Implementation of Phase Based Optic Flow Algorithm for Obstacle Detection

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Abstract

Optic flow is the apparent visual motion that one experiences during motion. A fundamental problem in Machine Vision and processing of image sequences is the estimation of the optic flow, which is the projection of the 3D surface point motion on a 2D sensor plane.

This paper deals with the phase based algorithm for optic flow computation. The phase based optic flow technique is robust with respect to smooth shading and lighting variations and is amplitude invariant. Therefore, in this method phase contours are tracked over time. The image sequence is spatially filtered using a bank of Gabor filter quadrature pairs and its temporal phase gradient is computed. The velocity estimates with directions orthogonal to the filter pair's orientations are combined at a specific spatial location. The component velocity is rejected if the corresponding filter pair's information is not linear over time.

A detailed study was carried out on the optic flow algorithms with a specific interest for its utility in Micro Air Vehicles (MAV). The related research by Temujin Gautama and Marc M. Van Hulle was selected and reviewed in view of its relevance to phase stability with respect to geometric deformations and its linearity as a function of spatial position. The selected algorithm was implemented through a developed MATLAB code and its results were correlated with that derived through a developed C code. The simulated results were also compared with pertinent-published results. The error metrics were identified and a performance evaluation of implemented phase based optic flow algorithm was carried out with the available standard synthetic image sequences. The implemented algorithm was also tested for its validity with the real time sequences.

Key Words: Machine Vision, Optic Flow, Phase Contours, Velocity Tuned Spatial Filters

1. INTRODUCTION

Optic Flow is the apparent visual motion one experiences as one moves, the experience of the motion is apparently opposite. Machine vision is usually concerned with the 2D images and hence the 3D image motion when projected upon the 2D image or a sensor plane is called as optic flow. When viewed from an air vehicle, this motion can also tell how close the viewer is to the different objects seen. Distant objects like clouds and mountains move very slowly, hence they appear almost still. The objects that are relatively close, such as buildings and trees, appear to move backwards. The closer objects appear to move faster than the distant objects. Very close objects, move so fast they whiz right across. This motion has enough information also to tell how close is the moving object relative to a visible obstacle. Further techniques could be developed to find out the Time To Contact (TTC) and then avoid them or deviate based on decision logics.

A. Verri and T. Poggio [1] have shown that the 2-D motion vector field which is the perspective projection on the image plane of 3-D velocity field of a moving scene, and the optical flow are in general different, unless special conditions are satisfied. Optic flow defined as the estimate of the motion field can be derived from the first-order variation of the image brightness pattern. The motion vectors may relate to the whole image (global motion estimation) or specific parts, such as rectangular blocks, arbitrary shaped patches or even per pixel. The motion vectors may be represented by a translational model or many other models that can approximate the motion of a real video camera, such as rotation and translation in all three dimensions and zoom. But the authors clarify that the flow in detail for each pixel may not be required for motion estimation but only a smoothened version could be enough. Moreover it is the optic flow which is the basic and fundamental problem in processing velocities from the sequence of images. This stand is confirmed by Barron and the co authors in [2]. Further [2] authors have carried out exhaustive and quantitative evaluation performed with various proposed techniques.

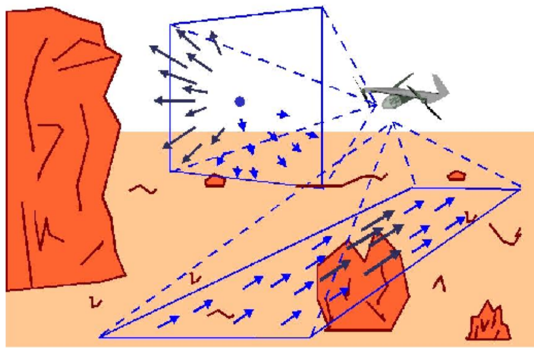


Fig. 1 Optic flow as seen from an aircraft [3]

The figure 1 as taken from [3] shows what the optic flow might look like from an aircraft flying over a rocky desert. Looking downward, there is a strong optic flow pattern due to the ground and rocks on the ground. The optic flow is fastest directly below the aircraft. It is especially fast where the tall rock protrudes from the ground. Looking forward, there is another optic flow pattern due to the upcoming rock and anything else the aircraft might be approaching. The circular dot directly at the center shows the "focus of expansion" or FOE. The FOE tells the aircraft the specific direction it is flying. The aircraft sees a large optic flow to the right of the FOE, which is due to the large rock on the left-hand side of this picture. The aircraft also sees smaller optic flow patterns in the downward-front direction, due to the ground. Towards its upper left, it sees no optic flow because this region of the visual field only has the sky. The forward optic flow pattern reveals that the aircraft will fly close by the big rock, perhaps dangerously close. If the optic flow on the aircraft's right grows larger, then the aircraft should take that as a hint to turn away.

