# Compound Phase Correlation for Multiple Motion Decomposition in Target Extraction and DEM Generation

**The recent research of SEAS DTC project SEN001 is focused on multiple motion decomposition to improve the accuracy of disparity measurement of optical flow for target tracking and DEM generation. The research has led to a major technical breakthrough in the development of a novel method: Compound Phase Correlation (CPC). Consequently, a new combined approach has been implemented in the Phase Correlation Image Analysis System (PCIAS) for automatic PC/CPC scanning to achieve optimal accuracy and processing speed for disparity estimation in image pairs with sharp boundaries of motions or topography. Beside, a simple method for phase correlation quality is also proposed, which is the key parameter for the automation of the combined phase correlation scan.**

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## Introduction

The PCIAS (Phase Correlation Image Analysis System) that we developed with the SEN001 project has shown powerful functionality for motion estimation based on phase correlation algorithms. Beside its high performance in accurate moving target tracking, the PCIAS has demonstrated its great ability for DEM (digital elevation model) generation from very narrow baseline stereo image pairs. However, we have noticed that phase correlation, as an area feature matching technique, is not robust and accurate around motion boundaries or depth discontinuity areas. Solving this problem will not only refine the moving target extraction and speed estimation but, more importantly, also lead to a solution of the DEM generation of very steep surfaces which is the case of urban areas.

This paper reports our investigation into the characteristics of phase correlation of complicated motion properties between two overlapped sequential images. We proposed a novel technique to identify and decompose the multiple motion patterns in phase correlation matrix at subpixel accuracy. This is a technical breakthrough in improving the robustness and accuracy of phase correlation feature matching around motion boundary or depth discontinuity. Our experimental results demonstrated that the proposed approach achieved very good performance in extraction of moving targets from a panning background and in stereo matching for DEM generation (especially at sharp edges) using synthetic and real image pairs from different sensor platforms and spectral bands.

## Multiple motion decomposition: compound phase correlation method

In our previous research, we found that the robust 2D fitting or SVD based phase correlation method is capable of measuring the motion of a moving target in a stationary background as long as the target is the dominant feature in the image frame, but both algorithms fail when the target is small in comparison with the background [1]. In this case, a rather messy phase correlation matrix with overlaid and interfered multiple fringe patterns is generated, which cannot be unwrapped properly. Our investigation indicates that these multiple fringe patterns in the phase correlation matrix are in different orientations and frequencies, which correspond to motions in different directions and speeds in a multiple motion case. Identification and decomposition of these patterns thus enable accurate speed measurement when the targets are small in the phase correlation window; while for DEM generation, the accuracy of disparity measurements between a stereo image pair along a sharp edge corresponding to a steep slope, where the parallax changes sharply, can also be improved. We understand that this is a fundamental technical issue in improving the phase correlation based motion estimation around the moving object boundaries and stereo matching in depth discontinuity areas, where our original phase correlation based technique and other existing techniques perform unsatisfactorily.

It is a difficult task to identify and decompose the multiple motion patterns directly in the phase correlation matrix. However, if we apply the inverse Fourier transformation to the phase correlation matrix, the multiple motions can be clearly separated as different Delta function impulses. The corresponding motion can then be easily estimated based on the locations of these Delta function impulses, but only at a pixel level accuracy. This is so called Delta function based phase correlation method [3]. In order to robustly estimate the corresponding motions at subpixel accuracy, we designed a compound phase correlation (CPC) method which benefits both advantages of easy decomposition of multiple motions from Delta function method and subpixel accuracy of the direct phase correlation technique for individual motion. The CPC method is outlined below:

1. Apply SVD or 2D fitting phase correlation to an image pair with multiple motions.

2. Perform the inverse Fourier transformation of the phase correlation matrix to obtain the corresponding 2D Delta function.

3. Locate the dominant peaks of the 2D Delta function impulses which correspond to the multiple motions in image sequence. It should be noticed that a peak of the Delta function determines the integer part of the corresponding motion while the close neighbourhood of the peak determine the subpixel part of the motion.

