Digital Image Stabilization Based on Harmony Filter

Xiaofei Wang
College of Electronics and Information Engineering, Sichuan University, Chengdu, China
Arts & Sciences College of Sichuan Normal University, Chengdu, China
Email:scu_xfwang@163.com

Xiaohai He, Qizhi Teng
College of Electronics and Information Engineering, Sichuan University, Chengdu, China
Email: hxh@scu.edu.cn, qzteng@scu.edu.cn

Mingliang Gao
School of Electrical & Electronic Engineering, Shandong University of Technology, Zibo, China
Email: scu_mlgao@163.com

***Abstract*— A digital image stabilization algorithm based on a harmony filter is presented in this paper. The corner points are extracted from the reference image. A new motion estimation method based on diamond search (DS) and partial distortion elimination (PDE) algorithm is proposed in the feature block matching. The global motion parameters are obtained based on the affine transformation model and the least square solution. Then a new filter algorithm named harmony filter is adopted to smooth the global motion by separating the active scanning movement from random jitter of camera. Finally, the original jitter sequences are compensated by the correction vectors. Experimental results show that our method can eliminate the high frequency tremble, keep active motion of camera and realize real-time image stabilization.**

***Index Terms*— Digital image stabilization, Feature block matching, Global motion estimation, Harmony filter**

I. INTRODUCTION

Digital image sequences captured from physical imaging devices often display unwanted high frequency jittering motion due to unstable camera holding or platform moving. Such jittering motion will affect the visual quality and hinder the subsequent processes, e.g., video display, video coding, and video surveillance. The aim of image stabilization is to remove undesired image fluctuations from a sequence so as to improve the visual quality.

Many approaches have been proposed to solve the image stabilization problem. They can be classified into three categories: electronic image stabilizer (EIS), optical image stabilizer (OIS) and digital image stabilization (DIS) [1-3]. The EIS method stabilizes the image sequence by employing motion sensors to detect the camera movement for compensation. As regards to the OIS method, a prism assembly is used to compensate for unwanted camera motion, and motion sensors and an active optical system also employed for stabilization. The DIS method relies on digital image processing techniques that can remove unwanted camera motion and keep the intentional motion. The DIS approach is a machine-independent method, which is highly precise and the most flexible technique among the three categories [4].

The DIS system is mainly composed of three processing modules: motion estimation (ME), motion filter (MF) and motion compensation (MC), as shown in Fig. 1. The ME can be further divided into the local motion estimation and global motion estimation. Local motion is the movement of an individual image pixel between two consecutive image frames. The global motion represents the camera motion from the previous frame to the current frame. The aim of MF is to eliminate the high frequency tremble and keep the active motion of camera. The MC part accomplishes the motion correction by shifting the current picking window according to the compensation parameters. Among the three modules, the accuracy of the global motion estimation is crucial as the first step of digital image stabilization because the accuracy of the estimated motion parameters ultimately determines the effectiveness of the stabilization process. For this reason, many algorithms have been proposed to obtain fast and precise motion vectors, such as block matching algorithm (BMA) [5], edge pattern matching (EPM) [6] and bit-plane matching (BPM) [7]. In recent years, much attention has been paid to feature block matching because the image feature is more suitable to process [8, 9].