Many researchers consider optical flow estimation as an important low level stage of spatial motion recovery from a sequence of images. It is supposed to yield an estimate of the 2D projection of the velocity field on the image plane, which is submitted to further analysis aimed at inferring high level, 3D motion description. Optic flow field (u, v), is a vector field that shows the direction and magnitude of the intensity pattern change of a given pixel from one image to the next in the sequence as shown in Figure 2.

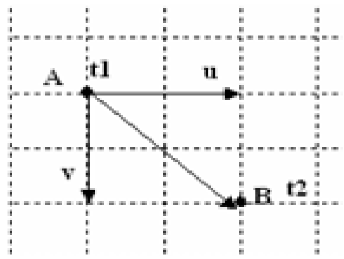


Fig. 2 Velocity vectors u and v [3]

If a point A at t1 has moved to B at t2, the component of motion in the horizontal direction is given by u and that in the vertical direction is given by v. AB is the Optical Flow vector.

In a wider view, literature reveals that optic flow techniques are widely used in various applications like motion estimation [3], Biometrics [4] and film industry [5]. In [6] the author Geoffrey L Barrows discusses about motion detection, object segmentation, TTC, FOE calculations, motion compensated encoding and stereo disparity measurements.

Ted Camus in [7] rightly mentions that for an organism there exists two kinds of motion perceptions one is the real and the other is the apparent, the correspondence problem must be solved to differentiate the features between the earlier and later visions but the method to solve it varies if the apparent image has a sufficiently small or a larger motion. In the larger motion the structures may have to be correlated but in the smaller one each detail has to be studied.

The author Ted in [8], illustrates a clear distinction between motion field and optical flow. A perfect non textured, featureless, rotating sphere will not induce any optical flow but motion field is non zero. But if the same sphere is non-rotating but a lighting source moves so as to induce a changing shade over the sphere, then motion field is zero but optical flow exists. For a sufficiently textured surface both would be closely the same. However it is the requirement that states what techniques should be chosen and what algorithms yield better velocity estimates.

In an image representation a single pixel itself is represented by an intensity value which again depends on the factors like intensity, colour, location, light source, optical and electrical properties of the imaging device etc. For a real time implementation of the optic flow usage, all the parameters including noise and its variations must be modelled without which its response in these variations would not be known or the algorithmic performance would not be guaranteed unless the algorithm takes care of its immunity to noise or any such above mentioned real time factors. However literature on statistical model of all these factors implemented or efforts to do so, for the optic flow in real time is almost non existent.

1.1 Overview of Optical Flow Techniques

Generally Optic Flow based velocity vectors can be computed using various methods. The authors in [5] have surveyed them and classified them as a) intensity based differential-methods, b) multi-constraint methods, c) frequency based methods, d) correlation based methods, e) multiple motion methods and f) temporal refinement methods, however if an attempt is made to reclassify them, the broad classifications could include the following:

Intensity based Methods: Intensity based methods use spatial and temporal partial derivatives, to estimate optical flow at every position in the image. Gradient Based methods are one of them. They compute image velocity from spatio-temporal derivatives of image intensities. The image domain is therefore assumed to be continuous (or differentiable) in space and time.

Correlation based Methods: Correlation based methods use matching concepts. Typically, good and defined features, such as corner points and edges, are used for matching. Correlation based matching technique define displacement (which is an approximation to velocity) as a shift that yields the best fit between contiguous time varying image regions.

Intensity based Correlation Method: The intensity based correlation techniques begin with intensity constancy and adopt a matching strategy. Given a region in one image the goal is to find the displacement of that region in the next image that minimizes the error.

Feature based Correlation Method: The only difference between the two correlation methods is that the input to the feature based optical flow system is preprocessed to get the edges and in the intensity method, there is no feature detection before the application of the optical flow algorithm. Feature based techniques could be made to run faster by only estimating optical flow vectors for the regions of edges in the images.

