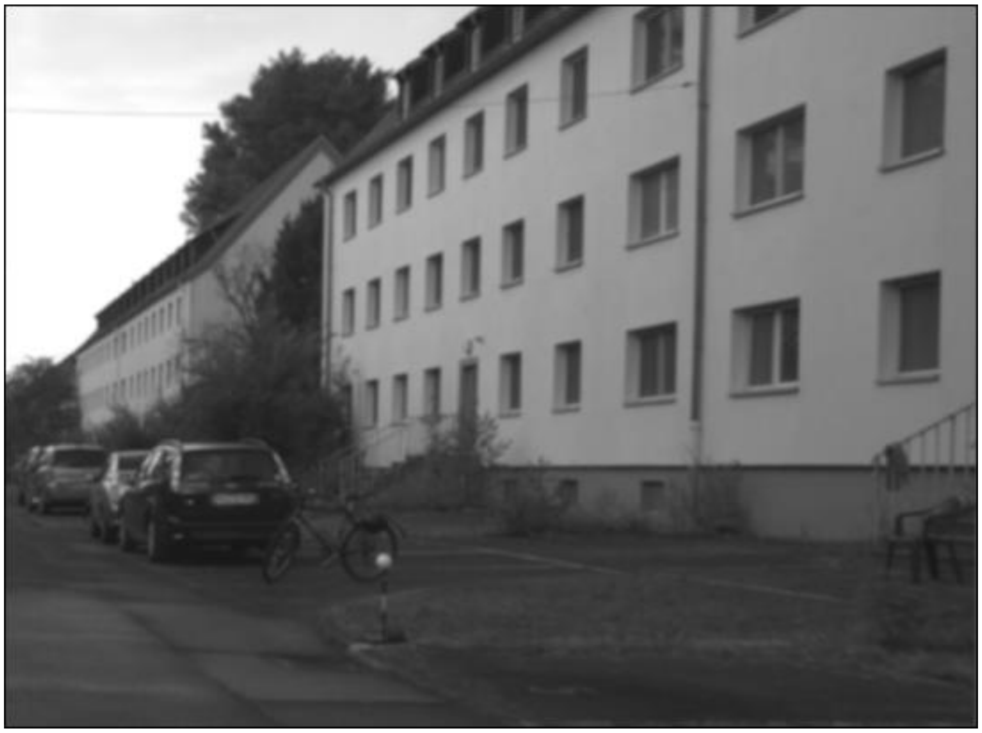
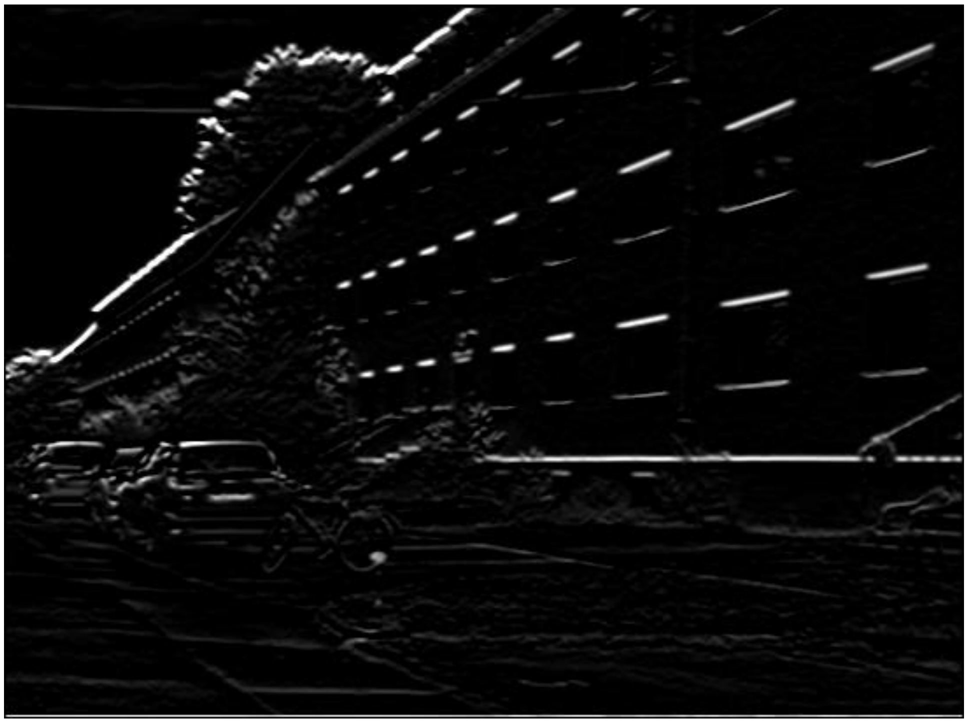