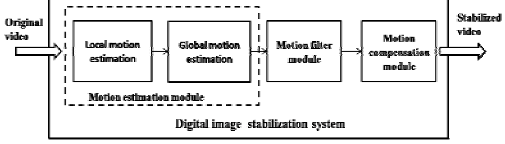

Figure 1. Flow diagram of DIS system

Corresponding author: Xiaohai He. E-mail: hxh@scu.edu.cn

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The principle of the feature block matching is to find the most similar candidate feature macro block in the reference frame for each feature macro block in the current frame. The most accurate block matching algorithm is full search (FS) which compares every candidate macro block in a search window with the current macro block but the algorithm is computationally intensive. For this reason, many fast algorithms have been developed such as three step search (TSS) [10], new three-step search (NTSS) [11], four-step search (FSS) [12], diamond search (DS) [13]and cross diamond search (CDS) [14], etc. DS is a fast and superior algorithm and has been adopted by the MPEG-4 international standard. In this paper, the partial distortion elimination (PDE) [15] is adopted to improve DS. Then the global motion vectors are obtained by the Least Squares Method based on the affine model as illustrated in section IV. In the motion filter part, a new filter named harmony filter is applied to remove the unwanted camera motion and the compensation parameters are calculated. Lastly, in the compensation stage, the image effect that is caused by unexpected camera jittering motion is eliminated from the input image frame. Experimental results show that the method can eliminate high frequency tremble, keep active motion of camera and realize real-time image stabilization.

II. Harris Feature Point

Harris detector which has been successfully applied to different fields recently [16, 17] is proposed by Harris and Stephens [18] based on the auto-correlation matrix. . Harris detector procedure mainly consists of the following steps:

(1) The gradient distribution in a local neighborhood of a point (x, y) is calculated by the auto-correlation matrix M :

$$M = \begin{bmatrix} A & C \\ C & B \end{bmatrix} \tag{1}$$

where $A = \left(\frac{\partial I}{\partial x}\right)^2 \otimes w$, $B = \left(\frac{\partial I}{\partial y}\right)^2 \otimes w$, $C = \left(\frac{\partial I}{\partial x}\frac{\partial I}{\partial y}\right) \otimes w$, $\otimes$ is the convolution symbol and w is an Gaussian window function. Given an original image $I(x, y)$, the gradient of the image in horizontal and vertical directions can be obtained by filtering the image with the differential operator in both directions:

$$\frac{\partial I}{\partial x} = I \otimes \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix}, \frac{\partial I}{\partial y} = I \otimes \begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{bmatrix}. \tag{2}$$

(2) The corner response function (CRF) is obtained by $C = detM - k \times (trM)^2$, where $detM$ and trM are the determinant and the trace of the matrix M . k is a constant, and the typical value of which is 0.04.

(3) The local maxima of C is extracted using non-maximum suppression.

III. Feature Block Matching

A feature window $P \times P$ centered at each selected feature point is designed to divide the current frame into a matrix of macro blocks. Then the macro blocks are compared with the corresponding block and its adjacent neighbors of the following frame to create a vector that stipulates the movement of a macro block from one location to another. In this paper, we integrate the partial distortion elimination algorithm with the diamond search to improve the efficiency of the matching.

A. Partial Distortion Elimination (PDE)

The Sum of Absolution Difference (SAD) is a typical matching criterion used in the block matching and it can be obtained as follows:

$$SAD(v_x, v_y) = \frac{1}{M \times N} \times \sum_{i=0}^{N-1} \sum_{j=0}^{M-1} \left| f_{cur}(i, j) - f_{ref}(i + v_x, j + v_y) \right|. \tag{3}$$

where N and M are the height and width of the block. $f_{cur}(i, j)$ and $f_{ref}(i, j)$ are the pixel intensities at the current block and candidate block, respectively. i and j denote the index of directions of horizontal and vertical within the block. v_x and v_y denote the motion vectors of the candidate block. The minimum of SAD determines the best block matching.

The block matching algorithms compare the current minimum SAD with the final SAD. This is a time consuming part in the block matching algorithm. PDE [15] is one of the techniques that reduce the unnecessary computation during the SAD calculation. PDE algorithm uses the partial sum of matching distortion to eliminate the improper candidate before finishing the matching distortion calculation. In the PDE algorithm, the row based k -th partial SAD to check during the matching is as follows:

$$ParticalSAD(k) = \sum_{i=0}^{k} \sum_{j=0}^{M-1} \left| f_{cur}(i, j) - f_{ref}(i + v_x, j + v_y) \right|. \tag{4}$$

where M denotes the block width, and k $(k = 0, 1 \cdots N-1)$ denotes the number of rows. If an intermediate sum of matching distortion is larger than the minimum value of matching distortion at that time, the remaining computation for the matching distortion will be unnecessary.

