Basic of Optical Flow

Thought Experiments -

1. **The number-one use of optical flow in visual effects is for retiming a sequence — speeding it up or slowing it down. Describe how optical flow could be used to create slow motion video. You can find the answer in Amazing Slow-Motion Videos with Optical Flow video on YouTube.**

   Answer –

   Interpolation is a method by which we can estimate new frames between 2 consecutive frames. Optical Flow uses the concept to interpolation for estimating the most probable frame which can be fitted between the two frames. For example, let say we have 2 frames, and we need to add one more frame in between two frames, we can simply find the mean of both frames and fit the resultant frames between two frames. This additional frame will convert our videos in slow motion.

2. **In The Matrix, one of the most remembered, iconic use of the tactic comes during the rooftop scene where Neo effortlessly dodges one bullet after another. (Re-)watch "Bullet Time" here and explain briefly how optical flow is used. You may also find this amazing video on bullet-time interesting.**

   Answer –

   Slow motion videos can be created using either recording the video at very high fps rate or by adding frames between existing frames using interpolation. We can deploy multiple number of cameras to catch a greater number of frames per shot and we can combine the frames taken by multiple cameras. Also, we will have camera at different such that we will be able cover 360 degrees spectrum of the shot. Also, we can use the concept of interpolation to find the intermediate frames and add those frames to make video smoother and slower. In the case, they have combined the concept amazingly well to create the illumination. Bullet time is created in The Matrix on a green screen set with a succession of stationary cameras encircling the subject. The cameras are turned on in quick succession, and the generated frames are presented with additional CGI interpolated frames, giving the impression that the camera is moving quicker than the subject.

3. **So breathtaking, heartbreaking and brimming with emotion, WDMC is a journey into the afterlife and deals with a dead man's attempt to reunite with his wife. Catch a glimpse of the" Painted World" here! You will now describe briefly on how optical flow is used to create this "painterly effect".**

   Answer –

To get the painterly effect, we will first determine the change vector for each pixel. We must find the optical flow between two frames and then plot this optical flow on the frame. Optical flow works by generating a motion vector map for every pixel in a frame. For each frame, a sub-pixel positional value of x and y is created, which can then be compared to the next. This effectively tracks the movement of each and every piece within a composition.

4. **Consider a Lambertian ball that is: (i) rotating about its axis in 3D under constant illumination and (ii) stationary and a moving light source. What does the 2D motion field and optical flow look like in both cases.**

   Answer -

   - In 1^{st} case when the Lambertian ball is rotating about its axis and the light source is fixed, we will not be able to find any optical flow even though the ball is continuously moving. This happens because the surface of the ball is even throughout and there is no change in intensity at time t and t+dt.
   - In 2^{nd} case when the Lambertian ball is fixed and the light source is moving, we will get the optical flow even though the ball is not moving. This is because the light source is moving so the shadow and the pixels which are the facing the light will change constantly. So, there will be some difference in intensities of pixel at time t and time t+ dt which will give us the optical flow.

   In both cases, the optical flow is not equal to the motion field.

Concept Review

1. **List down the important assumptions made in optical flow estimation. Describe each one of them in one-two lines.**

   Answer -

   The two important assumptions made in optical flow estimation are as follows:

   - **The observed brightness of any object point is constant over time**: The assumption is based on the consideration that pixels in a small window usually follow the similar displacement and hence the movement of the pixels under considerations in consecutive frames over a window will give the similar optical flow.
   - **I Nearby points in the image plane move in a similar manner (velocity smoothness constraint):** The assumption is based on the consideration that pixels in a small window have a similar flow and tend to follow it. Hence, we get similar intensity values over the small window of pixels.

2. **Formalize the objective function of the classical optical flow problem. Clearly mark the data term and the spatial term. What does the objective function imply about the noise distribution?**

   Answer -

   In Optical Flow problem, we make basic assumptions that the intensity of pixel at time t is equal to intensity at time t+dt.

   $$\mathbf{I(x, y, t\text{-}1) = I(x + u, y + v, t)}$$

   $$\mathbf{I(x, y, t\text{-}1) = I(x, y, t) + I_x{*}u + I_y * v}$$

   $$\mathbf{I_x * u + I_y * v + I_t = 0}$$

   Here, I_x = dI/dx (partial differential of I w.r.t to x)

   I_y = dI/dy (partial differential of I w.r.t to y)

   I_t = dI/dt (partial differential of I w.r.t to t)

   The Ix and Iy terms in the equation are called data terms and it is the spatial term.

   Before finding the optical flow, we must apply Gaussian blur to the image to decrease the noise distribution because the objective function does not include a noise distribution term, we must first pre-process the image before applying it.

3. **In optimization, why is the first-order Taylor series approximation done?**

   Answer-

   The brightness constancy assumption in optical flow is that the intensity of pixels in a narrow window remains constant over time. So,

   f(x,y,t) = f(x+dx, y+dy, t+dt) = f(x+dx, y+dy, t+dt) (where x, y is pixel value at x, y and t is the temporal dimension)

   Because the difference is very little, we can use the Taylor series approximation on the given equation. The Taylor series approximation's higher-order terms become very close to 0 and are hence discarded. As a result, we're left with only the first-order Taylor series approximation terms. We just consider the change in intensity rather than the intensity values in each subsequent frame with the help of this optimization.

4. **Geometrically show how the optical flow constraint equation is ill-posed. Also, draw the normal flow clearly.**