4. Filter out all other parts of 2D Delta function impulse and only keep the close neighbourhoods of the dominant peaks, and then apply Fourier transformation to each peak neighbourhood to obtain a submatrix of phase correlation that corresponds only to one dominant motion.

5. Apply 2D fitting algorithms to each of the phase correlation submatrices to achieve subpixel accuracy of the multiple motion estimations.

6. In the case of phase correlation scan for subpixel optical flow generation, repeat steps 1~5 in each calculation window to achieve accurate local estimation of multiple motions, though it is more likely that there is only one motion in relation to the background (which can be in motion as well) if the window is small.

Figure 1 shows an example of motion decomposition through the proposed CPC method. The experiment is conducted using a picture of a tank model inserted into different positions in a Landsat TM image pair, which is generated by artificially shift one image by 6.5 pixels (right) in horizontal direction and 10.5 pixels (down) in vertical direction in relation to the other. The tank position change between the pair of images in Figure 1(a) and Figure 1(b) is 17 pixels horizontally and 16 pixels vertically. The phase correlation matrix between the image pair is shown in Figure 1(c) while Figure 1(d) illustrates that the inverse Fourier transformation of the phase correlation matrix resulted in two distinctive Delta function peaks corresponding to the tank motion and the background motion respectively. Figure 1(e) and (f) show the decomposed phase correlation matrices of the moving tank and the background based on which, the motions of tank and the background were estimated as presented in Table 1. This example indicates that the CPC method is able to achieve about 1/20 subpixel accuracy.

In fact, the general approach of the CPC method requires linking each Delta function peak to it corresponding motion; which is not straight forward for automation. The simplest situation is a moving target in a relative stationary back ground (background motion can be removed via frame registration using the SVD phase correlation method [2]) or equivalently, a steep slope boundary in contrast to gentle fluctuation of topography in the case of stereo disparity for DEM generation. In this case, the still background will generate a dominant peak always at the fixed position of zero movement in the 2D Delta function field while the only motion to be identified is represented by another dominant peak that is not at the zero motion position. This only non zero motion peak can then be located automatically. This simplest situation can be largely achieved in phase correlation scan using reasonably small window as implied in the step 6 of the CPC method.

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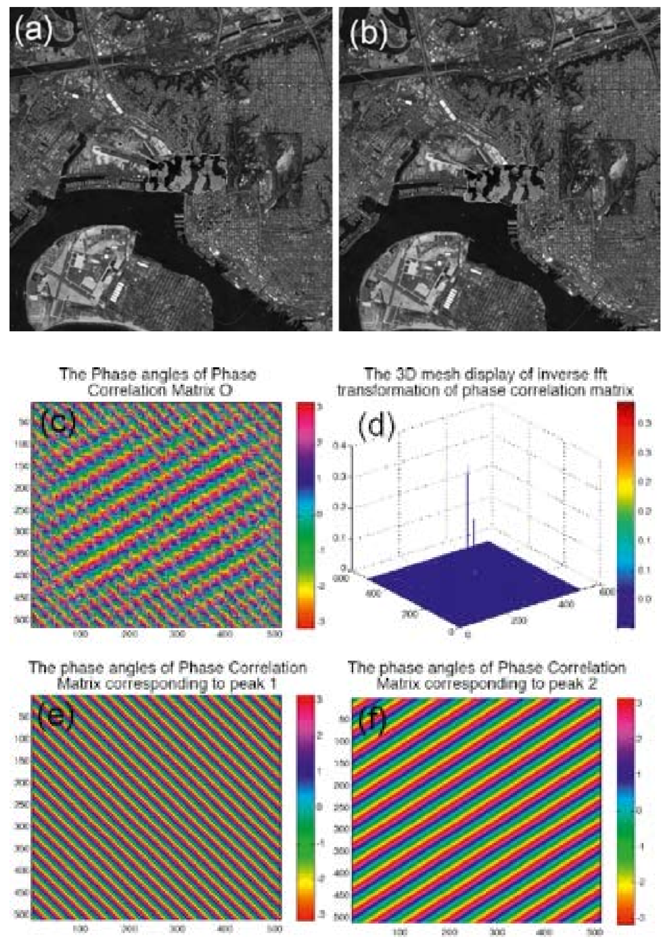


Motion decomposition using the proposed CPC method. An image pair (a) and (b) show a moving tank in a shifted background. (c) The phase correlation matrix between the image pair. (d) Two distinctive peaks of the Delta function that correspond to the tank motion and the background motion respectively. (e) The decomposed phase correlation matrix of the moving tank. (f) The decomposed phase correlation matrix of the moving background.