B. DS Based on PDE

We integrate the partial distortion elimination with the diamond search (PDE-DS) to improve the efficiency of the block matching.

In the classic DS, two different types of fixed patterns are used: one is large diamond search pattern (LDSP), and the other is small diamond search pattern (SDSP). These two patterns are illustrated in Fig.2.

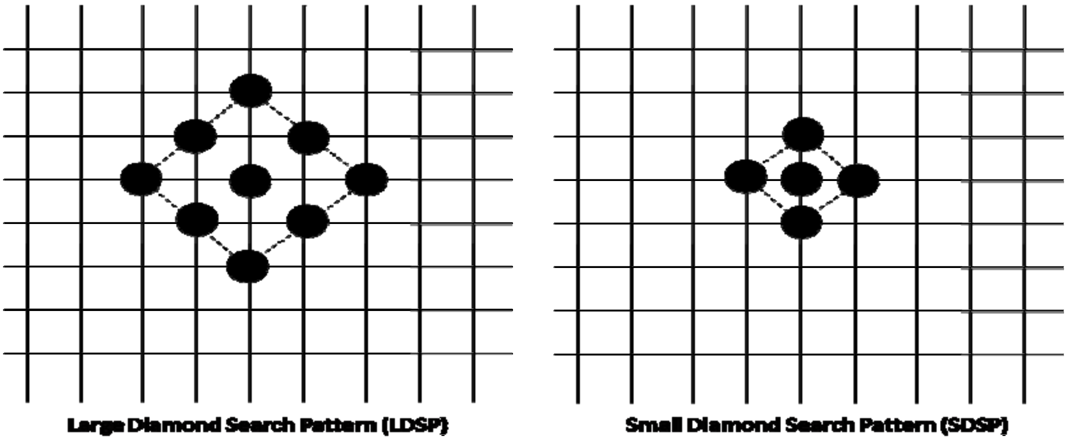


Figure 2. Two search patterns in DS

Step 1. The initial LDSP is centered on the origin of the feature block, and nine checking points of LDSP are tested using the PDE algorithm. If the minimum block distortion (MBD) point calculated is located at the center position, go to Step 3; otherwise, go to Step 2.
Step 2. The MBD point found in the previous search step is re-positioned as the center point to form a new LDSP. If the new MBD point obtained is located at the center position, go to Step 3; otherwise, recursively repeat this step.
Step 3. Switch the search pattern from LDSP to SDSP. The MBD point found in this step is the final solution of the motion vector which points to the best matching block.

IV. Global Motion Estimation

The global motion can be estimated from the local motion vectors. Under the 3D camera model, pixel locations (x, y) in image frame k and (x', y') in frame $k+1$ are related by:

$$\begin{pmatrix} x' \\ y' \\ \lambda \end{pmatrix} = s \begin{pmatrix} R_{11} & R_{12} & R_{13} \\ R_{21} & R_{22} & R_{23} \\ R_{31} & R_{32} & R_{33} \end{pmatrix} \begin{pmatrix} x \\ y \\ \lambda \end{pmatrix} + \begin{pmatrix} l_x \\ l_y \\ l_z \end{pmatrix}. \quad (5)$$

where s is the scale factor and λ is the focal length of the camera. From Eq. (5), we can get:

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = s \begin{pmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} sR_{13}\lambda + l_x \\ sR_{23}\lambda + l_y \end{pmatrix}. \quad (6)$$

Eq.(6) shows that using a 2D affine transformation, one can get the same visual effects as using a 3D transformation with different parameters. If the rotation angle outside the image plane is quite small between successive frames, and the scene is far away from the camera thus $s = 1$, the above model can be simplified as