Original photo:



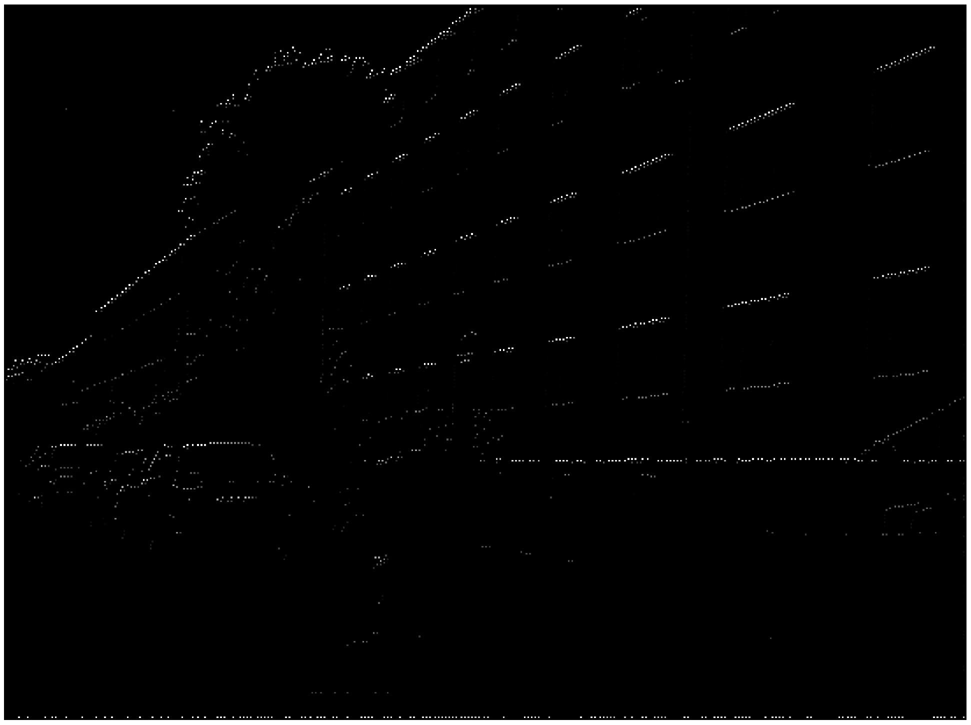
Gaussian filter:



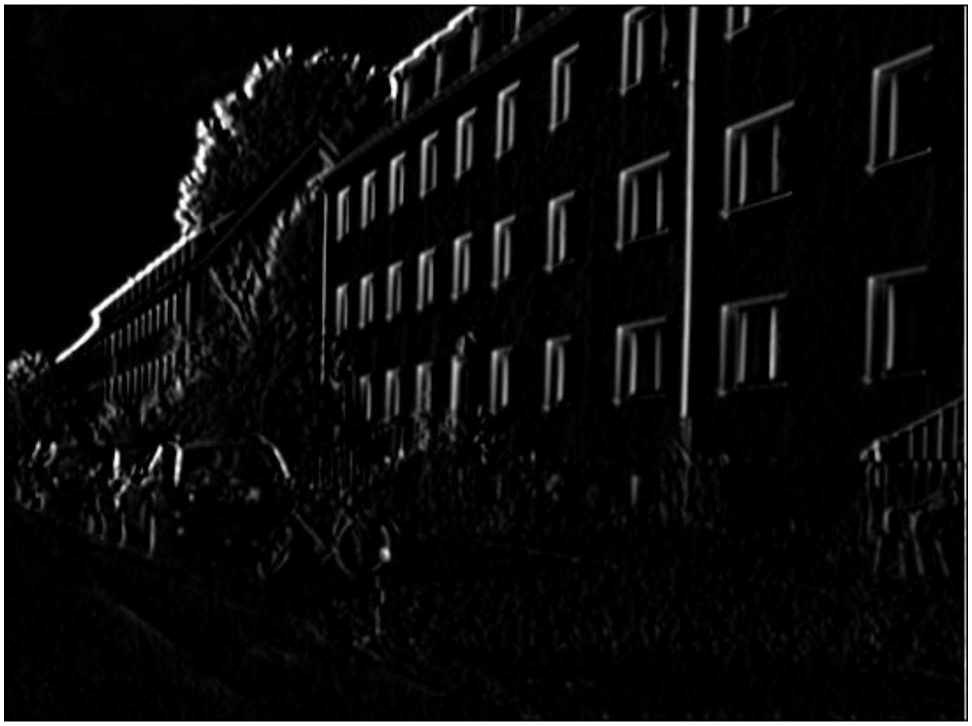
Horizontal sobel filter:



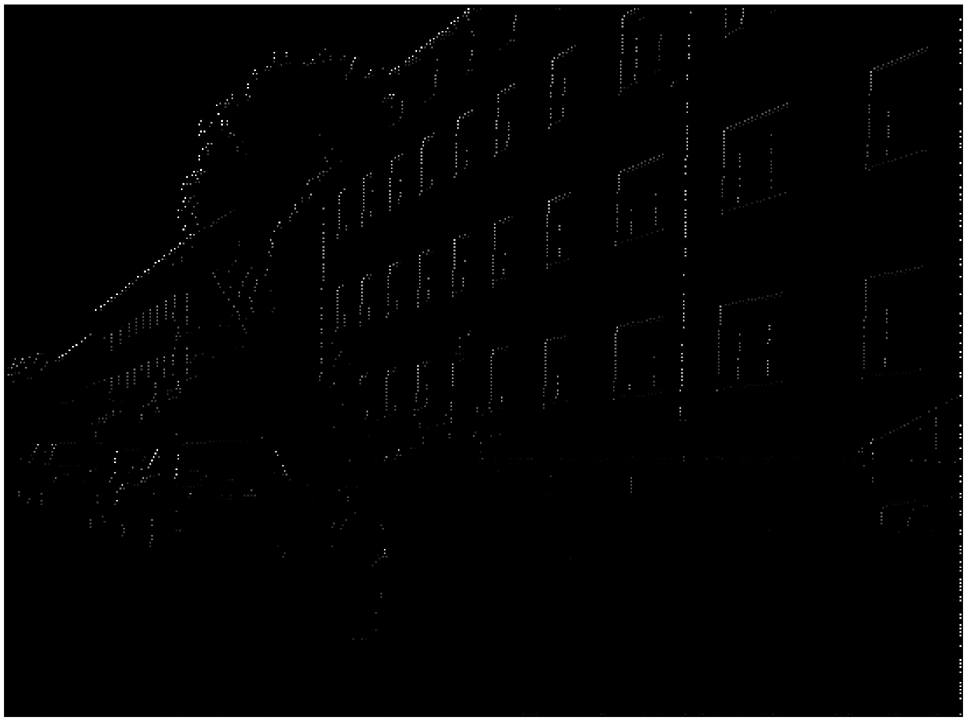
Horizontal sobel + non max supp



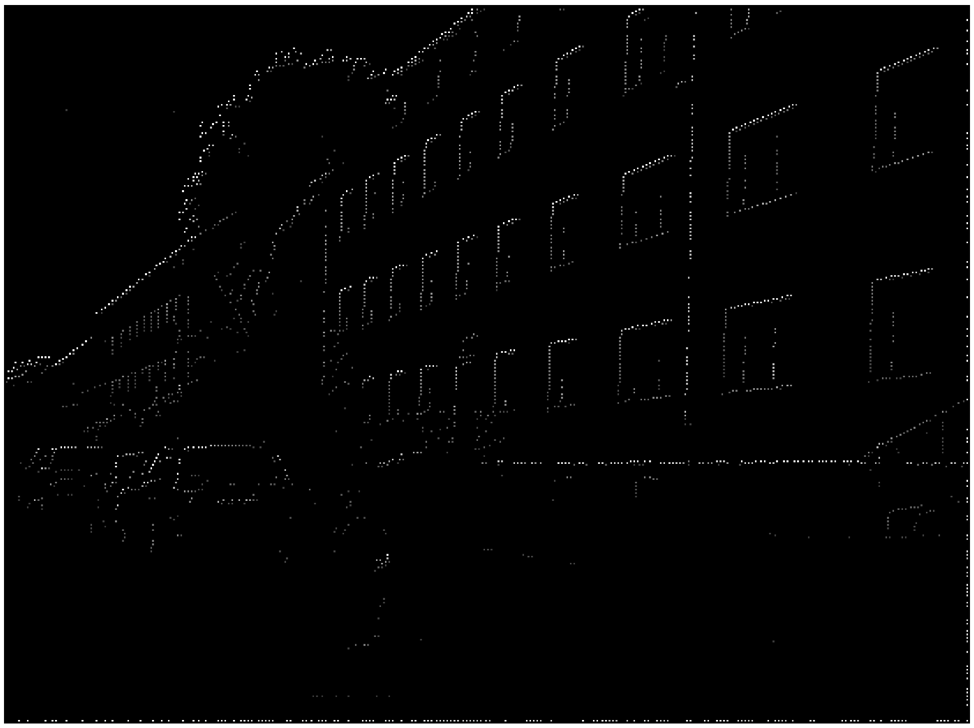
Vertical sobel filter:



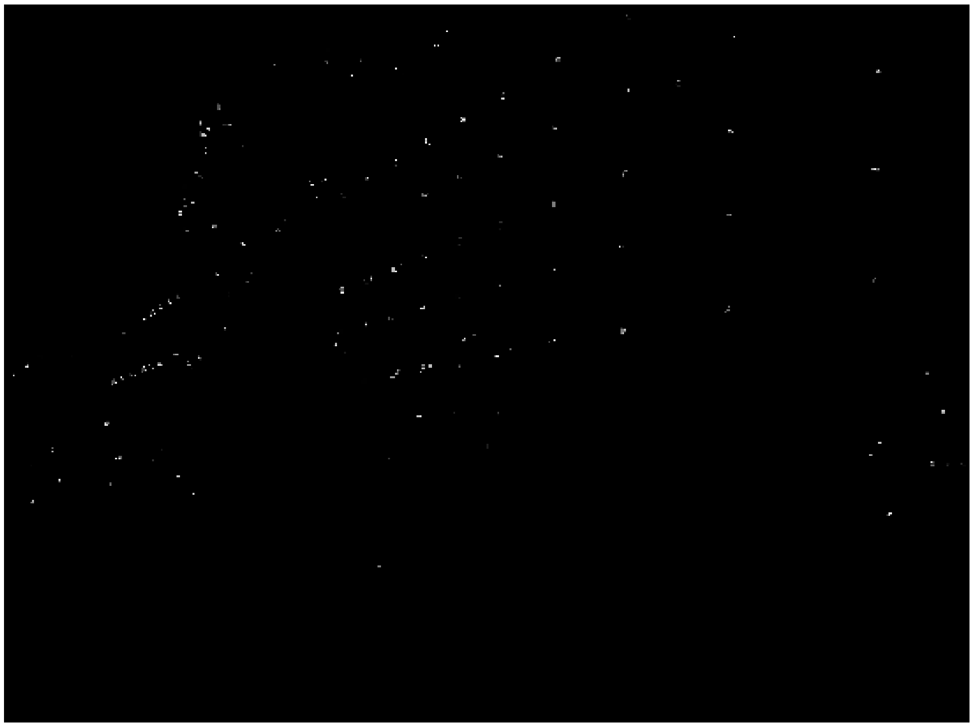
Vertical sobel + non max supp



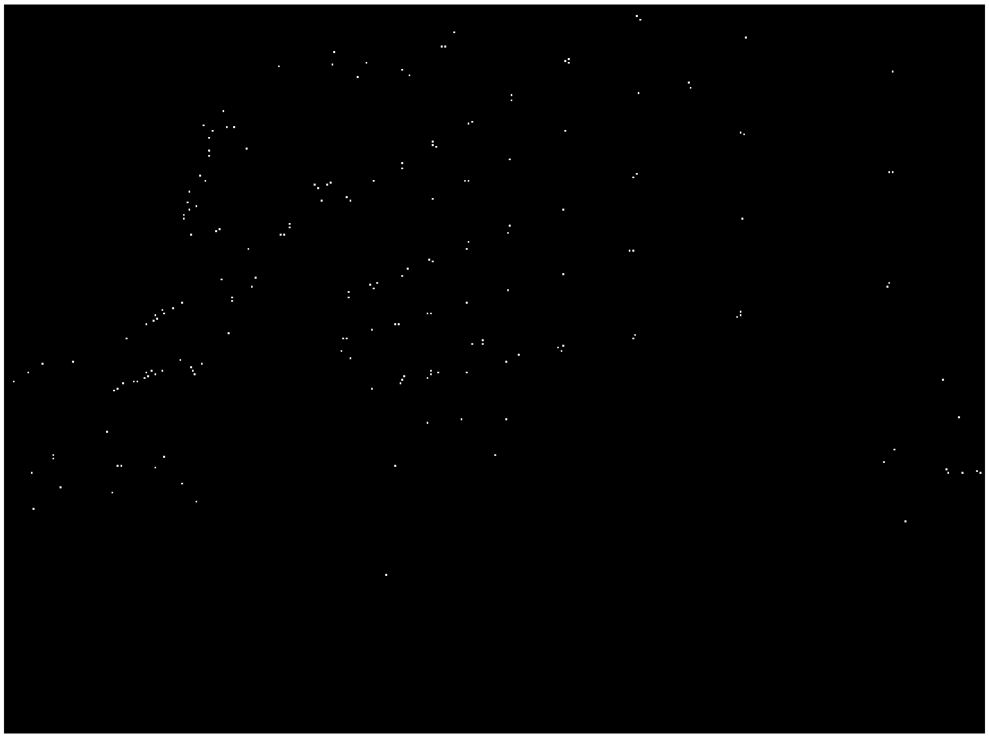