Table 1

| | Tank | Background |
|---|---|---|
| True shift x | –17 | 6.5 |
| True shift y | 16 | 10.5 |
| CPC method x | –16.9655 | 6.5213 |
| CPC method y | 15.9623 | 10.4343 |

Results of motion decomposition.

### Combined optical flow estimation procedure for local disparity mapping

Phase correlation method has been applied for obtaining local motion estimation and disparity map for stereo matching and surface structure [4,5] and its degraded performance around motion boundaries or depth discontinuity areas is well recognised.

We have tested the proposed CPC method to generate optical flow of the estimated local motion (disparities). Here, the scanning window size is crucial for the quality of the motion estimation and automation feasibility. If the window size is too small, then the number of data points will be insufficient to achieve accurate measurement of the extracted feature shift, while if it is too large it may include multiple motions, especially around depth discontinuity areas for DEM generation.

The proposed novel CPC method has much better performance for optical flow estimation around motion boundaries or depth discontinuity than the original robust 2D fitting technique, but it is generally less efficient and slightly less accurate in normal areas without motion boundaries or depth discontinuity. So we designed a combined motion (disparity) estimation algorithm that employs the corresponding advantages of the both techniques. The key issue of this newly designed combined motion estimation algorithm is to locate the motion boundaries where the phase correlation data are messy, and apply the CPC for motion (disparity) estimation only in these selected areas while keeping the original robust 2D fitting phase correlation as the default phase correlation engine for most parts of the image. This simple and effective automatic processing procedure comprises two steps:

1. Carry out the raster scan of the image pair using a moving window to estimate the motion of each pixel centred in the window with the robust QMDPE 2D fitting phase correlation algorithm.

2. In each window, the QMDPE technique is applied to find the best fitting to the unwrapped phase angle data. The estimation would be poor around motion boundaries where the phase angle data are contaminated by incorrect unwrapping and multi-structure mode because of poor correlation and high noise level. If the ratio of the outliers to the inliers of the best fitting estimation plane model exceeds a certain threshold, the robust 2D fitting motion estimation is supposed to be poor, and then the CPC technique is used to determine the dominant motion within the phase correlation window.

The amplitude of phase correlation has to be normalised to 1 and therefore there is no direct measurement of correlation quality in frequency domain. In the step two above, we used a simple ratio of outliers to inliers as an assessment of phase correlation quality. This hints a general method to use the 2D fitting quality assessment as an assessment of phase correlation quality. Beside the ratio of outliers/inliers, we can also use linear regression correlation coefficient or RMSE (root mean square error) between the actual phase shift angles and the first rank estimation of the phase shift angles derived via either SVD or 2D fitting algorithm.

### Experimental results

#### Moving target extraction with clean sharp edge

Figure 2 shows a pair of tank images generated in a similar way as described in Figure 1(a) and (b), which simulate a vertical view sequence of a moving military target in a sand desert background (no motion). The tank in the image on the right is shifted 2.5 pixels to the left and 3 pixels upward. The image pair was scanned locally using the newly developed combined optical flow estimation procedure to compute the optical flow field shown in Figure 2(c); and the magnitude image of the estimated optical flow field is shown in Figure 2(e). For comparison, the optical flow field from original robust 2D fitting technique without motion decomposition is shown in Figure 2(d), and its magnitude image is shown in Figure 2(f).

Figure 2(c) shows consistent motion velocity within the tank body where inconsistent motion directions and magnitudes occur in Figure 2(d) indicating obvious errors. These errors are also illustrated by varying shade patterns in the magnitude image Figure 2(f) in comparison with the solid homogeneous patch of the tank body indicating identical speed in Figure 2(e).