Frequency based Methods: Frequency based methods use velocity-tuned filters to determine optical flow fields. The frequency based techniques use orientation sensitive filters in the Fourier domain of time varying images [9,10].

Energy based method: The methods are based on measuring the output energy of the velocity tuned filters; these are classified as the frequency based methods because the velocity tuned filters are designed in the Fourier domain. The literature shows that all non-zero power related to the translating 2D pattern lies on the plane through the origin in the frequency space. The literature reveals that some of them are also shown equivalent to the correlation based and some others to gradient based methods.

Phase based method: The phase based method consists of spatiotemporal filters by which the phase contours are tracked with respect to the sequence of image-related time. The filter concerned are so designed that they are the functions which are dependent on the spatial dimension of the image as well as the time which is the sequence flow. The zero crossings could be measured or phase gradients could be calculated or phase correlation could be performed for computing the optic flow vectors. This paper implements a method which has the filter whose design is based on spatial dimension of image alone and the phase gradients of the sequences are calculated which has certain benefits compared to the spatiotemporal solution.

1.2 Applications of Optic Flow

Avoiding Obstacles is a natural phenomenon in the living beings, this concept can be explained with a classic example of a dragonfly [3].

Speed Control through Dense Environments: In some cases, one may want to change the flight speed to fly slower when in a cluttered environment as referred from [3].

1.3 Summary

An Optical Flow is a Technique used in variety of applications; various time and spatial methods are available for the computation of the optic Flow. The focus of this paper is mainly with reference to Micro Air Vehicles (MAV)'s. The intention is to approach towards TTC.

2. MATLAB CODE FOR PHASE BASED OPTIC FLOW

In the earlier sections a clear methodology was developed for the implementation of the phase based method of optic flow, after providing a literature overview on various techniques in spatial domain and frequency domain. In this section attempt is made to summarize the theory behind phase based methods, further as mentioned in the methodology a phase based method which was mentioned as the best among the surveyed literature in the phase based method was chosen for implementation.

2.1 Algorithm Design for Development in MATLAB

It was concluded from the existing literature that The Phase based Methods are advantageous in Velocity Resolution, Sub pixel Accuracy and Robustness with respect to the smooth contrast changes, scale, Orientation and speed than amplitude measures [11].The literature reveals that the representation based on the Spatiotemporal filter outputs is efficient and because it is sub sampled at reasonable rates and quantized. It is hoped that even lower sampling rates could be tolerated with similar or better accuracy with better forms of interpolation [12]. The current techniques require that the relative errors in optical flow to be less than 10% [13]

The literature reveals the arguments which summarize that accurate estimates of the 2D motion field are generally inaccessible due to the inherent differences between the 2D motion fields and the Intensity variations [14]. Despite of their many differences most of the techniques can be viewed conceptually in terms of three stages of processing namely pre-filtering, enhancement of Signal to Noise Ratio (SNR) and extraction of basic measurements. Pre-filtering or smoothing include filter design, generally low pass filters. Band pass filters are used to extract the structure of interest and to enhance signal to noise ratio. The extraction of basic measurements includes obtaining the spatiotemporal derivatives or phase contours. This helps to measure normal components of velocity or local correlation surfaces the integration of these measurements to produce a 2-D flow field with assumptions of the smoothness involved in the underlying flow field. The technique used here is not strictly limited to Gabor Kernels alone; other filters with non separable Kernels with unit aspect ratio could be used but specifically requires that they should be quadrate pairs and exhibit constant phase properties [14].

2.2 Design Specifications

The Frequency based methods use velocity-tuned filters to determine optical flow fields. The frequency based techniques use orientation sensitive filters in the Fourier domain of time varying images. Frequency based method is further classified into two types, namely energy based method and phase based method.
Phase-based approach proceeds in three stages. First, the image sequence is spatially filtered using a bank of quadrature pairs of Gabor filters, and the temporal phase gradient is computed, yielding estimates of the velocity component in directions orthogonal to the filter pairs' orientations. Second, a component velocity is rejected if the corresponding filter pair's phase information is not linear over a given time span. Third, the remaining component velocities at a single spatial location are combined and are used to derive the full velocity. Spatial filtering not spatiotemporal filtering bank of 11 quadrature gabor filter based filter is constructed. Every quad pair filter yields the estimate of component velocities, direction which are orthogonal to the filter pairs in the spatial orientation

2.3 Theory - Phase Information and Stability

As previously mentioned spatial domain operable methods generally are sensitive to temporal illumination changes. It is already mentioned that phase information is rich enough for extracting essential information of the images with regard to motion analysis. Many researchers suggested the zero crossing methods through the usage of phase information's but, that zero-crossings are not sufficient. Fleet et al [15] proposed the use of the phase for the computation of optical flow. In linear systems theory it is known that the phase of the Fourier transform of a signal carries the frequency information which is reliable. An image can still be recognized when the amplitude information is lost, but no longer, when the phase is lost [16]. Global illumination changes the amplitude of a signal but not its phase.

