Assignment 1

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Lucas-Kanade Optical flow

Optical Flow tries to estimate the movement present in a scene captured as a sequence of Image. In this implementation we estimage the optical flow at subsequent intervals (location) in an image between two pairs of image at a single scale. This essentially boils down to finding two displacements in the x and y directions, between two subsequent images. The general algorithm for lucas kanade takes into consideration a window of pixels around a given pixel and tries to find the displacement in the window by comparing it with the similar window in the next Image. It works on the assumtion that there is small movements between successive frames of the image and brightness consistency holds at all pixels in the window. Under these circumstances we can find the velocity vector(V_x, V_y) in x and y as follows.

If $V_x = \dfrac{dx}{dt}$ and $V_y = \dfrac{dy}{dt}$ we can write $I(x, y, t) = I(x + dx, y + dy, t + dt)$. By taylors series expansion of the RHS we arrive at the form

$$I_x V_x + I_y V_y = -I_t$$

where I_x and I_y are the gradients of the image at x and y directions. Let $q_1, q_2, q_3 \ldots q_n$ form the set of pixels in the neighbourhood of pixel (x, y). Then we can open up the previous equation and write it in a matrix product form.

$$\begin{bmatrix} I_x(q_1) & I_y(q_1) \\ I_x(q_2) & I_y(q_2) \\ \vdots & \vdots \\ I_x(q_n) & I_y(q_n) \end{bmatrix} \begin{bmatrix} V_x \\ V_y \end{bmatrix} = \begin{bmatrix} -I_t(q_1) \\ -I_t(q_2) \\ \vdots \\ -I_t(q_n) \end{bmatrix}$$

$$Av = b$$

Here we have again assumed that all the pixels in the neighbourhood move by the same amount V_x, V_y. Now, this is a over determined system of equations hence we need to find a least square solution to the problem.

$$v = (A^T A)^{-1} A^T b$$

In matrix form this becomes

$$\begin{bmatrix} V_x \\ V_y \end{bmatrix} = \begin{bmatrix} \sum_i I_x(q_i)^2 & \sum_i I_x(q_i) I_y(q_i) \\ \sum_i I_y(q_i) I_x(q_i) & \sum_i I_y(q_i)^2 \end{bmatrix}^{-1} \begin{bmatrix} -\sum_i I_x(q_i) I_t(q_i) \\ -\sum_i I_y(q_i) I_t(q_i) \end{bmatrix}$$

The $A^T A$ matrix is the 2nd moment matrix

In [1]:

```
import warnings
import cv2
import matplotlib.pyplot as plt
import os
import numpy as np
warnings.filterwarnings('ignore')
eps = np.finfo(float).eps
```

In [2]:

```
import ipdb
```

In [3]:

```
def showImage(imageSet, figsize=(6,5)):
    plt.figure(figsize=figsize)
    for i,image in enumerate(imageSet):
        plt.subplot(1,len(imageSet),i+1)
        plt.imshow(image, cmap='gray')
    plt.show()
```

Getting the Intensity Derivatives in the x and y directions

Getting the intensity derivatives in the x and y direction is done by subtracting the neighbouring pixels at (x,y) and averaging the difference i.e.

$$grad_x(x, y) = \frac{I_{(x+1,y)} - I_{(x-1,y)}}{2}$$

and similarly

$$grad_y(x, y) = \frac{I_{(x,y+1)} - I_{(x,y-1)}}{2}$$

where $I_{(x,y)}$ is the intensity at pixel (x, y)

In [4]:

```
def getIxIy(img):
    auxImg = np.hstack((np.zeros([img.shape[0],1]), img, np.zeros([img.shape[0]
    Ix = (auxImg[:, 2:] - auxImg[:, :-2]) / 2

    auxImg  = np.vstack((np.zeros([1, img.shape[1]]), img, np.zeros([1, img.sha
    Iy = (auxImg[2:, :] - auxImg[:-2, :]) / 2
    return Ix, Iy

def getIt(img1, img2):
    return img1 - img2
```

Finding the velocity vectors in x and y directions

In this function we actually find the velocty vector by performing the computations stated above. Given is the intensity deivatives in x and y direction, and the derivative w.r.t t, two images, the starting position, the kernel size (window) which is usually 15x15 or 31x31 as well some thresholding to limit the displacement magnitude in the output. It also returns the magitude of calculated velocity vector and the orientation in the image. Magitude and directions are only used for image segmentation purposes.