This experiment illustrates that our proposed CPC method based combined processing procedure successfully extracts moving target with sharp motion edge, which is a big challenge to most existing techniques including simple phase correlation methods.

### Disparity measurement in DEM generation

One of important applications of CPC method and the combined optical flow estimation procedure is to improve the accuracy of disparity measurement across steep slopes in very narrow baseline stereo image pair for DEM generation.

A stereo pair of images from CMU Roof sequence are shown in Figure 3(a) and (b). The disparity map (directly relevant to DEM) generated using the CPC based combined approach is shown in Figure 3(c). For comparison, the disparity map from robust 2D fitting technique without motion decomposition is shown in Figure 3(d). The test results are self evident; the new method has obviously improved performance, especially in disparity estimation around the sharp edges of buildings and walls. Figure 3(e) is a 3D perspective view of the Roof image reconstructed from the estimated disparity map. It demonstrates that fine details and depth discontinuity can be quite effectively recovered.

### Conclusions

In this paper, we reported the recent technical break through of the PCIAS development as summarised below:

1. A novel CPC (Compound Phase Correlation) method has been developed. The method combines the merits of accurate motion (disparity) measurements from the SVD and 2D fitting phase correlation algorithms and the ability to separate multiple motions from the phase correlation-Delta function algorithm. Thus multiple motions and disparities can be decomposed and measured accurately.

2. A new approach: combined optical flow estimation procedure, has been implemented in the PCIAS. This procedure automatically chooses to use the CPC only when it is necessary otherwise, the QMDPE 2D fitting PC is used by default. This optimises the processing to achieve the highest possible accuracy with speed.

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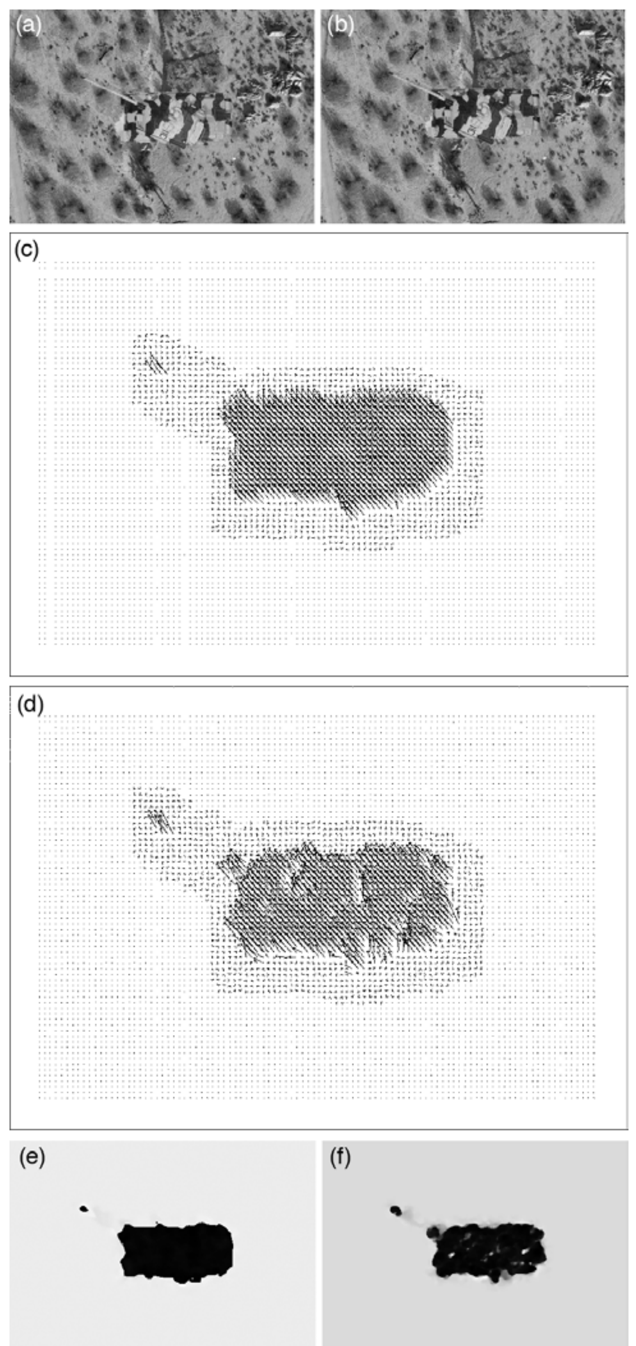