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} \Delta X \\ \Delta Y \end{pmatrix}. \quad (7)$$

where θ denotes the rotation angel in the image plane, and ΔX , ΔY are translation displacements along x and y axis, respectively. Each pair of the matched points introduces two equations and subsequently, the least squares solution of contradictory equations $B = AM$ can be obtained, where

$$B = \begin{bmatrix} x_{i,1} - sx_{j,1} \\ y_{i,1} - sy_{j,1} \\ \cdots \\ \cdots \\ x_{i,N} - x_{j,N} \\ y_{i,N} - y_{j,N} \end{bmatrix}, A = \begin{bmatrix} -sy_{j,1} & 1 & 0 \\ sx_{j,1} & 0 & 1 \\ \cdots \\ \cdots \\ -sx_{j,N} & 1 & 0 \\ sx_{j,N} & 0 & 1 \end{bmatrix}, M = \begin{bmatrix} \theta \\ \Delta X \\ \Delta Y \end{bmatrix}.$$

$(x_{i,k}, y_{i,k})$ and $(x_{j,k}, y_{j,k})$ are the k th matching points of the i th and j th frames.

V. Motion Compensation Based On Harmony Filter

The camera motion contains random jitter and active scanning movement. The purpose of stabilization is to remove the random jitter and keep the scanning movement. In this paper, a new filtering algorithm named harmony filter is proposed in our DIS system.

A. Harmony Search Algorithm

The harmony search algorithm is a meta-heuristic algorithm inspired by the improvisation process of music players [19]. It has been successfully applied to various optimization problems in computation and engineering fields such as design optimization, university course timetabling, economic and emission dispatch, shop scheduling, network reconfiguration, mine ventilation, carbon dioxide emissions forecasting and object tracking [20-30].

The harmony search algorithm simulates the mechanism of musicians' improvisation by keeping a matrix of the best solution vectors called the Harmony Memory (HM). The number of the vectors is known as the Harmony Memory Size (HMS). The next step following initialization is called improvisation. A new solution is improvised by using three rules: memory consideration, pitch adjustment and random selection [29]. The Harmony Memory Consideration Rate ($HMCR$) is a parameter that is set during initialization and controls how often the memory is taken into consideration during improvisation. A random number is generated for each dimension. If it is smaller than $HMCR$, the memory is taken into consideration; otherwise, a value is randomly chosen from the range of possible values for that dimension. If the memory is taken into consideration, the improvised value is chosen randomly from one of the values in the memory. The Pitch Adjustment Rate (PAR) is set during initialization, and controls the amount of 'pitch adjustment' done when the memory is taken into consideration. Another random number is generated and if it is smaller than PAR, the improvised value is pitch adjusted using [29]

$$x_{new}^{'} = x_{new} + rand() \times BW \tag{8}$$

where $rand() \in \{-1,1\}$ and BW is the parameter that controls the variation, and it is set during initialization. Once a new value has been improvised, the memory is updated by comparing the new improvisation with the vector in the memory with the lowest fitness. This process of improvisation and update continues iteratively until some stopping criterion is satisfied.

B. Procedure of the Harmony Filter

According to the above algorithm concept, the harmony filter procedure consists of the following five steps, as shown in Fig.3.