In [5]:

```
def computeVelocities(Ix, Iy, It, grayImg1, grayImg2, startpos, kernel, max_dis
    y, x = startpos

    window = ((max(0, x - int(kernel/2)), max(0, y - int(kernel/2))),\
              (min(grayImg1.shape[0], x + int(kernel/2)), min(grayImg1.shape[1]

    Ix = Ix[window[0][0] : window[1][0] + 1, window[0][1] : window[1][1] + 1].r
    Iy = Iy[window[0][0] : window[1][0] + 1, window[0][1] : window[1][1] + 1].r
    It = It[window[0][0] : window[1][0] + 1, window[0][1] : window[1][1] + 1].r

    A = np.hstack((Ix, Iy))

    try:
        mInv = np.linalg.inv(A.T.dot(A))   # inverse of the second moment matri
    except:
        return startpos, 0, 0              # 2nd moment matrix is singular

    u, v = -1 * mInv.dot(A.T.dot(It))

    # reduce the displacement amount
    # (only used to make the dense image more understandable with smaller lines
    u1 = np.sign(u) * min(np.abs(u), max_displacement)
    v1 = np.sign(v) * min(np.abs(v), max_displacement)

    new_point = (int(y + u1), int(x + v1))
    magnitude = (u[0]**2 + v[0]**2)**0.5
    direction = np.round(np.arctan2(v[0], u[0]) * (180 / np.pi))

    return new_point, magnitude, direction
```

Finding the optical flow

The optical flow is calculated by going through the image calculating the velocity vector at every interval point in the image. The resultant displacements are plotted as arrowed lines from the starting position.

In [6]:

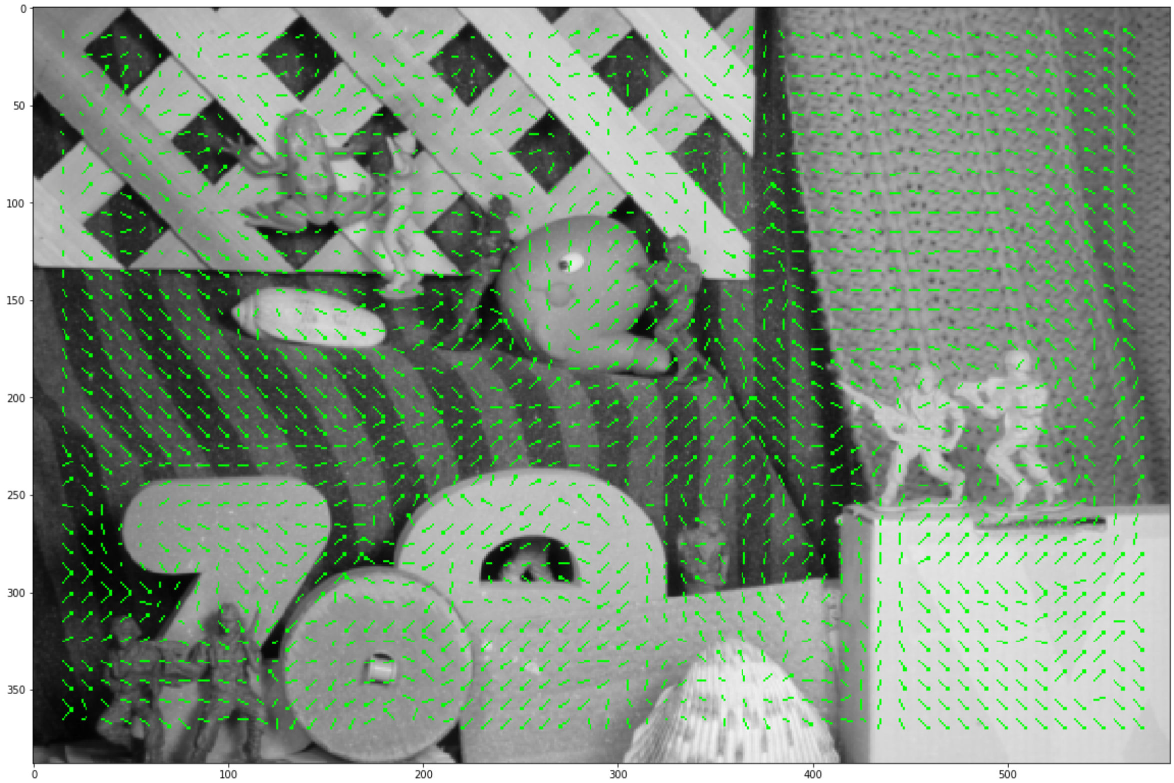
```python
def opticalFlow(img1, img2, kernel, stride = 10, max_displacement = 3, thicknes
    grayImg1 = cv2.cvtColor(img1, cv2.COLOR_RGB2GRAY)
    grayImg2 = cv2.cvtColor(img2, cv2.COLOR_RGB2GRAY)
    pad = int(kernel/2)
    centers = [[], []]
    for i in range(pad, grayImg1.shape[0] - pad, stride):
        for j in range(pad, grayImg1.shape[1] - pad, stride):
            centers[0] += [j]
            centers[1] += [i]

    magnImg = np.zeros(grayImg1.shape,dtype = np.float64)      # magnitude of d
    dirnImg = np.zeros(grayImg1.shape)                         # direction at e
    Ix, Iy = getIxIy(grayImg1)
    It = getIt(grayImg1, grayImg2)

    flowImg = img1.copy()
    for c in range(len(centers[0])):
        old_point = (centers[0][c], centers[1][c])
        new_point, magnitude, direction = computeVelocities(Ix, Iy, It, grayImg
                                                            kernel, max_displace
        magnImg[centers[1][c], centers[0][c]] = magnitude
        dirnImg[centers[1][c], centers[0][c]] = direction
        flowImg = cv2.arrowedLine(flowImg, old_point, new_point, (0,255,0), thi

    return flowImg, magnImg, dirnImg
```