Image (a) and (b) show a tank target moving in a still sand desert background. (c) The optical flow field produced by the CPC based combined processing procedure. (d) The estimated optical flow field produced by the original robust 2D fitting motion estimation method. (e) The magnitude image of the optical flow field (c). (f) The magnitude image of the optical flow field (d).





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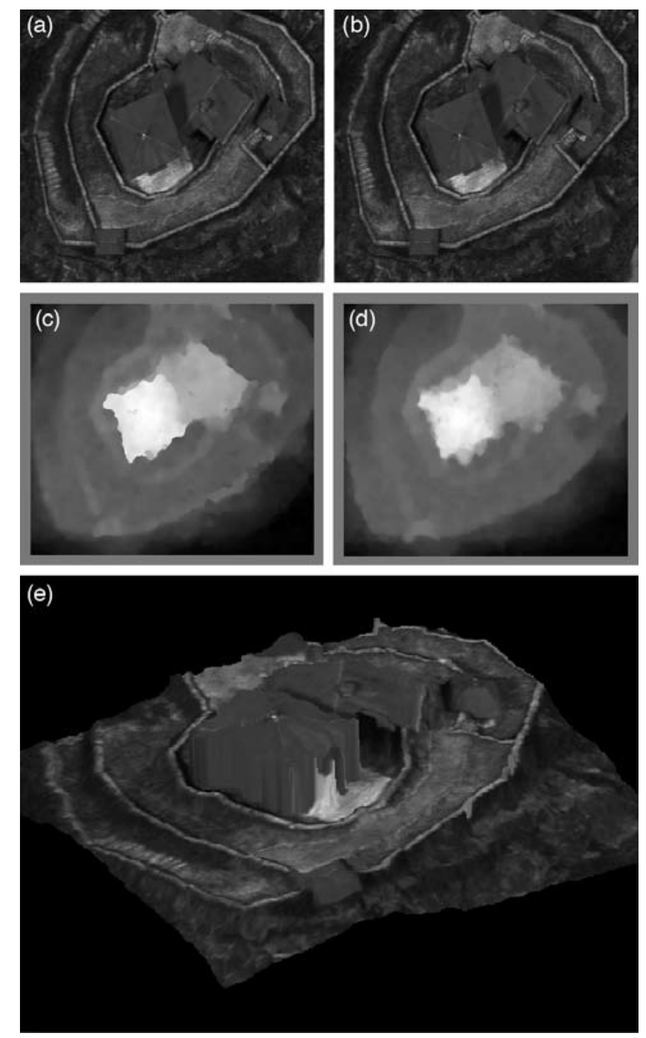


Experiment results of disparity estimation for DEM generation from a stereo image pair of CMU. (a)–(b) The original stereo image pair from the CMU Roof sequence. (c) The disparity measurement image produced by the CPC based combined optical flow estimation procedure. (d) The disparity measurement image produced by the original robust 2D fitting phase correlation. (e) The 3D perspective view of Roof image based on the CPC derived disparity measurement image (DEM) in (c).

3. One crucial parameter for the automatic decision of using the CPC is the phase correlation quality. We proposed a very simple solution: using the quality assessment of the 2D fitting of the phase correlation matrix data as an assessment of phase correlation quality. The assessment can be achieved via either outliers/inliers ratio, or linear regression correlation coefficient, or RMSE.

The significance of the new development reported in this paper is that the further refinement of the methodology will lead to the high quality urban DEM generation that has always been a difficult task because of the vertical surfaces of buildings and large occlusions. Accurate urban DEM is an essential element for autonomous manoeuvre of UAV and ULV in a cluttered urban environment.

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