As an introduction to the phase method, consider a planar 1-D wave with a wave number k and a circular frequency w, travelling with a phase speed u = w/k:

$$g(x,t) = g_0 \exp[-i(\phi(x,t))] = g_0 \exp[-i(kx - wt)] \quad \text{.....} (2.1)$$

The position and thus also the displacement is given by the phase. The phase depends both on the spatial and temporal coordinates. For a planar wave, the phase varies linearly in time and space.

$$\phi(x,t) = kx - wt = kx - \mu kt \quad \text{.....} (2.2)$$

where, k and w are the wave number and the frequency of the pattern, respectively. Computing the temporal and spatial derivatives of the phase, i.e., the gradient in the xt space, yields both the wave number and the frequency of the moving periodic structure

$$\nabla_{xt}\phi = \begin{bmatrix} \frac{\partial \phi}{\partial x} \\ \frac{\partial \phi}{\partial t} \end{bmatrix} = \begin{bmatrix} k \\ -w \end{bmatrix} \quad \text{.....} (2.3)$$

Then the velocity is given as the ratio of the frequency to the wave number

$$\mu = \frac{\omega}{\kappa} = -\frac{\partial \phi}{\partial t} \Big/ \frac{\partial \phi}{\partial x} \quad \text{.....} (2.4)$$

This formula is very similar to the estimate based on the optical flow. In both cases, the velocity is given as a ratio of temporal and spatial derivatives. Thus at first the phase method appears to offer nothing new. Replacing the gray value by the phase is, however, a significant improvement, since the phase is much less dependent on the illumination than the gray value itself. Using only the phase signal, the amplitude of the gray value variations may change without affecting the velocity estimates at all.

So far, an ideal periodic gray value structure was considered. Generally images are composed of gray value structures with different wave numbers. From such a structure we cannot obtain useful phase estimates. Consequently, we need to decompose the image into a set of wave number ranges. This implies that the phase method is not appropriate to handle two-dimensional shifts; it is essentially a 1-D concept which measures the motion of a linearly oriented structure, a planar wave, in the direction of the gray value gradients. From this fact, Fleet and Jepson [17] derived a new paradigm for motion analysis. The image is decomposed with directional filters and in each of the components normal velocities are determined. The 2-D motion field is then composed from these normal velocities. This approach has the advantage that the composition to a complete motion field is postponed to a second processing step which can be adapted to the kind of motion occurring in the images. Therefore this approach can also handle more complex cases as motion superimposition of transparent objects.

Fleet and Jepson [18] use a set of Gabor filters for the directional composition. Gabor filters are quadrature filters with a shifted Gaussian-shaped transfer function. Fleet and Jepson used six directional filters with an angle resolution of 30° and a bandwidth of 0.8 octaves. The phase can directly be computed from quadrature filter pairs because of the following properties: Each quadrature filter pair consists of an even and odd kernel, + Q and -Q, which have the same magnitude of the transfer function.

The even filter does not cause a phase shift, while the odd filter shifts the phase of all wave numbers by $\pi/2$. Therefore the phase is given by

$$\phi(x,t) = \tan^{-1}\frac{q-(x,t)}{q+(x,t)} \quad \text{.....} (2.5)$$

From the partial derivatives of the phase function, one can obtain the velocity estimate.