Results

Optical Flow

In [59]:

```
imagesDir = '../eval-data-gray/Army/'
img1Path = imagesDir + 'frame10.png'
img2Path = imagesDir + 'frame11.png'
img1 = cv2.cvtColor(cv2.imread(img1Path), cv2.COLOR_BGR2RGB)
img2 = cv2.cvtColor(cv2.imread(img2Path), cv2.COLOR_BGR2RGB)
flowImg1, _, _ = opticalFlow(img1, img2, kernel = 31, stride = 10, max_displace
showImage([flowImg1], figsize = (20,20))
```



In [60]:

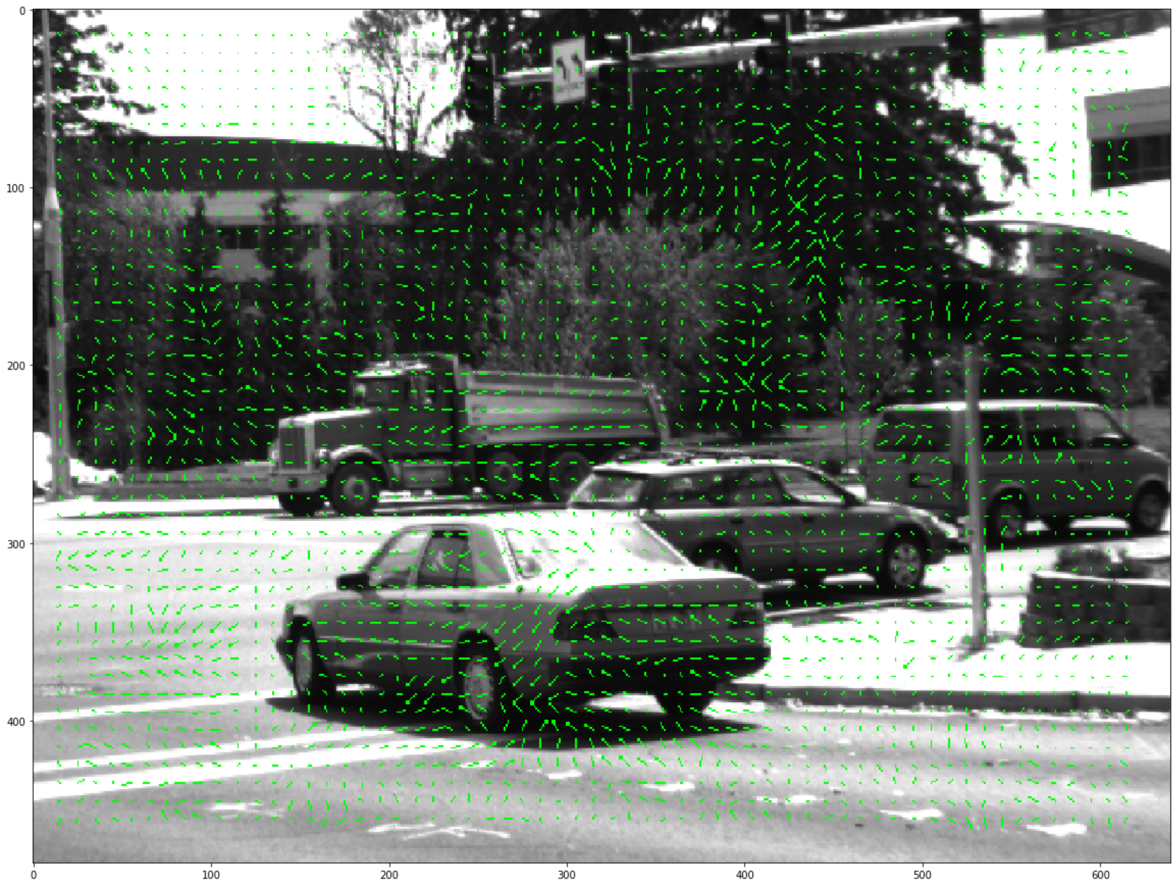
```
imagesDir = '../eval-data-gray/Backyard/'
img1Path = imagesDir + 'frame10.png'
img2Path = imagesDir + 'frame11.png'
img1 = cv2.cvtColor(cv2.imread(img1Path), cv2.COLOR_BGR2RGB)
img2 = cv2.cvtColor(cv2.imread(img2Path), cv2.COLOR_BGR2RGB)
flowImg2, _, _ = opticalFlow(img1, img2, kernel = 31, stride = 10, max_displace
showImage([flowImg2], figsize = (20,20))
```