Vertical + horizontal sobel filter + non max suppression:



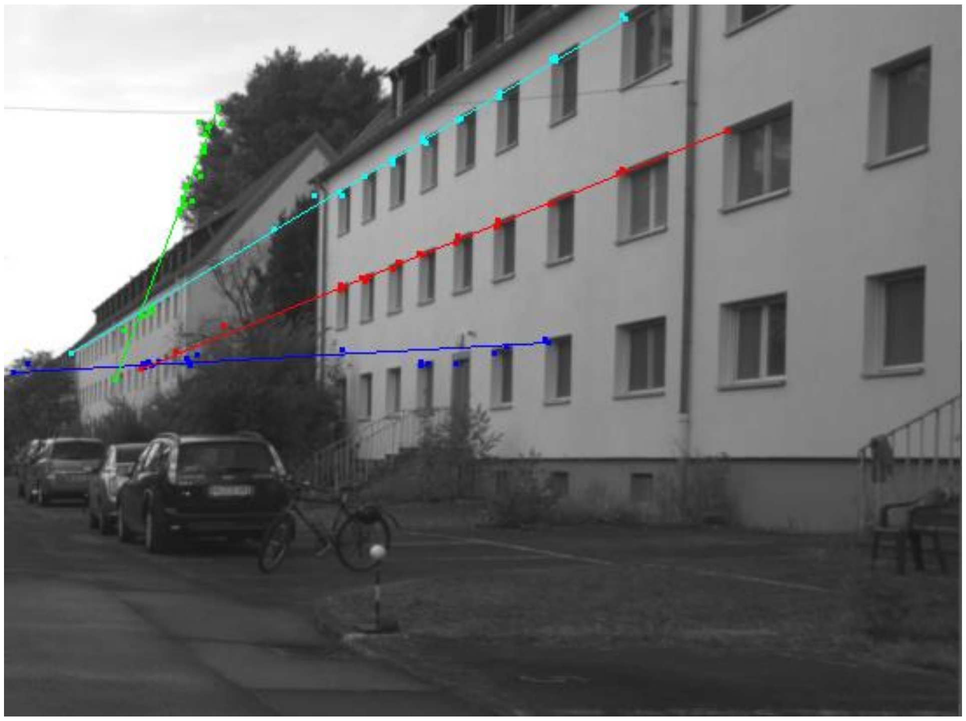
Hessian:



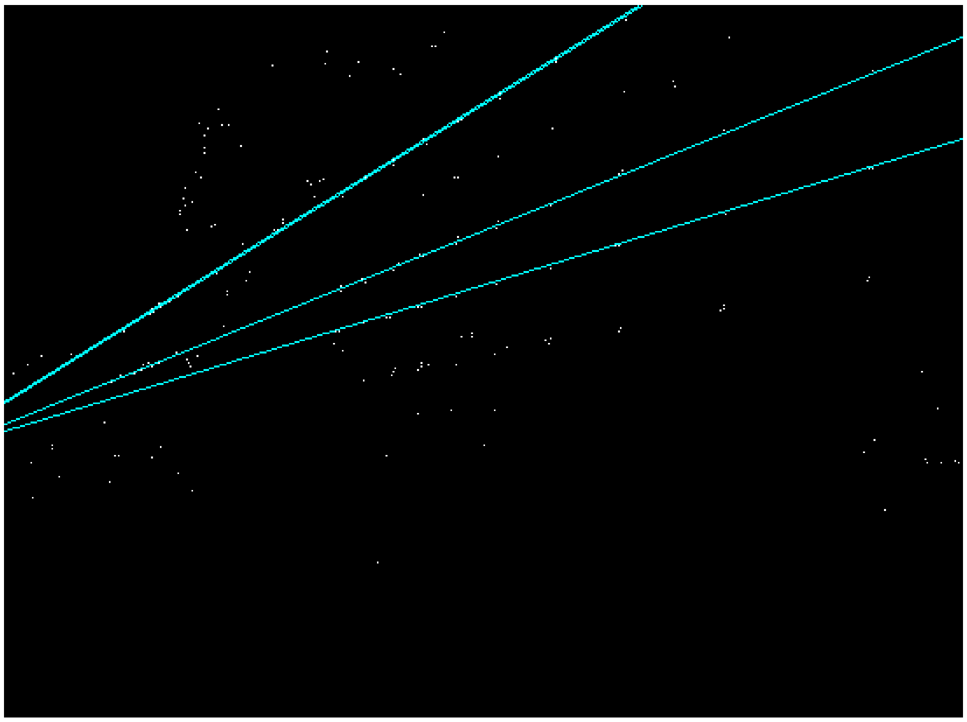
Non max suppression:



Ransac (over original photo):

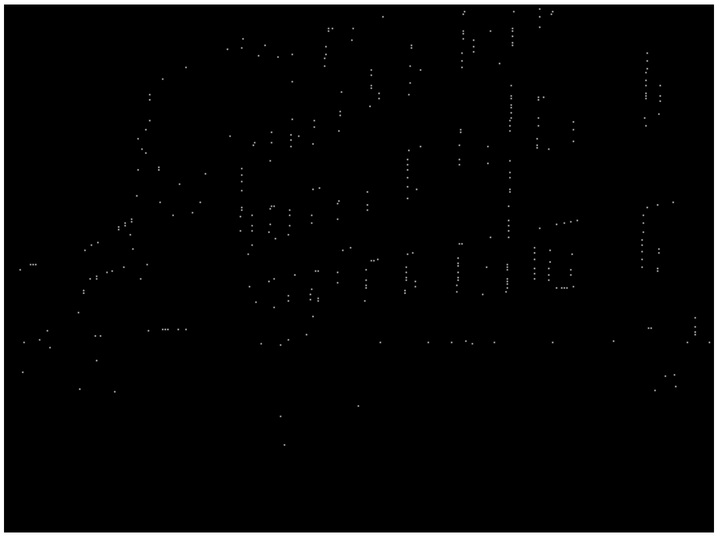


Hough transform:



As illustrated by the pictures, the general work flow was to apply the gaussian filter, apply the vertical and horizontal sobel filters, apply non-max suppression, threshold the hessian determinant, apply the non-max suppression again, run ransac and run hough.

I decided to apply the non-maximum suppression once after the sobel filters to give the hessian function a clearer input and to ensure that weak pixels would not show up later.



In the hessian function, I chose to add the sum of the neighboring pixels' derivatives because without adding them, I found that the resulting image has a vertical edge bias. (The image to the right only takes the current pixel's derivatives into account and has a threshold of 15.)

For RANSAC, I followed the algorithm outlined from the slides (Week 3, page 58).

For Hough, I followed the algorithm outlined from the slides (Week 4, page 14).