Computation of Phase Gradients: Direct computation of the partial derivatives from the phase signal is not advisable because of the inherent discontinuities in the phase signal (restriction to the main interval $[-\pi,\pi]$). From equation we obtain phase values which are additively ambiguous by 2^π and thus cause discontinuities in the phase signal if the values are restricted to the principal interval $[-\pi,\pi]$. As pointed out by Fleet and Jepson [18], this problem can be avoided by computing the phase gradient from gradients of q+(x,t) and q-(x,t). Using (4.2) and (4.5), we obtain

$$\nabla_{xt}\phi(x,t) = \frac{q^2{}_+(x,t)}{q^2{}_+(x,t)+q^2{}_-(x,t)}\left(\frac{\nabla_{xt}q-(x,t)}{q_+(x,t)} - \frac{q_-(x,t)\nabla_{xt}q+(x,t)}{q^2{}_+(x,t)}\right)$$
$$= \frac{q_+(x,t)\nabla_{xt}q_-(x,t) - q_-(x,t)\nabla_{xt}q+(x,t)}{q^2{}_+(x,t)+q^2{}_-(x,t)} \quad \text{.....} (2.6)$$

This formulation of the phase gradient also eliminates the need for using a Trigonometric function to compute the phase signal. The optical flow is given by

$$^p f = -\frac{q_+\frac{\partial q_-}{\partial t} - q_-\frac{\partial q_+}{\partial t}}{q_+\frac{\partial q_-}{\partial x} - q_-\frac{\partial q_+}{\partial x}} \quad \text{.....} (2.7)$$

Selection of Quadrature filter: In signal processing there is a well established and commonly used method for filtering known as quadrature filters which are used in low-level image processing for computing the local energy and local phase of a signal. We know that the local energy is an estimate of the local intensity structure and the local phase provides information about the local shape of the signal. By enlarge in 1D cases the quadrature filter are well defined by an even part, a bandpass filter, and an odd part, the Hilbert transformation of the bandpass filters. The filter output is the analytic signal, a representation of the signal from which the local energy and local phase can easily be computed. Denis Gabor In 1946, [18] as cited by Boukerroui in [18] introduced the windowed Fourier transform, also called the Short Time Fourier Transform (STFT). Essentially, instead of using a sinusoidal basis function e^{iwx} which is well localized in frequency but not localized in time, he used what are now called "Gabor atoms". These are constructed by translating in time/space and frequency a real and symmetric time/space window g:

$$g_{x0,wo}(x) = g(x-x_0)\exp[iw_0 x] \quad \text{.....} (2.8)$$

The energy of $q_{\frac{x0}{w0}}$ is concentrated in the neighborhood of $x0$ over an interval which can be measured by the standard deviation σ_g of $\|g\|^2$. Its Fourier transform is a translation by $\omega 0$ of the Fourier transform G of g. Therefore the energy of $q_{\frac{x0}{w0}}$ is concentrated near $\omega 0$, over an interval of size σ_g. In a time-frequency (scale-space) plane (x, w), the energy spread of Gabor atoms can be represented as a rectangle of width $\sigma_g \sigma_G$ centered on $(x_{o,} w_0)$. Such a rectangle is called a "Heisenberg rectangle" [20] as cited in [21] and the uncertainty principle shows that its area satisfies:

$$\sigma_g \sigma_G \geq \frac{1}{2} \quad \text{.................................... (2.9)}$$

Equality applies only when g is a Gaussian, in this case the atoms $q_{\frac{x0}{w0}}$ are called Gabor functions. A one-dimensional Gabor function is a Gaussian modulated complex exponential.

$$g_b(\sigma, w_0)(x) = n_c \frac{1}{\sqrt{2\pi\sigma}} \exp\left(-\frac{x^2}{2\sigma^2}\right) \exp\left[iw_0 x\right] \quad \text{...... (2.10)}$$

$$G_{b(\sigma, w_0)}(w) = n_c \exp\left(-\frac{\sigma^2}{2}(w - w_0)^2\right) \quad \text{(2.11)}$$

where $w_o = 2\pi/\lambda_o$ is the peak tuning frequency and nc is a normalization constant which is application dependent. Two alternative normalization conditions have been used most frequently in the literature:

Maximum condition:

$$\max G_b(w) = 1 \Rightarrow n_c = 1$$

Constant energy condition:

$$\|g_b(x)\| = \int_{-\infty}^{\infty} g_b{}^*(x) g_b(x) dx = 1 \Rightarrow n_c = \sqrt{2\sqrt{\pi\sigma}} \quad \text{(2.12)}$$

The half-response spatial frequency bandwidth (in octaves) is defined as

$$\beta = \log_2\left(\frac{w_2}{w_1}\right) \quad \text{(2.13)}$$

Where ω_1 and ω_2 are the solutions of $G_b(w)|n_c = 1/2$ and $w_1 \langle w_2$. It follows that the bandwidth of the Gabor filter(s) is the following function of $K_\beta = \sigma\omega_0$:

$$\beta(k_\beta) = \frac{\ln\left(\frac{k_\beta + \sqrt{2\,In(2)}}{k_\beta - \sqrt{2\,In(2)}}\right)}{In(2)} \quad \text{.................. (2.14)}$$

Alternatively:

$$k_\beta = \sqrt{2\,In(2)} \frac{2^\beta + 1}{2^\beta - 1} \quad \text{...................... (2.15)}$$

2.4 Component Velocity

Quadrature Gabor filter pairs are used, characterized by their center frequencies, (f_x, f_y), and the width of the enveloping radially symmetric Gaussian, σ.