In [61]:

```
imagesDir = '../eval-data-gray/Teddy/'
img1Path = imagesDir + 'frame10.png'
img2Path = imagesDir + 'frame11.png'
img1 = cv2.cvtColor(cv2.imread(img1Path), cv2.COLOR_BGR2RGB)
img2 = cv2.cvtColor(cv2.imread(img2Path), cv2.COLOR_BGR2RGB)
flowImg3, _, _ = opticalFlow(img1, img2, kernel = 31, stride = 10, max_displace
showImage([flowImg3], figsize = (20,20))
```

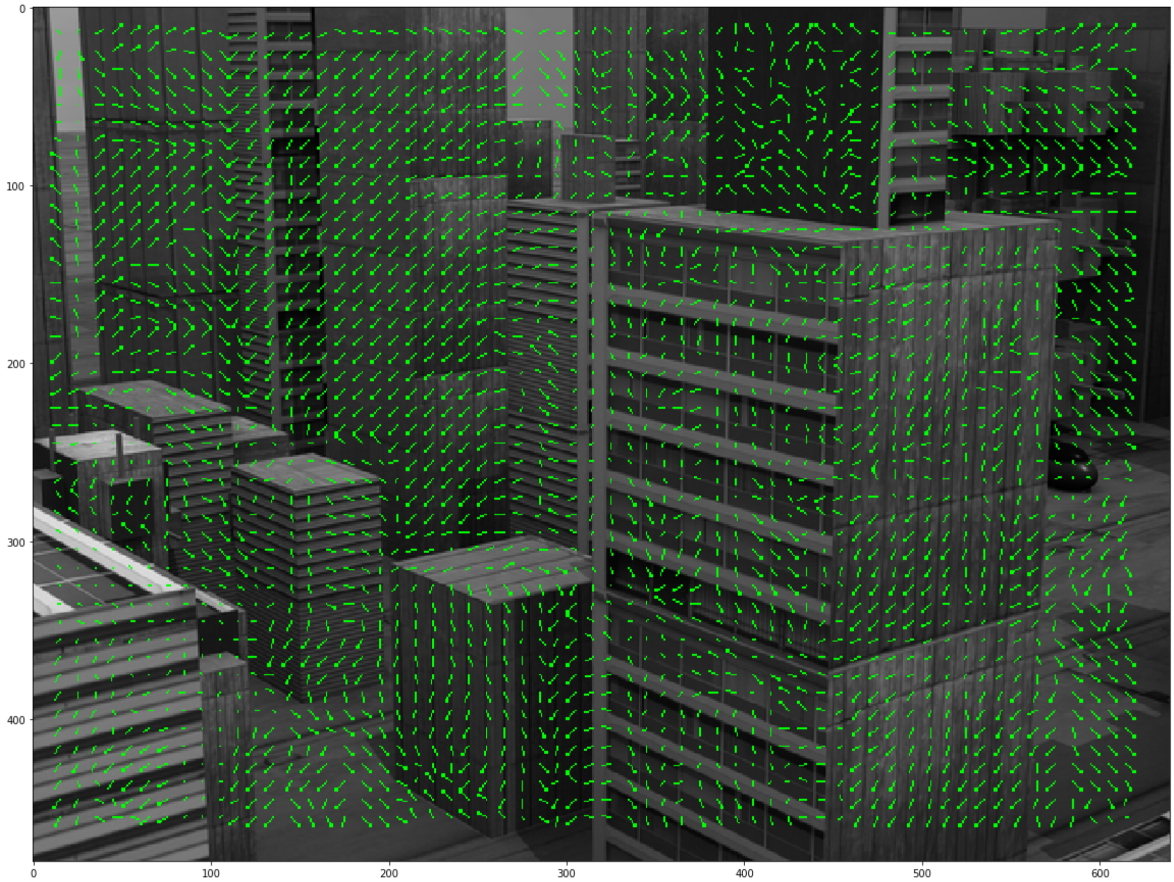
In [62]:

```python
imagesDir = '../eval-data-gray/Dumptruck/'
img1Path = imagesDir + 'frame10.png'
img2Path = imagesDir + 'frame11.png'
img1 = cv2.cvtColor(cv2.imread(img1Path), cv2.COLOR_BGR2RGB)
img2 = cv2.cvtColor(cv2.imread(img2Path), cv2.COLOR_BGR2RGB)
flowImg4, _, _ = opticalFlow(img1, img2, kernel = 31, stride = 10, max_displace
showImage([flowImg4], figsize = (20,20))
```