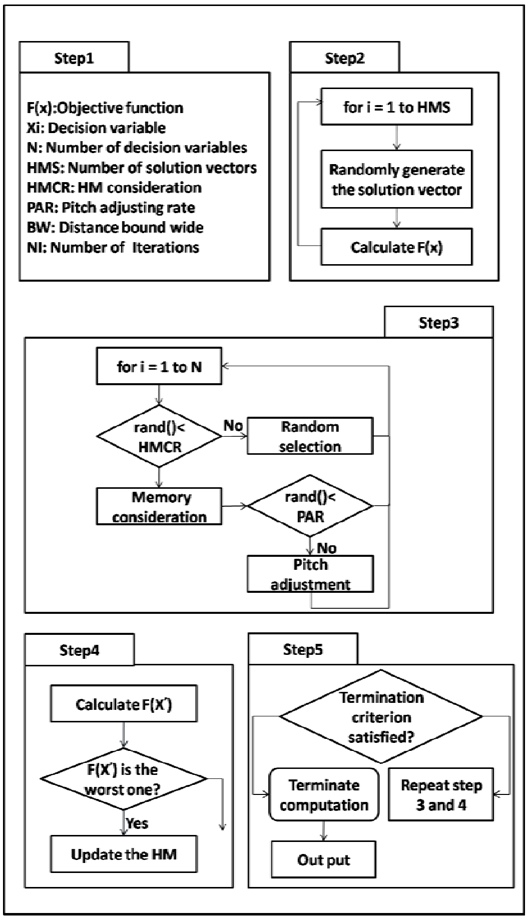


Figure 3. Flowchart of the proposed HS

Step 1: The optimization problem

The optimization problem can be defined as minimize (or maximize) $F(\mathbf{x})$, where $F(\mathbf{x})$ is the objective function, $\mathbf{x}$ is a candidate solution consisting of N decision variables (x_i) $LB_i \le x_i \le UB_i$, and LB_i and UB_i are the lower and upper bounds for each decision variable, respectively. In our work, there are three variables, $\theta,\ \Delta X, \Delta Y$, then $N=3$ and $F(\theta, \Delta X, \Delta Y) = \left|cf \times (\theta - \theta^{'})\right| + \left|\Delta X - \Delta X^{'}\right| + \left|\Delta Y - \Delta Y^{'}\right|$, where cf is a coefficient associated with the image size, $cf = \frac{1}{4}\sqrt{(imgWidth)^2 + (imgHight)^2}$. $\theta,\ \Delta X$ and ΔY are the variants in the HM, and $\theta^{'},\ \Delta X^{'}$ and $\Delta Y^{'}$ are the globe motion vectors in section IV. The corresponding parameter selection will be specified in the next section.

Step 2: Harmony memory initialization and evaluation

The algorithm maintains a store of solution vectors known as Harmony Memory (HM), that is updated during the optimization process. HM is an $HMS \times (N+1)$ augmented matrix:

$$HM = \begin{bmatrix} x_{11} & x_{21} & \dots & x_{N1} & f(X^1) \\ x_{12} & x_{22} & \dots & x_{N2} & f(X^2) \\ \dots & \dots & \dots & \dots & \dots. \\ x_{1HMS} & x_{2HMS} & \dots & x_{NHMS} & f(X^{HMS}) \end{bmatrix} \quad (9)$$

The initial harmony memory is generated from a uniform distribution in the ranges $\left[LB_i, UB_i\right]$, where $1 \le i \le N$. This is done as follows:

$$x_{ij} = LB_i + r \times (UB_i - LB_i),\ j = 1, 2, ...HMS \quad (10)$$

where $r \sim U(0,1)$ and U is a uniform random number generator.

Step 3: New harmony improvisation

Generating a new harmony is called improvisation. The new harmony vector, $x^{'} = (x_1^{'}, x_2^{'}, ..., x_N^{'})$, is generated using the following ways: memory consideration, pitch adjustment and random selection. The procedure is illustrated in Fig. 4.

Harmony Search Improvisation

for each $i \in (1, N)$ **do**

  if $U(0,1) \le HMCR$ **then**

    $x_i^{'} = x_{ij}\ (j = 1, 2, ...HMS)$

      if $U(0,1) \le PAR$ **then**

      $x_i^{'} = x_i^{'} \pm r \times bw$

   end if

  else

    $x_i^{'} = LB_i + r \times (UB_i - LB_i)$

  end if

end

Figure 4. Pseudo code of HS improvisation

Step 4: Harmony memory update

The generated harmony vector replaces the worst harmony in HM, only if its fitness (measured in terms of the objective function) is better than that of the worst harmony.

Step 5: Termination criterion check

The optimization algorithm continues iterating from Step 3 to 5 until the given termination criteria are satisfied. It should be noted that different termination criteria can be used to stop the computation, for example, the iteration reaches a given number, the objective function reaches a specific value, or no improvement in the objective function is achieved for a specific number of passed iterations. In this paper, both the first and the last termination criterion are used.