Filters with constant bandwidths of β octaves, measured at one standard deviation in the frequency domain.

Spatial Width being:

$$\sigma = \frac{2^\beta + 1}{(2^\beta + 1) 2\pi \sqrt{f_x^2 + f_y^2}} \quad \text{.............. (2.16)}$$

Output of the quadrature Gabor filter pair is complex-valued, and the phase component of the output is denoted by $\phi(x, t)$.

Let $\phi(x, t) = c$

Differentiating with respect to x we obtain

$$\nabla\phi(x,t).\nabla x = \nabla\phi(x,t).(v,1) = (\phi_x, \phi_t).(v,1) = 0$$

$$\begin{aligned} \phi_t &= -(v.\phi_x) \\ &= -\|\phi_x\|(v.\phi_x^n) \\ &= -\|\phi_x\| proj_{\phi_x^n}(v) \end{aligned} \quad \text{.......... (2.17 a)}$$

This defines the aperture problem. Figure 3 a) shows the equation and Figure 3 b) shows its physical significance.

The component velocity is denoted by v_c, and computed as

$$v_c = proj\phi_x^n(v)\phi_x^n = -\frac{\phi_t(x)}{2\pi(f_x^2 + f_y^2)}(f_x, f_y) \quad \text{.......... (2.17 b)}$$

Substitute the spatial phase gradient ϕ_x by the frequency vector $2\pi f_x, 2\pi f_y$ which, only holds if the bandwidths of the filters approach zero.

For every filter pair *i*, the temporal phase gradient, $Q_{t,i}(x)$ is computed from the temporal sequence of its phase components by performing a least-squares linear regression on (t, ϕ) - pairs.

Phase-unwrapping is performed by compensating for the phase wrap-around is done by adding or subtracting $(k.2\pi)$ if $|\phi(x, t + \Delta t) - \phi(x, t)|$ exceeds π.

Gradients larger than π cannot accurately be estimated and lead to large regression errors.

The slope of the (t, ϕ)-regression line corresponds to the phase gradient, $\phi_t(x)$.

At $\phi_x = \pm 180^0$, the phase gradient does not yield stable results: small changes in phase can correspond to large spatial displacements due to phase wrap-around. The simple phase-unwrapping technique is not suited for large phase gradients [19], and these will be detected by examining the quality of the least-squares regression.

Confidence Measure: A measure used for determining the correctness of the computed velocities is called confidence measure, which greatly influences the performances of different optical flow algorithms. Referenced by Barron [20].Confidence Measures are used as thresholds to retain a subset of valid estimates that is to be used as weights in subsequent computations. These are the two-fold constraint on the component velocity proposed by Fleet and Jepson's suggested phase based method's estimates, one on the local frequency, to ensure that the detected local frequency is within the pass band of the spatiotemporal filter pair, and one on the local signal amplitude.

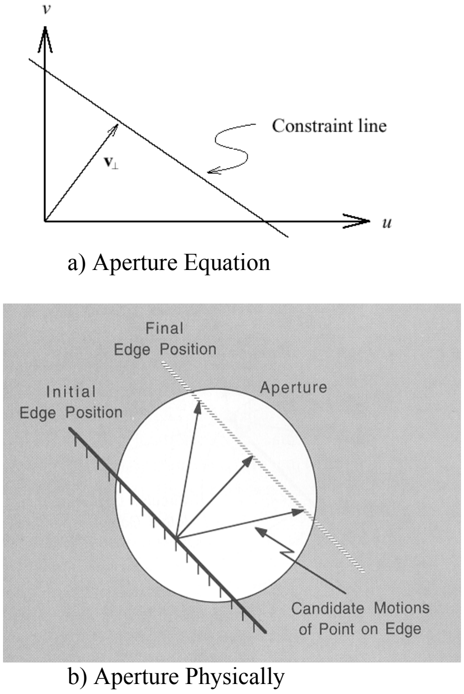


Fig. 3 Aperture problem illustrated, in equation and physics

System Architecture: The sequences of images are processed spatially at every time frame with a set of quadrature filters pairs and their phase responses are computed. The phase gradients actually give the component velocities, reliability of these component velocities is examined and rejected if found unreliable. At every spatial location, the component velocities from the different filter pairs are combined to produce an estimate of the full velocity, v, at that position. Figure 6 shows the sequence by which the operations have to be carried out.