In [63]:

```
imagesDir = '../eval-data-gray/Urban/'
img1Path = imagesDir + 'frame10.png'
img2Path = imagesDir + 'frame11.png'
img1 = cv2.cvtColor(cv2.imread(img1Path), cv2.COLOR_BGR2RGB)
img2 = cv2.cvtColor(cv2.imread(img2Path), cv2.COLOR_BGR2RGB)
flowImg5, _, _ = opticalFlow(img1, img2, kernel = 31, stride = 10, max_displace
showImage([flowImg5], figsize = (20,20))
```



Object Detection and Visualization

To detect objects based on their optical flow we try to find bounding boxes for regions of image that have similar flow magnitude and orientation. For every point (x, y) find a neighbourhood around it that have flow similar to it. If the bounding box found is too large or too small based on some input threshold ignore it. Otherwise the neighbourhood is approximated as a bounding box and labelled as an object. Overlapping bounding boxes are merged into one to give a cleaner appearance. In order for multiple regions of the image to be detected for objects we have to perform object detection at multiple scales by resizing the image.

We find a bounding box around a pixel by iterating horizontally and vertically around the decision point. At every point we check if the magnitude of flow is close to the original point by a threshold theta. We similarly check if the angle of orientation is within a threshold value. However both these metrics are prone to failure in places where different parts of an object move at different velocities or move by different angles. This is somwhat mitigated by using different scales of the image. Since lucas kanade makes the implicit assumtion that the differences in object motion is minor between two frames we expect the variations to be minimal.

In [49]:

```
# finds a bounding box around a pixel
def getBoundingBox(magImg, dirImg, pos, mth, orth, stride=1):
    c, r = pos
    u,l = [c,r], [c,r]
    iInt, iDir = magImg[r][c], dirImg[r][c]
    if iInt == 0:
        return u, l

    # [Upper left corner]
    # find similar points above
    i = 0
    while r - i >=0:
        if magImg[r-i][c] == 0 or abs(magImg[r-i][c] - iInt) > mth or abs(dirIm
            break
        i += stride
    u[1] -= i

    i = 0
    # find similar points to the left
    while c - i >=0:
        if magImg[r][c-i] == 0 or abs(magImg[r][c-i] - iInt) > mth or abs(dirIm
            break
        i += stride
    u[0] -= i

    i = 0
    # [Lower right corner]
    # find similar points below
    while r + i < magImg.shape[0]:
        if magImg[r+i][c] == 0 or abs(magImg[r+i][c] - iInt) > mth or abs(dirIm
            break
        i += stride
    l[1] += i

    i = 0
    # find similar points to the right
    while c + i < magImg.shape[1]:
        if magImg[r][c+i] == 0 or abs(magImg[r][c+i] - iInt) > mth or abs(dirIm
            break
        i += stride
    l[0] += i

    return u, l
```

In [111]:

```python
def mergeRectangles(rects):
    if not len(rects):
        return []
    rects = sorted(rects)
    res_rects = [rects[0]]
    i = 1
    while (i < len(rects)):
        t1h, t1c, b1h, b1c = tuple(res_rects[-1])
        t2h, t2c, b2h, b2c = tuple(rects[i])
        if (b1c <= t2c or b1h <= t2h):
            res_rects.append(rects[i])
        else:
            res_rects[-1][2] = max(b1h, b2h)
            res_rects[-1][3] = max(b1c, b2c)
        i += 1
    return res_rects

def detectObjects(imageSet, kernel, mth = 4, orth = 180, scale = 1, minw = None
    imageScaled = [cv2.resize(image,None,fx=scale,fy=scale) for image in imageS
    stride = 5
    pimg, mImg, dImg = opticalFlow(imageScaled[0], imageScaled[1], kernel, stri

    # bounds to eliminate bounding boxes that are too small
    H, W, _ = imageScaled[0].shape
    if minw == None:
        minw = imageScaled[0].shape[1] * 0.1
    if minh == None:
        minh = imageScaled[0].shape[0] * 0.1

    # bounds to eliminate bounding boxes that are too large
    maxw, maxh = imageScaled[0].shape[1] * maxsc, imageScaled[0].shape[0] * max

    resImg = np.zeros(imageScaled[0].shape,dtype = np.uint8)
    pad =int(kernel/2)
    i,j = pad,pad
    bboxes = []
    while i < (imageScaled[0].shape[0]-pad):
        mxDisp = 1
        while j < (imageScaled[1].shape[1]-pad):
            u, l = getBoundingBox(mImg, dImg, (j,i), mth, orth, stride)
            if abs(u[0] - l[0]) > minw and abs(u[0] - l[0]) < maxw and abs(u[1]
                bboxes.append([u[1], u[0], l[1], l[0]])
            # skip some indices already evaluated
            j += (l[0] - j + 1)
            mxDisp = (l[1] - i + 1) if mxDisp == 1 else min(mxDisp,l[1] - i + 1
        i += mxDisp
        j = 0

    bboxes = mergeRectangles(bboxes)
    res_bboxes = []
    for bbox in bboxes:
        uh, uc, lh, lc = tuple(bbox)
        if (lc - uc) <= 0.3*W and (lh - uh) <= 0.4*H:
            res_bboxes.append([int(uh/scale), int(uc/scale), int(lh/scale), int
            cv2.rectangle(resImg, (uc, uh), (lc,lh), (0,255,0),2)

#     print (res_bboxes)
    resImg = cv2.resize(resImg, (imageSet[0].shape[1],imageSet[0].shape[0]))
    return resImg, res_bboxes
```