C. Motion Compensation Parameters

The compensation parameters for each image frame are obtained as the difference between the harmony filtered and the original variants, and each current frame is warped back to achieve stabilization. The transformed coordinates are not always in the integer pixels; hence, the nearest interpolation method is applied.

VI. Experiments And Discussions

This section presents results obtained from a video sequence, recorded from a camera mounted on a dithering platform. The experiments are conducted on an Intel(R) Core(TM) 2 Duo 2.93GHz with 2GB memory and the Windows XP operating system. The software platform is built in Visual studio 2008.

In our work, the ranges of θ, ΔX and ΔY are $(-0.01 \sim 0.01)$, $(-20 \sim 20)$ and $(-20 \sim 20)$, respectively. $HMS = 100$, $HMCR = 0.95$, $PAR = 0.15$ and the number of improvisations or stopping criterion $NI = 200$. The size of the input image is 320×240. One frame in the video sequence is shown in Fig.5.

Figure 5. One frame in video sequence

Fig. 6-8 show the results of smoothing motion vectors with harmony filter. The curves show that the harmony filter can successfully remove the high frequency jitter and smoothly follow the global motion trajectory. The results show that the digital image sequences display unwanted high frequency jittering motion and the harmony filter can remove the undesired image fluctuations.

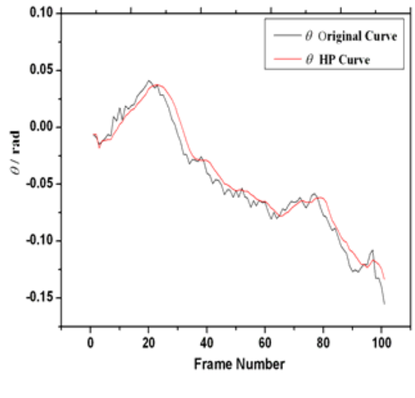


Figure 6. Measured curve and filtered result for vector θ

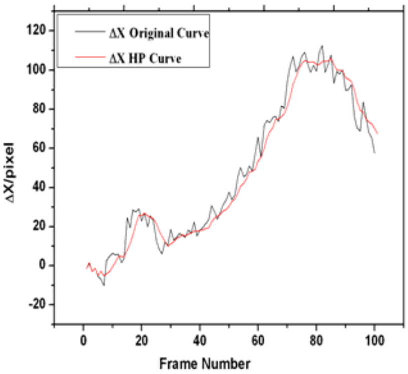


Figure 7. Measured curve and filtered result for vector ΔX

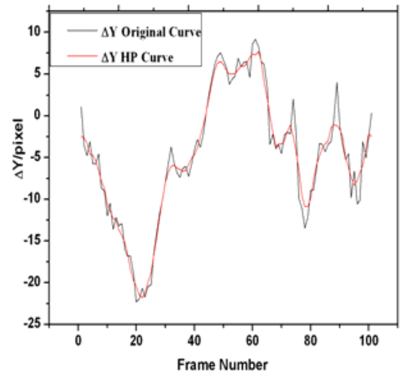
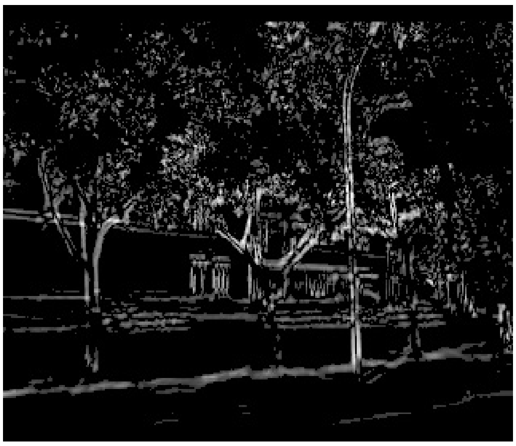
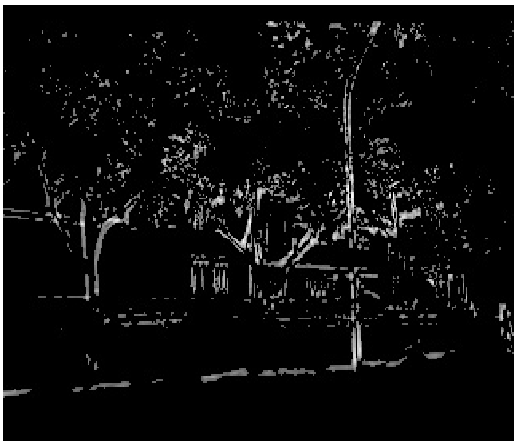