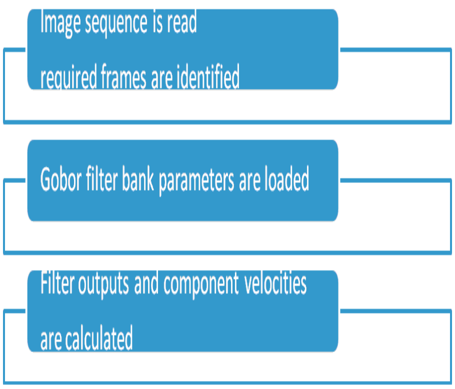


Fig. 4 Sequence of operations in phase based optic flow

Advantages and Disadvantages: There are various general advantages compared to the spatial and time domain approaches of the algorithms like robustness with respect to the smooth lighting variations etc. further compared to the other phase based methods, temporal evolution of contours of constant velocity leads to better approximation than constant amplitude used by Fleet and Jepson in [21].

Some disadvantages include phase information could be unstable with respect to phase singularities which is a constraint in 2-d velocity. Here phase non-linearity is measured rather than stability and reject unreliable estimates which is a loss of information.

The image is spatially filtered, the phase information is extracted through the 11 banks of Gabor filters which are quadratures and the phase contours are obtained. Temporal phase gradient is computed orthogonal to filter pair's orientation, the gradient of those phase contours provide the component velocities. A component velocity is rejected if the corresponding filter pairs phase information is not linear over a given time span. The remaining component velocities at a single spatial location are combined to compute the full velocity. The basic is shown in the flow chart in Figure 4 and 5.

According to the directions from the results in the [25], [26] the Yosemite sequence is tested and each step is then explained with the help of its contours.

To calculate the Filter outputs and component velocities, following procedures are availed $\phi_t = -(v.\phi_x)$.

2.5 Design of A GUI Based Architecture in MATLAB

A MATLAB Graphical User Interface GUI was designed for the Correlation, Gradient based by Horn and Schunck and Lucas Kanade and phase based method.

A GUI was designed with an integrated Windows Media Player to play the Windows Media Video files. Other supported formats could also be played through this. This integrated ActiveX object acts as an input to the whole set of programs integrated therein. Figure 6 shows the outputs obtained of which the optic flow vectors could be compared, moreover this GUI displays the processing time taken by each method and displays vectors in the specific colour chosen by the user for that method.

2.6 Process Options in GUI

The '**File/open'** gives a option to choose a '.gif', a '.avi' or any other video file supported Which will be played, this will be then taken as the input for the selected program for execution. Media player play buttons below are to be played when required by the user for the verification.

Code flow for the Phase based Optic flow: The '**Choose Colour' and 'Colour'** buttons provide a way to choose the colour of the vectors to be displayed on the image .The buttons '**Phase Based'**, **'Gradient Based'** and '**Correlation Based'** Toggle- Buttons are meant to be clicked for the selection of the required method of execution .Their names suggest the methods to be implemented, but the Gradient method has two other subsets which would be selected through the Toggle Buttons '**By Lucas Kanade'** and '**By Horn and Schunck'**. Further some advanced options are designed as to select if the input image frames are stored, or if a stored video is available or a Real time camera based scenario they are '**Framewise Calculation'** , '**Stored Video Uncontrolled'** and '**Real time Scenario'** respectively . The axes displays one frame out of the sequence and displays flow vectors on them as an estimate of the 2D velocity vector. The computation time with respect to the selected colour and the name of the method are all summarize at the right top of the GUI window. The '**Run simulation'** processes the selected items and executes the run and '**Run Integrated Simulation'** executes all the methods and the optic flow is displayed one above the other in their selected colours.