In [119]:

```python
# do object recognition at multiple scale and combine them
def multiScaleObject(imageSet, kernel, mth=4, orth=180, scaleset = [1], minw =
    combImage = np.zeros(imageSet[0].shape, dtype=np.uint8)
    combFlow = np.zeros(imageSet[0].shape, dtype=np.uint8)
    for i in scaleset:
        objImg = segmentObjects(imageSet, kernel, mth=mth, orth=orth, scale=i,
        flowImg, _, _ = opticalFlow(imageSet[0], imageSet[1], kernel,stride=5,
        combImage = cv2.add(combImage, objImg)
    omage = cv2.addWeighted(combImage, 0.3, imageSet[0],0.7,0)
    showImage([omage], figsize=(10,10))
```

In [58]:

```python
def movingObjectDetection(imageSet, kernel, scale = 1, mth=4, orth=180, minw =
    objImg = detectObjects(imageSet, kernel, mth=mth, orth=orth, scale=scale, m
    boxObjImg = cv2.addWeighted(objImg, 0.3, imageSet[0],0.7,0)
    return boxObjImg
```

In [59]:

```python
def getGoodPoints(img, pad, feature_params):
    corners = cv2.goodFeaturesToTrack(img[pad:-pad,pad:-pad], mask = None,**fea
    cset = []
    for c in corners:
        cset += [[int(c[0][0]),int(c[0][1])]]
    return cset
```

Feature Tracking through optical flow in an Video

Previously we had seen computed the direction and magnitude od flow at every point in the image. However all points in an image are not suitable for tracking purposes as they may not be sufficiently detailed for matching between subsequqnt frames of a video. Instead to find out good points for we use only those points where the eigenvalues of the 2nd moment matrix are both sufficently large. In other words we choose corner points in an image to track accross multiple frames of the video. The general procedure is as follows.

1. The good features that can be tracked are extracted. This can be done through harris corner detector. However opencv has an implementation goodFeaturesToTrack that automatically does this for us.
2. Consider two consecutive frames of the video. Calculate the gradients in x and y direciton of the first frame.
3. Perform lucas-Kanade feature tracking between the two frames taking a window around the detected corner point. The time gradient is taken as the difference in frames. If the framerate of the camera is sufficiently high we can assume that the difference between the frames is low and lucas kanade works
4. Repeat steps 2,3 for every consecutive frame in the video and trace out the movement of the corner point using the velocity gradient calculated at each step using LK.