Figure 8. Measured curve and filtered result for vector ΔY

To offer a subjective visual effect of the result, the differences between the consecutive two frames in the original and stabilized sequences are shown in Fig.9.



(a) Original difference



(b) Stabilization difference

Figure 9. Comparison of difference image

For the sake of an objective evaluation of the image stabilization algorithms, the peak signal-to-noise ratio (PSNR) is used as a measure. The PSNR between consecutive images I_t and I_{t+1} is defined as:

$$PSNR(I_t, I_{t+1}) = 10\lg\frac{255^2}{MSE(I_t, I_{t+1})} \quad (11)$$

$$MSE(I_t, I_{t+1}) = \frac{1}{M \times N}\sum_{m=1}^{M}\sum_{n=1}^{N}(I_t(m,n) - I_{t+1}(m,n))^2 \quad (12)$$

Fig.10 shows the effect of stabilization. The lower curve is the PSNR of the original video, and the upper curve is that of stabilized video. It can be seen that the PSNR of stabilized video is evidently increased.

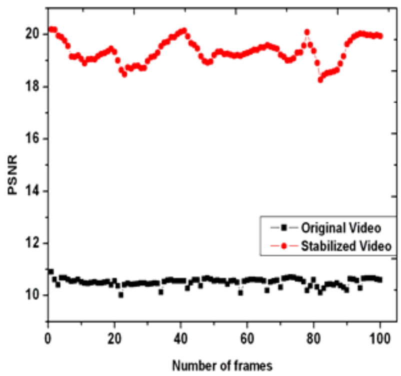


Figure 10. The PSNR curve of the original video and stabilized video

VII. Conclusion

An image sequence stabilization system based on Harmony filter has been demonstrated. Firstly, the corners in the image are extracted using Harris operator, and then a new feature block matching algorithm named PDE-DS is proposed to get the local motion parameters.

Secondly, the global motion parameters are obtained based on the affine transformation model and the least square solution. Thirdly, we introduce a new filter algorithm, named harmony filter to smooth the global motion. Finally, the original jitter sequences are compensated by the correction vectors. Experimental results show that our proposed algorithm can remove the undesired image fluctuations and improve the visual quality.

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Xiao-fei Wang is a faculty member of the Institute of information technology, Arts & Sciences College of Sichuan Normal University. He is currently pursuing a doctor degree at College of Electronics and Information Engineering of Sichuan University. His main research interests include analysis of motion and image processing.

Xiao-hai He received his Ph.D. degree in Biomedical Engineering in 2002 from Sichuan University, China. He is a professor in College of Electronics and Information Engineering at Sichuan University. Dr. HE is a senior member of the Chinese Institute of Electronics. He is an Editor of both the Journal of Information and Electronic Engineering and the Journal of Data Acquisition & Processing. His research interests include image processing, pattern recognition, image communication.

Qi-zhi Teng received her Ph.D. degree in Biomedical Engineering in 2003 from Sichuan University, China. She is a professor in College of Electronics and Information Engineering at Sichuan University. Dr. Teng is a senior member of the Chinese Institute of Electronics. Her research interests include digital image processing, image communication and pattern recognition.

Ming-liang Gao a faculty member of School of Electrical & Electronic Engineering at Shandong University of Technology. His main research interests include meta-heuristic optimization, analysis of motion, and tracking in image sequences.