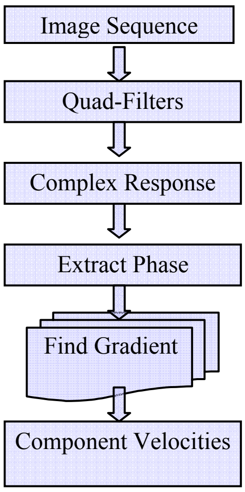
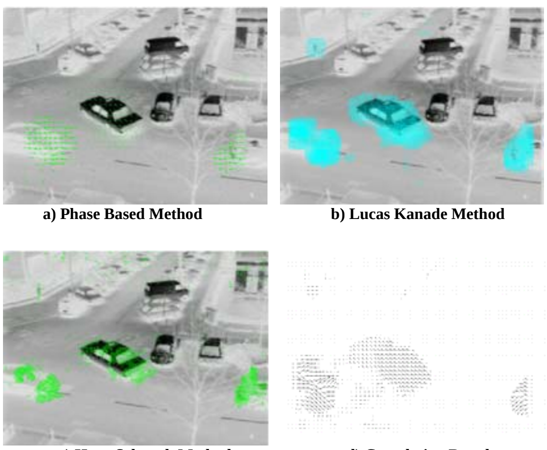


Fig. 5 Flow Chart for the Optic Flow –MATLAB Design

2.7 Performance Evaluation of the Algorithm



a) Phase Based Method b) Lucas Kanade Method

c) Horn Schunck Method d) Correlation Based

Fig. 6 GUI Design output for the four Optic Flow methods

As mentioned in [23], [24] & [25] the performance evaluation for the optic flow methods in general could be performed in many ways but one of the most commonly used methods is chosen in this thesis so that a measurable comparison could be made with the available published literature. If u and v is the velocities obtained then the vectors could be computed to get V $\vec{v} = \frac{1}{\sqrt{u^2 + v^2}}(u, v, 1)$ and $V = (v_1, v_2)$ the error estimates are obtained by comparing the available correct vectors and those obtained from the algorithm in the following way

$$\psi_e = \arccos\left(\vec{v}_c, \vec{v}_e\right)$$

Where: Vc are the correct vectors and Ve the vectors obtained through the algorithm.

2.8 Error Metrics

The table 1 clearly shows the errors found with the Yosemite fly through sequence. The final row shows the implemented result and the row above shows the literature results from [26] and all the other rows show various methods compared.

Table 1 Error Metric Evaluation and Comparison

Technique	Av. Err (deg)	St. Dev(deg)	Dens%
H Schunck > 5.0	5.48	10.41	32.90
Lucas K > 1.0	4.10	9.58	35.10
Fleet & Jepson t = 2.5	4.29	11.24	34.10
Gautama & V. Hulle	4.40	3.74	34.70
Gautama & Hulle (Imp) (15.6870 sec)	4.29	5.36	25.10

The observed Coverage: 24.54 %
The observed Angular error (full): 13.7232 deg (10.7188 deg).
Figure 7 shows the mid frame with the vectors over it.

2.9 Results and Conclusion

The known sequences were tested with the ground truth, synthetic sequences could have confidence. The performance of each of the algorithm is analysed based on these parameters. Moreover for the real time sequences the flow is mapped onto the 2D image and the reader is supposed to verify the results.

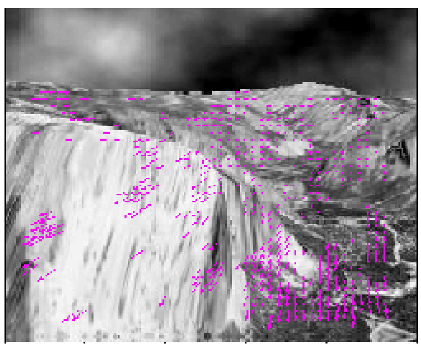


Fig. 7 Optic Flow Vectors of Frame 3 and Frame 4 of Yosemite sequence superimposed on one of them

3. SUMMARY

A detailed study was carried out on the optic flow algorithms with a specific interest for its utility in Micro Air Vehicles (MAV). The related research by Temujin Gautama and Marc M.Van Hulle [25] was selected and reviewed in view of its relevance to phase stability with respect to geometric deformations and its linearity as a function of spatial position. The selected algorithm was implemented through a developed MATLAB code and its results were obtained. The simulated results were compared with pertinent-published results. The error metrics were identified and a performance evaluation of implemented phase based optic flow algorithm was carried out with the available standard synthetic image sequences.

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