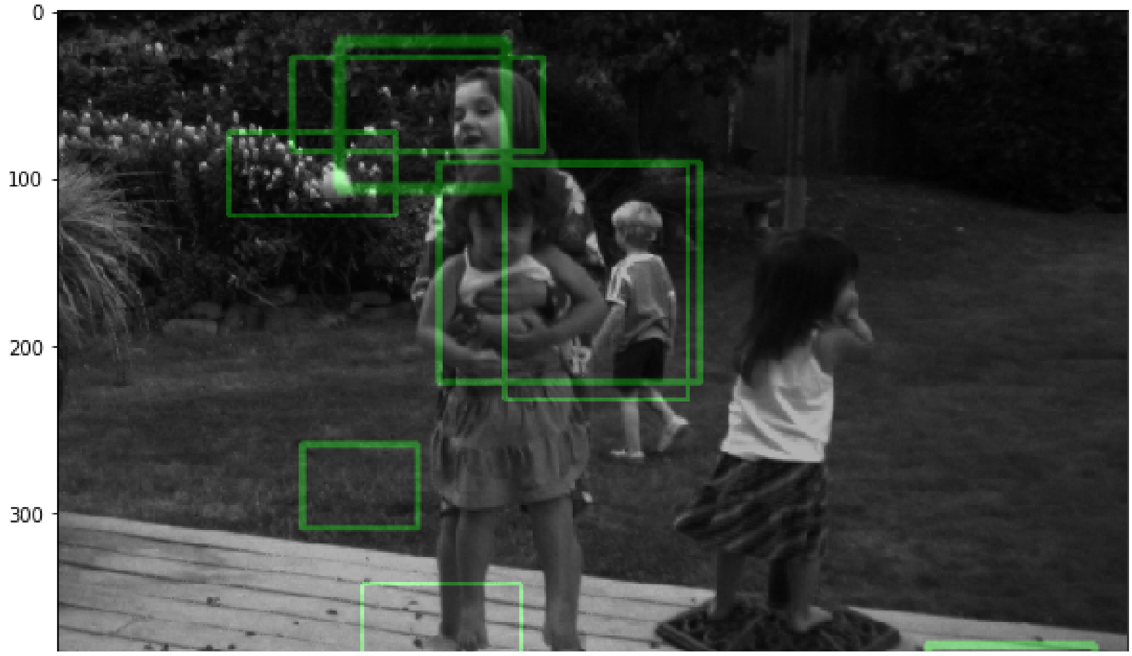
In [46]:

```
def goodPointsTracks(videoSet, kernel, tpoints = 5, mth = 0, PATH_TO_OUTPUT_VID
    feature_params = dict( maxCorners = tpoints,
                           qualityLevel = 0.01,
                           minDistance = 7,
                           blockSize = kernel )

    ret, image = videoSet.read()

    FRAME_WRITE_RATE = 25
    height, width, layers = image.shape
    frame_dims = (width, height)
    vid = cv2.VideoWriter(PATH_TO_OUTPUT_VIDEO, cv2.VideoWriter_fourcc(*'MP4V')

    grayImage = cv2.cvtColor(image,cv2.COLOR_BGR2GRAY)
    pad = int(kernel/2)
    corners = cv2.goodFeaturesToTrack(grayImage[pad:-pad,pad:-pad],mask = None,
    pathImg = np.zeros(image.shape)
    pathImg = np.uint8(pathImg)

    cset = getGoodPoints(grayImage, pad, feature_params)

    while 1:
        ret, image2 = videoSet.read()
        if not ret:
            break

        nextGrayImage = cv2.cvtColor(image2,cv2.COLOR_BGR2GRAY)

        xg,yg = getIxIy(grayImage)
        It = getIt(grayImage, nextGrayImage)

        nset = []
        path_modified = False
        for c in cset:
            n, dist, dirn = computeVelocities(xg, yg, It, grayImage, nextGrayIm
            if dist > mth:
                cv2.line(pathImg, (n[0], n[1]), (c[0], c[1]), (0, 255, 0), 2)
                nset += [n]
                path_modified = True

        cset = nset
        grayImage = nextGrayImage

        if path_modified:
            image2 = cv2.addWeighted(pathImg, 0.2, cv2.cvtColor(image2,cv2.COLO
            image2 = cv2.cvtColor(image2, cv2.COLOR_RGB2BGR)
            vid.write(image2)

    vid.release()
    return
```

Object Detection

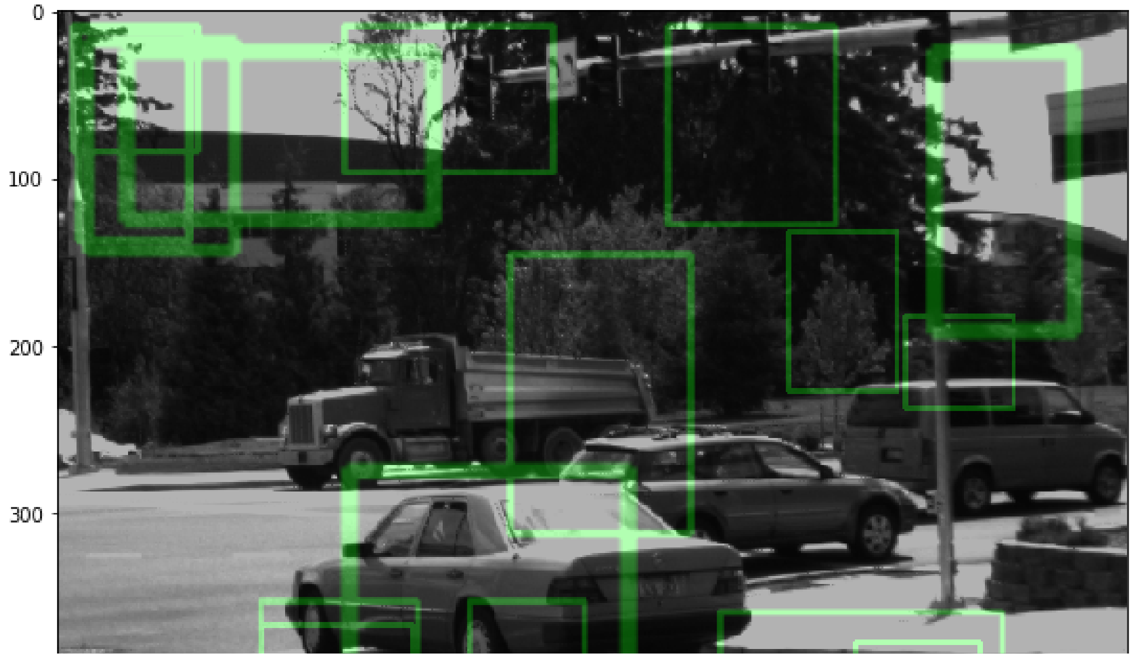
In [120]:

```
imageLoc = '../eval-data-gray/Backyard/'
imageSet = [imageLoc + str(image) for image in sorted(os.listdir(imageLoc))]
image = [cv2.cvtColor(cv2.imread(image), cv2.COLOR_BGR2RGB) for image in imageS
multiScaleObject(image, 25, mth = 2.5, orth = 180, scaleset = [0.3,0.4,0.6,0.8,
```



In [121]:

```
imageLoc = '../eval-data-gray/Dumptruck/'
imageSet = [imageLoc + str(image) for image in sorted(os.listdir(imageLoc))]
image = [cv2.cvtColor(cv2.imread(image),cv2.COLOR_BGR2RGB) for image in imageSe
multiScaleObject(image,25,mth=2.5,orth=180,scaleset=[0.3,0.4,0.6,0.8,1],minw=No
```



In [17]:

```
FRAME_WRITE_RATE = 25
PATH_TO_OUTPUT_VIDEO = "./traffic_detection.mp4"

imageLoc = './traffic_detection_frames/'
imageSet = [imageLoc + str(image) for image in sorted(os.listdir(imageLoc))]
rgbImageSet = [cv2.cvtColor(cv2.imread(image),cv2.COLOR_BGR2RGB) for image in i
```

In [20]:

```
vid = None
for i in range(len(rgbImageSet)-1):
    print (i, end=" ")
    if not vid:
        height, width, layers = rgbImageSet[0].shape
        frame_dims = (width, height)
        vid = cv2.VideoWriter(PATH_TO_OUTPUT_VIDEO, cv2.VideoWriter_fourcc(*'XV
    objImg = movingObjectDetection([rgbImageSet[i], rgbImageSet[i+1]], 15, mth=
    vid.write(objImg)
vid.release()
```

...

Object Detection OUtput Video:

[https://drive.google.com/file/d/19_wQra-T6hMINGHz7Y_eTORh3pflzND-/view?usp=sharing (https://drive.google.com/file/d/19_wQra-T6hMINGHz7Y_eTORh3pflzND-/view?usp=sharing)](https://drive.google.com/file/d/19_wQra-T6hMINGHz7Y_eTORh3pflzND-/view?usp=sharing)

Tracking with LK

In [41]:

```
video = cv2.VideoCapture('./traffic.mp4')
PATH_TO_OUTPUT_VIDEO = "./tracking_traffic.mp4"
goodPointsTracks(video, 31, tpoints = 10, mth = 0.05, PATH_TO_OUTPUT_VIDEO=PATH

```

...

Object Tracking Input Video:

[https://drive.google.com/file/d/1hQ-2Pi-xk6e1yjlovc6PMaOXaiLaJtf2/view?usp=sharing (https://drive.google.com/file/d/1hQ-2Pi-xk6e1yjlovc6PMaOXaiLaJtf2/view?usp=sharing)](https://drive.google.com/file/d/1hQ-2Pi-xk6e1yjlovc6PMaOXaiLaJtf2/view?usp=sharing)

Object Tracking Output Video:

[https://drive.google.com/file/d/1b7QHbbJxvMzjlJX1tphRqtt0-joLe7rH/view?usp=sharing (https://drive.google.com/file/d/1b7QHbbJxvMzjlJX1tphRqtt0-joLe7rH/view?usp=sharing)](https://drive.google.com/file/d/1b7QHbbJxvMzjlJX1tphRqtt0-joLe7rH/view?usp=sharing)

In [ ]:

```

```